Environmental Risk in Crop Insurance

An Overview

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Executive Summary

Changes to the natural environment in which we live and work are ongoing. Some changes are cyclical and expected. Some are caused by or exasperated by human activity. Regardless of the reason for the change, certain environmental changes will have an impact on crop insurance, both directly and indirectly. In addition, agricultural producers can be a source of environmental risk themselves incurring a liability that may or may not be insured. As actuaries, we should be aware of the ways in which various environmental risks can affect the products that we price. This paper will endeavor to identify some of the many environmental risks that impact agriculture, or are caused by agriculture, providing an overview for actuaries whose products may be affected by these risks.

Introduction

Crop insurance plays an important role in mitigating food production disasters and keeping a robust food production system in the United States. Crop insurance increases stability in food and fiber production, smoothing variability which would otherwise occur because of weather patterns and changes in international trade regulations and markets. Stability increases the ability of farmers to make long-term investments that increase production efficiency and keep productive land in agriculture.

By its very nature, crop insurance is affected by climate change. Weather related crop perils, such as windstorm, hail, frost, drought and flooding are directly affected by climate change. Increasingly stressed crops become more susceptible to diseases, insect damage, and weed competition. Livestock and aquaculture are also affected. Other climate change effects, such as saltwater intrusion and ocean acidification can also be problematic.

Policy decisions, wildlife management, and human lifestyles alter the environment affecting crop insurance. Ever-increasing global trade and travel, including long-distance pressurized transport, are introducing new plant and animal species and the diseases they carry (Ascunce et al. 2011). Human activity can affect crops directly through the introduction of new chemicals in the environment. Changes in wildlife activity can also inadvertently affect crops.

On the other hand, farm and livestock operations can themselves cause environmental harm. Producers can damage public water systems, surface water, natural resources, or air quality via irrigation runoff, fertilizer, chemical spills, leaking storage tanks, concentrated animal waste, or other methods. The value of neighboring properties can be damaged through overspray, disease or parasite spreading, or nutrient loading in water bodies.

On the bright side, considerable research into ways to mitigate the effects of or adapt to environmental changes is ongoing. That said, understanding the trends and effects of environmental risks related to crop insurance can be beneficial to actuaries. This paper seeks to provide that general understanding.

Crop Insurance Worldwide

Worldwide, crop insurance means many different things. Actuarially sound insurance sold by private companies, government or international disaster assistance, price supports, or some combination of the three is available. The European Union has a public-private partnership approach to co-finance disaster protection. However, the risk management varies by country and some provide more direct disaster assistance and/or subsidies tied to rural development goals, while others have farmers rely more on private insurance (Meuwissen et al. 2018).

High numbers of small farms in some regions can add to the complexity of insuring crops due to high expenses and lack of data. Index insurance (aka parametric), where all insured farmers in an area are paid out the same amount (or same percentage of a predetermined per farmer or per acre limit) based on an estimated average loss for a given measured peril, can help lower expense and ease complexity. For this insurance type payouts are made based on historical vs. current weather and crop production. Index insurance is prevalent in the developing world.

South Asia is one of the fastest growing agricultural insurance markets in the world. As of 2015, 6 of the eleven countries had agricultural insurance programs featuring public sector programs (Indonesia and Philippines) and public-private partnerships. Multiple peril crop insurance (MPCI), named peril, and weather index insurance (parametric) are all available. (Yorobe et al. 2015) Africa is in the early stages of developing insurance. Latin American crop insurance is also in the developmental stages. The most common crop insurance there is public private partnership with premium and technical support subsidies. Swiss Re (2016) noted that the penetration in Latin America was about half of that in the United States at that time.

Environmental changes will have varying effects on each of these crop loss mitigation insurance systems. Because these systems vary considerably from each other and from the U.S. products, we will focus here on the effects of environmental risks on U.S. crop insurance products. In some cases, the reader may infer how the environmental risks discussed here may impact the global products with which they work.

U.S. Crop Insurance Structure

The U.S. Federal Crop Insurance Program (FCIP) began in 1938 with the goal of maintaining viability of farming and ensuring the stability of the nation's food supply. It was restructured in 1980 and again in 1994 when Congress combined crop insurance and disaster assistance into one program, increased subsidies, and created the Risk Management Agency (RMA) to administer it. The FCIP is a public-private partnership with private-sector companies selling and servicing the policies and the U.S. Department of Agriculture (USDA) subsidizing, regulating, and reinsuring the policies. Currently, there are two types of crop insurance in the United States: crop-hail insurance and Multiple Peril Crop Insurance (MPCI). Crop-hail insures against crop damage caused by hail and may include extended coverages such as fire and lightning while MPCI covers loss of crop yield or revenue due to many types of natural disasters including excessive moisture, drought, or extreme temperatures.

Crop insurance developed differently from many privately sold insurance products due to the difficulty of spreading the risk for crop damage. Insurers tried to develop a multi-risk crop insurance business but failed due to insufficient data to set adequate rates and tendency of widespread catastrophic losses especially in regional areas. The difficulty of risk spreading was one cause leading to the creation of a federal crop insurance program. Since hail does not typically affect large contiguous areas, it is more amenable to private insurance and developed as its own product.

Table 1
BASICS OF U.S. CROP INSURANCE

	Crop-hail	MPCI
Purchase Timeline	From when 50% crop visible to harvest, before hail damage	Prior to planting dates set by FCIP
Coverage Amount	Forecast harvest price	Yield-based or revenue-based
Liability-holder	Private or FCIP	FCIP

Information from Congressional Research Service 2021.

CROP-HAIL INSURANCE

Crop-hail coverage was introduced in 1880 (Business Insurance 2020). Hail ruins crops in specific defined areas and is easily identified and assessed. One side of a field may be ruined by hail while the other side is undamaged, and the cause of the damage is clear and demonstrable. A crop-hail policy may also cover additional, easily identifiable perils such as fire, and possibly vandalism. Fire, hail, and vandalism exhibit randomness. As part of the hail coverage, the policy may pay for replanting if the hailstorm is early in the growing season and the damage is severe enough to warrant replanting. The farmer would still receive compensation for the reduction in expected yield due to the later planting date just as they would receive for reduced yield if there had been no replanting. The policy may also cover damage caused by lightning and transit to storage after harvest.

Crop-hail can be purchased during the growing season from the time when 50 percent of the crop is clearly visible to the anticipated harvest date, as long as the crop has not already been damaged by hail. Most insurers offer policies for major grain and hay crops. Coverage for specialty and vegetable crops is more limited. Farmers can insure all crops in which they have a financial interest including crops on leased land. They can insure any portion of their crops. Coverage is purchased per acre and coverage amount is forecast harvest price. Though the expected value of the crop at the time of loss may be higher than the forecast value, the claim payment cannot exceed the original underwriting limit. Coverage may be increased throughout the season.

