

AGRICULTURAL ADAPTATION TO CLIMATIC VARIATION

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Abstract. Assumptions underlying impact assessments of climatic change for agriculture are explored conceptually and empirically. Variability in climatic conditions, the relevance of human decision-making, and the role of non-climatic forces are reviewed and captured in a model of agricultural adaptation to climate. An empirical analysis of farmers' decisions in light of variations in climate and other forces is based on a survey of 120 farm operators in southwestern Ontario. Many farmers were affected by variable climatic conditions over a six-year-period, and some undertook strategic adaptations in their farm operations. Frequency of dry years was the key climatic stimulus to farming adaptations. However, only 20 percent of farmers were sufficiently influenced by climatic conditions to respond with conscious changes in their farm operations.

1. Introduction

The prospect of global climatic change has prompted interest in the sensitivities of ecological and economic systems to environmental variations. Climate represents a powerful environmental constraint on many human activities. Among the most frequently cited human systems likely to be affected by climatic change are agriculture and food production. For example, the objectives of the United Nations Framework Convention on Climate Change (see Article 2) include as a key element: "... to ensure that food production is not threatened. . ." (UNEP, 1993, p. 5).

Impacts of climatic change on agriculture have been estimated in a variety of ways, ranging from analyses of effects on agro-climatic conditions and crop growth at the plant and plot scale, through assessments of impacts on regional food production and economic returns, to studies of implications for crop choices, international trade, and public policies. For the most part, agricultural impact studies have focused on crop yields and production assuming a changed climate. Increasingly, the importance of human adaptation and the effects of non-local and non-climatic forces have been recognized, and captured in impact studies usually via assumption and simulation (Rosenzweig and Parry, 1994; Darwin et al., 1995).

Yet a recognized weakness in climate impact studies generally is the limited understanding and treatment of human adaptation, not only to scenarios of changed average climatic conditions, but also to variability in climate, to climatic conditions other than temperature and precipitation, and to forces in addition to climate

which will influence responses in the 'exposure unit' (Carter et al., 1994).* The IPCC assessment and synthesis notes that impact projections are difficult because of climatic uncertainty, the limited understanding of critical processes, and the influence of multiple environmental and non-environmental factors; and very few impact studies have considered the evolving responses of systems.

Two established bodies of research are helpful in addressing these needs, particularly in the case of agriculture. Farming systems research has provided much useful information on the nature and dynamics of agricultural production systems and their responses to variable and uncertain conditions (Flora, 1992; Ikerd, 1991; Turner and Brush, 1987). Natural hazards research has also explored the way in which people perceive environmental conditions and adapt to them (Burton et al., 1993; Kunreuther and Slovic, 1986; Palm, 1990). One of the broad aims of this paper is to illustrate the way in which the concepts and methods from these fields can contribute to climate impact assessment by identifying actual adaptations in farming to climatic variability. This knowledge can then be used to better estimate responses to future climatic variation and changes.

This paper has three main parts. First, climate impact research in agriculture is briefly reviewed to highlight some research needs. A conceptual model of agricultural adaptation to climatic variations is then presented to illustrate the connection between climatic and other forces of change in agriculture, and the role of farmer decision making. This framework then guides an empirical analysis of farmers' responses to climatic variations in southwestern Ontario, within the Great Lakes region of North America.

Thus, the paper explores adaptations to variations in climate. By examining human responses which conventionally are assumed in climate impact work, the analysis represents an 'interaction approach' rather than a scenario-driven 'impact approach' (Kates, 1985; Parry and Carter, 1988; Carter et al., 1994). Furthermore, agriculture is taken to mean more than simply crop yields and production; also included is the structure of farm operations which evolve over time, and which, in aggregate, become regional agricultural systems (Smit and Smithers, 1993). In this sense, the paper builds on Parry's (1986) conceptualizations of climate change and human development.

The empirical analysis in this paper deals not with hypothetical climate change nor with assumed behaviours, but with actual farmers' experiences with climate, and their responses to climatic conditions relative to other factors which influence their decisions. A distinction is drawn between, on the one hand, *effects*, which are the direct and short-term consequences of a climatic condition, and on the other hand, *responses* and *adaptations*, which are purposeful or conscious decisions taken in reaction to effects, and which alter the nature of farming and regional agricultural systems. The adaptations examined in this paper are those made by

* Terms such as *exposure unit*, *effect*, *impact*, *adaptation*, *sensitivity* and *vulnerability* are used in this paper in a manner largely consistent with the definitions in the Intergovernmental Panel on Climate Change (IPCC), especially the Technical Guidelines (Carter et al., 1994).

farmers and sometimes called 'autonomous' or 'spontaneous', to distinguish them from adaptations to climate which are initiated or prompted by public policy (Carter et al., 1994; Smit, 1993).

2. Developments in Research on Climate and Agriculture

Conventional approaches to climate impact assessment make bold assumptions about climate and human responses. Assumptions are a necessary element of analyses attempting to isolate the effect of a particular force of change, in this case climate. The studies to date in agriculture have addressed the basic questions first, such as impacts on crop growth and productivity (Smit et al., 1988; Warrick et al., 1986). But to provide credible assessments of the implications of climatic variation for agricultural systems and food production, these assumptions need to be examined (Parry, 1986; Riebsame, 1988; Rosenberg et al., 1993; Smit, 1991). This brief review addresses assumptions pertaining to: climatic norms and variability, human responses to climatic stimuli, and the role of non-climatic factors.

2.1. CLIMATIC NORMS AND VARIABILITY

Most impact studies employ scenarios of climatic change, usually specifying 'norms' (representing annual means over several decades) for a limited set of climatic attributes, most commonly temperature and precipitation. Two issues arise from this. First, climate is inherently variable, with or without climate change. In the Great Lakes Basin, for example, the year-to-year variations in temperature (a range of almost 4 °C over a century) greatly exceed changes in norms commonly associated with global climatic change (less than 1 °C per century) (Figure 1). Further, agricultural systems, as with other human activities, evolve not in response to average conditions (B or C on Figure 1), but in response to variable and largely unpredictable conditions, including occasional extremes (A on Figure 1). With climatic change, the probability distribution of this variation may change, via a shift in the whole distribution and/or with a change in the shape of the distribution (Houghton et al., 1990; Parry, 1986). In any event, understanding responses in agriculture requires explicit attention to climatic variability.

