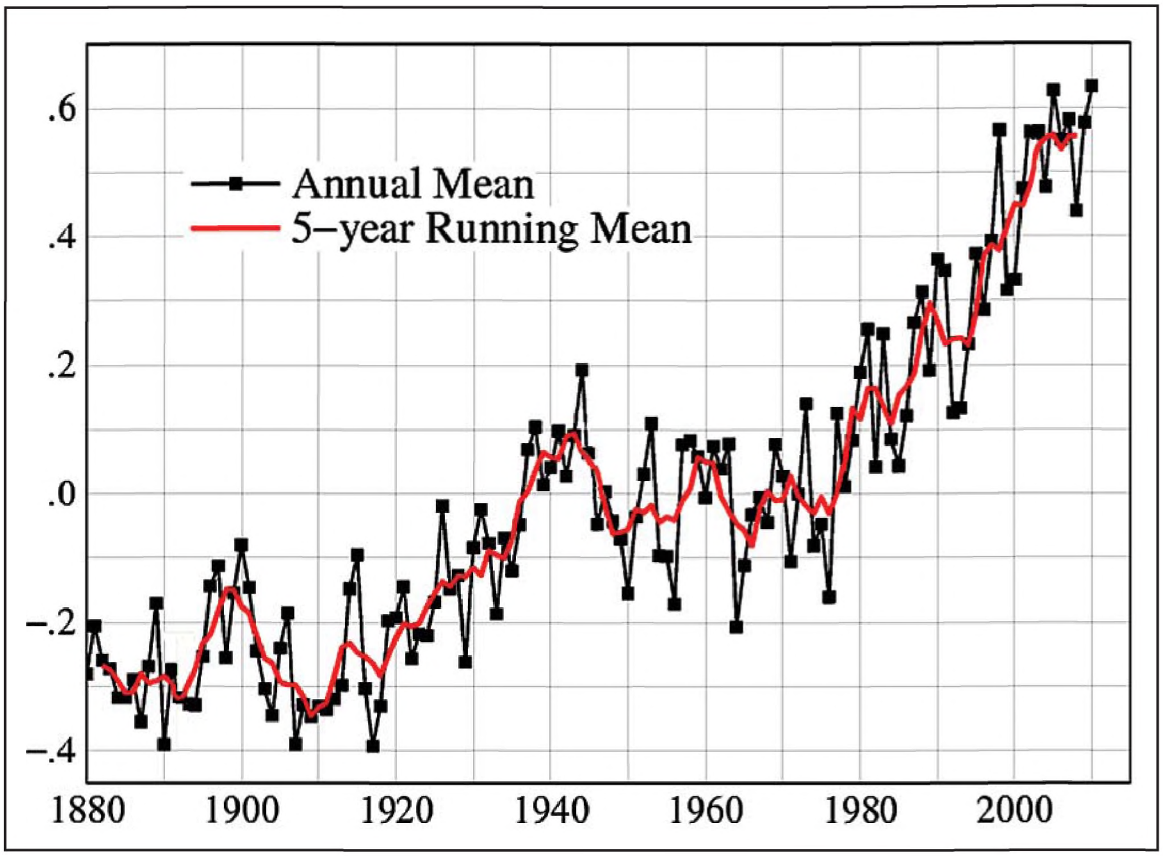
Agriculture and the Changing Climate[1,2]



Global annual and 5-year running-mean land-ocean temperatures
relative to the 1950-1980 mean.[3]

- *Climate change is occurring, e.g. Earth is warming*[2].
- *Over the past 50 years, global research investments to increase agricultural productivity have simultaneously reduced carbon emissions at low cost compared to prior periods.*[4]

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1 Eaglesham, A. and Hardy. R.W.F. NABC Report 21: Adapting Agriculture to Climate Changes. Ithaca. NY: National Agricultural Biotechnology Council (2009). http://nabc.cals.comell.edU/pubs/pubs_reports.cfm#nabc21.

2 National Research Council. Advancing the Science of Climate Change. Washington, DC: National Academies Press (2010).

3 NASA Goddard Institute for Space Studies. GISS Surface Temperature Analysis (2011). http://data.giss.nasa.gov/ gistemp/graphs/.

