Transforming Farm Management
For an Uncertain Climate and Energy Future

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Climate change preparedness makes good business sense

The climate is always changing, but the pace of change projected for this century is far beyond what any previous generation of farmers has had to face. Today's farmers cannot rely on historical climate "norms" or calendar dates for making agronomic decisions such as when to plant, what crop to grow, or how to grow it. Farmers will be on the front lines of coping with climate change, but there will be cascading effects beyond the farm gate and throughout regional and national economies. While climate change will create unprecedented challenges, for high latitude regions like Eastern Canada and the Northeastern U.S., there are likely to be new opportunities as well, such as developing new markets for new crop options that may come with a longer growing season and warmer temperatures (Hoffmann and Smith 2011).

Taking advantage of any opportunities while minimizing the adverse consequences of climate change makes good business sense, but this will require new decision tools for strategic adaptation. Adaptations will not be cost- or risk-free, and inequities in availability of capital or information for strategic adaptation may constrain effective preparations for climate change by some farmers (Adger et al. 2007).

Another challenge for farmers today is rising and/or fluctuating energy costs, and future energy supplies and policies that are difficult to predict. Currently there is enthusiasm about unconventional fossil fuels, such as shale oil and hydrofracking for natural gas, but these have environmental costs and may not reduce local energy costs. Many farmers are responding by improving the energy efficiency of their operations, and exploring alternatives to fossil fuels, such as wind, solar, and biofuel crops. Improving nitrogen fertilizer use efficiency turns out to be important because fertilizer cost is tightly linked to energy prices, and excessive applications increase the release of nitrous oxide (N_2O), a very potent greenhouse gas. Fortunately, there are many win-win approaches to farming that make sense economically, address concerns about greenhouse gas emissions, and improve resilience to climate change. Many farm best management practices for greenhouse gas mitigation and soil carbon sequestration coincide with a conservation agriculture approach to farming (e.g., rotation with legumes, reduced tillage, winter cover cropping), which builds healthy soils, and can increase crop productivity and resilience to climate change if properly implemented (Hobbs and Govaerts 2010).

Decision Making Under Uncertainty

Climate change assessments often assume farmers will accept climate change information or experience and make so-called “autonomous” adaptations (those using existing knowledge and technology, Easterling et al. 2007) accordingly. However, inequities in adaptive capacity, and the multitude of uncertainties that a farmer must weigh in making management and capital investment decisions may preclude or prevent timely adaptation. Also, it has become increasingly apparent that individual perceptions and engagement with climate change are inevitably filtered through personal experience and pre-existing cultural worldviews and value systems (Wolf and Moser 2011).

Before a farmer will consider adaptation they must first be convinced the climate is indeed changing. Detecting a climate “signal” against the background “noise” of weather variability is often difficult for climate scientists as well as farmers. A recent survey of close to 5000 farmers in the Midwest U.S. (Arbuckle 2012) found that 66% believed climate change was occurring, 33% thought this was due equally to human and natural causes, and 25% attributed it to mostly natural causes.

Projecting the future climate has inherent uncertainties associated the climate model assumptions and calculations. One of the largest sources of uncertainty, however, is whether or not humans will act meaningfully to develop energy solutions that reduce future greenhouse gas emissions and limit climate change. Collectively, these uncertainties fuel the public debate about how serious the threat is, and what type of adaptation or mitigation cost today is warranted to avoid negative economic costs in the future. Some farmers are more concerned about the policy reaction to climate change than they are about the threat of climate change *per se*. The debate has become highly politicized, making it difficult for farmers, the public, and policymakers to sort through the information for decision-making purposes.

Adaptation Strategies

One general approach to farm management suggested for an uncertain climate is diversification (Reidsma and Ewert 2008). In a diverse system, if one crop or planting date or management approach does not do well due to weather in a given year, all is not lost, and it is even possible that another crop or planting date on the farm may benefit and compensate for losses. The logic seems clear, but empirical evidence of the success of this approach is sparse. A more optimum strategy would be to target a specific agronomic and land management approach for a given climate change or weather forecast, but for this to be successful many of the uncertainties discussed above must be minimized.

