Overview

Climate change will produce winners and losers in agriculture. Climate change impacts on subtropical and tropical regions will be predominately negative. Yields of major cereal crops (rice, wheat, maize, and sorghum) in the tropics and subtropics are expected to decline with an increase in temperatures as little as 1° C above 1990 levels, which could occur as early as 2030. Adaptation measures could offset some of the expected productivity decline from modest temperature rise, through warming of 3° C or more is likely to diminish the effectiveness of adaptation measures resulting in potentially significant losses of productivity in low-latitude regions. Moreover, sea-level rise threatens highly productive rice-growing megadeltas in Asia, and glacial retreat will eventually reduce the dry-season supply of glacial meltwater, an important source for irrigated agriculture in South and Central Asia, the Andean Region and Western China.

Agriculture in cold-limited (high latitude and high altitude) areas is expected to benefit from modest levels of warming that would effectively increase the length of the growing season. Regions that would benefit from a poleward shift in agriculture under future warming include northern China, northern Europe, northern North America, and the South American cone. However, agriculture in these areas will have to be carefully administered in order to efficiently manage water, especially in areas that depend on snowmelt, and to reduce risks from secondary climate change impacts such as those related to soil degradation and increased pest pressure.

Near and medium-term impacts of climate change on agriculture are more likely to arise from increased climate variability and extreme events, rather than from changes in mean climatic conditions. Potential manifestations of increased climate variability on agriculture include more extreme hot days during the growing season, a shift in precipitation towards heavier but less frequent rainfall events, and longer periods between rains, which, when coupled with increased rates of evapotranspiration under warmer temperatures, could increase moisture stress, especially in rainfed agriculture. The frequency and severity of extreme events are also expected to increase possibly resulting in record droughts, shorter return period for floods, and longer and more intense heatwaves. Indeed, recent climate trends indicate that the proportion of heavy rainfall events has increased and longer and more intense droughts and heatwaves have occurred.

While a warmer world will mean a wetter world, regions that are currently dry could become drier. Long-term regional shifts in precipitation patterns are expected to lead to an overall drying trend in the subtropics, including Southern Africa, Western Australia, West Asia, the Mediterranean Basin and parts of Central America. Intercontinental areas could also become drier. An overall increase in precipitation is projected for high latitude regions. Significant disagreement among climate models still remains regarding the long-term direction of precipitation for large areas of tropical South America, Africa and Asia. Across most land areas, precipitation is likely to become increasingly aggregated, with the possibility that wet years will become wetter and dry years drier, while the frequency of extreme wet and dry years is expected to increase.

Warming trends are expected to continue and possibly accelerate. Global average surface temperatures have risen 0.6° C since the mid-twentieth century and warming trends are expected to accelerate over the course of this century. By the end of this century, average summer temperatures could exceed what are currently the hottest summers on record. Heat impacts on agriculture will vary by farming system and region, with crops that are currently near climate thresholds expected to be the most impacted. For example, suitable zones for growing high-elevation crops such as coffee and tea could diminish or shift dramatically, and cereal production in the tropics will suffer. Earlier blooming of fruit trees will increase risks of blossom damage from spring frosts. Higher minimum temperatures are expected to reduce cold stress on livestock in temperate regions and significantly increase heat stress on livestock in sub-tropical and tropical regions.

Secondary (indirect) impacts from climate change, such as increased rates of runoff and soil erosion and increased damage from pests, could magnify production losses. Climate change is likely to accelerate soil erosion and land degradation due to shifts in rainfall distribution towards fewer and heavier rainfall events, increased wind velocity, loss of vegetative cover on degraded soils, and increased rates of soil organic matter mineralization. Increased pest (insects, pathogens, and weeds) pressure on agriculture is expected to occur as a result of range expansion of existing pests, invasion of new pests, and increased pest densities, combined with a potential narrowing of current pest management options. Observations of earlier insect emergence and expansion of pest overwintering ranges, provide early evidence that climate change is already intensifying some of these secondary effects.

Key indicators and measures

1. *Agricultural water use*
    a. Increasing drought risks in water-scarce regions could exacerbate competition for water resources between agricultural and nonagricultural uses. How might farming systems need to shift in response to climate change and competition from nonagricultural water users, especially where water is currently over-allocated?
    b. Shifts in seasonal water availability caused by reduced snowpack, earlier discharge of spring snowmelt or changes in rainfall patterns. How can the capacity to capture and store water for agriculture use be enhanced, and what are the implications of this for nonagricultural water use?

2. *Soil management*
    a. Soil erosion and runoff risks are likely to intensify with the increase in heavy storm events, and increased soil aridification in some regions. What is the scope for managing increased runoff/soil erosion risks through zero/conservation tillage systems in row crop agriculture, use of cover crops, and ground cover in perennial systems? What are the implications for managing weeds and soilborne diseases; for carbon sequestration and nitrogen management under conservation tillage?