4 Bumey. J.A., Davis. S.J. andLobell, D.B. Greenhouse gas mitigation by agricultural intensification. PNAS 107(26) 12052-12057 (2010).

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Providing an open forum for exploring issues in agricultural biotechnology

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The National Agricultural Biotechnology Council (NABC), a consortium of twenty-five-plus major research and educational institutions in the United States and Canada, has developed *Agriculture and the Changing Climate.*

The report summarizes the information on agriculture and climate change as we know it to date, providing global and agricultural perspectives. Agriculture is a significant contributor to climate change and, in turn, is—and will continue to be—impacted by climate change. Agricultural mitigation and adaptation responses, focused on Canada and the United States, are outlined.

We welcome your comments.

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Introduction

Climate change is normal, but the rate of change in recent years exceeds normal and is posing risks and providing potential benefits for agriculture and other human and environmental systems. This report summarizes the information relating to agriculture, as we know it to date. It is provided primarily for agricultural stakeholders in Canada and the United States.

Since climate change is a worldwide issue, we start with a global perspective followed by an agricultural perspective. We conclude with a summary of agricultural mitigation and adaptation responses—focused on Canada and the United States—to ensure food security in a climate-changing world.

Global Perspective

Climate change is occurring, as indicated by increasing land-ocean temperatures (cover page). It is projected to not only continue, but accelerate if greenhouse-gas (GHG) emissions are not limited. Evidence includes:

- The Earth's average surface temperature increased by 0.8°C from 1880 to 2000; it has remained flat during the past 10 years; this plateau has been attributed recently to sulfur particles from coal burning in China. There are regional differences; for example, wanning to date has been less in much of the United States and Australia.[5]
- Associated changes include increases in frequency of intense rainfall, decreases in snow cover and sea ice, more heat waves, rising sea levels, and ocean acidification.
- Normal climate variability does not explain all of the recent warming trend.

Much of the warming during the last century can be attributed to human activity resulting in increases in GHGs from the burning of fossil fuels, coal, oil and natural gas, but agriculture—land-use change—urbanization and some industrial activities are contributory.

Positive radiative forcing[6] occurs from (in order of impact) anthropogenic carbon dioxide ($C0_2$), methane (CH_4), halo-carbons and nitrous oxide (N_2O), for which the level of scientific understanding is high. Negative forcing occurs from cloud cover and maybe sulfur particles, of which the level of scientific understanding is medium to low. The role of CO_2, CH_4 and N_20 in increasing water in the atmosphere with cloud formation adds to the complexity of the system.

Atmospheric $C0_2$ is the major GHG contributing to climate change. Having been stable at 270-280 ppmv from 1000 to 1770 AD, it has increased to almost 400 ppmv today; most of the increase was in the last 50 years. Of the net emissions of $C0_2$ from fossil-fuel combustion and land-use change, it is well established that -50% accumulates in the atmosphere and it is somewhat established that -25% is taken up by the oceans. However, the fate of -25% remains to be determined; some think that it is due to increased uptake of $C0_2$ in mid-latitude ecosystems. The CO_2 balance sheet needs to be completed. Are there other sinks for $C0_2$? Also, models projecting climate change need further refinement. Average warming trends of+0.25°C per decade, calculated by twenty-plus climate models, overshoot actual measurements of +0.07 to 0.20°C per decade.

Understanding how land and atmosphere exchange $C0_2$ is key to projecting future atmospheric CO_2 levels. Terrestrial gross primary production (photosynthesis) is being more accurately estimated, but the difference between the high and the low estimates is about four times the emissions of CO_2 from burning of fossil fuels. Further refinement is necessary to produce more reliable projections.

The systems affected by climate change are broad, including:

- Increasing sea-level rise and impact on coastal environments.
- Increasing ocean acidification.
- Altered freshwater resources.
- Altered ecosystems, ecosystem services, and biodiversity.
- Altered agriculture, fisheries and food production.
- Warming of soil and its increased respiration.