Adaptation strategies have been reviewed in detail elsewhere (e.g., Easterling et al. 2007; Wolfe 2013; Wolfe et al. 2011). A few key categories are discussed briefly, below.

Shift/Diversify Planting Dates, Crops, and Crop Varieties

Among farmer adaptation options, an earlier planting date can be an effective, low-cost option to take advantage of an earlier spring and longer growing season,including possibly double-cropping or expanding the use of winter cover crops.. Certainly, as seasons get longer producers may be able to switch to longer season varieties, with greater yield potential, or plant several varieties that mature at different times during the growing season. Planting date shifts can also be used to avoid crop exposure to anticipated adverse weather (e.g., high temperature stress, low rainfall), assuming the timing of adverse events can be predicted. When uncertainty is high, staggered planting dates may be an effective strategy. However, some farmers are taking the opposite approach, and buying new planting equipment that will allow them to seed more acreage at a single planting date in order to establish crops quickly during short windows of time when soil and weather conditions are ideal for germination. Predicting the optimum planting date for maximum profits will be very challenging in a future with increased uncertainty regarding climate effects on not only local productivity, but also on supply from competing regions. Farmers will need to project their harvest dates in relation to the supply/demand in the market place and effects this has on market prices.

Varieties with improved tolerance to heat or drought will be available for some crop species. New molecular-assisted crop breeding strategies may provide new genetic types more tolerant of environmental stress and pests and pathogens. To date, many such efforts have focused on a few high-caloric major world food crops such as rice and corn, while high-value fruit and vegetable crops important to many the agriculture economies of Eastern Canada and the Northeastern U.S. have received less attention. Diversifying or even intercropping with a combination of crops with varying heat and drought tolerance capacities may be a viable strategy for some that could allow at least reasonable yields under a much wider range of conditions.

There are a number of situations in which changing varieties or crops might be an expensive or ineffective strategy. An obvious case is perennial fruit and nut crops, where changing varieties is extremely expensive and new plantings take several years to reach maximum productivity. Even for annual crops, changing varieties is not always a low-cost option. Seed for new stress-tolerant varieties is sometimes expensive or regionally unavailable, new varieties often require investments in new planting equipment, or require adjustment in a wide range of farming practices. Markets must be found for any venture with a new crop or crop variety. In some cases, it may not be possible to identify an alternative variety that is adapted to the new climate, *and* is also adapted to local soils and farming practices, *and* meets local market demand regarding timing of harvest and quality features related to cultural preference, such as size and color.

Improved Monitoring and Control of Pests, Pathogens, and Weeds

Farmers in many high latitude regions will experience new challenges with insect management, as longer growing seasons increase the number of insect generations per year, warmer winters lead to larger spring populations of marginally overwintering species, earlier springs lead to the earlier arrival of migratory insects, and the habitable range of some species moves northward (Hatfield et al. 2011; Wolfe et al. 2008).

Climate change has potential impacts on plant diseases through both the host crop plant and the pathogen. An increase in the frequency of heavy rainfall events projected for many regions will tend to favor some leaf and root pathogens (Garrett et al 2006).

The habitable zone of many weed species is largely determined by temperature, and weed scientists have long recognized the potential for northward expansion of weed species' ranges as the climate changes. The habitable zone of kudzu (*Pueraria lobata*, var. montana), an aggressive invasive weed that currently infests more than one million hectares in the southeastern United States, is projected to reach into the northeastern part of the country by end of century due to climate change (Wolfe et al. 2008). Many C_3 weeds have a stronger growth response to increasing carbon dioxide concentrations than most cash crops (Ziska and George 2004), and glyphosate (e.g., Roundup), loses its efficacy on weeds grown at the increased carbon dioxide levels likely to occur in the coming decades (Ziska et al. 1999).

