AGRICULTURE: IS CLIMATE CHANGE A SERIOUS ISSUE?

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Abstract

A changing climate coupled with rapidly increasing demand for agricultural products will offer challenges greater than any previously experienced by global agriculture. The changing above ground environment, including air temperature, precipitation and carbon dioxide concentrations, will impact crops directly as these factors impact plant physiologic processes. Less well recognized is that for world agricultural demands to be met, vast increases of nutrients and water must be supplied to crop plants from soils in which they grow. This must occur while expansive areas of currently farmed soils are being degraded, projected increased frequency of climate extremes will intensify current soil degradation pressure, and aquifer stress is limiting production in important grain producing areas. Expansion of agriculture into currently unfarmed areas could improve global food security; however continued conversion of agricultural land to other more economically viable uses will act to counterbalance agriculture's spatial expansion. The soil scientist challenge to help maintain soil productivity on soil less suitable for crop production in the face of increasing crop production demands will require imagination, innovation, and investment greater than currently occurring.

Keywords
Climate Change, Greenhouse Gas, Soil Degradation, Food Security

Introduction

Agriculture's ability to supply products in sufficient quantity and quality to meet rising demand will be challenged more in the coming years than ever before, even if climate were to remain stable and relatively favorable for food production. A stable favorable climate for food production seems unlikely as evidence exists that climate change has already negatively impacted maize and wheat production over recent decades (1). Agriculture must deal with a finite set of resources required for food, feed, and biofuel feedstock production while population and standard of living continues to increase across a broad group of developing societies; with these increases come increasing demands for basically all agricultural products. Of great importance, most products in demand are deemed necessary for human survival. Agriculture must not fail this challenge as failure could result in the greatest negative impact to global human civilization ever experienced. The objective of this paper is to highlight selected critical issues related to global food security, agriculture and climate change, and to suggest areas of soil science research and practice requiring significant advances to meet the impending challenges.

Increased Agricultural Commodity Demand

World population will continue to expand with a virtually certain 35% increase in the next 40 years. A majority of this increase will occur in undeveloped and developing regions of the world (2). Many of these areas are currently suffering from food and water shortages and projections are that future shortages will become more serious (3). Because of economic realities, many people in these regions cannot afford food imports from developed nations. Meeting the basic human need for food (daily caloric intake) will depend upon agricultural production increases in regions currently experiencing food shortages to balance the increasing demand expected from a growing population. As discussed later, anticipated climate changes will likely make this a difficult scenario to fulfill, at least without substantial outside investment in both improved management practices, technology, and infrastructure (such as irrigation).

In developing countries, the increase in middle class is occurring at record rates and with this increase comes rapidly improving diets that amplify demands for both food/feed quantity and quality, especially increased demand for meat and dairy products. The increased demand for meat products in particular will amplify the demand for grain production on agricultural land. Cattle, for example, require approximately 8 kg of feed to produce 1 kg of meat; as meat consumption increases, land area required to feed livestock increases dramatically compared to land area needed to feed a population that is dominantly vegetarian. United Nations Secretary-General's High-level Panel on Global Sustainability (4) estimates that in the next 20 years, 3 billion people will enter the 'middle class' with elevated demands for resources including food, water and energy. Meat consumption is expected to increase by 73% by 2050 (5). To meet the rising population and middle class food demands, the world will need at least 50% more food by 2030 than currently is produced (4). As meat products will make up a greater portion of the world diet, meeting the 50% increased food demand by 2030 will require crop production increases considerably greater than 50% as more grains are consumed by animals to meet the rising demand for meat. At no time in history has such a large segment of the world population elevated class status so rapidly with a concurrent demand increase on world resources tied to increasing agricultural production.

In addition to growing demands for agriculture food products, increased use of traditional food and/or feed for non-food products, such as corn grain for ethanol, is reducing food/feed supplies. For example, in the United States approximately 40% of harvested domestic corn grain is processed for ethanol production (6), which equates to approximately 15% of world corn grain production. Not only does alternative uses impact supply of food and feed directly, it has significant impacts on food prices (7). Food price is particularly critical for nations experiencing poverty.

