Building a Sustainable and Resilient Agricultural System for a Changing Global Environment

by Mary Jane Angelo

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Summary

The vast majority of scientists agree that in the coming decades, climate change will have profound impacts on the global environment. During this same time, the world population is expected to grow, and many developing regions of the world are poised to become more affluent. These changes will result in increased demand for food and other agricultural products. Agriculture is vulnerable to a number of impacts that are likely to occur as the global climate changes. Increased temperatures and changed rainfall patterns are likely to result in crop losses from drought, increases in disease and pest damage, and changes in growing seasons. Modern industrialized agriculture is comprised of monocultures, relies on heavy inputs of fossil fuel-derived pesticides and fertilizers, and requires fossil fuels for production, processing, and transportation machinery. As a consequence of these features, modern industrialized agriculture is particularly not well-suited to adapt to the changes that are likely to occur. Modeling agricultural systems on the types of ecologically resilient systems that occur in nature will reduce agriculture's vulnerability and improve its capacity to adapt.

Recently, the world's population crossed the threshold of 7 billion inhabitants.[1] While many of the more affluent countries, including the United States and most of the European Union, were muddling through severe economic turmoil, parts of the developing world continued to experience unprecedented improvements in their standard of living. As the global population grows, demand for food and fiber will continue to increase. As populations in some countries, particularly in Asia, become more affluent, their diets will become more varied and they will consume more animal products. These changes will inevitably add increasing stressors to an already precarious global food system.

To complicate matters, all of these changes are occurring against the backdrop of immense uncertainty surrounding not only worldwide financial stability, but also global climate change. One recent sign that agriculture may be faced with changing climactic conditions is the recent revision of the U.S. Department of Agriculture's (USDA's) Plant Hardiness Zone Map,[2] which shows a shift in most areas to warmer zone designations.[3] As we move forward into an uncertain future, our global and national food systems must adapt to changing conditions.

Our modern industrial agricultural system has a number of significant shortcomings. The current form of centralized industrial agriculture is a major contributor to many problems, including air and water pollution, inefficient energy use, climate change, loss of biodiversity, and human health effects. It is not the type of sustainable and resilient system that will be needed to ensure food security in a world with a growing population and complex and unpredictable modifications likely to occur as a result of global climate change.

I. The Link Between Agriculture and Climate Change

The academic and popular literature is filled with discussions of the link between carbon emissions and climate

Editors' Note: This Article has been adapted from Mary Jane Angelo, Into the Future: Building a Sustainable and Resilient Agricultural System for a Changing Global Environment*, in* Food, Agriculture, and Environmental Law *(Mary Jane Angelo, Jason J. Czarnezki, and William S. Eubanks II eds., 2013).*

1. *See* Sam Roberts, *U.N. Says 7 Billion Now Share the World*, N.Y. Times (Oct. 31, 2011), http://www.nytimes.com/2011/11/01/world/united-nations-reports-7-billion-humans-but-others-dont-count-on-it.html?_r=1 (last visited Oct. 20, 2013).
2. USDA Plant Hardiness Zone Map, http://planthardiness.ars.usda.gov/PHZMWeb/ (last visited Oct. 20, 2013).
3. USDA is careful to point out that the new map should not be used as evidence of climate change. *See* http://planthardiness.ars.usda.gov/PHZMWeb/AboutWhatsNew.aspx.

change, and the potential global harms that are likely to occur as a result.[4] According to most scientists, no environmental problem in human history is as potentially harmful as the climate change crisis.[5] The vast majority of scientists predict that without dramatic and timely reductions in releases of carbon into the atmosphere, various global climatic changes will occur that will make all other environmental crises pale in comparison.[6] Anticipated consequences of climate change include future warming,[7] increased frequency of heat waves,[8] increased heavy precipitation in some areas,[9] increased droughts,[10] more intense tropical storms,[11] and rises in high sea level.[12]

Climate change and agriculture are closely linked in several ways. The likely changes in temperature and rainfall patterns as a result of climate change have the potential to dramatically impact worldwide food production.[13] Conversely, current agricultural practices are themselves significant contributors to greenhouse gas (GHG) emissions that are fueling climate change.[14] Agriculture is therefore in the unique position of both contributing to climate change and having the potential to mitigate some of climate change's impacts.