An obvious adaptation to increased pest and weed pressure will be increased use of pesticides and herbicides, although this is an added financial burden, can lead to increased chemical loads to waterways, and for organic farmers, chemical controls will not be an option. Reduction in the negative economic and environmental impacts of a trend for increased chemical loads will require pre-emptive development of alternative non-chemical weed, insect and disease-control strategies, and/or development of new varieties with resistance or tolerance.

For animal agriculture, the challenges will be most extreme for species susceptible to parasites, such as sheep. For example, the sheep producers in Nova Scotia anecdotally report increasing problems with internal parasites over the past few years as winter temperatures have increased. While there are indications through modeling that control strategies can be successfully developed (Morgan and Wall 2009), it will be important to coordinate regional monitoring and assessment, and develop rapid response plans for managing parasites new to a region.

Those farmers who make the best use of integrated pest management (IPM), such as field monitoring, pest forecasting, recordkeeping and choosing economically and environmentally sound control measures, are most likely to be successful in dealing with a rapidly changing pest, disease, weed complex. Adaptive management is likely to involve increased investment in agricultural consultants and skilled employees by farms, as well as applied research and extension programs by universities and government agencies. Poor farmers and regions lacking funds to support IPM or similar programs will be increasingly at a disadvantage.

Water Management- drought

Even in many temperate humid regions such as Eastern U.S. and Canada, where growing season rainfall is not projected to decline, crop water demand (i.e., potential evapotranspiration) will increase with warmer summer temperatures and longer growing seasons, increasing the requirement for supplemental irrigation (Hayhoe et al. 2007; Wolfe et al. 2011). Irrigation systems are a relatively expensive option, and a challenge for farmers will be determining when the frequency of yield losses due to summer water deficits has or will become frequent enough to warrant such a capital investment. Improving soil water holding capacity through reduced tillage, and use of winter cover crops and compost or other organic amendments can buffer crops from short-term soil water deficits.

Water Management- flooding

Farms in some coastal zones and flood plains will be subject to increased frequency of severe flooding due to more extreme rainfall events, increased frequency of large near-shore storms and associated storm surges, and sea level rise. A more widespread problem that is observed across the Northeastern U.S. and Eastern Canada today is increased frequency of high rainfall events (e.g., more than 5 cm in 48 hours). This recent trend is projected to continue or become worse with climate change (Groisman et al. 2004). In addition to direct crop flood damage associated with anaerobic soils, negative economic consequences include: delayed spring planting and reduction in the growing season; lack of access to the field during critical periods for farm operations; soil compaction because of tractor use on wet soils; increased nitrogen fertilizer loss through nitrate leaching and greenhouse gas (N_2O) emissions; increased crop foliar and root disease; increased soil erosion losses; and increased runoff of chemicals or manures into waterways or crop-growing areas, with negative implications for human health (Hatfield et al. 2011; Wolfe et al. 2011).

Ditch or tile drainage systems are a relatively expensive option, and as in the case of decisions about investment in irrigation, the challenge for farmers will be determining when the frequency of yield losses due to flooding has or will become frequent enough to warrant such a capital investment. In extreme cases farmers may choose to abandon flood-prone fields, at least for production of high-value crops, and seek higher ground or better drained soils.

A low cost option that can buffer against minor or short-term flooding problems is to maintain or improve soil drainage by increasing soil organic matter. Also, maintaining vegetative cover year round with winter cover crops can minimize soil erosion losses during heavy rainfall events. Changing planting date to avoid wet periods (if they can be predicted) or switching to more flood tolerant crops or crop varieties will be other relatively low-cost options when and where available.

Frost and Freeze Damage Protection

Despite a well-documented trend for warmer winters and earlier springs across the globe, the risk of frost and freeze damage continue, particularly for perennial fruit and nut tree crops, with several damaging events in the past decade. For example, midwinter-freeze damage cost New York Finger Lakes wine grape growers millions of dollars in losses in the winters of 2003 and 2004 (Levin 2005). This was likely due to de-hardening of the vines during an unusually warm December, increasing susceptibility to cold damage just prior to a subsequent hard freeze. Another avenue for cold damage, even in a relatively warm winter, is when there is an extended warm period in late winter or early spring causing premature leaf out or bloom, followed by a damaging frost event, such as occurred throughout the Northeast in 2007 (Gu et al. 2008), and again in 2012 where apple, grape, cherry and other fruit crops were hard hit (Halloran 2012).