Food cost considerations

Demand for food is increasing, and data suggests it is increasing as rapidly as is our current ability to increase food/feed production/supply (8). With rising demand and a marginal ability to meet that demand, especially in some regions, food price and price stability are vulnerable to small production shocks such as those due to abnormal climate events (9). Not only will the risk of food shortages rise for a variety of reasons discussed in this paper, the cost of food that is available may be increasingly unaffordable to the less-affluent people of the world. Food price and availability have had, and will likely have, impacts beyond those living in poverty. High food prices and food shortages have been implicated in political unrest in multiple countries in recent years, with concerns that these situations could become more prevalent (10). The need for an efficient, stable, and highly productive agricultural industry is critical.

Agricultural land depletion

While demand for agricultural products is increasing, land suitable for agricultural production worldwide is decreasing. China has lost productive land due to urban expansion since 1986. It seems land consumed by urban expansion has been replaced with other land, but the replacement land is of lower productivity. As China's economy expands, rate of agricultural land conversion, however, seems to be accelerating and concerns exist about this impact on food security (11). Land use plans have called for as much as 42% of Indonesia's high producing paddy rice fields to be converted to nonagricultural purposes (12). In the United States over 9.3 million hectares of agricultural land was converted to nonagricultural uses from 1982 to 2007, or about 2.5 percent of the United States farm land (13). Recent estimates indicated conversion of agriculture land to nonagricultural land use in Bangladesh is at an annual rate of 0.56%; loss of rice production ranges from 0.86 to 1.16 percent annually (14). By 2030, 7% of farmland that existed in 2002 will be lost to other uses (15). As economies expand, agricultural land tends to assume uses that have higher economic value and financial return than that obtained through agricultural production. Loss of productive land worldwide has significantly reduced agricultural production potential and unless creative policies and means of enforcing those policies are developed, this loss is likely to continue.

Agriculture utilizes 11% of the world's land surface. Globally, 25% of agricultural land is considered to be highly degraded such that livelihoods have been compromised, production capacity has been seriously diminished, and opportunities to renovate are limited or nonexistent (16). Further, many of these degraded lands occur in regions with high poverty and only marginal or no potential to increase food production. Estimates indicate that yields have been compromised 20% by erosion in India, China, Iran, Israel, Jordan, Lebanon, Nepal, and Pakistan (17). Land degradation associated with soil erosion in Ghana will reduce agricultural income by a total of about US $4.2 billion over the 2006-2015 period or about five percent of its total agricultural gross domestic product (18). While absolutely imperative that world soil resources be managed in a sustainable manner, it is unlikely that the pace of land degradation will slow in the near future given the historical trend and stress placed on these resources due to rising demand for food, feed and fuel production. Management of soils to maintain or even increase productive potential should be one of, if not the highest, priority for the agricultural sciences.

Irrigation and aquifer stress

Water availability and food production are tightly linked. Agriculture consumes 70% of all fresh water withdrawals, mostly for irrigation purposes (19). While covering only 18% of the world's agricultural land, the production of 40% of world food/feed/fuel feedstock is assisted by irrigation (20). Irrigation yields are not only high, they are very stable, as irrigated land has less risk of crop production failure than does rain-fed land. In a world of growing food demand, high and stable yields (year to year yield consistency) are critical for maintaining stable food supplies and for reducing sharp price fluctuations that can be devastating for those in poverty and that can have significant impact on political stability (10).

While irrigation offers high crop yields and stable production, a substantial portion of water extracted for irrigation comes from ancient aquifers that are being stressed and in some locations depleted. Multiple countries relying on irrigation for food production face serious to severe water stress issues. Saudi Arabia exemplifies a country that has produced wheat for their own citizens until recently as water resources used for irrigation have been severely stressed. Wheat harvest, dependent on irrigation from ancient aquifers, peaked at 4.1 million tons in 1992 and dropped 71% to 1.2 million tons in 2005. Irrigation subsidies have been removed. Some farmers reportedly were pumping water from depths greater than 1200 meters (21). Irrigated land in China produces approximately 75% of the country's cereals, and about 90% of its cotton, fruits vegetables and other agricultural commodities (22). Northern China produces nearly all of China's maize and wheat through irrigation (22); this area of China has severe water stress issues, which will negatively impact the country's agricultural production (21, 23). Brown (21) identifies 15 countries that were over-pumping aquifers in 2005; these countries had a combined population of 3.3 billion people and included population centers of China, India, and Pakistan. Dominant cause for nearly all over- pumping activities was irrigation for food production. Feeding a growing world population on less water for crop production seems a stark reality and one that places increasing pressure on rain-fed agricultural areas.