This point has not gone unnoticed, and studies have assessed impacts under changing (mean) and variable (about the mean) climate (e.g. Brklacich and Smit, 1992; Mearns and Rosenzweig, 1994). One approach is to expand the range of scenarios and assess production impacts for mean conditions and for deviations from the mean. Wheaton et al. (1990) assess the impacts of an actual extreme (drought) year. Warrick (1984) superimposes the drought conditions of the 1930s on contemporary production patterns to assess production impacts. This employment of temporal analogues to capture climatic variability in the base scenario is a distinctive feature of the MINK study (Easterling et al., 1992; Rosenberg et al.,

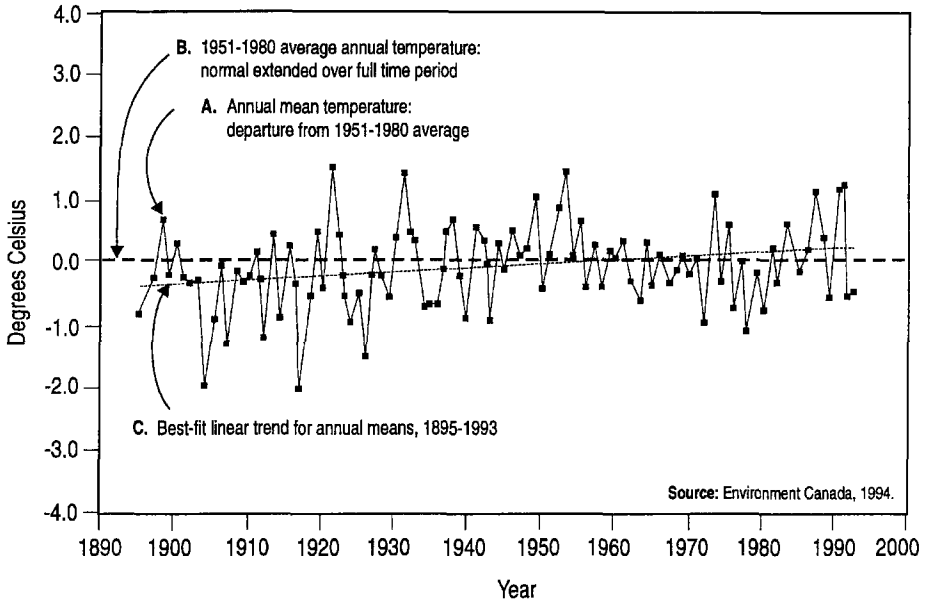


Figure 1. Annual temperature variations in Great Lakes Basin, 1895–1993.

1993). The IPCC Guidelines (Carter et al., 1994) outline several ways of specifying climate scenarios which include variability.

An additional argument for an improved consideration of climatic variability is its current relevance. For many people, including the general public in most countries and many government representatives in non-industrialized countries, long-term climatic change is not a pressing issue; not even a pressing environmental or climatic issue. To this large portion of the world's population the climatic change problem is considered rather esoteric relative to the current realities of climate, particularly the consequences of climatic variations as manifest in droughts, floods, starvation, mass migration, and political unrest. Such implications of climatic variations are obvious (and recurring) in parts of Africa and Asia, but they are also pertinent in other regions. For example, in North America, as governments attempt to reduce expenditures, the public costs of compensating property owners, farmers and transportation businesses exposed to variable climatic conditions are becoming an important political issue (Smit, 1993, 1994). Hence, understanding socio-economic sensitivities and adaptations to climatic variability is not only necessary for improved assessments of the implications of long-term global climatic change, but it is also relevant to current decisions on resource use and development in most parts of the world.

The second methodological issue stemming from climatic scenarios relates to the attributes of climate which are included in the scenario-based impact studies, and assumed to be necessary and sufficient to estimate agricultural sensitivities, impacts and responses. Scenarios based on global climate equilibrium models

focus on temperature and sometimes precipitation and direct CO₂ effects. Scenarios based on temporal analogues can consider a wider array of climatic variables. For example, the MINK agricultural study considers relative humidity, solar radiation, and windspeed (Easterling et al., 1992). These variables are chosen because they are assumed to be the pertinent ones, a reasonable assumption for estimates of annual crop yields. But whether these are the key climatic stimuli to changes in farm practices remains to be explored. Annual production levels reflect not only the effects of seasonal agroclimatic conditions on crop yields but also the strategic decisions made by farmers earlier, such as what crops to produce in the first place (Parry, 1986).

Little is known about the climatic conditions (or combination of conditions) which prompt changes in the ongoing nature and management of agricultural systems (as opposed to crop yields). Conditions other than seasonal heat and moisture may be important, such as frost severity and timing, frequency and return period of dry spells, moisture accumulation, or isolated events such as hail or severe wind. The magnitude and frequency of extreme climatic events are increasingly recognized as relevant (Burton et al., 1993; Changnon, 1989; Parry, 1986; Smit, 1993), but little is known about the properties of extremes and variations which prompt changes in human systems. Does a single drought year generate the same response as two or three drought years? Does the return period influence adaptations to such conditions? There is a need to better understand the responses of agricultural systems to climatic variations, including identifying (rather than assuming) the climatic attributes to which farmers are sensitive and adapt.

2.2. HUMAN RESPONSES TO CLIMATE

Most research about climatic impacts on agriculture deals with biological processes and effects, especially estimating crop yields under specified conditions. To the extent that implications for production levels, land use patterns, economic returns, or management practices are considered, it is usually via assumptions of one kind or another. Thus, estimates of spatial shifts in agricultural zones (Blasing and Solomon, 1983; Carter et al., 1991; Rosenzweig, 1985) implicitly assume that widespread changes in crop choice are somehow made. Studies which link biophysical models with economic models to assess impacts on production, economic returns, and regional employment (e.g. Parry et al., 1988; Arthur and van Kooten, 1992) also make assumptions about farmers' decisions as to what to produce and how. Most of the early impact studies presumed no adaptations in land use and management practices, invoking what has become known as the 'dumb farmer' assumption (Easterling et al., 1992a; Rosenberg, 1986; Smit, 1991).