Strategies for managing the impacts of climate change can generally be grouped into two broad approaches: mitigation strategies and adaptation strategies. Climate change mitigation is often referred to as "avoiding the unmanageable" through policies that seek to reduce net GHG emissions. Climate change adaptation, on the other hand, is referred to as "managing the unavoidable" impacts that will result as the globe warms. The majority of strategies that have been employed to address the impacts of climate change have primarily fallen under the category of mitigation. Nevertheless, research suggests that even if the atmospheric concentrations of GHGs could be stabilized through mitigation measures, climate change's impacts on agricultural production will continue without stabilizing for some time after GHG emissions reach equilibrium.[15] It is therefore critical that policymakers focus not only on mitigation, but also on adaptation in order for agriculture to respond to the impacts of global climate change. Meeting the global population's future food supply demands within the context of climate change will require both mitigation in the form of policies that reduce fossil fuel inputs and GHG emissions from agriculture and policies that encourage the development of agricultural systems that are resilient enough to be able to adapt to the likely changes that will occur.

II. Agriculture's Contribution to Climate Change

High-intensity industrial agriculture has a large "carbon footprint." Inputs such as pesticides and fertilizers that are relied on in industrial agriculture are derived from fossil fuels.[16] Nitrogen fertilizers are made from natural gas,[17] and most synthetic pesticides are made from fossil fuels.[18] Fossil fuels, especially diesel and gasoline, are used for heavy machinery such as tractors and combines, as well as for transportation of agricultural products to processing facilities and ultimately to retail grocery stores.[19] Agriculture accounts for approximately 20% of U.S. fossil fuel consumption as well as 15% of worldwide GHG emissions.[20] It is estimated that it takes "[10] calories of petroleum to yield just one calorie of industrial food" and about two-thirds of a gallon of gasoline to produce one bushel of corn.[21]

Another significant agricultural GHG contributor is methane production.[22] Animals, particularly cows that are kept in confined feeding operations and fed large quantities of corn and other grains, emit substantial amounts of methane gas.[23] Methane is a GHG that has been demonstrated to be approximately 20 times more powerful than carbon dioxide in exerting a greenhouse effect.[24] While methane gas is obviously a natural waste product produced by animals, the enormous quantities of methane gas produced in modern agriculture are directly