3. *Pest management*
    a. Losses from current pests are likely to increase and new pest problems are likely to emerge. How can pest surveillance systems be improved? What is the scope for updating disease-forecasting models so as to account for nonlinear pathogen responses to temperature and changes in humidity?
    b. Management options could narrow. How can agricultural pest management respond to risks from, for example, major gene resistance breaking down under high temperatures, regional inoculum loads making field-scale pest management efforts less effective, herbicides potentially becoming less effective if weeds allocate more carbon to roots and nodules, increased density of overwintering inoculum resulting in early and more intense damage to crops?

4. *Temperature rise*
    a. Higher temperatures will present opportunities to increase food production in cold-limited environments. What is the scope for taking advantage of longer growing seasons? What new limitations or risks could emerge?

b. Heat stress on crops and livestock will increase in many systems. How will crop suitability change? What high-value crops are at risk from temperature rise? What is the scope for breeding for increased heat tolerance?

Data sources, potential and limitations

Regional downscaling of global climate models can simulate climate features down to about a 5 km square grid, and can thus provide data at relevant spatial scales to inform planning for the water and temperature indicators (1 and 4). However, regional climate models do not always adequately capture the full range of landscape-climate interactions, are generally not that robust with respect to changes in precipitation, and are prone to error propagation. An ensemble approach, in which information about future conditions is estimated from the mean of multiple climate models linked to a range of future emissions scenarios, provides a more robust analysis than reliance on one single model or emission scenario. Downscaled climate model data should be cautiously interpreted, given the limitations of the models themselves and the uncertainties about future emissions scenarios. Combining climate model outputs with data from other sources, such as regional water planning models, can help to inform a series of “what if” scenarios—what if the droughts periods are *n* years longer, if temperatures increase *n* degrees, if the flood return period is reduced by *n* years — can provide a means to focus planning efforts.

Coupled models, in which future climate parameters from a climate model are used to parameterize weather inputs to a crop or hydrology model can provide an estimate of potential impacts on crop yields or water resources (indicators 1 and 4). Also, recent progress in coupling climate models with soil erosion models has improved the capacity to estimate the impact of increased storm intensity and extreme events on soil erosion (indicator 2). While coupled models can approximate broad changes in production under current and future mean climatic conditions, they have limitations related to errors and uncertainties in climate models, and in the spatial scale mismatch between climate models and crop models. Additionally coupled models do not effectively simulate the influence of extreme events like flooding or wind damage on crop yields.

Pests: The response of pests (indicator 3) and their hosts to environmental change is complex, highly variable, and poorly understood, thus significant uncertainty exists as to the future impact of climate change on crop loss from pest damage. However, advances in mathematical models and in the use of molecular tools have helped to better identify the emergence of new pest problems, adequately differentiate pathovars and races, and monitor their movement in the landscape. Continued advances in linking remote sensing, predictive models, and GIS, as well as coupling of wind dispersal and crop models to track wind-dispersed spores, seeds and insects will be needed in order to better detect emerging pest threats, and predict where new threats may appear. The development of temperature- and moisture-based simulation models can also help to identify where shifts in pest range or intensification of pest damage are possible with climate change.

Data sources: Comprehensive global data sets for climate change and agriculture are limited. The FAO/IIASA’s Global Agroecological Zoning system is the most comprehensive, though it does not utilize dynamic climate modeling. Also, the FAO-administered Global Terrestrial Observation System and the Global Climate Observation System provide sources of comprehensive earth observing satellite data for monitoring the climate system that would have relevance to agriculture.

Conditions and trends in key indicators

On a global basis, climate risks to agriculture have increased over the past several decades as a result of increased climate variability and early climate change, as well as to a range of nonclimate factors—land degradation, simplification of agricultural systems, global movement of pests through agricultural trade, salinization and waterlogging of soils in irrigated agriculture, etc.—that heighten the exposure and risk of agriculture to the vagaries of climate. In this respect, climate change is likely to act as a push factor that could lower the threshold for a multitude of nonclimate stressors. For US agriculture, the time trend for key indicators 1 through 3 is from the present through the remainder of the century or longer, and indicator 4 is likely to become more prominent by mid-century.

Status of knowledge or ignorance

It is not possible to estimate the magnitude of future conditions or trends in the key indicators, only their likely direction. The highest certainties are that warming trends will continue and likely intensify and that extreme events, and seasonal and inter-annual climate variability, will increase. The knowledge base for these key indicators has improved in recent years, though significant knowledge gaps still exist. Moreover, the degree of uncertainty associated with climate change is vast, owing to uncertainties associated with future greenhouse gas emissions trajectories, nonlinearities in the climate system, and the potential for positive feedbacks and ‘tipping points’ in atmospheric, terrestrial, and marine systems that could accelerate climate change and amplify its impacts. Examples of positive feedbacks include warming trends that force terrestrial carbon sinks to flip into sources, which could accelerate warming and lead to even stronger feedbacks, and melting of permafrost with a subsequent release of methane and CO_2.