Since hail coverage is provided by both private crop-hail and federally subsidized MPCI, farmers may drop coverage for hail under the MPCI in exchange for reduction in premium. Crop-hail can typically be bought for first dollar coverage or with deductibles.

MULTIPLE PERIL CROP INSURANCE (MPCI)

MPCI is sold through the Federal Crop Insurance Program which is a public-private partnership. Private companies (currently 16 of them (Congressional Research Service 2021)), authorized by the United States Department of Agriculture Risk Management Agency (USDA RMA), provide the insurance. There is a Standard Reinsurance Agreement through which private insurers share the risk with three pools by state: commercial, developmental, and assigned risk fund. The amount covered by the federal government increases from former to latter. Insurers can also reinsure in the private market. Unlike private insurance, crop insurers are reimbursed by the federal government for administrative and operating costs. Premiums are paid at the end of the insurance period and not collected on policies under which claims have been filed for which the premium is deducted from amounts owed instead. Coverage must be purchased prior to planting (before cutoff dates set by the federal government).

MPCI covers low yield and crop quality losses due to adverse weather and unavoidable insect and disease damage. MPCI is available for over 100 crops including most economically significant agricultural crops. USDA RMA insurance is available for specified states and counties only which vary by agricultural product. For those crops not covered there is limited protection offered by the Noninsured Crop Disaster Assistance Program. There is essentially a deductible as it covers up to 100% of expected market price but never 100% of yield.

CATASTROPHE COVERAGE

Catastrophe coverage is entirely subsidized by the federal government; farmers pay only an administrative fee. Yield-based crop insurance policies pay out if the farmer's yield is below his historical average yield; typically, if a farmer loses 50% of a normal yield he will receive 55% of the estimated crop value under yield-based policy (Other yield levels available are 65% and 75%.). Under a revenue-based policy the trigger would be revenue. Farmers can buy additional coverage under a "buy up" program in which the federal government subsidizes a portion of the premium. In addition to individual risk, there is "group risk" insurance for which yield guarantees are based on county average and payment is in any year that county average yield falls below the yield guarantee. Coverage is by "unit" (entire acreage of the crop planted in one county by the farmer), by "section" (one-square mile), or by irrigated or dryland. Any claim payment is based on the average reduced yield for all the fields in the unit.

LIVESTOCK

The USDA also offers livestock coverage, for meat and dairy. These provide protection against a decline in revenue (yield and/or price) or gross margin (market value of milk minus feed costs) on milk produced from dairy cows or Livestock Gross Margin (LGM) for cattle, swine, and lamb sold for slaughter primarily intended for human consumption covering loss of market value of livestock minus feeder animal and feed costs. Livestock can be covered under the whole-farm revenue protection (WFRP) plans as well.

AQUACULTURE

The USDA RMA is expanding to cover not just terrestrial crops, but aquaculture as well. Currently there is group risk plan (GRP) coverage for oysters based on county-level data covering drought, flood, hurricane and other natural disasters. There is inventory-based coverage for clams covering oxygen depletion (due to vegetation, microbial activity, harmful algae bloom, or high water temperature), disease, freeze, hurricane, change in salinity, tidal wave, storm surge or ice flow. Other aquaculture commodities can be covered under the WFRP plans.

PARAMETRIC (INDEX) INSURANCE

Parametric crop insurance has been available in the United States since the 1990s. As with the international parametric insurance, it pays out according to a predefined schedule based on the probability of loss given a stated trigger. If a triggering event occurs within the defined locale, the policy pays out a set amount. The triggering events must typically be recorded or registered with a third party. Several examples:

- A triggering event may be an earthquake of a certain magnitude, measured by the United States Geological Survey, which triggers a payout of an index amount (a percentage of the limit) based on the magnitude.
- A triggering event may be a low temperature between certain dates, measured by a government or industry weather station.
- A triggering event may be a particular category of hurricane.

Parametric insurance has the advantage to insurers of lower adjusting costs and advantages for both insurer and insured of speedier payouts and more certain payments. The key difference between standard and parametric insurance is that parametric insurance is not tied to an actual loss; the policy pays out a predetermined amount based on the trigger regardless of the severity of the insured’s actual loss.

UTILIZATION OF CROP INSURANCE

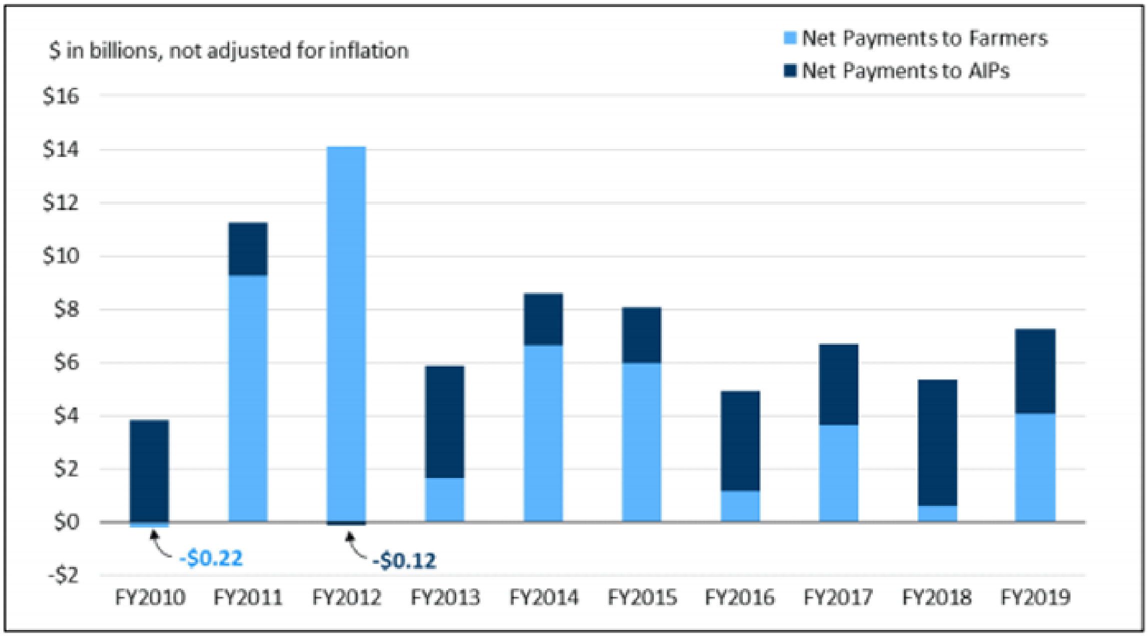
The FCIP insured crops and livestock valued at over $116 billion in 2019- 28% of the value of U.S. agricultural production. Staple crops are highly covered with over 90% of corn, soybean, and cotton planted acres and over 85% of wheat planted acres insured through the FCIP. The FCIP is the largest component of the federal farm safety net. For 2014-2018 the FCIP paid 52% of the total paid by farm safety net programs. (Congressional Research Service 2021).