In recognition that farmers are likely to modify their operations in light of changed conditions, more attention has been given recently to adaptive responses to climate-related yield changes (Brklacich and Smit, 1992; Kaiser et al., 1993; Klein et al., 1989; Darwin et al., 1995). The MINK study explicitly assumes managerial

responses to climatic change, even to the point of distinguishing between short-term and longer-term cumulative responses (Easterling et al., 1993). These and other studies recognize the distinction between an *effect* (e.g. change in yield given a chosen crop and management system) and *response* (e.g. a decision to change a crop or management system). To illustrate the importance of this distinction, if no one is growing corn in a region at the time a climatic change is assumed, then information on corn yield effects under the changed climate is not very helpful in assessing food production impacts. Assessments of climate-change impacts must include consideration of responses as well as effects.

To date the consideration of farmer responses and adaptations has been largely by assumption. The MINK study includes scenarios in which 'smart' farmers are assumed to adapt to the changed climate (Easterling et al., 1992b). However, there has been very little analysis of how farmers actually respond, adapt, or adjust, to changed climatic conditions. A recent selection of assessment methodologies (Carter et al., 1994) shows modelling, expert judgement, and qualitative estimates as the predominant methods, with only one empirical analysis listed (Parry et al., 1988). In effect the 'dumb farmer' assumption has been replaced by the 'clairvoyant farmer' assumption (Smit, 1991), wherein farmers are presumed to accurately perceive the future climatic conditions and adapt their farm types and production practices accordingly.

Few impact studies have explored actual or reported adaptive responses to climatic perturbations in agriculture or other sectors. In particular, the distinctions between short and long term, consequential and purposeful, tactical and strategic, autonomous and planned adaptations (Carter et al., 1994; Smit, 1993) have rarely been addressed empirically. To improve estimates of climate impacts on agriculture there is a need to know more about how farmers perceive climate and how they respond, in both the short- and long-term, to variable climate conditions, including the magnitude and frequency of extreme conditions.

2.3. ROLE OF NON-CLIMATIC FACTORS

Another important development in impacts research relates to the assumption that all conditions other than climate remain constant, or 'everything else remains equal' (Timmerman, 1989). The assumption is adopted to isolate the influence of climate, but it serves to discount the role of economic, cultural, government, technological or environmental forces which may amplify, negate or otherwise modify impacts of climate on agricultural systems. This point is often recognized, and is addressed explicitly in several modelling studies. At the farm and regional levels, factors such as commodity demands, land supply, and environmental policy have been captured via constraints in programming models (e.g. Kaiser et al., 1993; Klein et al., 1989; Smit et al., 1991). The MINK study pursues this issue assiduously by predicting economic and technological conditions for the year 2030 in the absence of climatic change as an alternative basis for assessing impacts (Easterling et al., 1993). Global

equilibrium models of food production have incorporated such factors as changes in demand, commodity prices, and trade (Kane et al., 1992; Liverman, 1986, 1987; Rosenzweig and Parry, 1994; Darwin et al., 1995).

These increasingly comprehensive modelling analyses incorporate non-climatic factors in a similar manner to the treatment of adaptive responses, that is via assumption. The focus is on demonstrating the potential influence of these forces and adaptations. Few studies have examined the actual role of climate relative to other forces, or in conjunction with other forces, in prompting farmers to alter aspects of their farm operations (Downing, 1992). The situation is complicated by the fact that these other forces – economic, technological, environmental, socio-cultural, and government – are often as variable and unpredictable as climatic conditions (Smit, 1994).

The remainder of this paper explores, first conceptually and then empirically, the influence of climatic variations, together with non-climate forces, on the nature of farming systems. The empirical analysis examines the experience of farm operators as reported by the farmers themselves, and is guided by a conceptual model of agricultural adaptation to climatic variations. This descriptive model draws on ideas from several areas of scholarship, including farming systems, natural hazards, decision-making, and innovation adoption.

3. A Model of Agricultural Adaptation to Climate

Individual farm operators decide on what to produce and how to produce it – strategic decisions – in light of a suite of external or exogenous forces (Figure 2), most of which are variable and uncertain. At the time farmers make these strategic decisions they do not know for certain the climatic conditions, prices and costs, government programs, and so on which may influence the outcomes. Furthermore, there is variation among farmers in their perception of, and sensitivity to exogenous forces, according to the particular characteristics of individual farms, farm operators and farm families (Figure 2).

After the farmer has decided on certain products and inputs, the growing season's conditions are reflected in yields and levels of production (Figure 2), the focus of much impact research. These represent direct *farm effects* or consequences, which may be translated into economic terms by incorporating input costs and commodity prices. The economic impact of growing season conditions will also be influenced by prices and by government programs, such as *ad hoc* drought relief or compensation (Smit, 1994). In commercial economies it is this overall economic effect which is most likely to stimulate changes in farming systems.