Strategies to avoid damage from spring frost events on perennial crops include careful site selection, heaters and overhead sprinklers, and air circulation with wind machines, helicopters, or other means. For midwinter freeze risks, approaches might include changes in winter pruning strategies and mulching to insulate the trunk of young plantings. New research will be required to integrate weather forecasts into early-warning systems for extreme events like hard freeze and spring frost events to help perennial fruit crop growers through a phase of climate change transition that may include increased frequency of winter cold-damage risk.

Improved Cooling Capacity of Livestock Facilities

Dairy milk production declines with even mild heat stress. Increased heat loads and increased numbers of insect pests such as flies associated with climate change will negatively affect dairy cattle operations in Eastern Canada and the Northeastern U.S. without adaptation (Wolfe et al. 2008). Alternative housing systems that reduce heat loads to individual animals and non-chemical means to control insect population growth can be adopted, although the costs and benefits of such strategies require that producers have effective decision-making tools to assist them. Certainly, new barns should not be designed based on the 20th century climate, but rather for the increased heat loads anticipated in the 21st century. A recent analysis suggested low-cost options for cooling, such as use of fans combined with sprinkler systems within barns, can pay for themselves and can be effective for moderate heat stress conditions (Wolfe et al. 2011)

Adaptations Beyond the Farm Gate

Climate change impacts on crops will have environmental, human health, and political ramifications that cascade beyond the farm gate. For this reason, adaptations that involve societal investment or private industry responses are also likely to be warranted. Smit and Skinner (2002) described a “typology” of agricultural adaptations that included technological developments, government programs, and farm household financial management, in addition to farm production practices. Below are some specific examples along these lines:

- *Technological/applied research developments* (e.g., crop and animal breeding for climate stresses, decision-support tools for farmer adaptation; new irrigation technologies)
- *Information delivery/extension systems* (e.g., delivery of real-time local weather data and weather risk forecasts for integration into farm-management; better integrated pest management (IPM) monitoring of potential invasives).
- *Locally-available design and planning assistance* for farmers or for water management in farm regions
- *Disaster-risk management and crop insurance.*
- *Financial assistance* (e.g., low-cost loans and cost-share programs for adaptation investments).
- *Major capital investments* at a regional or state level (e.g., new dams or reservoirs, new flood-control and drainage systems)
- *Policy and regulatory decisions* (e.g., to facilitate adaptation by farmers; to alter regulations; to create financial incentives for adaptation or mitigation investment; to stimulate local, renewable energy production).
- *Research investment on new crops, new pest, animal health & environmental control approaches, and water management strategies.*

Mitigation Strategies

Improving farm energy efficiency and increasing use of renewable energy sources buffers farmers from fluctuating and/or rising energy costs, and also reduces the farm's "carbon footprint". Many of the management options for greenhouse gas emission reductions are cost neutral or could potentially increase farm profits, while benefiting the environment and increasing climate change resilience (Wolfe 2013). Some of them involve increasing soil carbon sequestration, which not only plays an important role in climate change mitigation (Lal 2004), but also improves soil health, crop productivity, and resilience to climate change by improving soil drainage and water holding capacity (Hobbs and Govaerts 2010). Some key best management practices for mitigation are:

- *Improve energy efficiency*, and minimize use of synthetic fertilizers and other energy-intensive inputs to lower energy costs and reduce carbon dioxide emissions
- *Explore renewable energy options*, such as biofuel crops, biogas capture from manure waste, and wind and solar
- *Enhance ruminant animal digestion efficiency* to reduce methane emissions
- *Improve manure handling* and storage to reduce methane and carbon dioxide emissions
- *Improve integration of animal/aquaculture/cropping systems for capture and use of energy and nitrogen from waste products, and for integrating pest control solutions (e.g., Ogburn and White 2011)*
- *Improve nitrogen use efficiency* to reduce nitrous oxide emissions, and use organic sources of nitrogen such as legume rotation crops and manure when possible
- *Increase soil carbon sequestration* and improve soil health and crop productivity by building up soil organic matter through use of winter cover crops, use of composts and other organic matter amendments, and reducing tillage.