Impact of Changing Climate and Weather Patterns on Covered Perils

“The increasing frequency and severity of extreme weather events like droughts and floods have taken a toll on the midwestern U.S. in recent years” notes Josh Anusewicz of the Yale School of the Environment (Anusewicz 2021). As a result, the Federal Crop Insurance Program (FCIP), which paid out $4.1 billion in damages between 2001 and 2010 paid out $10.8 billion in 2011 alone.

The chart below (Figure 1) provided by the Congressional Research Service (2021) shows FCIP payments this decade both directly to farmers and to Approved Insurance Providers (AIPs). Each and every individual year from 2011 through 2019 had an annual payout higher than the entire previous decade (2001-2010). Note also, the volatility in the total annual payout amounts.

Figure 1
FCIP NET PAYMENTS TO FARMERS AND APPROVED INSURANCE PROVIDERS BY FISCAL YEAR

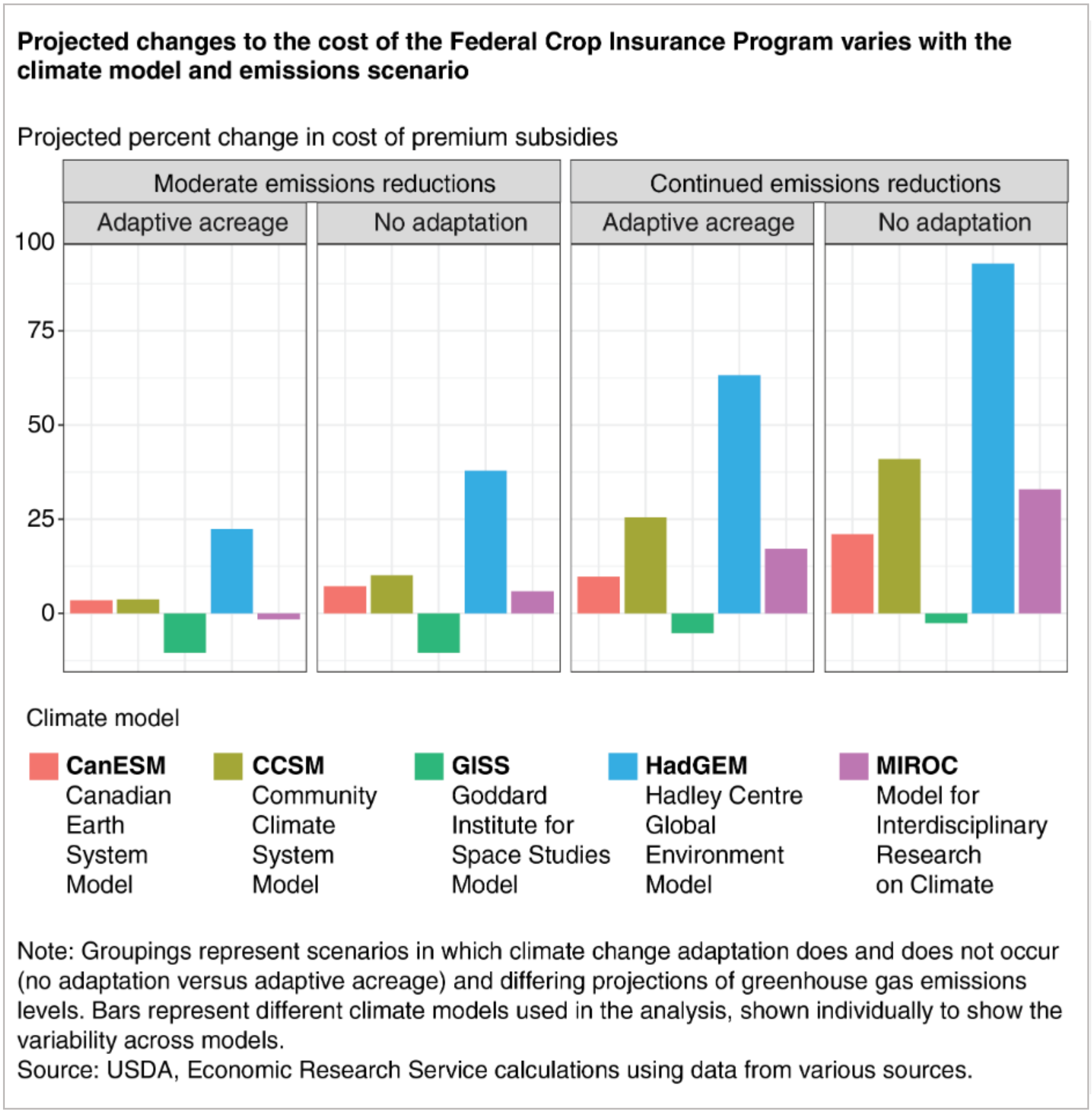


Source: Federal Crop Insurance: A Primer, Congressional Research Service (2021) CRS calculations using data from USDA, Office of Inspector General, Federal Crop Insurance Corporation/Risk Management Agency's Financial Statements, audit reports FY2010-FY2019

Future costs are projected to be even higher. Changing climate conditions are projected to lead to a 6% - 13% decrease in crop yields (Matzrafi et al.) which would increase any yield-based insurance payouts. The decrease occurs when plant physiological processes such as photosynthetic efficiency, growth rate, and stomatal conductance are negatively affected by higher temperatures and CO_2 levels. The future cost to insurers depends on the adaptations, emissions, and of course the pricing and structure of the policies.

The projection of the USDA Economic Research Service (2019) is shown below for two emissions scenarios and five climate models (Figure 2). The chart explores potential impacts in the year 2080 and compares using climate scenarios arising from different projections of greenhouse gas emissions. Adaptive acreage indicates climate change adaptation such as adjustments on what farmers plant, where they plant it and how they manage it. Although each climate model predicts varying levels of impact, the various models all consistently indicate a larger change in cost with less emission reduction and less adaptation. Under the scenario with moderate emissions reductions and adaptation, the cost of today's FCIP would be on average about 3.5% higher than with a climate similar to the recent past. Under a scenario in which emissions trends continue, the cost of FCIP would increase an average of 22%.

