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Predicting the risks from climate change to forage and crop production for animal feed

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Implications

- Climate change is expected to bring warmer temperatures, changes to rainfall patterns, and increased frequency of extreme weather.
- Projections of climate impacts on feed crops show that there will likely be opportunities for increased productivity as well as considerable threats to crop productivity in different parts of the world over the next 20 to 50 years.
- On balance, we anticipate substantial risks to the volume, volatility, and quality of animal feed supply chains from climate change.
- Adaptation strategies and investment informed by high quality research at the interface of crop and animal science will be needed, both to respond to climate change and to meet the increasing demand for animal products expected over the coming decades.

Key words: animal feed, climate change, crops, maize, soybean

Introduction

There is increasing evidence from climate observations that the climate is changing. Global mean temperature has risen by 0.8°C since the 1850s, with warming found in three independent temperature records over land and seas and in the ocean surface water (IPCC, 2007).

Carbon dioxide (**CO_2**) levels in the atmosphere have gone up from about 284 mg/kg in 1832 to 391 mg/kg in 2012 (Tans and Keeling, 2012), mainly due to the burning of fossil fuels, with smaller contributions from land-use changes (IPCC, 2007). There is a clear theoretical link through fundamental physics between more greenhouse gases in the atmosphere and increased global warming. Thus, the IPCC concluded that "most of the observed increase in globally averaged temperature since the mid-20th century is very likely (more than a 90% chance) due to the observed increase in anthropogenic greenhouse gas concentrations" (IPCC, 2007).

So, climate change due to human activities is expected to bring warmer temperatures, changes to rainfall patterns, and increased frequency of extreme weather. By the end of this century, it is thought that global mean temperature will be 1.8 to 4.0°C warmer than at the end of the last one (IPCC, 2007). How will these future changes in climate impact forage, oilseed, and cereal crops grown for animal feed?

Impacts of Climate Variability and Change on Crops

Agriculture is inherently sensitive to climate variability and change, whether due to natural causes or human activities. Climate change due to emissions of greenhouse gases is expected to directly impact crop production systems for food, feed, or fodder; affect livestock health; and alter the pattern and balance of trade of animal products. These impacts will vary with the degree of warming and associated changes in rainfall patterns, and from one location to another, but underpinning these impacts are a number of direct effects on the physiology of forage crops grown for animal feed.

Increasing the concentration of CO_2, one of the main greenhouse gases, enhances the productivity of most crops due to enhanced rates of photosynthesis (Drake et al., 1997). This boost to productivity is apparent for all crops that use the C_3 photosynthetic pathway, such as wheat, barley, rice, and soybean. Reviews of hundreds of early plant studies found an average yield gain of 33% (Kimball, 1983) under doubled CO_2. And although there is some disagreement about whether the full extent of these benefits to crops can always be found under field conditions (Long et al., 2006), we can expect increasing CO_2 to benefit the productivity of most pasture grasses and feed crops such as soybean.

There are, however, a number of important crops that have a different response to increased CO_2. Maize, sorghum, millets, and sugarcane use the C_4 photosynthetic pathways (Drake et al., 1997). The leaf photosynthetic rates of C_4 plants are not substantially enhanced by elevated concentrations of CO_2; hence, yield gains in plants grown under elevated CO_2 are much more modest than for C_3 plants (Kimball et al., 2002). There is also a small improvement in how efficiently both C_3 and C_4 crops use water under enhanced CO_2 conditions (Drake et al., 1997).

Warmer temperatures affect the rate at which crops grow and develop and potentially the survival of plants and grain at extremes of temperature. The duration from sowing to flowering, and to crop harvest, is determined by mean temperature and daylength (Craufurd and Wheeler, 2009). As climate warms, the duration to harvest shortens, at least until a really hot optimum mean temperature is exceeded. So, in a warmer climate, generally we expect the areas where crops are grown to move northwards in the northern hemisphere. Farmers will most likely try to adapt to these

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changes by using new long-season varieties or different crops for their region. Where longer season varieties cannot be used, crop yields will decline with warmer temperatures. For example, an analysis of 20,000 variety trials of maize across Africa found that for each degree-day above 30°C, yields declined by 1 to 1.7% (Lobell et al., 2011). Some of the negative impacts of warmer temperature can partly be offset with a shift to adapted varieties (Easterling et al., 2007, Figure 5.2).

Extremes of hot temperature will become more frequent under climate change. Where hot days coincide with a sensitive stage of crop development, such as flowering, we find dramatic decreases in seed or grain yields because of disruption to pollination (Wheeler et al., 2000). For example, grain-set of rice cv. IR64 spikelet fertility was reduced by 7% for every degree above 30°C (Jagadish et al., 2007), and the grain-set of wheat declined above 31°C (Ferris et al., 1998).