These effects – of climatic conditions together with economic, government and other conditions – may prompt *farm responses*, of which two types are frequently distinguished. Short-term decisions to help cope with or mitigate an impact, sometimes called 'adjustments' (Burton et al., 1993; Easterling et al., 1992), are here

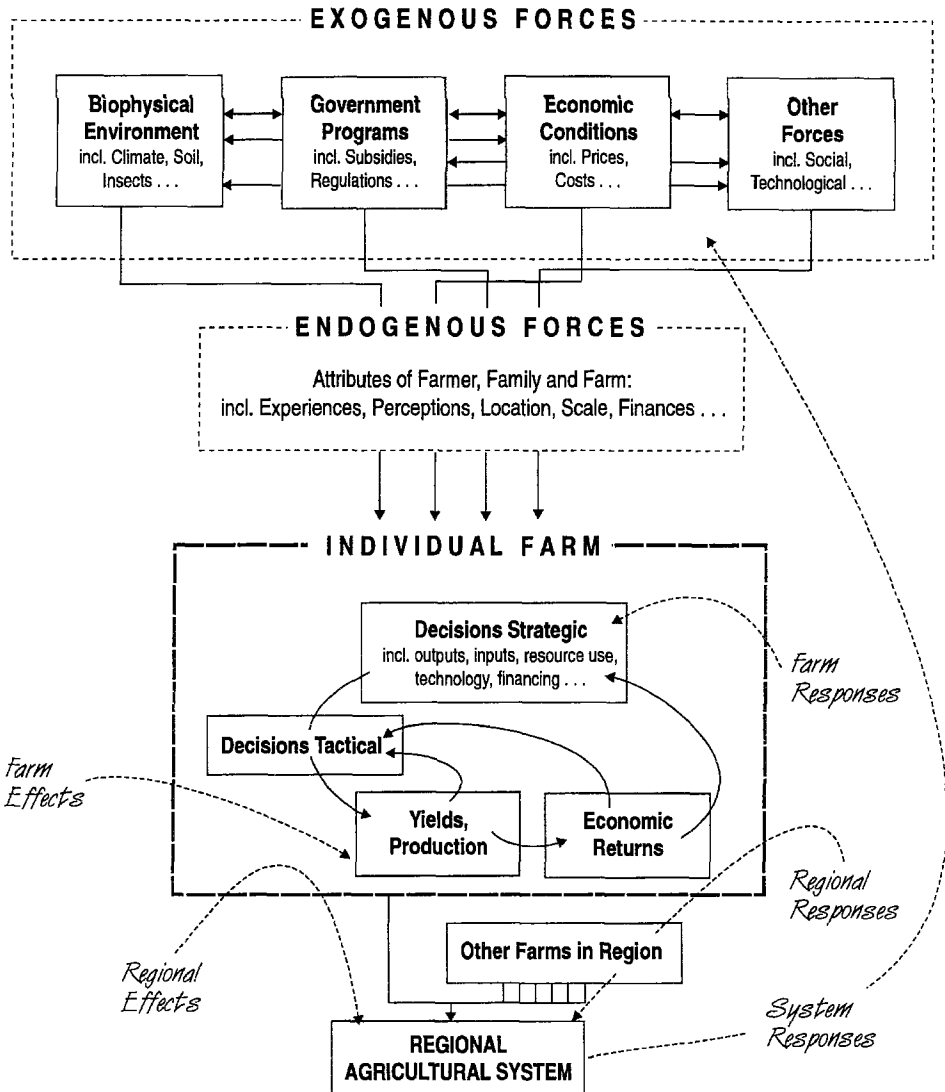


Figure 2. Conceptual model of agricultural adaptation to climatic variation.

termed *tactical* responses. Those which involve longer-term commitments, perhaps changing a feature of the farm operation, such as type of crop or livestock or management system, and sometimes called ‘adaptations’, are here termed *strategic* responses. These are responses which result in observable changes in a farming system beyond a single season.

It is possible to aggregate production or economic effects over all farms in a region to calculate a *regional effect*, which is what many hierarchical or nested analyses of agricultural impacts do (e.g. Smit et al., 1989; Williams et al., 1988; Wheaton et al., 1990). When many farms in a region undertake strategic responses

or adaptations, a change in the regional agricultural system (*regional response*) becomes apparent (Figure 2). Regional responses can be categorized further as 'purposeful' (e.g. result of many farmers deciding to change crops, to adopt irrigation, or invest in crop insurance) or 'incidental' (e.g. result of some farms becoming insolvent and the land abandoned or sold to new or neighbouring operators who may use the land differently). In the latter case the regional agricultural (incidental) response or adaptation is different from the simple aggregation of individual purposeful adaptations (Smit, 1993). Regional effects and responses are not simply a scaling-up problem. Studies of agricultural innovation and diffusion have demonstrated the roles of social networks and media in influencing the speed and spatial extent of regional changes in farming practices (Ilbery, 1985).

Responses, both short- and longer-term, may also occur beyond the farms in the region. The effects (and/or responses) on farms in a region may have ramifications for broader economic conditions, technology development or government programs (see Figure 2). Common examples are commodity price responses to regional crop failures or booms, and the implementation of *ad hoc* government compensation or relief (a short-term, tactical *system response*) or ongoing government incentives, such as subsidized crop insurance (a longer term or strategic *system response*). Other feedbacks could be added to the model, such as the implications of regional differences in production effects for interregional trade and hence for prices and government programs (Reilly, 1994; Darwin et al., 1995).

Notwithstanding its simplicity, the model indicates that to better estimate climate impacts on regional agricultural systems and production, there is a need to understand changes made by farmers and the reasons for those changes. The remainder of this paper reports on an analysis of farmers' decisions in light of variations in climate and other forces. The analysis serves to illustrate how some of the concepts outlined above might be explored empirically.

4. Methodology

Investigations of agricultural effects and responses in the past can take various forms. Historical analyses have considered effects and aggregate regional responses (de Vries, 1985; Parry and Carter, 1985; Riebsame, 1990). The experiences of the drought conditions of the 1930s in the U.S. Great Plains have provided some insights into aggregate system adaptations (Borchert, 1971; Butzer, 1980; Lockert, 1981). Warrick (1980) examined changes in sensitivity to drought stresses over a 90-year period in the American mid-west. This analysis suggested that crop production sensitivity had not changed, but that farm enterprises were less vulnerable because of various farm and societal buffering strategies. These analyses are at the aggregate, regional scale, and over time periods which precluded behavioural investigations.

The research approach employed here examines perceptions and decisions of individual farmers. It builds on the 'temporal analogy' scholarship (Glantz, 1991), the 'natural hazards' literature (Burton et al., 1993), and the 'behavioural' tradition in agricultural geography and rural sociology (Green and Heffernan, 1987; Saari-nen, 1966; Smit and Smithers, 1992). It focuses on human responses to biophysical effects, and does so via a survey of farmers. By analyzing changes reported by farm-ers, and the reasons behind these changes, we should learn something about how farm operators are affected by, and respond to external forces, including climatic variations.