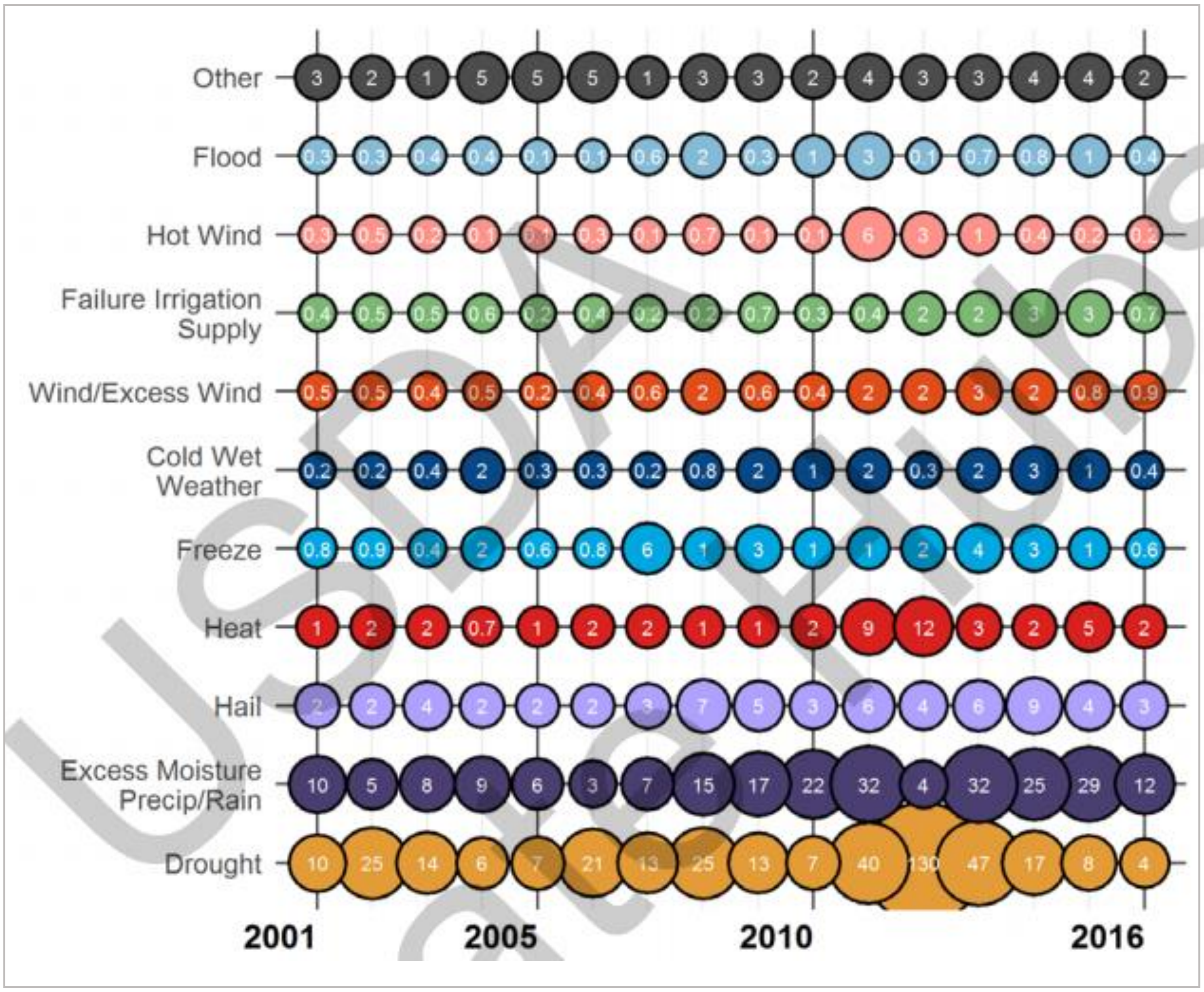
Figure 2
PROJECTED CHANGES TO COST OF FEDERAL CROP INSURANCE PROGRAM



USDA Economic Research Service (2019)

Figure 3 shows a breakdown of absolute annual indemnities into climate related cause of loss. The size of a bubble indicates how large the loss was for each cause of loss for each year (2001 – 2016). The numbers within the bubbles correspond to hundreds of millions of dollars. Note the larger bubbles near the bottom. Precipitation (or lack thereof) is the major source of loss; and the magnitude of the losses is growing.

Figure 3
USDA BUBBLE PLOT OF ABSOLUTE ANNUAL INDEMNITIES FOR CLIMATE RELATED CAUSES OF LOSS



Bubble plot of absolute annual indemnities (hundreds of millions of dollars) for climate-related causes of loss from 2001-2016. Size of circle indicates amount of annual indemnity. (figure from Reyes et aL. 2018)

The chart above indicates losses related to specific climate/ weather related events. However, as climate change is inflating crop losses directly, it is also causing indirect effects on non-weather causes of loss, such as disease, insect and weed damage, and soil composition.

WINDSTORMS/HAIL

Hail is caused by the strong updraft of a thunderstorm. Larger thunderstorms with a very strong updraft are necessary to produce larger hail and damage caused by hail is often actually damage caused by a combination of wind and hail. After a hailstorm, disease management is important while the plants are vulnerable.

Crop damage due to wind and hail depends on the size and timing of the storm. The growing stage of the crops impacts whether the damage will permanently impair the crop yield or revenue. (Prichard, 2018) For example, hail that happens early in the spring while corn's growing point is still below the soil surface may not cause permanent damage, but hail later in the growing cycle can impair the value of the crop.

Hail is frequent in the Midwest, especially in the area known as hail alley (predominantly within the states of Texas, Oklahoma, Colorado, Kansas, Nebraska, and Wyoming). However, there is evidence that the frequency of severe hail is increasing in hail alley and the footprint of hail producing thunderstorms is expanding, causing uncertainty and concern among producers and their insurers (Meyer, 2021). Interestingly, the top eight states with the most hail damage between the years 2017 and 2019 excluded Oklahoma, Colorado, and Wyoming, but included the more northerly Minnesota, Illinois, Missouri, and Iowa.

Insured crop hail losses have increased from $285 million in 1980 to nearly $400 million annually in the early 1990s. In 2019, reported crop hail claims were nearly $990 million. (Ahmed, 2020)

Other windstorms, such as tornadoes, and their frequency and severity may be changing. Tornado severity, for example, is the product of energy and wind shear. Climate change is increasing the energy doming as warm, moist, unstable air from the Gulf of Mexico. Windshear is decreasing, however, as it is highly influenced by the strength of the jet stream which is weakening. The storms of the future may be violent hail or straight-line winds as opposed to tornadoes (National Geographic, 2020).