Animal Feed Supplies

In this paper, we concentrate on forage, oilseed, and cereal crops grown for animal feed and exclude managed and natural pastures. Throughout the world, there are close links between animal and crop production, as both wheat and coarse grains (e.g., corn, barley, oats, sorghum, milo, and rye) are used extensively as high quality feeds for animals (Pond and Pond, 2000), particularly monogastrics such as pigs and poultry. Monogastric animal production typically uses dietary protein with a greater efficiency than ruminant production systems, primarily due to the digestive events occurring in the rumen. In some regions, these cereals are produced in excess of local requirements for human consumption, and thus are fed to animals, or they are produced specifically for use as animal feeds. In addition, processing cereal grains and oil seeds to derive foods for humans or biofuels gives rise to co-products of nutritional value to animals, which provides an outlet for their use, adds value to the crop, and is an efficient use of a potential "waste product" for producing animal-derived foods for human consumption.

Specific categories of animal feedstuffs include forages and roughages, the primary feeds for ruminants and high-energy and high-protein "concentrates," such as maize grain or protein meals derived from oil seed processing (e.g., soybean meal). Forages and roughages include grasses or legumes that are grazed or harvested and preserved as low-moisture hays or higher-moisture material that is preserved by ensiling. High-moisture silages include whole-crop maize or cereals, which are used extensively as feeds for ruminants in many regions. In addition, roughages would include numerous high-fiber co-products from cereal and oil seed processing, such as soybean or cottonseed hulls.

The most recent data from the United States Department of Agriculture (http://www.ers.usda.gov/data-products/feed-grains-database.aspx) estimated that globally ("foreign" plus US production) 1.149 billion metric tons of coarse grains such as maize, sorghum, barley, rye, and oats were produced in 2011 and 2012 and that 663 million metric tons were used for feed, which is 57% of the total. In some countries of sub-Saharan Africa where food insecurity is high, coarse grains remain important in direct human consumption, with up to 80% of the grain harvest consumed in this way (FAO, 2002). For wheat (Figure 1), which is more commonly grown for human consumption, 695 million metric tons were produced in 2011, of which 21% was ultimately used for animal feed.

The extent to which these crops are affected by adverse weather conditions varies considerably depending on the crop, soil conditions, and other regional factors. For example alfalfa (lucerne), with an extensive tap root, is more drought resistant than many grasses, but cannot be grown successfully in all soil types and climates. Major effects of climatic conditions such as water supply and temperature on crop quality are generally related to effects on the relative maturity of the plant at harvest, as well as the timing of the stress relative to the growth stage of the plant. As plants mature, the fiber content tends to increase as protein content decreases in leaves and stems while the starch, oil, and protein content of seeds increases. Of particular importance for herbivores is the degree of lignification of the fibrous material present, as lignified plant cell walls are generally less digestible and thus have a lower energy value, which limits production. In addition, less digestible material is more filling, which limits intake and thus further reduces rate of production compared with more digestible feeds (Van Soest, 1994).

Figure 1. In the United States, 695 million metric tons of wheat were produced last year, 21% of that ultimately being used for animal feed (source: Robert Couse-Baker).

The drought in the US has affected the quality of corn produced in 2012. Corn planted for grain production in many areas has typically not

Figure 2. Oil seed meals include soybean (above), rapeseed (bottom left), and cottonseed (bottom right). In 2011, soybean meal accounted for more than two-thirds of plant protein meal consumption in 2011 (source: Carol Von Canon; David Ian Roberts; Brian Hathcock).

reached maturity in terms of ear and starch concentrations. One option for farmers is to harvest the stunted plants and ensile them as a forage crop for ruminants, which can be sold to recoup production costs (http://msue.anr.msu.edu/news/harvesting_drought-damaged_corn_for_silage). Although lacking in starch content compared with “normal” corn silage, the plant may have greater sugar content and a more digestible fiber fraction. However, a concern is the potential for drought-stressed plants to have increased concentrations of nitrates, which can be toxic.

The prospect of higher grain prices due to reduced supply relative to demand is an obvious potential impact of climate change if crop production is negatively affected. As may well be the case in the US with the drought of 2012, projected reductions in grain supply affect the costs of animal production, not only through the price of grains and thus primary forage supply, but also through reduced availability and cost of co-products such as distillers’ grains from the biofuels industry.