4. *See, e.g.*, Intergovernmental Panel on Climate Change, Climate Change 2007: The Physical Science Basis, Summary for Policymakers 10 (2007) (stating that most of the increase in global temperatures is very likely attributable to greenhouse gas (GHG) concentrations), *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf.
5. *See* Raymond B. Ludwiszewski & Charles H. Haake, *Climate Change: A Heat Wave of New Federal Regulation and Legislation*, Fed. Law., June 2009, at 32 (explaining that global climate change is currently the top environmental concern).
6. *See* Linda R. Larson & Jessica K. Ferrell, *Precautionary Resource Management and Climate Change*, Nat. Resources & Env't, Summer 2009, at 51, 52.
7. According to the Intergovernmental Panel on Climate Change (IPCC) Report, it is "[v]irtually certain" (>99% probability of occurrence) that future warming will occur. IPCC, Climate Change 2007: Synthesis Report 53 (2007), *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf. For explanation of the probability terminology, see *id.* at 27.
8. According to the IPCC Report, it is "[v]ery likely" (>90% probability of occurrence) that there will be an increased number of heat waves. *Id.*
9. According to the IPCC Report, it is "[v]ery likely" (>90% probability of occurrence) that there will be increased heavy precipitation in some areas of the globe. *Id.*
10. According to the IPCC Report, it is "[l]ikely" (>66% probability of occurrence) that there will be an increased number of droughts. *Id.*
11. According to the IPCC Report, it is "[l]ikely" (>66% probability of occurrence) that there will be more intense tropical storms. *Id.*
12. According to the IPCC Report, it is "[l]ikely" (>66% probability of occurrence) that there will be increased incidents of high sea level. *Id.*
13. *See* Christina Ross et al., *Limiting Liability in the Greenhouse: Insurance Risk-Management Strategies in the Context of Global Climate Change*, 43A Stan. J. Int'l L. 251, 297-98 (2007).
14. William S. Eubanks II, *A Rotten System: Subsidizing Environmental Degradation and Poor Public Health With Our Nation's Tax Dollars*, 28 Stan. Envtl. L.J. 213, 269-70 (2009).
15. *See* Steven K. Rose & Bruce A. McCarl, *Greenhouse Gas Emissions, Stabilization and the Inevitability of Adaption: Challenges for U.S. Agriculture*, 23 Choices, 1st Quarter 2008, *available at* http://www.choicesmagazine.org/2008-1/theme/05.pdf.
16. *See id.*; *see also* Peter Warshall, *Tilth and Technology: The Industrial Redesign of Our Nation's Soils*, *in* Fatal Harvest: The Tragedy of Industrial Agriculture 221, 225 (Andrew Kimbrell ed., 2002).
17. *See* Rose & McCarl, *supra* note 15; *see also* Warshall, *supra* note 16.
18. Warshall, *supra* note 16, at 225.
19. Eubanks, *supra* note 14; Warshall, *supra* note 16, at 225.
20. Eubanks, *supra* note 14.
21. *Id.* (citing Daniel Imhoff, Food Fight: The Citizen's Guide to a Food and Farm Bill 102 (2007)) (internal quotation marks omitted).
22. *See id.*; Joshua A. Utt et al., *Carbon Emissions, Carbon Sinks, and Global Warming*, *in* Agricultural Policy and the Environment 151, 156 (Rodger E. Meiners & Bruce Yandle eds., 2003).
23. Eubanks, *supra* note 14.
24. *Id.*

attributable to the sheer numbers of animals in confined feeding operations, which would not exist if not for cheap corn and soy production.[25]

A complicating factor arises from the search for alternative renewable fuels, which has resulted in substantial increases in corn ethanol production. With the intense focus on both climate change and the desire for domestic energy independence in recent years, scientists and policymakers have searched for alternative energy sources that could be produced domestically and that would not contribute to climate change to the extent that fossil fuels do. One of the major alternative energy supplies heavily subsidized by the federal government is corn ethanol.[26] Production of corn ethanol has increased from approximately 175 million gallons in the early 1980s to almost 6.5 billion gallons in 2007.[27] In 2008-2009, 34% of all U.S. corn production was used for ethanol production, up from 20% just two years prior.[28] Often touted as a "renewable" or "alternative" energy,[29] the use of ethanol as a major source of fuel is not without controversy.[30] U.S. policy continues to promote corn ethanol as an alternative fuel source despite the fact that scientific studies consistently demonstrate that reliance on corn ethanol will not help to solve the climate change crisis and poses additional environmental and social problems.[31] The rapid acceleration in corn ethanol production is at least in part attributable to the heavy subsidies that have been provided since the 1970s.[32] Although the U.S. Congress allowed corn ethanol subsidies to lapse at the end of 2011, other programs still in effect continue to encourage its production. Specifically, the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007 created a renewable fuel standard that provides a ready market for corn ethanol.[33] These policies contribute to the ongoing practice of growing large-scale monocultures of industrialized corn.

III. Climate Change Impacts on Agriculture

In addition to being a major contributor to climate change, industrial agriculture is also vulnerable to the likely impacts of climate change. Climate change has the potential to greatly impact global food security as its effects become more prevalent.[34] The effect of changing weather patterns on the volume and quality of global and regional food production will greatly impact food availability and food accessibility. Research suggests that the most significant changes in precipitation and temperature will be in the world's poorest and most vulnerable regions.[35] Climate change's disproportionate impacts on the livelihoods and food security of the poor will present significant challenges as we struggle to meet the ever-increasing global population's demands for food and resources.