4.1. STUDY AREA

The survey was conducted in the southern Ontario portion of the North American Great Lakes Basin for the period 1986–1991. In order to have some control over variations in farm types but still allow for differences in climatic experiences and sensitivities, and for logistical reasons, three townships were selected for the survey: Guelph in Wellington County, Fullarton in Perth County, and McKillop in Huron County (Figure 3). An analysis of crop insurance claims (a surrogate indicator for a wide array of agro-climatic conditions) showed considerable variation over the period for the counties of the study area (McNabb, 1992). The years 1986, 1988 and 1989 tended to be less climatically favourable for agriculture than the other three years, and sensitivity seemed to decrease somewhat from west to east. A pre-survey indicated that drought, ('dry spells' or insufficient moisture) represented a widespread climatic condition of significance to farmers in this region over the past decade, and is given particular attention in the survey.

Data from weather stations in or adjacent to one of the townships (Figure 4) show that two commonly measured agroclimatic indicators (growing season precipitation and Corn Heat Units (CHU), a measure of heat availability) varied annually both within and beyond the study period; but they also show that these conditions varied remarkably from location to location within the study area. For example, 1986 was particularly wet for two sites, but not for the third located less than 30 kilometers away. Similarly, the temporal variation in CHUs over the study period differs from location to location. Not only are we not aware of which climatic attributes are important for farmer adaptation, but even if these were known, the spatial variability in conditions means that an extreme year at a measuring station may not be an extreme year on many farms.

The farms in the study region are generally mixed grain and/or livestock operations (McNabb, 1992). All three townships have significant proportions of farms classified as mixed grain and livestock, cash grain, cattle, hogs, and dairy operations. There is as much variation in farm types within the three townships as between the townships.

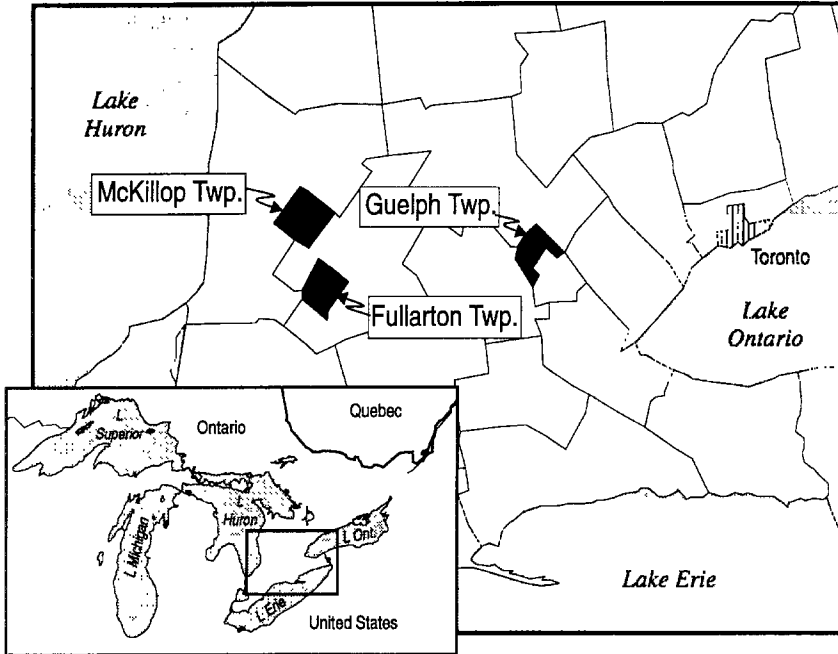


Figure 3. Study area and sample townships.

4.2. QUESTIONNAIRE DESIGN

The survey was based on a questionnaire, administered by personal interview, to a random sample of farmers from the three townships. This method was adopted to ensure an acceptable response rate and to facilitate collection of detailed information which is rarely feasible via telephone or mail surveys (Sheshkin, 1985). The survey depended upon respondents being able to recall past conditions and their effects and responses, so the study period was limited to 5 years. A pre-test comparison with documented evidence (crop types and areas, livestock numbers, fertilizer inputs, etc.) showed that farmers were able to accurately recall this information for the previous five years.

The questionnaire included open and categorized questions, based on a carefully designed and pre-tested structure (McNabb, 1992). The researchers' interest in climate was not revealed to respondents at the outset, in order to avoid bias in identifying the relative role of climate in influencing farm changes. Sample farmers agreed to participate in a survey of "farm management decisions over recent years in light of external economic, environmental and policy conditions" (McNabb, 1992).

The Questionnaire had 7 parts:

- (A) General information on the farm operation – helped establish rapport with respondent, and provided data to compare farms.