Development of lands that are not being farmed, but that are suitable for crop and/or animal production, seems necessary if we are to meet projected food demand increases. Potential for expansion of rain-fed agriculture to lands (including forested areas) unfarmed in the 1994 – 1996 period was evaluated by Fischer et al. in 2002 (3). Through use of available technology they concluded that substantial areas currently unfarmed could support rain-fed agriculture. Greatest potential for expansion was in East and Middle Africa and South America. Developing countries contain nearly three times as much potential rain-fed farmable land as the developed countries. Globally, it is estimated that in the 1994-1996 period less than 60% of the gross available land was under cultivation (3). While this land has potential for rain-fed agricultural production, Fisher et al. cautioned that the much of this area is not prime farmland. Further, the unfarmed area identified must have space allotted for infrastructure, settlements, and legally protected areas that will be unavailable for agriculture; estimates are that from 10 – 30% of the gross area would be allotted to competing uses. They also determined that large areas of Asia unsuitable for rain-fed agriculture were being farmed; these are areas with limited future rain-fed production potential. Considering land degradation rate of current farmed land, conversion of agricultural land for other uses, increasing stress on aquifers used for irrigation, and growing global demand, agricultural expansion into areas with cropping potential will likely be necessary in the coming decades and will increasingly be seen as high priority. Caution is advised against seeing this as a panacea for mitigating current food production concerns, however. Ability to build infrastructure, to manage sustainably, to enhance production through development and use of appropriate technology, and adapt to changing climate in these regions are critical unknowns that the agricultural science must address, assuming the political will exists to allow or encourage sustainable expansion.

Yield increase

While soil resource limitations and water stress seem serious concerns as we look to the future, crop yields and world production have experienced a consistent increase for multiple decades although these increases have not been uniform across regions. Global maize yield, for example, has experienced a linear annual yield increase of about 63 kg ha -1 since 1966 (8). Improved genetics (the green revolution) coupled with increased fertilizer use and expansion of irrigated land resulted in dramatic production increases of wheat and rice. Recently, however, the rate of increase has diminished in relation to growing demand, especially in areas such as the US and Europe where advanced crop production technology is being practiced and high yields (and total production) are observed. The slowing pace of crop yield increases suggests further challenges for global food security in that these existing high producing areas seem to be approaching a yield and production plateau (8); little additional land exists in these countries for agricultural expansion. Further, management practices (high yielding varieties, sound fertility practices, and high plant populations) are nearly optimum for production in these countries and thus yield improvements attributed to management improvements in these areas will likely be marginal or nonexistent. These same authors also pointed to developing evidence that irrigated corn in the US has plateaued, further suggesting that even under mostly resource non-limiting production conditions we may have reached our yield peak. Agricultural production increases must occur in regions currently experiencing lower yields as it seems that these areas, through improved technology, have the greatest opportunity for production increases; all things considered, demand increases threaten to outpace production increases in the near and extended future (8). Thus, future yield increases on lands currently supporting high production levels must come from continued yield enhancing genetic modifications. It is quite conceivable that genetics will face greater challenges in fostering higher yields in significant areas that already are highly productive. Increasingly higher yields must occur on soils that are experiencing significant degradation through soil erosion and soil organic matter loss. Further, challenges to continued yield increases may be based on basic plant physiology principles. Sinclair (24) clearly articulates that continued crop yield increases are not likely in that yield is coupled to transpiration and that water limitations and our inability to continually move more water through the crop will cap yield advances.