Closer to home, climate change has the potential to alter growing seasons and change the kinds of crops and crop varieties that can be grown in particular regions of the United States. Changes in rainfall patterns are likely to result in increased droughts in some areas and increased flooding in others, and creating the need for new or different water management practices in many agricultural regions.[36] Moreover, probable increases in insect pest damage, weeds, and crop disease have the potential to alter agricultural production in the United States in ways not yet fully understood. Sea-level rise and saltwater intrusion will cause problems for agriculture in some coastal regions. All of these impacts of climate change on agriculture will indirectly impact human health. For example, if crop yields are reduced, food prices and child malnutrition are likely to rise.[37]

There is considerable uncertainty about the extent to which crop yields are likely to increase or decrease in a warming climate. Changes in crop yield will vary dramatically by geographical region depending on whether a particular locale experiences changes in rainfall and other conditions. However, general trends are very difficult to predict. While it may seem intuitive that warmer temperatures will lead to increased yields due to longer growing seasons and lower vulnerability to frost, the reality is much more complex. The U.S. Climate Change Science Program has reported that for numerous reasons decreased yields are

25. *See id.*
26. *See* Gary D. Libecap, *Agricultural Programs With Dubious Environmental Benefits: The Political Economy of Ethanol*, *in* Agricultural Policy and the Environment, *supra* note 22, at 89 (explaining that ethanol has received over $10 billion in subsidies).
27. James A. Duffield et al., *Ethanol Policy: Past, Present, and Future*, 53 S.D. L. Rev. 425, 425 (2008); *see also* Karl R. Rabago, *A Review of Barriers to Biofuel Market Development in the United States*, 2 Envtl. & Energy L. & Pol'y J. 211, 212 (2008) (describing the remaining barriers to full commercial success for biofuels in the United States).
28. Cattlenetwork.com, Percentage of Corn Crop Used for Ethanol, http://www.cattlenetwork.com/Percentage-Of-Corn-Crop-Used-For-Ethanol/2008-06-20/Article.aspx?oid=595584 (last visited Oct. 20, 2013).
29. *See, e.g.*, Growth Energy, About Growth Energy, http://www.growthenergy.org/2009/about/index.asp (last visited Oct. 20, 2013).
30. *See, e.g.*, Christopher Jensen, *Caution Flags Raised Over Ethanol Industry's 15% Solution*, N.Y. Times, May 10, 2009.
31. *Id.*
32. *See* Wallace E. Tyner, *The U.S. Ethanol and Biofuels Boom: Its Origins, Current Status, and Future Prospects*, 58 Bioscience 646, 646 (2008); *see also* Robert W. Hahn, *Ethanol: Law, Economics, and Politics*, 19 Stan. L. & Pol'y Rev. 434, 437-45 (2008) (describing how federal subsidies have driven the development of the ethanol fuel industry in the United States); Libecap, *supra* note 26, at 89.
33. Energy Policy Act of 2005, Pub. L. No. 109-58, 119 Stat. 594 (2005); Energy Independence and Security Act of 2007, Pub. L. No. 110-140, 121 Stat. 1492 (2007). *See also* Mark Holt & Carol Glover, Cong. Research Serv., Energy Policy Act of 2005: Summary and Analysis of Enacted Provisions 100 (2006), *available at* http://lugar.senate.gov/energy/links/pdf/Energy_Policy_Act.pdf; Fred Sissine, Cong. Research Serv., Energy Independence and Security Act of 2007: A Summary of Major Provisions 6 (2007), *available at* http://energy.senate.gov/public/_files/RL342941.pdf.
34. The United Nations Food and Agriculture Organization (FAO) defines "food security" as existing when "all people at all times have physical or economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." The FAO definition encompasses four dimensions: food availability; food accessibility; food utilization; and food systems stability. FAO CC & Food Security, 3.
35. Susan Charles, *Climate Change: Impacts on Food Safety*, 26 Nat. Resources & Env't 44 (Summer 2011).
36. *Id.*
37. International Food Policy Research Institute, Food Policy Report—Climate Change: Impact on Agriculture and Costs of Adaptation 2009.