STRESS

Abrupt changes in climatic variables often result in stressed crop plants leading to a positive feedback loop of stressors. The stressed plants are then more vulnerable to insect pests, pathogens, and weeds (Ramesh et al. 2017). When crops survive any severe weather-related event, such as a windstorm, hail, or frost, the plants will become more vulnerable to other issues potentially increasing insured losses.

WEEDS

Crop loss due to weeds are about 45% of total yield on average globally and overshadows crop losses due to insects, disease, and animal pests. The increased CO_2 concentrations associated with climate change have different effects on different plant types, including weeds. Increased competition between plants and weeds could lead to additional crop loss (Valerio et al. 2013). Many weeds are C4 plants[1] which would flourish with increased temperatures, because the C4 photosynthetic pathway is more efficient at higher temperatures.

Additionally, increased temperatures and elevated CO_2 levels reduce the sensitivity of some common weeds (*Conyza canadensis and Chenopodium album*) to glyphosate, one of the most widely used pesticides (Matzrafi et al. 2019). An indirect type of damage is that associated with increased pesticide use whether because of reduced sensitivity of weeds to the pesticide or because of weakening of the crop plant due to heat stress or increased disease.

DISEASE

Plant diseases arise as the product of the host / pathogen / environment interaction. Therefore, climate change can influence diseases of crops by influencing any of these 3 factors (reviewed by Burdon et al. 2020). For example, climate change may influence the host plant, allowing it to survive in different habitats and thereby exposing it to different disease organisms, or by increasing stress on the plant, and decreasing its immune function, and increasing

[1] Photosynthesis is the process plants use to turn light, CO_2, and water into sugars that fuel plant growth using the primary photosynthetic enzyme Rubisco. The majority of plant species use C3 photosynthesis in which the first carbon compound produced contains three carbon atoms. Carbon dioxide enters a plant through its stomata (openings on the leaves) and the enzyme Rubisco fixes carbon into sugar in the Calvin cycle. While the stomata are open to let the CO_2 in, they let water vapor out leaving C3 plants at a disadvantage in high temperature or drought environments. A C4 plant is one that cycles carbon dioxide into four-carbon sugar compounds prior to entering the Calvin cycle. C4 plants use bundle sheath structures to deliver CO_2 straight to Rubisco and to fix carbon while the stomata are closed. Photorespiration is minimal in C4 plants compared to C3 which allows the plants to retain water. Thus, C4 plants are better adapted than C3 plants in environments with high daytime temperatures, intense sunlight, drought, or nitrogen limitation.

its susceptibility to pathogens that were already present in the environment. Climate change may also influence the pathogen, by increasing the ability of the pathogen to grow, reproduce or spread, potentially increasing the severity of the plant disease (Kocmánková et al. 2009; Newbery et al 2016). And finally, climate change has a direct influence on the environment in which the host and pathogen coexist.

There are also indirect effects of climate change on plant disease. For example, increased CO_2 increases biomass production and the density of crop stands; increasing humidity within the canopies (Thompson et al. 2017), altering the ability of some pathogens to propagate. Additionally, the effects on insects (see below) mean that insect-vectored diseases, as described by Harrington et al. (2007), are likely to increase.

INSECTS

Because insects develop and reproduce more quickly and have higher metabolic rates (i.e., eat more and burn more calories) in warmer conditions, crop losses to insects are expected to increase as the climate changes. In addition, a shift to higher latitudes of the level of cold temperatures that are lethal for many insects may lead to a northward shift of insect populations in North America. In their review of crop losses to insects, Deutsch et al. (2018) found global yield losses of rice, corn and wheat are projected to increase by 10 to 25% per degree of global mean surface warming, with more severe losses associated with temperate areas. Ramsfield et al (2016) found high risk of increased losses in forestry.

When plants assimilate more CO_2 without having access to more nitrogen, the ratio of carbon to nitrogen in their tissues increases. In these conditions, the plant can become nutrient limited, and may not have the nitrogen or other compounds required for producing high enough concentrations of defense compounds. This can lead to increased insect damage on crops (reviewed by Gregory et al. 2009).

Insects are not only a risk to plant agriculture but can also be a risk in animal husbandry. The new world screwworm (several species of *Cochliomyia*), for example, causes the infection and death of domestic animals, leading to losses of agricultural productivity (Mastrangelo and Welch 2012).

PLANT POLLINATOR PHENOLOGY

Phenology, the timing of the annual cycles of plants and animals, is sensitive to climate change. When mutualists are involved, such as the case of a plant and its pollinator, a change in phenology of one not shared by the other could cause a breakdown of the mutualistic relationship to the detriment of one, the other, or both.

DROUGHT

Droughts are expected to increase with the alterations in precipitation associated with climate change. Li et al. (2009) predict significant increases in crop losses due to drought on all continents. Kane et al. (2021) note that drought increases transpiration by plants which leads to closing of stomata causing reduced rates of photosynthesis which shrinks grain yields. Maize yields under reasonable future climate scenarios would drop between 20% and 80%.

FIRE

Under climate change scenarios, more areas are expected to be subject to fires. Increased fire frequency and a longer fire season are also expected (Sun et al. 2019) which would likely lead to additional crop and especially forestry losses due to fire.

FLOODING AND EXCESSIVE MOISTURE

Inundation of coastal agricultural lands, and increased damage due to storm-related flooding during extreme weather events are both well-documented aspects of the impacts of climate change on agriculture. In fact, flooding and excessive moisture are expected to cause additional damages to U.S. corn crops alone of $3 billion per year during the time period from 2002-2032 (Rosensweig et al. 2002). Aside from the direct damage due to the flood event itself, more damages come from root damage associated with anoxic conditions in waterlogged soils, increased risk of plant disease and insect damage, and direct planting or harvesting (reviewed by Rosensweig et al. 2002). Disruptions to global atmospheric circulation phenomena like the El Nino Southern Oscillation, can lead to both excessive moisture in some areas and drought in others, causing significant crop losses as reviewed by Tubiello et al (2010).

FROST AND LOW TEMPERATURE

Like hail, the timing and frequency of frost impacts the damage done to crops. In addition, the heaviness of the frost and the freeze's relationship to the fruit of the crop impacts the damage. (Berglund) Cold spells may decrease insurable farm productivity, as ~10% of annual crop losses in the U.S. are associated with cold (USDA-ERS 2019). The crops could be damaged directly by the cold, or cold could disrupt pollination (since insect activity is lower in colder temperatures), or the cold could reduce crop germination or growth rate.