Priorities for Building Climate Change Resilience

First steps toward building resilience involve developing a clear vision for a successful agriculture sector in the context of a changing climate, and improving regional and bi-national networking to support and enable effective win-win adaptation and mitigation strategies. Farmers will need new technologies, crop varieties, and information that can reduce uncertainty about climate change, its impacts in the systems they are managing, and the effectiveness of adaptation and mitigation options. Below are some specific suggestions::

- *A bi-national institute for regional coordination.* Establish a binational institute (or other organizational structure) to: establish a vision for the region; identify research and organizational priorities; short- and long-term strategies; integrate and foster communication across disciplines, institutions, and with stakeholder groups; provide incentives and support for development of win-win adaptation and mitigation strategies, share information, new tools, technologies, and success stories.
- *Economic decision tools for strategic adaptation.* Develop decision tools for determining the optimum timing and magnitude of investments for strategic

adaptation to climate change for maintaining and maximizing profits over multiple planning horizons.

- *New tools for greenhouse gas management.* To improve mitigation efforts in the agriculture sector we need better tools for monitoring, accounting, and management of energy, carbon, nitrogen, and associated greenhouse gases.
- *Pest, parasite, and weed control*. Improve regional monitoring and IPM communication regarding weed, pest and parasite range shifts and migratory arrivals; enhance real-time weather-based systems for weed and pest control; develop non-chemical options for new pests and parasites; and develop rapid response action plans to control invasive species.
- *Water management.* Improve water delivery and management systems and irrigation scheduling technology in drought-prone regions. Identify options for flood-prone regions. Encourage soil-building management strategies that improve water holding capacity and drainage (an adaptation strategy for drought and flooding), and sequester soil carbon (a mitigation strategy).
- *New crop and livestock options.* Identify genetic traits important for the region in coping with climate change. Identify gaps in breeding efforts not being filled by the private sector. Help farmers evaluate new crop and livestock options in relation to the changing climate.
- *Communication.* Advances coming out of the social sciences on topics such as risk perception, cognitive and cultural barriers to effective decision-making under uncertainty, temporal discounting, participatory processes, equity, framing and story-telling should be taken into account in the design of effective communication about climate change adaptation and mitigation.

References Cited

Adger W.N., S. Agrawala, M.M.Q. Mirza et al. Assessment of adaptation practices, options, constraints and capacity. IN: Parry M.L., O.F. Canziani, J.P. Palutikof et al. (eds.) *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. Cambridge, UK.

Arbuckle J.G. 2012. *Climate Change Beliefs, Concerns and Support for Adaptation and Mitigation Among Corn Belt Farmers*. Iowa State University. Available on-line at www.sustainablecorn.org.

Easterling W.E., P.K. Aggarwal, P. Batima et al. 2007. Food, fibre, and forest products IN: Parry M.L., O.F. Canziani, J.P. Palutikof et al. (eds.) *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. Cambridge, UK.

Garrett K.A., S.P. Dendy, E.E. Frank, M.N. Rouse, S.E. Travers. 2006. Climate change effects on plant disease: Genomes to ecosystems. *Annual Review Phytopathology* 44: 489-509.

Groisman PY, RW Knight, TR Karl et al. 2004. Contemporary changes of the hydrological cycle over the contiguous U.S. : Trends derived from *in situ* observations. *Journal of Hydrometeorology* 5 : 64-85.