Selected authors suggest the world's agriculture aided by continuously improving technology, better management of food resources, better government policies and increased investment in agricultural research can produce sufficient food to minimize impact of hunger (25, 26, and 27). Current and recent events suggest that we are not moving in this direction, or moving nearly fast enough to mitigate hunger in significant areas of the world. Little evidence supports the contention that we are improving accessibility of food but rather suggests we are moving towards more accessibility challenges. That evidence includes, but is not limited to, relatively low stocks-to-use ratio of multiple crop and food products, relatively high world food prices, political unrest attributed at least in part to food shortage and cost (28), and increased concern over food and food related issues as this impacts security of nations (29). Even under relatively favorable production conditions, evidence is mounting that agriculture's ability to meet growing food, feed, fiber and fuel demand could face serious challenges. A changing climate could amplify these challenges.

Climate Change

Climate change potentially modifies or impacts each stress associated with agriculture's ability to meet the growing demand for agricultural products. In many cases, when considered globally, climate change acts as a multiplier to existing challenges. Increasing variability of climate components and increased frequency of extremes will very likely have negative impacts on production of existing crops in current agricultural areas, which further magnifies the importance of positive production advances being made in agricultural sciences. And while agriculture must adapt to climate change, it also contributes substantially to greenhouse gas emissions leading to climate modification (30).

Climate change components can be divided into those which are highly dynamic (those that vary sufficiently to affect biological systems at the daily and sometimes smaller time scales) and those that are less dynamic but change predictably and more uniformly in space and time. The more dynamic components also tend to vary spatially and can be exemplified by precipitation and air temperature; long term predictability is relatively challenging and accuracy of predictions within short time scales or regionally with current technology is problematic. In contrast, a component such as CO_2 concentration changes slowly, consistently, and quite predictably. Its impact on biological productivity may be as important as the more dynamic changes, but its change is more gradual, and as such, its impact more easily addressed. Further, modeling long term impacts of the less dynamic components is more easily conducted and with a higher degree of confidence, especially if modeling is done independently of highly variable components such as precipitation and air temperature.
From the agricultural perspective, we must recognize that biological system performance, i.e., crop productivity, is limited by environmental extremes, not by environmental averages. Conditions that fall outside the range favorable or even tolerable for agriculturally related biological processes, i.e. elevated temperature impacts on plant pollen survival, will likely have deleterious production impacts with increasing frequency. It is the impact of extreme conditions that will define productivity levels, and not the averages against which we conduct much of our research. Research addressing crop response to variance in climate components is lacking and an area that demands much attention. Additionally, growth affecting climatic factors that interact, i.e., CO_2, temperature and rainfall, must be addressed factorially as understanding only main effects greatly limits our understanding of real world outcomes. Climate variability will play an increasingly important production roll in the coming decades.

Carbon Dioxide Concentration

Increasing CO_2 concentration has positive photosynthesis effects and therefore favorable crop production impacts, at least under controlled environmental conditions; these effects have been well documented (31). Research quite conclusively indicates that, with all other factors being held constant, increased CO_2 concentration, or CO_2 fertilization, will increase crop production potential, with C3 crops responding more than C4 crops. However, caution is advised in interpreting this to mean rising CO_2 levels will increase global food security. To illustrate, plants are composed of 16 different nutrient elements, with 13 of these obtained from the soil. Healthy crop seeds or fruit, the most important human food component of plants, have higher nutrient needs and are more sensitive to nutrient deficiencies than most other plant organs. For CO_2 enrichment to favorably affect global food security, sufficient additional nutrients must be absorbed from the soil to compliment elevated carbon fixation occurring during photosynthesis, thus promoting normal healthy plant organs, including seeds and/or fruit. High level of crop production on most world soils is nutrient and/or water limited; thus unless the nutrient absorption kinetics at and near the root surface are changed such that nutrient absorption occurs more rapidly under what is currently considered nutrient limiting conditions, or agriculture expands to soils for which nutrients and water are non-limiting, or substantial increases in soil nutrient application occur on nutrient deficient soils, increasing CO_2 concentration is unlikely to add dramatically to quality food production. Ainsworth and McGrath analyzed literature and concluded that yield increases attributed to CO_2 concentration increases will be less than multiple studies have suggested and that quality of the consumable plant component will be lower than that associated with lower CO_2 concentrations (32).