HIGH AND LACK OF LOW TEMPERATURES

Tubiello et al (2010) report that with increased average temperatures, there may be small beneficial effects on crop yields in temperate regions and negative yield impacts in tropical regions. Since plant development is associated with the number of days the plant experiences suitable temperature and moisture, it stands to reason that in most of the U.S., with slightly warmer days (all other things being equal) that crops would mature more quickly potentially leading to greater yields. However, extreme heat can reduce harvest levels or quality, sometimes leading to plant reproductive failures such as kernel abortion in maize which dramatically decrease yields (Kane et al, 2021). This tradeoff has also been demonstrated experimentally. In their study of sunflowers, Moriondo et al. (2010) discovered that with increasing average temperatures, the benefits of faster plant growths was offset by the increased heat stress frequencies, leading to severe yield reductions in sunflower crops. Excessive heat can also lead to heat-related deaths of poultry and livestock. Warming waters increase disease prevalence in aquaculture.

SALTWATER INTRUSION

Saltwater intrusion into agricultural and forest soils is increasing especially in eastern Coastal and Gulf States which negatively impacts productivity and profitability. Saltwater intrusion can cause tree and crop death, and reduced growth and yield. The reduced yield may make it economically infeasible to continue productive use of the lands. Soil salinization driven by saltwater intrusion can be caused by sea-level rise, storm surge, higher high tides and more frequent king (exceptionally large) tides, rising saline groundwater, drought, or excessive groundwater pumping. Both chronic (sea-level rise and migrating tidal boundaries) and episodic (storms) causes contribute to the problem. Higher tides and storm surge push saltwater further inland while drought and excessive groundwater pumping decrease freshwater availability to push out salt water.

Current and prior land management can exacerbate the problems. While some tide gates and valves can block saltwater, they can also keep it trapped and unable to drain away. Drainage canals and ditches can be conduits for saltwater to reach further inland.

Salinization occurs in dryer climates as well. Often dry climates and low precipitations cause excessive salts not to be flushed from the earth. Rising temperatures can increase the evaporation rate, increasing the salts on the surface. Here too, management can improve or worsen the situation. Soil salinization often increases with removal of deep-rooted vegetation which causes a raised water table.

OCEAN ACIDIFICATION

As atmospheric CO_2 rises, much is absorbed by the ocean. As the CO_2 dissolves into the oceans it reacts with seawater forming carbonic acid. The pH of the ocean falls, and water is more acidic making it more difficult for calcifying organisms to produce shells. Aquaculture is one of the fastest growing global food sectors, accounting for 40% of the total "catch" as early as 2012 and it is already clear that ocean acidification has imposed negative impacts on calcifying organisms such as shellfish. In laboratory research and in aquaculture, lowered pH has been tied to die-offs of larvae as well as reduced production. The overall effects on finfish are not as well understood, but increased acidification has been shown to impact their otoliths (organs for balance and orientation) as well as hindering respiration and impairing growth and development. (Clements and Chopin, 2016)

Impact of Globalization on Covered Perils

Ever-increasing global trade and travel, including long-distance pressurized transport, are increasing the transport frequency of animal and plant species and the diseases that they carry (Ascunce et al. 2011). As these newcomers pervade their expanded environment, the effects on crop insurance can vary considerably.

INVASIVE SPECIES

An invasive species is defined as an organism that causes ecological and/or economic harm in a new environment where it is not native. Invasive species can have extensive influence on insurable crop risks. Competition from invasive plants can diminish the yield of native plants (Pimentel et al. 2005). Herbaceous invasive insects decrease useable product (Oerke 2006); Invasive seeds or plant parts can contaminate crops decreasing their value (USDA-APHIS 2018). Rodent, mammal and aquatic invasives can impact agricultural crops, livestock and/or fisheries.

U.S. agriculture loses $13 billion in crops annually because of invasive insects, such as vine mealybugs (*Planococcus ficus*) (USF&W 2012). A notable example is the red fire ant (*Solenopsis invicta*). Red fire ants damage young citrus trees, potatoes, dry crop seed, and other crops. They also attack domestic animals in large numbers, stinging simultaneously causing injury (Ascunce et al. 2011). Another insect that causes significant agricultural costs is the Africanized honeybee (a hybrid *Apis* species) which disrupts the traditional pollination service industry, causing enormous agricultural losses (USDA 2020). The spotted lanternfly (*Lycorma delicatula*), native to China, Bangladesh, and Vietnam, is causing huge agricultural damage to grapes, apples, hops, hardwood, and other crops. Insecticide costs have trebled, and some growers are losing entire vineyards (USDA 2020)

The highest losses attributable to invasive plants are either the cost of management/removal or agricultural losses. However, the invasive salt cedar (of many species of *Tamarix*) causes indirect damage to crops in addition to control costs. *Tamarix* thrive in dry areas, hogging precious water, causing areas to become dryer and secreting salt into the soil. The resulting increased soil salinity, increased fire frequency, low water tables, water loss within irrigation, and flooding from impeded water channels causes economic damage (Conroy et al. 2020).

Invasive rodents and mammals are increasingly affecting crops and livestock. Nutria (*Myocastor coypus*) and feral swine (*Sus scrofa*) are examples. In addition to eating crops (particularly sugar cane and rice), the nutria, a large rodent, frequently breaches and undermines water-retention and flood-control levees promoting saltwater intrusion and damaging irrigation systems. They also spread diseases including pathogens and host parasites which can infect livestock. Feral swine cause an estimated $1.5 billion in damage and control costs in the United States each year, inflicting major damage on agriculture and transmitting diseases to livestock. (Conroy et al. 2020)

Impact of Human and Wildlife Factors

Current policies and human activities can increase crop losses. Recently, losses associated with herbicide drift of dicamba have been documented extensively. When farmers applied dicamba to herbicide resistant soybeans, the herbicide drifted over and damaged many neighboring crops (US-EPA 2017). Water resources in rural communities, damaged by the introduction of chemicals, have been documented to lead to agricultural losses in India (Reddy and Behera 2006) with similar agricultural losses possible in the U.S.