Sources of protein in animal diets include animal waste products (e.g., meat and bone meal, blood meal, feather meal, fish meal, and whey) and plant proteins (e.g., oil seed meals), although costs and concerns over disease transmission have curtailed the use of animal proteins for animal feed in many countries. Oil seed meals, co-products of the extraction of oil for human consumption, include soybean, rapeseed (canola), cottonseed, palm, peanut, and copra, but soybean meal accounted for more than two-thirds of plant protein meal consumption in 2011, with 48% of soybean meal produced consumed by poultry and 26% consumed by swine (http://www.soystats.com/; Figure 2). This high rate of use of soybean meal compared with other protein meals reflects the fact that soybeans accounted for 56% of global oil seed production (452 million metric tons) as well as the nutritional value of soybean meal in animal diets. Soybean oil also accounts for 28% of vegetable oil consumption globally, second only to palm oil (33%) in terms of global utilization (151 million metric tons). Soybean production (Figure 2) and utilization has developed substantially in the last 60 years, and now soybeans represent a major export commodity, particularly for the US and Brazil (78% of all exports). In this regard, imports of soybeans into China have risen sharply in recent years, primarily to supply protein for animal production (Naylor et al., 2005)

Alternatives to soybean meal in animal diets include other plant protein meals, including algal protein and other developing products, but costs and nutritional value compared with soybean meal typically limit their utilization. Feeding of distillers grains, which are relatively high in protein, has increased with their availability as biofuel industries have developed in certain regions. Another alternative protein source in ruminant diets is urea and other non-protein N sources, which can be used for microbial protein synthesis in the rumen, but there are limits to their rate of inclusion in commercial rations, and thus other sources of protein are required for efficient rates of production to be achieved. This has led to even greater levels of protein feeding to dairy cattle, to ensure maximal production. In the future, if protein supplies are limited by availability and costs, then more precise feeding of protein to dairy cattle may be required. Alternatively, a reduction in the rate of milk production may be an inevitable cost associated with a more efficient utilization of dietary protein accompanying lower dietary protein concentrations.

Projections of Climate Risks to Animal Feed Supplies

Projections of climate risks and opportunities for feed crops require numerical methods to calculate the net effects of future climates on the crop physiological processes outlined in Section 2. For this, the output of climate models is combined with crop simulation models. This is not straightforward, however, because of: mismatches between the spatial and temporal scales of crop and climate models; the need for extensive input datasets to run projections over large areas; and uncertainties in future trends of greenhouse gas emissions, agricultural technology, and many other factors. Nevertheless, there are a range of research methods available that have been used to try to examine the impacts on crops of climate change over the coming decades. These include:

- downscaling climate projections using a weather generator to a particular location where you can run a detailed crop simulation model (e.g., Semenov and Porter, 1995);
- simplifying the crop simulation so that it can use climate model output for large regions or the entire globe (e.g., Challinor et al., 2004); or
- defining analog climates for crop regions in the future that match those found now (e.g., Jarvis et al., 2008).

No method is perfect and each has its own drawbacks and uncertainties, but we will use three examples of climate impact projections at different spatial scales (global, continental, and regional) for either maize or soybean to illustrate the range of impacts on animal forage crops that have been reported.

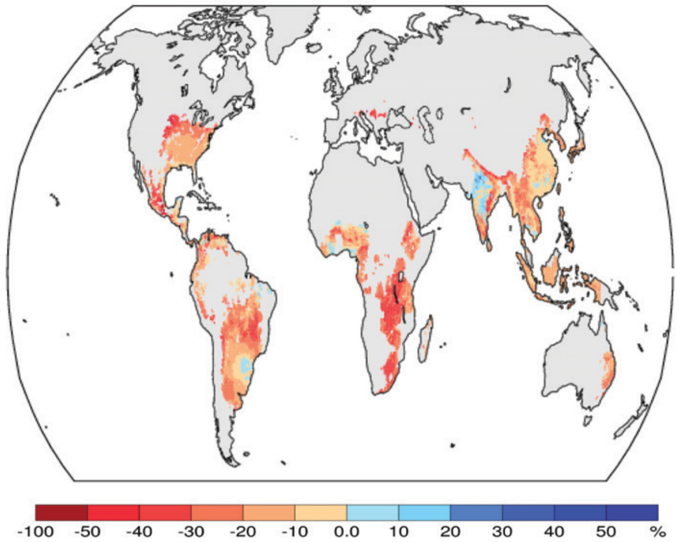

Figure 3. Projected changes in soybean productivity (%) from a baseline period of 1961–1990 to the year 2050 using the A1B greenhouse emission scenario with the CCCSR MIROC climate model and the GLAM crop model. Full details are found in Osborne et al. (2012).

