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CLIMATE RESILIENCE AGRICULTURE PRACTICES

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Climate change is going to present society with a variety of new challenges. Individuals, households, and communities around the world-but particularly in low-and middle income nations-will all be affected in the coming years and decades. Changes in mean temperature are going to affect food production and water availability, changes in mean sea level will increase coastal inundation, and more-frequent and more-intense extreme events will result in more damage and loss of life from floods and storms. On top of this, rising temperatures can increase the burden of malnutrition, diarrheal illnesses, cardio respiratory diseases, and infections. These challenges are felt particularly strongly in some of the poorest regions of the world.

Environmental changes may affect many different aspects of agricultural production. With greater climate variability, shifting temperature and precipitation patterns, and other global change components, we expect to see a range of crop and ecosystem responses that will affect integral agricultural processes. Such effects include changes in nutrient cycling and soil moisture, as well as shifts in pest occurrences and plant diseases, all of which will greatly influence food production and food security (Fuhrer, 2003). These changes are expected to increase abiotic and biotic stress, forcing agricultural systems to function under greater levels of perturbation in the future.

Resilience is defined as the propensity of a system to retain its organizational structure and productivity following a perturbation (Holling, 1973). Thus, a resilient agroecosystem will continue to provide a vital service such as food production if challenged by severe drought or by a large reduction in rainfall. In agricultural systems, crop biodiversity may provide the link between stress and resilience because a diversity of organisms is required for ecosystems to function and provide services. Removing whole functional groups of species or removing entire trophic levels can cause ecosystems to shift from a desired to less-desired state, affecting their capacity to generate ecosystem services (Folke *et al*., 2004). This effect highlights the possibility that agricultural systems already may be in a less-desired state for the continued delivery of ecosystem services.

Biodiversity—which allows for the coexistence of multiple species, fulfilling similar functions, but with different responses to human landscape modification—enhances the resilience of ecosystems (Walker, 1995). This concept is linked to the insurance hypothesis (Yachi and Loreau, 1999), which proposesthat biodiversity provides an insurance, or a buffer, against environmental fluctuations because different species respond differently to change, leading to more predictable aggregate community or ecosystem properties. Such diversity insures the maintenance of a system's functional capacity against potential human management failure that may result from an incomplete understanding of the effects of environmental change (Elmqvist *et al*., 2003).

Advantages of diversified agroecosystems

Current knowledge suggests that climate change will affect both biotic (pest, pathogens) and abiotic (solar radiation, water, temperature) factors in crop systems, threatening crop sustainability and production. More diverse agroecosystems with a broader range of traits and functions will be better able to perform under changing environmental conditions (Matson *et al*., 1997), which is important given the expected changes to biotic and abiotic conditions. The following are a few of the major ways that the greater functional capacity of diverse agro ecosystems has been found to protect crop productivity against environmental change.

Pest suppression

In agricultural systems, as in natural ecosystems, herbivorous insects can have significant impacts on plant productivity. The challenges of pest suppression may intensify in the future as changes in climate affect pest ranges and potentially bring new pests into agricultural systems. It is expected that insect pests will generally become more abundant as temperatures rise as a result of range extensions and phenological changes. This abundance will be accompanied by higher rates of population development, growth, migration, and overwintering (Bale *et al*., 2002). Changes in the distribution and abundance of species and communities are unlikely to occur at the same rates. Migrant pests are expected to respond more quickly to climate change than plants, and they may be able to colonize newly available crops and habitats (Bale *et al*. 2002). However, there are a variety of barriers to range expansions, including such biotic factors as competition, predation, and parasitism from other species (Patterson *et al*. 1999).Promoting such barriers to range expansion and pest viability will have an immediate negative impact on pest outbreaks and will help protect agricultural production.

Disease suppression

Losses caused by pathogens can contribute significantly to declines in crop production, and changes in climate potentially could affect plant disease distribution and viability in new agricultural regions. From 2001 to 2003, 10% of the global crop losses in wheat, rice, and maize were shown to be a result of pathogens (Oerke, 2006).

The diversity of crop species in an agroecosystem has a much less predictable effect on microbial pathogens compared with crop pests, as microclimatic conditions play an important role in the development and severity of a disease (Matson *et al*., 1997; Fuhrer, 2003).The effect of climate change on disease prevalence is therefore much less certain. Climate change could have positive, negative, or no impact on individual plant diseases (Chakraborty *et al*., 2000), but it is suspected that milder winters may favor many crop diseases, such as powdery mildew, brown leaf rust, and strip rust, whereas warmer summers may provide optimal conditions for other diseases, such as cercosporea lead spot disease (Patterson *et al*., 1999).Global change is also predicted to alter the distribution and abundance of arthropod vectors that distribute viruses, thereby affecting the rates of and chances for crop transmission (Anderson *et al*., 2004).

Climate variability buffering and mitigation

Diversified agro ecosystems have become more important for agriculture as climate fluctuations have increased. Research has shown that crop yields are quite sensitive to changes in temperature and precipitation, especially during flower and fruit development stages. Temperature maximums and minimums, as well as seasonal shifts, can have large effects on crop growth and production. Greater variability of precipitation, including flooding, drought, and more extreme rainfall events, has affected food security in many parts of the world (Parry *et al*., 2005).

Agricultural vulnerabilities have been found in a number of important crop species. Studies of wheat have demonstrated that heat pulses applied to wheat during anthesis reduced both grain number and weight, highlighting the effect of temperature spikes on grain fill (Wollenweber *et al*., 2003). In maize, researchers observed reduced pollen viability at temperatures above 36 degrees Celsius, a threshold similar to those in a number of other crops.

Agro forestry systems are examples of agricultural systems with high structural complexity. Although the primary crop of interest (e.g., coffee, cacao) is sometimes grown in more intensively managed systems with little shade cover, the more structurally complex systems have been shown to buffer crops from large fluctuations in temperature, thereby keeping crops in closer-to-optimal conditions. The more shaded systems have also been shown to protect crops from lower precipitation and reduced soil water availability because the over story tree cover reduces soil evaporation and improves soil water infiltration.

Conclusions

It is abundantly clear that farmers are facing growing stress from climate change, and that the greater implementation of diversified agricultural systems may be a productive way to build resilience into agricultural systems. The challenges to increasing adoption of diversified agricultural management strategies are both scientific and policy based. In the scientific realm, the adoption of diversified agricultural systems could be bolstered if farmers had a better idea of how to optimize a diversified structure to maximize production and profits. Crop and landscape simulation models that can model a range of climate scenarios and landscape modelling with farm profitability scenarios would help farmers find optimal strategies for maintaining production and profit. Stakeholder-based participatory research would also be highly beneficial, as researchers could model strategies that seem plausible to farmers.

In the policy realm, diversification within agricultural systems could potentially increase in the United States through the adjustment of the farm income support systems to incentivize more diverse cropping systems that support small farmers. Internationally, diversified agriculture can have a large role in protecting food security and production in regions where farmers have little access to chemical, structural, or technological resources.

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