Gu L., P.J. Hanson, W.M. Post, D.R. Kaiser, B. Yang, R. Nemani, S.G. Pallardy, T. Meyers. 2008. The 2007 Eastern U.S. spring freeze: Increased cold damage in a warming world? *BioScience* 58(3): 253-262.

Halloran A. May 17, 2012. Growing uncertainties: climate change is forcing farmers in the Northeast to rethink their seasonal strategies. *Metroland News*. Albany, NY. http://metroland.net.

Hatfield JL, KJ Boote, BA Kimball, RC Izaurralde, D Ort, A Thomson, DW Wolfe. 2011. Climate impacts on agriculture: implications for crop production. *Agronomy Journal* 103:351-370.

Hayhoe K, C. Wake, T. Huntington, L. Luo, M. Schwartz, J. Sheffield, E. Wood, B. Anderson, J. Bradbury, A. DeGaetano, T. Troy, D.W. Wolfe. 2007. Past and future changes in climate and hydrological indicators in the U.S. Northeast. *Climate Dynamics* 28:381-407.

Hobbs P.R., B. Govaerts. 2010. How conservation agriculture can contribute to buffering climate change. IN: Reynolds M. (ed.) *Climate Change and Crop Production*. CABI, Wallingford, UK. Chapter 10.

Hoffmann MP and DL Smith. 2011. *Feeding Our Great Cities: Climate Change Opportunities for Agriculture in Eastern Canada and the Northeastern U.S*. Cornell University, Ithaca, New York and McGill University, Montreal, Canada.

Lal R. 2004. Soil carbon sequestration to mitigate climate change. *Geoderma* 123: 1-22.

Levin MD. 2005. Finger Lakes freezes devastate vineyards. *Wines and Vines*, July 2005 issue.

Morgan E.R. and R. Wall. 2002. Climate change and parasitic disease: farmer mitigation? Trends in Parastitology 25(7): 308-313.

Ogburn D.M and I White. 2011. Integrating livestock production with crops and saline fish ponds to reduce greenhouse gas emissions. Journal of Integrative Environmental Science 8(1): 39-52.

Reidsma P. and F. Ewert. 2008. Regional farm diversity can reduce vulnerability of food production to climate change. *Ecology and Society* 13(1): article 38, on line: www.ecologyandsociety.org/.

Smit B., M.W. Skinner. 2002. Adaptation options in agriculture to climate change: A typology. *Mitigation and Adaptation Strategies for Global Change* 7: 85-114.

Wolf J., S.C. Moser. 2011. Individual understandings, perceptions, and engagement with climate change: insights from in-depth studies across the world. *WIREs Climate Change* 2(4): 547-569.

Wolfe D.W. 2013. Contributions to climate change solutions from the agronomy perspective. IN: Hillel D. and C. Rosenzweig (eds.) *Handbook of Climate Change and Agroecosystems: Global and Regional Aspects and Implications*. Imperial College Press. London. Chap. 2, pp. 11-29.

Wolfe D.W., J. Comstock, A. Lakso, L. Chase, W. Fry, C. Petzoldt, R. Leichenko, P. Vancura. 2011. Agriculture. IN: Rosenzweig C., W. Solecki, A. DeGaetano et al. (eds.) *Responding to Climate Change in New York State*. pp. 217-254. New York Academy of Sciences. Blackwell Pub., Boston, MA. Chapter 7.

Wolfe D.W., L. Ziska, C. Petzoldt, A. Seaman, L. Chase, K. Hayhoe. 2008. Projected change in climate thresholds in the Northeastern U.S.: Implications for crops, pests, livestock, and farmers. *Mitigation and Adaptation Strategies for Global Change* 13: 555-575.

Ziska, L.H., K. George. 2004. Rising carbon dioxide and invasive, noxious plants: potential threats and consequences. *World Resource Review* 16: (4) 427-447.

Ziska L.H., J.R. Teasdale, J.A. Bunce. 1999. Future atmospheric carbon dioxide may increase tolerance to glyphosate. *Weed Science* 47: 608-615.