likely for many crops including corn, rice, and sorghum. For example, as changes in rainfall result in less water availability in many areas, longer growing seasons will require increased water for irrigation. Many studies suggest that weeds, pest insects, and diseases are likely to increase, all of which could adversely affect crop yield.[38] Studies also show that increased carbon dioxide levels promote weed growth. Warmer temperatures promote increased pests and diseases and can create hospitable conditions that result in new pests and diseases moving into areas previously inhospitable due to cold temperatures. Moreover, there are likely to be many unanticipated effects. For example, one study shows that growing soybeans in increased carbon dioxide environments results in dramatic increases in pest damage to soybean plants.[39] Other studies indicate that some weed control chemicals that are widely relied upon, such as glyphosate, will lose their efficacy in an environment with elevated carbon dioxide.[40]

Most studies predict that the likely impacts of climate change on agriculture over the coming century will be both positive and negative. The type and intensity of the impacts will vary by location. The production practices and crop types grown in a particular region will determine how well-suited that region is to adapt to the likely changes.[41] Many experts believe that the likely negative impacts on developing regions of the world could be slightly offset by some limited positive impacts in developed regions.[42] Thus, while the aggregate overall impact to global food production may not be large, many regions may suffer significant impacts.[43]

IV. Adapting to Climate Change

Strategies for adapting agriculture to climate change include a mix of technological and institutional policy changes, and they typically distinguish between changes that could be made at the individual and institutional levels. Technology-based proposals include increased development of crop varieties; innovations in resource management including water conservation measures; development of forecasting systems; development of improved irrigation systems; and changes in land use and timing of planting.

Institutional and policy proposals typically involve increased government support for agriculture, including subsidies and incentives. Although technological fixes and increased government support may be necessary components of any climate change adaptation plan, these types of proposals for piecemeal fixes ignore the need to look at the entire farming system to ensure it will be able to adapt to the inevitable and unpredictable changes that will occur. Of particular concern is the fact that our current industrial agriculture system has become so highly dependent on large fossil fuel inputs that, if such inputs become scarce or too costly, farm production will plummet. Equally as significant, through this type of large-scale farming, we have eliminated the natural ecosystem functions that make ecosystems more resilient and better able to adapt to changing conditions. For farming systems to be able to readily adapt, they will need to become more ecologically resilient.

A. *Ecological Resilience*

Ecological resilience has been described as "a measure of the amount of change or disruption that is required to transform a system from being maintained by one set of mutually reinforcing processes and structures to a different set of processes and structures."[44] The concept of ecological resilience is based on the understanding that ecosystems can exist in multiple stable states.[45] Ecological resilience should not be confused with "engineering resilience," which is a measure of the time it takes for a system to return to a steady state after experiencing a perturbation.[46] In contrast, ecological resilience, a measure of the magnitude of a perturbation that a system can absorb before the disturbance, causes the system to shift into a different regime of behavior with different controlling processes.[47] As such, ecological resilience captures the strength of redundancies in an ecosystem stemming from reinforcing processes and compensating functions provided by more than one species. These redundancies enable the system to absorb disturbances and persist despite the disruption.[48] When applied to an agricultural system, ecological resilience is a measure of an agricultural system's ability to continue to function and provide yield despite changes or perturbations such as increased pest populations, disease, or changed rainfall patterns. By ensuring that the ecological resilience of an ecosystem, including an agricultural ecosystem, is maintained or reintroduced, it is more likely that the ecosystem will be able to withstand a greater range of perturbations without undergoing a shift to, for example, a nonproductive agricultural system.

To ensure that any ecological system, including an agricultural ecosystem, is resilient, a number of factors must