Osborne et al. (2012) used a large-scale crop model with 14 climate models to investigate the impact of climate change on the global productivity of soybean in the year 2050 and how adaptation through planting improved varieties and changing sowing date could moderate the impacts of climate change. Impact on soybean yield varied among climate models and with adaptation scenario but ranged from -43% to +10% yield change across the full range. Changes in potential areas of production were found. Without adaptation, most impacts on yield were negative, with considerable spatial variation worldwide (Figure 3) and a large degree of uncertainty due to climate model (Osborne et al., 2012).

Knox et al. (2012) reviewed all studies to date of climate impacts on maize crops across Africa using systematic review criteria as a quality filter. A range of modeling methods, time periods, and ensemble size (from a single climate model to an ensemble of 20 or more climate models) were included. Maize yield declined by 7%, averaged across all time projections, from 2030 to 2100. There was considerable variation from one country to another, with 9 out of the 30 studies even reporting yield increases, mainly in East, West, and Northern Africa.

Finally, Jones and Thornton (2003) used high-resolution climate projections to study climate change impacts on maize yields across East Africa (Figure 4). They found that yield was projected to decline by 10% on average across the region by the year 2055. However, even on this fine scale, there was spatial variation in both the magnitude and sign of the impact of climate change on maize yields.

Synthesizing our understanding of the complex impacts of climate change on forage crops and cereals grown for animal feed across the body of the evidence is challenging. However, we propose five key aspects of the response of feed crops under climate change from studies to date:

a. There will be considerable **spatial variation** in the impacts of climate change on feed crop impacts. The expected impacts of climate change alter over time and vary from one part of the world to another. Many projections of feed crops under climate change

Figure 4. A young maize farmer in Ethiopia. The effects of climate change are projected to reduce maize yields across East Africa by 10% on average by 2055. (source: C. Robinson/CIMMYT)

find that the magnitude and sign of change in feed crop productivity changes over the spatial domain that is studied. Spatial differences at a global scale are important for feed businesses that source through global supply chains, but local detail within the large-scale global trends is important for providing information to farmers and their advisers seeking to adapt to these new challenges.

b. There is considerable **uncertainty** about future climate change impact projections. Uncertainties arise from greenhouse gas emission scenarios and from the climate and crop models that are used (Challinor et al., 2009). Numerical methods can be used to better define the boundaries of uncertainty, by running ensembles of climate models (for example, Osborne et al., 2012), or by systematically varying parameters within climate (Murphy et al., 2004) or crop models (Challinor et al., 2005), but considerable uncertainty to projections will still remain. Thus, a risk-based approach to planning for climate change impacts on feed supplies is needed.

c. **Adaptation** of crop selection and management can counter some negative impacts of climate change, or even turn negative impacts into local opportunities where these are expected (for example, Osborne et al., 2012). Adaptation will certainly produce new areas of potential production.

d. The impact of **climate variability** will be of particular importance for feed crop productivity and quality. Climate variability will become an increasingly important source of volatility in both feed crop volumes and quality.

e. There will be **substantial effects of non-climate factors** that can outweigh any climate change signal on feed crops. These may be driven by policy (for example, the use of maize as an energy feedstock); changes in meat consumption, particularly the consumption of pigs and poultry with a high demand for grain and protein feeds; or market prices for crop inputs.

Conclusions

Much attention has recently focused on how the global food system can cope over the coming decades with increases in the human population, changes in diet, and greater demands on energy and water resources (for example, Godfray et al., 2010). Climate variability and change will add further stresses on food production.

In the future, the competition for plant starch, protein, and sugars among animal feeding, biofuel production, and human food production will undoubtedly increase costs of both primary and secondary cereal and oil seed feedstuffs. Economic pressure may force animal production to either be more reliant on less digestible "feeds" and less reliant on human "foods," or put a brake on the growth of pig and poultry production. In this regard, ruminant animal production is well placed to provide milk and meat for human consumption using forages and fibrous co-products, as well as non-protein nitrogen sources that are unsuitable for human consumption.

As the demand for agricultural land increases alongside increased food production requirements, and particularly if there are negative effects of climate change on global crop yields per hectare, ruminant production of meat and milk from forages growing on non-arable land will be of even greater value for human food security. However, a key challenge is to maintain sufficient feed crop yields, while considering the potential impact of less efficient production on greenhouse gas emissions per unit of milk or meat produced. This will require the combined expertise of climate, crop, and animal scientists working together to reduce the risks of climate change on animal feed supplies.

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