Increased production of plastic and subsequent plastic waste can affect crop production and quality. When plastics degrade, they break down into tiny particles (often referred to as microplastics) small enough to enter the lungs and even pass through the cell walls in humans. The main methods of introduction to the human body are inhalation and ingestion. Once within the human body, the extent of health risks are not fully known, but microplastics have been linked to inflammation and compromised immune responses. They can also adsorb contaminants, accumulate heavy metals, and are a vector for priority pollutants. Wastewater treatment plant sludge often used on agricultural land as fertilizer contains microplastics, which have been detected in field-site soils 15 years after application. Microplastics also enter soils from fallout from the air and in precipitation. Microplastics have been found in crops and recently, Li et al. (2020) document uptake of different microplastics by wheat and lettuce in hydroponic cultures and sandy soil and found that plastic particles were subsequently transported from the roots to the shoots (edible portions of the plant) through transpiration pull. Agricultural soils are a major sink of microplastics. Boots et al. (2019) found reduced seed germination, reduction in shoot height, and reduced biomass when microplastics were present. Soil pH decreased and soil stability and water retention were also altered.

Policy decisions related to water use affect crop insurance. If water allocation deficits are known in advance farmers may let fields lie fallow or even destroy groves of fruit or nut trees. However, if crops are planted before the water limitations are known, the lack of water can trigger certain crop insurance policies. (Carlton, 2021)

The loss of bats in natural ecosystems is associated with crop loss in the U.S. The white-nosed syndrome (caused by a fungus) is leading to precipitous declines in bat populations nationwide. The decline in bats, which are primarily insectivores, would then increase the insect risks discussed above. In fact, researchers (Boyles et al. 2011) estimate that bats provide $22.9 billion worth of pest suppression services, so the loss of bats would lead to dramatic agricultural losses.

Deer can lead to crop losses (Palmer, Kelley, and George 1982). Rodents can bring pathogens into livestock-rearing areas. Although granivorous (Kross et al. 2019) and frugivorous birds (Anderson et al. 2013) are documented to cause yield losses for some crops, overall, insectivorous birds are important in preventing yield losses to insects (Maas, Clough, and Tscharntke 2013), so the overall impact of birds on agriculture appears to be positive.

Liabilities

INSURANCE FOR ENVIRONMENTAL LOSS

Before the development of large corporate farms and livestock confinement operations, state right-to-farm laws provided immunity from liability related to traditional farming operations. (Dybdahl, 2018). However, producers are not immune to liability for environmental damage and citizens have demanded that producers live up to their responsibilities when they damage public water systems, surface water, natural resources, or air quality. Other risks include fertilizer or chemical spills, leaking storage tanks, and reduction of neighboring property values.

The liability policy most producers carry does not cover these types of claims or their defense. Standard language in property and casualty policies, including those sold to farms, contain pollution exclusions. The most common pollution exclusion eliminates coverage for "bodily injury or property damage arising out of the actual, alleged or threatened discharge, dispersal, seepage, migration, release or escape of pollutants." "Pollutants" is defined as "any solid, liquid, gaseous or thermal irritant or contaminant, including smoke, vapor, soot, fumes, acids, alkalis, chemicals, and waste." "Waste" includes materials to be recycled, reconditioned, or reclaimed. To gain coverage for these losses and their defense, producers need a specialized environmental insurance policy. Environmental insurance policies are available for all types of farms.

NONPOINT SOURCE WATER POLLUTION

Often associated with nitrogenous wastes (agricultural fertilizer or animal-waste runoff), nonpoint source pollution can lead to serious environmental degradation in waterways, which may be associated with some insurable risks. Algal and plant growth may be fueled by the excess nutrients, and when this material dies and sinks to the bottom of waterways, the respiration (associated with their decomposition process) can deprive the waterway of oxygen. This phenomenon is termed eutrophication and is associated with fish and marine mammal die-offs and biodiversity declines. Eutrophication-driven declines in fish populations can lead to business risks to fishing-related tourism business, as well as to fishing businesses; algal blooms also can lead to human health risks (reviewed by Selman, Greenhalgh, Diaz, & Sugg, 2008).

There are no fines under the Clean Water Act for nonpoint source pollution. Despite the fact that since the mid-1980s, nonpoint source pollution is the largest contributor to water pollution, it is exempt from the federal law with the intent that states will regulate it (mandatory since 1987). Farms, in particular, are exempt from many federal environmental laws and regulations. Return flows from irrigated agriculture are specifically excluded from Congress' amended definition of point source (after the earlier exemption of farms of less than 3000 acres, animal feedlots, and silviculture was invalidated by Natural Resources Defense Council v. Costle 1977) (Salzman and Thompson 2014). Despite the current and historical pattern of no legal liability to husbandry for associated water pollution, as damages rise, states or the EPA may increase regulation or even legislate cleanup liability. The ruling in American Farm Bureau et al. vs EPA (2013) affirmed that the EPA, working with the states, has the authority to set science-based pollution limits for the Chesapeake Bay. It is likely that it would be used as precedent for any other body of water. There is thus liability for failing to uphold water standards. There is ongoing litigation in the Chesapeake and other watersheds over who is responsible for water quality.

NUTRIENT LOADING

Nutrient loading is also a problem in aquaculture where the nutrient loading from concentrated fish production can have adverse effects on benthic (bottom of the water body) communities (Clements and Chopin, 2016), some of which may be fisheries or related to fisheries thus causing economic as well as ecological damage.

AIR POLLUTION

It is estimated that agriculture causes half of the man-made air pollution in America and 55 percent in Europe. In many areas it is the largest single cause of air pollution-linked deaths. Concentrated animal feeding operations (CAFOs) cause large amounts of air pollution. The operations exude methane and ammonia which combine with NO_x from vehicles servicing the CAFOs and create $PM_{2.5}$. Manure dust is another irritant. The volatile organic compounds put off by the silage combine with NO_x into ozone which is toxic to humans at ground level. (Conroy 2020) Respiratory illness and heart conditions can result. Domingo et al (2021) estimate 17,900 annual air quality-related deaths from agriculture and sooner or later the agricultural producers may be held liable for the deaths and illnesses.

OVERSPRAY

Also known as pesticide/herbicide drift, overspray usually refers to unintentional chemical applications, particularly those that inadvertently damage a non-owned area or crop. In many states, the producer and applier can be held liable for this damage, especially those applied in a careless or negligent manner. (Schroeder, 2016)

When damage occurs, general farm liability insurance may provide coverage and or defense costs since liability insurance covers the unintentional harm to other people and their property. Overspray may or may not be covered by standard policies. Specific endorsements may be available to cover chemical overspray liabilities. It has been clear for many years that crop insurance, such as multi-peril crop insurance, does not cover the insured or their neighbors for chemical overspray. (Johnston, 2018)

DISEASE AND PARASITES

Diseases and parasites are an anticipated consequence (or should be) of any concentrated feeding organization. These are problematic within the organization in terms of lower yield or lower quality product and can become liabilities if spread outside the organization.

Climate-resilient farming methods and mitigation

There is quite a bit of research going on in terms of mitigating and adapting to the effects of environmental risks to agriculture.