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[5] Lobell, D.B., Schlenker, W. and Costa-Roberts, J. Climate trends and global crop production since 1980. Science 333 (6042)616-620 (2011).

[6] Radiative forcing: the amount that the Earth's energy budget is out of balance.

- Negative impacts on public health.
- Altered urban environments.

Because of the breadth of the systems and of the impacts of climate change on them, integrated interdisciplinary and interinstitutional research efforts are needed. The recent USDA-NIFA grants of about $20 million each for adaptation research on com, wheat and trees by interdisciplinary teams is an encouraging model for providing solutions and improving understanding of the complex relationship between agriculture and climate change.

Agricultural Perspective[7]

Agriculture is a significant contributor to climate change, producing 13% of radiative forcing globally. Agricultural sources, such as animal husbandry, manure management and sod cultivation account for 52% of global CH_4 and 82% of N_20 emissions. Electricity generation, fertizer synthesis, equipment operation, and transportation by/for agriculture contribute CO_2. Deforestation and grassland conversion have been major contributors to atmospheric $C0_2$, *e.g.*, prior to the 1970s, agriculture released more CO_2 into the atmosphere than resulted from burning of fossil fuels. Globally, cropland increased from 265 Mha in 1700 to 1,471 Mha in 1990, and the area allotted to livestock grazing increased from 524 to 3,451 Mha within the same period. From 1990 to 2010, about 75% of $C0_2$ emissions are attributed to fossil-fuel use and 25% to land-use change. Recent land-use changes have occurred mainly in tropical rainforest areas, *e.g.* Brazil, the Congo and Indonesia.

The projected increase in world population (to 9.5 billion by 2050), the increased consumption of meat in the developing world *(e.g.* China) and the expanding use of biofuels will require major increases in total agricultural production, especially of crops. High-yield agriculture is a necessity so that forest and other non-agricultural lands will not need to be converted to agriculture with the attendant major emissions of $C0_2$.

North America has a major role in meeting world food/feed needs (protein, calories, *etc.)* in a time of climate change. A useful metric may be GHG emissions per unit of protein or calorie produced. Commodities may be produced in a region because its metrics of production, *i.e.* product per unit of protein or calorie, are advantageous. Technology to reduce agricultural GHG emissions should be shared globally.

The effects of farming practices on temperature in the Canadian Prairies exemplify a role of agricultural practices on climate. From 1950 to 1975, acreage under summer fallow increased and maximum average June-July temperature increased by about 2°C, whereas from 1995 to 2000 summer fallow acreage decreased and temperature decreased by about 2°C.

The effects of increased temperature and increased atmospheric concentration of CO_2 on crop production are expected to vary with crop and location. Elevated CO_2 should increase net photosynthesis, especially of C_3 plants but also of C_4 plants. However, stress resulting from increased temperatures may lower crop yields, except in the more northern areas of the United States and the Canadian Prairies. The combined effects of a 1.2°C rise and a 60 ppm increase in $C0_2$ to 440 ppmv were projected in 2008 to increase yields of soybeans by 9.9%, rice by 5.6%, cotton by 3.5% and wheat by 0.1%, but to decrease yields of sorghum by 8.4% and of com by 3.0%; subsequent projections are less positive.

Responses

To date, climate change in agriculture has been small in North America compared to the rest of the world.[8] This may explain why farmers in this region are not greatly concerned over climate change, but that could change. Global warming is associated with increased occurrence of extreme weather events, including hot spells and excessive rainfall causing flooding, which, depending on the time of year, could be challenging for crop production. Reducing net emissions of GHGs by crop and animal agriculture and by modification of the surface energy budget are the major agricultural opportunities to limit climate change. Both plant and animal systems need to adapt to the stresses from future climate change. Mitigation is desirable and adaptation is necessary for future food security.

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[7] Footnote 1.
[8] Footnote 4.