38. Simon N. Gosling, *A Review of Recent Developments in Climate Change Science, Part II: The Global-Scale Impacts of Climate Change*, 35(4) Progress Physical Geography 451-53 (2011).
39. Diana Lutz, *In Elevated Carbon Dioxide, Soybeans Stumble but Invasive Cheatgrass Keeps on Truckin'*, Sci. Daily (June 22, 2010). *See also* Tsyr-Yan Yu et al., *Variability in C_3-Plant Cell-Wall Biosynthesis in a High-CO_2 Atmosphere by Solid-State NMR Spectroscopy*, 132(18) J. Am. Chemical Soc'y 6335 (2010).
40. Lewis H. Ziska & Ernie W. Goins, *Elevated Atmospheric Carbon Dioxide and Weed Populations in Glyphosate Treated Soybean*, 46 Crop Sci. 1354-59 (2006). *See also* Daniel J. Archambault et al., *The Effects of Elevated CO_2 and Temperature on Herbicide Efficacy and Weed/Crop Competition* (2001), *available at* http://www.parc.ca/pdf/research_publications/agriculture2.pdf.
41. Susan Charles, *Climate Change: Impacts on Food Safety*, 26 Nat. Resources & Env't 44, 44 (Summer 2011).
42. *Id.*
43. *Id.*
44. Garry Peterson, *Contagious Disturbance and Ecological Resilience*, at 216 (Ph.D. dissertation, Univ. of Florida, 1999).
45. Peterson, *supra* note 44, at 217.
46. C.S. Holling & Lance H. Gunderson, *Resilience and Adaptive Cycles*, *in* Panarchy: Understanding Transformations in Human and Natural Systems 28 (Lance H. Gunderson & C.S. Holling eds., 2002).
47. Lance H. Gunderson et al., *Resilience of Large-Scale Resource Systems*, *in* Resilience and the Behavior of Large-Scale Systems 4 (Lance H. Gunderson & Lowell Pritchard Jr. eds., Island Press 2002).
48. *Id.* at 6.

be present. Research suggests that one of the most significant factors in increasing a system's ecological resilience is to increase its species' richness. Because individual species are only able to perform limited ecosystem functions, the greater the species' richness, the greater functional diversity in the ecosystem.[49] The ability of a system to dampen the effects of perturbations depends in part on the extent to which one species can compensate for the loss of a function previously provided by another species.[50] Thus, to create a resilient agricultural system, it will be necessary to ensure a sufficient amount of redundancy in ecosystem controlling processes, such that unexpected disturbances, whether anthropogenic or natural, can be absorbed without causing the system to shift states. This can only be accomplished by introducing biodiversity back into the agricultural system.

The planting of large-scale monocultures strips farms of the diversity needed for ecological resilience. Monocultures by definition and design are comprised of only one crop variety, often spanning hundreds or thousands of acres. In contrast, alternative farming systems, where diverse numbers of crop types and varieties are planted in close proximity, where crops are rotated, or where natural refugia are provided on the farm, contain the biological diversity that reduces vulnerability to change. Not only does a variety of crops provide a safety net in case one crop is lost due to an outbreak of pests or disease, but by reducing the chemical inputs and providing natural refugia on site, natural populations of beneficial species such as predators and parasites of pest species, pollinators, soil microbes, and a diverse array of other organisms ensure that natural ecosystem functions are maintained and redundancies are built into the system to provide resilience.[51]

B. *Building a Sustainable and Resilient Agro-Ecosystem*

To ensure food security for a growing global population in a time of significant change, it will be necessary to build a more ecologically resilient agricultural system that contains the biodiversity, redundancies, and ecosystem functions that enhance its ability to adapt to new conditions. It will be necessary not only to have farms that are run in a more environmentally friendly, sustainable, and resilient way, but also to have food distribution systems that ensure food availability. Changes are needed both to environmental laws, which are not adequate to address the environmental risks posed by agriculture, and to current agricultural policy, which encourages unsustainable, nonresilient, industrialized practices.

Over the past few decades, scientists, policymakers, farm organizations, environmentalists, and others have called for new sustainable agricultural approaches to replace industrialized agriculture. One such approach, eco-agriculture, seeks to limit the harm to wildlife, biodiversity, and ecosystem services resulting from industrial agriculture by advancing farming practices that view the farm as a healthy sustainable living system, rather than an industrial facility. The premise of eco-agriculture is that the farm is a kind of ecosystem—an "agro-ecosystem"—made up of soil, plants, insects, and animals. A healthy farm ecosystem will have healthy and fertile soils, and healthy populations of natural predators and parasites, pollinators, and other beneficial species. The farm maintains many ecosystem services that provide benefits beyond the farm, and it reduces the negative externalities of farming. Farming practices are geared toward maintaining and enhancing ecosystem health and function, while at the same time maximizing yields within the constraints of maintaining a healthy ecosystem. The agro-ecosystem mindset represents a shift in thinking away from the idea that human activity and functioning ecosystems are mutually exclusive.