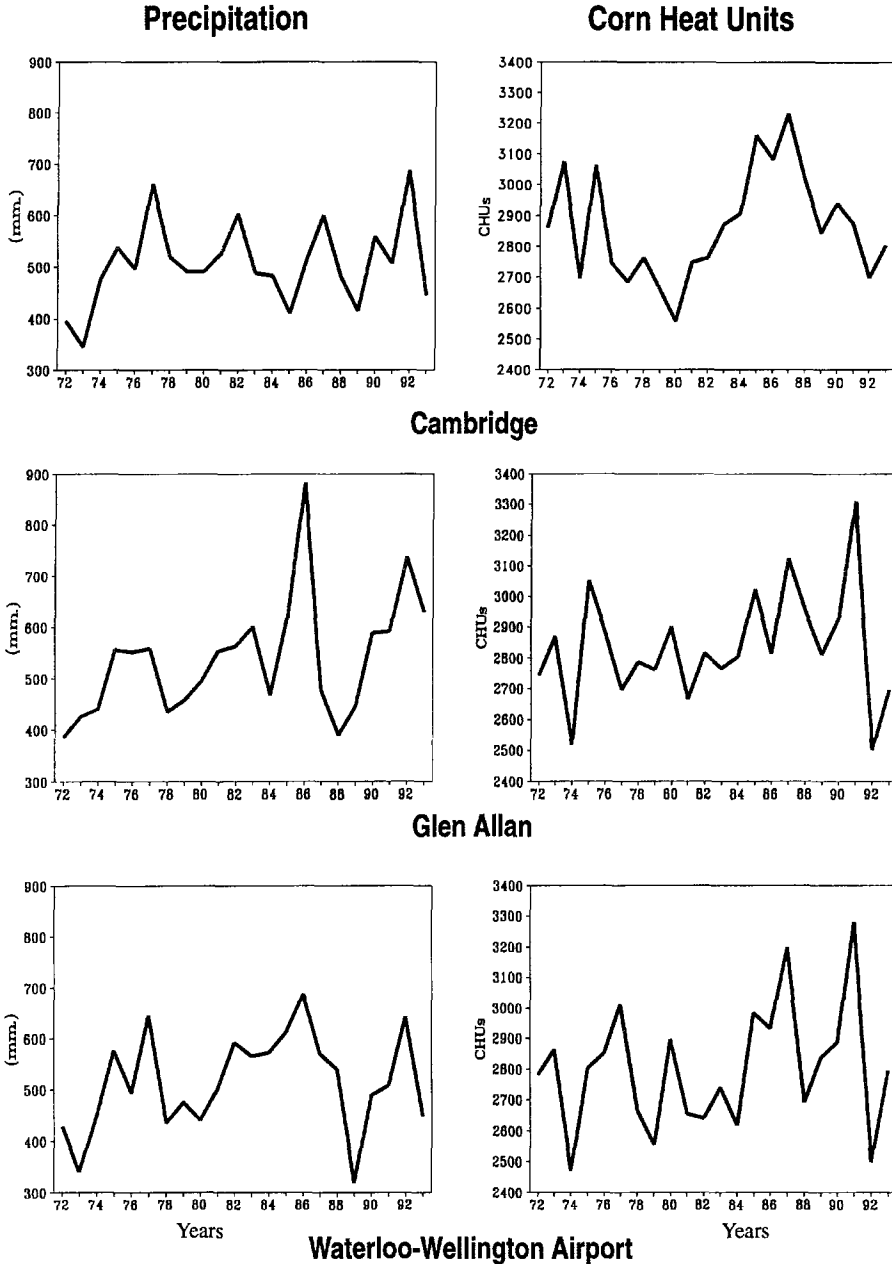


Figure 4. Growing season conditions for 3 stations, Guelph township, 1972–1993.

- (B) Changes undertaken in the last 5 years – identified types of changes implemented over a 5-year period, regardless of the motivation or force of change.
- (C) Forces of change over the last 5 years – explored the role of all forces of change, and only at the end focused on climate and dry years.

- (D) Climatic conditions (dry years) experienced in the last 5 years – examined perception of moisture conditions.
- (E) Responses to climate (dry years) in the last 5 years – documented responses to drought conditions; can be compared to answers in (B).
- (F) Future adaptation to scenarios – explored hypothetical responses.
- (G) General information on farm and farmer – facilitated analyses of responses relative to farm and farmer characteristics.

The analysis in this paper employs data from all parts except (F), which deals with hypothetical future conditions and responses.

4.3. SAMPLING FRAME AND QUESTIONNAIRE ADMINISTRATION

A list of all farmers was identified from municipal office records for each Township: 125 in Guelph, 255 in Fullarton and 291 in McKillop. A stratified random sample was drawn, with replacement (mainly for ‘farmers’ who were not *bona fide* farm operators), resulting in 40 respondents for each township. The survey process involved an introductory letter, a telephone call to confirm participation and set up a visit, and the interview proper. The survey was undertaken in the summer of 1991, so that the results pertain to production years 1985–1990 inclusive. The interviews were administered by two researchers who participated in questionnaire pilots and trials to ensure consistency.

5. Results

5.1. FARM CHANGES AND FORCES OF CHANGE

In what ways do agricultural systems evolve over time? Respondents were asked to identify as many changes in their farm operations as they could recall for each of the 5 years, regardless of the reasons for the changes. Approximately two thirds of farmers reported at least one significant change in their farm each year, and about half of these reported more than one change each year (Table I)*. Many of the changes identified were essentially consequences or effects rather than purposeful, tactical or strategic decisions (Table I). The most common of these consequential changes was a reduction in farm profit.

Of the changes which represent conscious adjustments or purposeful adaptations to the farm operations, changes in enterprise type were increasingly frequent (Table I), including types of crop, mix of livestock, or the enterprise mix of the farm operation. Some farmers expanded or reduced the size of their operations. Changes in management practices were quite common, including changing infrastructure, adopting new technology or equipment, or altering the amount or type of inputs

* Results are consistent across townships throughout the analyses unless otherwise stated.

Table I
Changes in farm operations by year^a

	1986	1987	1988	1989	1990
Number of respondents reporting at least one change	98	95	103	103	107
Consequential changes	68	69	72	72	73
Purposeful changes					
Enterprise type	28	33	44	63	58
Size	12	5	—	5	17
Management	38	36	36	47	47
Financial	9	6	5	9	9
Other	—	6	11	7	17

^a Numbers may not sum because respondents may report more than one change.

such as fertilizers, pesticides, or feed. Financial changes included refinancing debt or modifying participation in government stabilization programs.

These results show that farm operations are far from static over a 5-year period. Seasonal effects were reported, but these were rarely expressed as changes in yield, rather, as changes in farm profit, even though this was commonly associated with changes in yields. Furthermore, the nature of agriculture does not change with these consequential effects. Changes in the nature and distribution of farming systems (and subsequently, general patterns of agricultural production) occur via strategic decisions which may be stimulated by consequential effects.

The reasons given for the changes reported above are summarized in Table II. Personal reasons, such as health or age, prompted some of the changes. Of the forces exogenous to the farm family, economic reasons were clearly the most commonly cited. Environmental reasons included climatic conditions as well as pests, diseases and soil conditions. Policies of government, especially incentives and grants, also prompted some changes.