Mitigation

There are many ways in which plant and animal agriculture can reduce their GHG footprints. Various agricultural practices impact climate change. In most cases, these biochemical and biogeophysical effects are supportive, whereas in a few cases they are counteractive. The following plant-agriculture priorities—listed generally from the greatest mitigation of climate change to the least—include some that are win-win opportunities whereby both GHGs and production costs are reduced:

- Reduced dryland fallow.
- Reduced tillage.
- Better management of pests and pathogens.
- Increased water-use efficiency by crops, *e.g.* by irrigation management, plant genetics.[9]
- Fall planting and cover crops.
- Long stubble for snow trapping.
- Increased forage crops.
- Increased leaf albedo (less solar energy absorbed at the Earth's surface) by plant genetics.
- Increased biochar application. (Not yet proven for wide application.)
- Increased biofuel production. (Benefit varies depending on life-cycle analysis and use of existing agricultural land or conversion of non-agricultural land.)

Although the biochemical effect of deforestation increases climate change, a strong biogeophysical effect mitigates climate change. Some of the above information on mitigation is quantitative, whereas others are qualitative and research is needed to make them quantitative.

Although genetic, agronomic and husbandry improvements in the efficiency of crop agriculture and of animal and poultry production (dairy, meat, eggs) have reduced GHG emissions per unit of food produced, increased demands for these foods have reduced their overall favorable impact on climate. High-yield agriculture in the late 20th century reduced emitted $C0_2$ hugely—by 590 billion tons—about one third of the total emitted since the beginning of the industrial revolution. The important role of global agricultural research is revealed by the calculation that for every dollar spent on agricultural R&D from 1961 to 2005, $C0_2$ emissions were reduced by the equivalent of a quarter of a ton.[10]

Other opportunities to reduce GHGs, beyond high-yield agricultural systems, include:

- Improved efficiency of use of nitrogen to reduce fertilizer need and production of GHG-INO.
- Reduced CH_4 production by ruminants and paddy-grown rice.
- Reduced consumption of dairy, meat and egg products.
- Replacement of annual crops with perennial crops.

If mitigation does not produce a direct economic benefit to the producer—*e.g.* improved productivity—ethical considerations or economic incentives may be necessary to encourage mitigation practices. Such incentives might be viewed as public-sector reimbursement of growers for ecosystem services.

Adaptation

Agriculture must adapt to climate change to enable necessary yield increases to meet global food needs and biofuel production since the opportunity to expand acreage for agriculture is minimal. *NABC Report 21: Adapting Agriculture to Climate Change*[11] focused on this emerging area of agricultural research.

Genetic approaches, utilizing molecular and organismal (breeding) skills provide major opportunities. Efforts need to continue to further increase productivity per unit of input (acres, fertilizer, equipment, labor, fuel, *etc.)* or product (protein, calories, *etc.)* to produce 50% more product to feed 9.5 billion people by 2050 and also to produce biomass for biobased industrial products (fuels, chemicals, materials). Emerging research efforts need to be expanded to identify genetic, chemi-

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[9] NABC. Agricultural Water Security: Research and Development Prescription for Improving Water Use Efficiency, Availability and Quality. Ithaca, NY: National Agricultural Biotechnology Council (2010). http://nabc.cals.comell.edu/pubs/WATERandAGRICULTURE.pdf.

[10] Footnoted.

[11] Footnote 1.

cal, agronomic and engineering approaches to immunize crops to abiotic stresses (*e.g.* drought). Reducing large post-harvest losses is a major opportunity to meet the need for 50% more products.

Emphasis on soil needs to be expanded, including increasing organic matter, microbiological activity, water-holding capacity and nutrient retention. Methods of soil-carbon monitoring need to be improved as well as quantification of N_20 emissions. Efficiency of ruminant-animal agriculture may benefit from decreased CH_4 losses.

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This white paper summarizes the information on agriculture and changing climate to date. Global climate change is occurring with temperature rising more rapidly in the last 100 years than in the previous recent times. Anthropogenic $C0_2$ is the major GHG contributing to climate change, but CH_4 and N_20—originating mainly from agriculture—also contribute. Thus, agriculture is a significant contributor, but also will be impacted. Many opportunities are identified for mitigation and adaption by agriculture. Agriculture's record in mitigation (GHG products) over the past 50 years is spectacular with global research investments to increase agricultural productivity (high-yield agriculture) while decreasing carbon emissions at low cost.

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