In a recent report, the National Research Council of the National Academies described a "farming systems continuum," with conventional farming at one end and ecologically-based farming at the other, and a potentially infinite set of combinations of farming practices falling somewhere in between.[52] The concept of eco-agriculture relies on modern knowledge about the interactions within natural systems, as well as cutting-edge technologies, to achieve its results. When done properly, it can produce high yields and profits for farmers while protecting human health, animal health, and the environment. Eco-agriculture draws on the key techniques of sustainable agriculture including crop rotation, cover crops, reduced tillage and no-till practices, soil enrichment, maintenance and enhancement of natural pest enemies, integrated pest management, precision farming that utilizes detailed spatial information about soil conditions and crop performance to target crop management practices to the specific place they are needed, diversification of farms enterprises, which helps increase biodiversity, other agricultural best-management practices such as buffer or filter strips and wildlife habitat enhancement, and enhanced genetic resistance to climatic extremes, pests, and other threats.[53] These techniques may be used in a variety of combinations depending on the specific circumstances of the farm at issue. These techniques not only help to build a sustainable and ecologically sound system, but more specifically help to increase resilience within the agricultural system by building diversity, thereby making the system more adaptable to change. Working farmlands can reap the benefits provided by nature in the form of pest control through predators and parasites by promoting biodiversity on the farmlands themselves. Biodiversity on the farm can be enhanced through reduced pesticide use, intercropping, crop rotation, and the creation and maintenance of refugia on or near the farm field. Crops on working farmlands can

49. Peterson, *supra* note 44, at 209.
50. Gunderson et al., *supra* note 47, at 9.
51. *See generally* Robin Kundis Craig, *"Stationarity Is Dead"—Long Live Transformation: Five Principles for Climate Change Adaptation Law*, 34 Harv. Envtl. L. Rev. 9 (2010) (describing some activities that promote resilience in agricultural systems).
52. National Research Council, Toward Sustainable Agricultural Systems in the 21st Century 20-23 (2010) (NRC Report).
53. *Id.* at 21.

become more resistant to disease and pests through practices that maintain the health and fertility of soils, such as rotating crops and planting legumes and other cover crops that improve soil fertility.[54]

In recent years, attempts to adopt eco-agricultural approaches by using various combinations of the above-described techniques have been made throughout the world. A number of examples have been cited as eco-agriculture "success stories." For example, in parts of Central America, farmers have integrated trees into livestock pastures to provide habitat for forest birds. Also in Central America, farmers have had success with planting biodiversity-friendly coffee plantations. In California, a type of eco-agriculture has been implemented by flooding rice fields for birds during fallow seasons. In Indonesia, there are several successful examples of "agro-forests" that integrate agriculture and forestry, as has the integration of rice terraces with fish and vegetables. Each of these examples has been successful in some measure by introducing a level of biodiversity into the farming system. A number of domestic sustainable farming success stories are outlined in the 2010 NRC Report. Most of the success story farms shares certain commonalities. As described by the NRC, one such commonality is that "[m]any farmers emphasized the importance of maintaining or building up their natural resources base and maximizing the use of internal resources as key parts of their farming strategies."[55]

The Report emphasized the use of various combinations of farming approaches in each of the successful farms and also described how successful farms tended to readily adapt to new information.[56] In fact, many of the successful farms either carried out their own trials and experiments or participated in research conducted by universities "because they recognize the importance of adapting their farming approaches to local conditions."

The reliance on specifically-tailored combinations of ecologically based practices combined with the active participation in experimenting with and adapting farming practices to local conditions have led to the types of ecologically based sustainable farming that will be more resilient and better able to adapt to climate change.