However, the categories of Table II are not always distinct, in that 'economic' reasons are sometimes also 'environmental' or 'policy' in origin. Thus, a poor crop because of growing season conditions results in reduced gross and net income and prompts a change which is reported for 'economic' reasons. Similarly, some government programs including incentives and subsidies, are manifest to the farmer as economic stimuli, and reported as such.

An alternative approach to identifying the roles of exogenous forces involved asking farmers about specific forces: in turn, which economic, technological, government policy and environmental conditions prompted changes in farm operations over the study period? The results (Table III) show that economic conditions (prices, costs, etc.) are certainly a powerful force, but technology (equipment, hybrids, management techniques), public policies (programs, incentives, regula-

Table II
Reasons for changes in farm operations

Reason	Percent of respondents reporting reason ^a
Personal	11
Economic	61
Environmental	20
Policy	4
Other	9

^a Annual average 1986–90, $n = 120$; frequencies are stable over the period. Numbers do not sum to 100% because respondents may report more than one reason.

Table III
Forces of change in farm operations

Force	Percent of respondents reporting a change prompted by force ^a
Economic	72
Technological	58
Policy	47
Environmental	47
(Climate)	(15)

^a At any time over the study period; $n = 120$.

tions, taxes), and environmental conditions (weather, soil, disease, pests) are all important forces underlying farm-level adaptation, and hence changes in regional agricultural systems.

Among the environmental forces of change, diseases and pests were noted most frequently (21% of respondents). Climatic conditions were identified by 15% of respondents as prompting changes in their farm operations over the study period (Table III). These results indicate that farmers are indeed sensitive to climatic stimuli, farmers do make strategic changes in farm operations in response to climatic conditions, but the effects of, and responses to climate are interdependent with economic, technological and policy forces.

5.2. SENSITIVITY TO CLIMATIC CONDITIONS

What particular climatic conditions or events are problematic for farm operations? Responses to this open-ended question showed that moisture conditions, specifically drought and excessive rain, were the key variables in the study region (Table IV).

Table IV
Climatic conditions problematic for farming

Condition	Percent of respondents identifying conditions (<i>n</i> = 120)
Drought	58
Excess rain	58
Hail	8
Frost	7
Wind	3
Other	11

Hail, untimely frost, and excessive wind were also identified, but less frequently. These results were generally consistent across the 3 townships and across farm types, although excessive rain was more frequently a problem for cash crop and mixed farms than for livestock operations.

It is notable that growing season length, heat or solar radiation (the more commonly analyzed variables in scenario-based crop impact studies) were rarely identified. This may be because the broad thermal constraints are recognized in enterprise selection, and/or the more temperature-sensitive crops such as grain corn and soybeans are less dominant in the study area than further south and west (Smithers, 1994). This result may also follow from the thermal conditions not varying as much as moisture over the study period.

Table V lists those characteristics of farms identified as being vulnerable to climatic conditions, both generally and to the particular condition of drought. Crop yields are clearly the predominant vulnerability, but crop quality, livestock productivity and quality, and input costs (e.g. purchase of supplementary feed) represent characteristics of farm operations which are sensitive to climate and have been affected in dry years. Table V also presents reported 'impacts' of dry years, based on a question asked elsewhere in the interview. The congruence in results between these questions suggests that farmers were consistent with their responses and that the results are reasonably robust.

It is noteworthy that not all farmers reported their crop yields as being vulnerable to climatic conditions, and to drought in particular, even though irrigation is rarely practised in the study area. This result might be explained by farmers not having recently experienced adverse climatic conditions, some livestock farmers not relying on climate-sensitive crops, or farmers already factoring the possibility of such conditions into strategic decisions (e.g. purchase of crop insurance is interpreted by some farmers as reducing or removing their vulnerability to drought).

It is also noteworthy that while high proportions of respondents identified climatic conditions which were problematic ($\approx 60\%$, Table IV) and vulnerable to

Table V
Vulnerability to, and impacts of climate and drought

Characteristic	Percent of respondents identifying characteristic as vulnerable (<i>n</i> = 120)		Percent of respondents identifying impact (<i>n</i> = 120)	
	To climate	To drought	Of dry year	Impact
Crop yields	73	53	76	Reduce crop yields
Crop quality	15	8	8	Reduce crop quality
Livestock productivity	17	14	10	Reduce livestock productivity
Livestock quality	17	13	9	Reduce livestock quality
Input costs	12	8	24	Increase input costs

climate (>70%, Table V), only a modest proportion indicated they had made farm changes in response to climate (15%, Table III). This suggests several possibilities:

- farmers experience effects of climate, but simply absorb them (“bear the losses”, Burton et al., 1993), and do not make strategic changes in their operations in response;
- problematic climatic conditions are translated into economic stimuli, so that changes are attributed to economic rather than climatic forces; and/or
- the effects of climate are swamped by those of variations in costs, prices, public programs, technology, etc.

A series of statistical analyses (cross tabulations, contingency analysis and chi square tests) of sensitivity to climate (i.e. was climate reported as prompting a change or not) revealed that differences in sensitivity were not systematically related to commonly considered attributes of farms (e.g. location, farm type, size), and farmers (e.g. family experience, part-full time, farm organization membership) (McNabb, 1992). There is some evidence that younger farmers are more sensitive, perhaps because of less experience with climatic variations or because of different perceptions of climatic probabilities. Perception is recognized as an important filter between environmental hazards and behaviour (Parry, 1986; Whyte, 1986).