GOOD FARMING PRACTICES (GFP)

GFPs are science-based farming methods and processes that are recognized by agricultural experts. The practices are defined by the USDA's Risk Management Agency and required as a condition of insurance. New technologies, research and changes in the market, weather, and land management influence the adoption of updated GFPs. (National Crop Insurance Services).

GFPs help farmers address climate change and can improve conservation practices, soil health, and water conservation. GFPs can recognize new drought-resistant seed varieties or planting practices, more energy efficient irrigation systems, and promote no-till zones or cover crops to provide environmentally friendly guidance to producers.

INCREASED TECHNOLOGY

Use of increased technology in agriculture can aid in adaptation and mitigation. Artificial Intelligence, drones and robots can all be used to improve production while decreasing use of water, fertilizer, and pesticides.

INCREASING SOIL ORGANIC MATTER

When the organic matter in soil is increased, its water holding capacity and water infiltration ability is improved compared to similarly textured soils. These soils can protect crops from water vapor losses caused by extreme heat and drought. Kane et al. (2021) found statistically significant yield increases and resilience effects during drought from increased organic matter in the soil. A review of 351 studies found a significant increase in soil organic carbon when either no-till farming or less intensive tilling practices were implemented (Haddaway et al. 2017).

COMBATING DROUGHT

Li et al. (2009) suggest adaptation measures including incorporation of new crop varieties or new irrigation equipment, as well as international negotiation on region-wide initiatives for drought risk reduction. Degani et al. (2019) also found crop rotations as an effective strategy for promoting resilience in agroecosystems under drought stress.

GENETIC MODIFIED ORGANISMS (GMOS)

Genetic engineering is being used to address some of the risks to agriculture associated with climate change. For example, Ashraf and Akam (2009) review 10 plants that have been genetically engineered to increase the plant's ability to tolerate saline soils. Although these represent experiments, not commercially deployed plants, the demonstrated effectiveness is promising. Plants have also been engineered to increase their tolerance to cold (reviewed by Sanghera et al. 2011) or drought (reviewed by Shinwari et al. 2020), two of the extreme events that would occur with climate change.

The Sterile Insect Technique (as discussed by Dyck et al. 2021) notes that genetically modified sterile male insects have been successfully introduced to the wild. Females mating with these males produce no offspring and repeated releases can reduce populations dramatically. Screwworm flies were eliminated in North America using this technique as were several species of fruit flies which had previously been major crop pests.

WEED RISK ASSESSMENT

Pre-border weed risk assessments are carried out in many countries to determine whether preventing a plant's entry into the country is warranted. This often involves reviewing the plant's history in other parts of the world (has it become invasive there?), reviewing the plant's biology (how well does it establish, reproduce, and spread to new areas?), and reviewing whether there are sexually compatible weedy relatives.

COMBATTING SALTWATER INTRUSION

Both mitigation and adaptation measures can be used to combat saltwater intrusion. Mitigation measures include leaching with freshwater and installing water control structures. These are costly and may be unproductive so a cost benefit analysis will often disqualify this option. Adaptations include planting more salt-tolerant crops or releasing the lands from production into conservation easement (USDA 2021). Another mitigation technique used in dry areas involves planting salt-tolerant or deep-rooted cover crops.

Further Reading

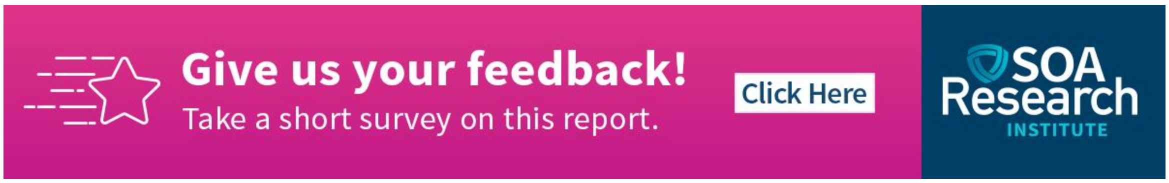
For more detail on impacts from climate change, globalization, forestry and fire, and the impact of agriculture on mortality and morbidity please see the prior articles in the series: "Climate Change and Environmental Risks: A Primer on Environmental Risks to the Insurance Industry"; "Environmental Risk from Globalization"; "New Fire Hazard risk from Policy Responses to Climate Change"; and "Effects of Pollution and Environmental Degradation on Mortality and Morbidity Rates and Healthcare Costs." [2]

[2] https://www.soa.org/resources/research-reports/2020/2020-environmental-risk-series/

Conclusion

Agriculture is dynamic. Climate change, globalization, changes in wildlife management, and technological progress are continually impacting agricultural loss and yield profiles. Changes to our environment and the risks associated with those changes are constant. Efforts to combat the ongoing changes introduce additional variables. How will the related insurance products be affected? This is the tough question that the actuary must answer.

Understanding the nature of the different types of environmental risks and the ways in which they can affect both crop and non-crop insurance products can help actuaries to assess how each piece of the puzzle is changing. But a full understanding is not be found here. This paper simply introduces the reader to some potential impacts. Further research related to specific products should be considered and ongoing awareness is imperative for these continually changing risks.



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About The Society of Actuaries Research Institute

Serving as the research arm of the Society of Actuaries (SOA), the SOA Research Institute provides objective, data-driven research bringing together tried and true practices and future-focused approaches to address societal challenges and your business needs. The Institute provides trusted knowledge, extensive experience and new technologies to help effectively identify, predict and manage risks.

Representing the thousands of actuaries who help conduct critical research, the SOA Research Institute provides clarity and solutions on risks and societal challenges. The Institute actuaries, academics, employers, the insurance industry, regulators, research partners, foundations and research institutions, sponsors and non-governmental organizations, building an effective network which provides support, knowledge and expertise regarding the management of risk to benefit the industry and the public.

Managed by experienced actuaries and research experts from a broad range of industries, the SOA Research Institute creates, funds, develops and distributes research to elevate actuaries as leaders in measuring and managing risk. These efforts include studies, essay collections, webcasts, research papers, survey reports, and original research on topics impacting society.

Harnessing its peer-reviewed research, leading-edge technologies, new data tools and innovative practices, the Institute seeks to understand the underlying causes of risk and the possible outcomes. The Institute develops objective research spanning a variety of topics with its strategic research programs: aging and retirement; actuarial innovation and technology; mortality and longevity; diversity, equity and inclusion; health care cost trends; and catastrophe and climate risk. The Institute has a large volume of topical research available, including an expanding collection of international and market-specific research, experience studies, models and timely research.

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