V. Policy Solutions

Scholars and practitioners have proposed a variety of reforms of U.S. law and policy geared toward building the type of environmentally responsible, sustainable, and resilient agricultural and food system that will be able to adapt to the inevitable global climate changes and likely political and economic challenges to food security. No one proposal will solve all of our problems, but there are proposals that independently and in the aggregate can help to move us in the direction of sustainability and resilience. For example, Prof. J.B. Ruhl has proposed paying farmers to do the "new right thing."[57] His proposal would provide financial incentives to famers to encourage the preservation and maintenance of ecosystem services on working farmlands. This proposal recognizes that farms can serve as houses of "natural capital capable of providing a diverse stream of goods and services, including ecosystem services such as increased biodiversity, carbon sequestration, pollination, groundwater recharge, and improvement of water quality."[58] By paying farmers to preserve the ecosystem services that are critical to the maintenance of a healthy environment, we are also encouraging farmers to engage in practices that produce more sustainable and resilient eco-agricultural systems.

William S. Eubanks has proposed a number of revisions to the farm bill that would eliminate or shift subsidies that currently promote large-scale industrialized farming in favor of more sustainable and ecologically sound agricultural practices.[59] The reforms offered by Eubanks not only would achieve many of the same agricultural benefits as those that would result from paying farmers to preserve ecosystem services, but they would also promote sustainability, resilience, and food security in a broader sense by enhancing the ability of smaller farms to compete, and by strengthening local food systems and rural communities. Removing subsidies to large industrial growers that allow them to undercut smaller growers and providing more flexibility in what farmers can grow while receiving subsidies will have the added benefit of promoting local and regional food systems capable of producing a range of healthy foods close to home. This, in turn, will provide greater food security and infrastructure development for rural communities, which have generally been devastated by decades of agricultural policies encouraging farm aggregation that has resulted in dwindling rural populations.

George A. Kimbrell has proposed modifications to one increasingly important aspect of industrialized farming—the growing of genetically modified crops, which has become a predominant force in global agriculture in recent years. His proposals call for better regulatory oversight to address the potential risks associated with planting genetically modified organisms (GMO) in the environment.[60] He also advocates for more precautionary approaches to ensure environmental protection, human health and safety, and economic stability. The fact that many scientists have identified new GMO crop varieties that are resistant to disease, pest, drought, or salinity as important tools in adapting to climate change underscores the need for an effective, transparent, and precautionary regulatory system to be in place before climate change impacts press us to introduce even more GMO crops into the ecosystem.

54. *Id.* at 94-110.
55. *Id.* at 355.
56. *Id.* at 397.
57. J.B. Ruhl, *Agriculture and Ecosystems Services: Paying Farmers to Do the* New *Right Thing*, *in* Food, Agriculture, and Environmental Law (Mary Jane Angelo et al. eds., 2013).
58. *Id.*
59. William S. Eubanks II, *Achieving a Sustainable Farm Bill*, *in* Food, Agriculture, and Environmental Law (Mary Jane Angelo et al. eds., 2013).
60. George A. Kimbrell, *Regulating Transgenic Crops Pursuant to the Plant Protection Act*, *in* Food, Agriculture, and Environmental Law (Mary Jane Angelo et al. eds., 2013).

Finally, Prof. Jason J. Czarnezki has explored use of food labeling as a means of achieving a more sustainable and resilient agricultural system.[61] He stresses the importance of individual behavior and the ability of consumer choice to influence the way in which food is produced, processed, and distributed. Czarnezki compares a number of food labeling regimes and proposes a new "eco-labeling" program that would employ environmental life-cycle analysis and best-practices standards to ensure consumers are aware of the full range of environmental and health implications of the foods they purchase. Well-informed consumers who demand that their food be produced, processed, and distributed in ecologically sustainable ways can provide market incentives that will encourage more ecologically based agricultural practice, which will be more resilient to the challenges likely to accompany climate change.

VI. Conclusion

To have a more sustainable and resilient agricultural system that is better adapted to climate change, it will be necessary to change a number of laws and policies. While no one proposal alone can solve all of the environmental, health, social, and economic issues related to agriculture, a multifaceted approach comprised of a combination of the types of proposals described in this Article offer a path for developing the type of sustainable and resilient food system that will be needed to adapt to the impacts of climate change and to provide food security for a growing and changing global population.

61. Jason J. Czarnezki, *The Future of Food Eco-Labeling: A Comparative Analysis*, *in* Food, Agriculture, and Environmental Law (Mary Jane Angelo et al. eds., 2013).