Table VI shows that farmers’ perceived experience with dry years varies greatly, even within a township. Whereas some farmers felt there were no dry years in the last decade, numerous neighbours identified 4 or 5 dry years in the last 10. A contingency analysis, based on Table VII, shows that farmers who perceived 2 or more dry years in the decade were significantly more sensitive to dry years than those who perceived zero or 1 dry years in the decade. Because of the considerable spatial – as well as temporal – variability in drought conditions, it is quite likely that farmers’ perceptions of dry-year frequencies reflect their actual experience,

Table VI
Perception of dry year frequency, last decade

Dry year frequency	Percent of respondents			
	Guelph twp. (<i>n</i> = 40)	Fullarton twp. (<i>n</i> = 40)	McKillop twp. (<i>n</i> = 40)	Total (<i>n</i> = 120)
0	28	5	5	13
1	15	18	30	21
2	30	53	28	37
3	15	15	25	18
≥ 4	12	9	12	11
Mean dry year frequency	1.7	2.3	2.2	2.0

Table VII
Respondents by sensitivity to drought and drought perception

Sensitive to drought ^a	Perception of dry year frequency ^b					
	0 or 1		2 or more		Total	
Yes	18	45%	53	66%	71	59%
No	22	55%	27	34%	49	41%
Total	40	100%	80	100%	120	100%

^a Respondents who identified drought as a problematic climatic condition.

^b Number of dry years identified over the last decade.

and it is this, rather than other attributes of farms and farmers, which underlies variations in sensitivities to climate.

5.3. RESPONSES TO DRY YEARS

Most farms sampled were affected by dry conditions during the previous 5 years (81% reported at least one dry year impact). Farmers were asked to describe changes, if any, they had made in response to dry periods. The intent was to focus on purposeful responses to the climatic condition. Two thirds of farmers indicated they took no action in specific response to dry years (Table VIII). Of course, 13% of farmers had not experienced dry years, and about 20% had not experienced any impacts of dry years, so a response to dry years might not be expected from them. Yet, approximately half the farmers experienced at least one dry year impact but reported no purposeful response. Presumably, for these farmers the climatic effects were not of sufficient magnitude or were compounded or outweighed by other forces.

Table VIII
Responses to dry years

Response	Percent of respondents (<i>n</i> = 120)
Nothing	66
Tactical only	13
Strategic	21

Of those who did report a purposeful response (34%), some (13%) noted relatively short-term, managerial adjustments only, here called tactical responses, such as reducing inputs (e.g. fertilizer or pesticides on crops suffering from moisture stress), buying-in feed, or selling some livestock as a temporary adjustment to dry conditions. A little over 20% of all farmers indicated a purposeful, strategic response to dry years, resulting in changes for subsequent years. These included changes in the nature of the farm operation such as in crop or livestock types or combinations, and in land use or tillage practices.

Variations in farmers' propensities to respond (either tactically or strategically) were not significantly related to the attributes of farms and farmers (McNabb, 1992). However, propensity to respond to dry years was significantly related to farmers' perceptions of dry-year frequencies. Of farmers who perceived that the last decade had less than 2 dry years, only 15% responded with changes in farm operations. Of those who perceived 2 or more dry years in the decade, 43% undertook purposeful responses. This result is consistent with Table VII and shows that frequency of dry years is an important climatic stimulus to farming adaptation in the study area.

6. Conclusions and Discussion

The empirical analysis addresses only some of the questions raised earlier in the paper. It demonstrates one way of improving our knowledge of the processes of adaptation to climatic variability. This study shows that climatic variations can have widespread agricultural effects (seasonal yields and economic returns), and that these are sometimes reflected in conscious decisions, both tactical responses to cope in the short term and strategic responses to adapt for subsequent seasons. However, in this study only a relatively small proportion of farmers were sufficiently influenced by climatic stimuli over a 5-year period that they responded with strategic changes in their farm operations.

Studies like this one are relevant to the assumptions inherent in climate impact assessments. The results suggest a need to review assumptions that farmers do not adapt to climatic variation or that seasonal production effects represent the essence of agricultural impacts. The study also raises questions about assumptions that farmers spontaneously or autonomously adapt to changes in climatic conditions.

Certainly, there is evidence for adaptive behaviour (20% of farmers adapted in some way to dry years over a 5-year period), but there is less certainty about the key climatic stimuli and the associated adaptive responses.

In this study, moisture appeared to be an important climatic attribute for farming, particularly the frequency of dry years. Farmers reporting more frequent recent experience with dry years had a greater tendency to respond strategically. But we are still a long way from identifying response thresholds and from identifying characteristics of farms and farmers which can account for variations in sensitivities and responses.

The conceptual model proved helpful in interpreting results from the survey, particularly in distinguishing effects and responses, and in unravelling exogenous and endogenous forces of change. Improvement in our comprehension of the human dimensions of climatic change and variability requires further development and empirical testing of such models, not only at the level of individual farmers, as in this study, but also at levels which are more aggregate spatially (e.g. examining responses at a regional scale) and which consider a longer time period than 5 or 10 years. While respondent recall becomes a problem beyond 5 or 10 years, analyses over longer periods may be necessary to capture a sufficient variation in climate (particularly frequency and magnitude) for thresholds to be exceeded and for strategic responses to be expected.

This study also illustrates that the role of climatic variations in prompting changes in agriculture cannot be understood without careful consideration of the role of other forces – economic, policy and environmental. It is not just that these influence the setting within which climate effects are felt, nor just that they provide adaptation options. These forces are inexorably intertwined with climatic forces such that it is very difficult to separate impacts or to ascribe independent stimuli for adaptations. This has implications for integrated regional impact studies. One important type of integration which has been little explored to date involves the interaction of climatic and non-climatic conditions to influence individual behaviour and system dynamics. Certain non-climatic forces (economic or government policy) may magnify or moderate or nullify a climatic effect, and this may greatly influence the nature (or occurrence) of responses. There is a need for integrated assessments to identify, rather than simply assume, significant interactions among forces and responses.

Acknowledgements

This research was supported by the Great Lakes – St. Lawrence Basin Project of Environment Canada; the Social Science and Humanities Research Council of Canada; the Ontario Ministry of Agriculture, Food and Rural Affairs; and the Eco-Research Program of the Tri-Council of Canada, via the Agroecosystem Health Project at the University of Guelph. The authors also gratefully acknowledge Philip

Keddie, Christine Kuisma, Robert Blain, Carol Hart, Marie Puddister, anonymous reviewers, and the farmers of southwestern Ontario who generously gave of their time and information.

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(Received 28 February 1995; in revised form 11 January 1996)