Under controlled conditions elevated CO_2 concentration reduce plant stomata openings, which results in lower transpiration rates and, in general, improved water use efficiency, again with all other factors remaining constant or nearly so. As atmospheric temperatures rise and rainfall variability increases, improving water use efficiency is highly desirable, especially in areas where production is water limiting. One must remain aware that transpiration cools the leaf and that lowering transpiration rate, while improving water use efficiency under controlled environmental conditions, also results in a warmer leaf. The combined impact of atmospheric CO_2 increases and lower transpiration rates, accompanied by elevated atmospheric temperature extremes on photosynthesis is less well understood (31), although modeling efforts suggest the effect of combined elevated CO_2 concentration and temperature may not decrease yield of wheat with adapted management practices (33). This issue remains a concern, however, as identified by Slingo et al. (34), cited by Mittler and Blumwald (35). Climate models predict combined increase of CO_2 and air temperature, basically assuring that future leaf photosynthesis will be occurring under elevated leaf temperatures.

Plant breeding and genetic engineering will be critical tools for adapting crop plants to changing climatic conditions (36). Genetic and management advances that adapt to, and even take advantage of, changing climate averages seem much easier to address than adapting to the variance of these conditions, however. For example, understanding plant response to increasing average atmospheric temperature is quite straight forward (31). Unfortunately, a changing climate is much more complex than simply changing average values of selected climate component(s). The variance is also likely to increase, that is, the variation about the mean value of different climate variables will likely be greater than it is today; frequency of extreme events and intensity of events are likely to increase (37); this is anticipated especially for atmospheric temperature and precipitation. Plant breeding and genetic modifications must increasingly address variance aspects of climate and interactions of climate components. Currently, research in this area is somewhat limited.

Temperature

Air temperature increases associated with rising concentrations of greenhouse gases have been well documented empirically and are predicted to occur through multiple ensembles of climate models (37). Anticipated average global, and even average regional temperature increases, seem realistically manageable from the agricultural production perspective when considered in light of potentially attainable genetic improvements and management modifications, such as increased irrigation and agricultural land expansion. Understanding that adapting to gradual rise in average temperature seems quite possible, the Intergovernmental Panel on Climate Change (IPCC) cautions that average surface temperature rise of 3°C may lead to reduction in agricultural production. Recently, temperature extremes have periodically devastated crops. The record heat and drought experienced in Europe (2003), Russia (2010) and Southern U.S. (2011) illustrate conditions predicted to occur with increasing frequency. Improving crops to not only survive such conditions, but to produce when such conditions exist during a significant period of the life cycle is increasingly important; it is also an incredible challenge.

A second challenge involves rising night time temperatures. Plant respiration consumes plant carbohydrate resources and this process is temperature dependent. Observed and predicted night time minimum temperatures are increasing at a rate faster than increases in daytime maximum temperatures. As night time respiration increases, photosynthate is consumed leading to a general understanding that crop yields will be negatively impacted. At the International Rice Research Institute in the period from 1979 – 2003, daytime maximums during the dry period increased by 0.35°C while night time minimums increased 1.13°C (38). Grain yield decreased approximately 10% for each 1°C increase in growing-season minimum temperature during the dry season. Multiple other studies, as exemplified by Loka and Oosterhuis (39) also illustrate direct relationships between night time temperature, leaf respiration, and loss of photosynthate. The respiration impact of elevated night time temperatures on rapidly growing plants, however, may be less than environmentally controlled studies tend to suggest (40). The magnitude of yield reduction associated with elevated night time temperature is not yet conclusive; however, the general consensus is that increasing night time temperature will have a negative effect on yields.

Precipitation

The earth's atmosphere is warming 0.13 °C per decade (41). Additionally, the atmosphere's water vapor content is increasing (42) with measured increases over the earth's oceans of about 0.41 kg/m*3* per decade since 1988 (43). Latent energy accompanies the added water vapor. The combination of heat energy associated with globally rising air temperatures and latent energy associated with increases in water vapor in the earth's atmosphere suggests greater atmospheric instability is likely; stated very simplistically, with increased instability the potential for high energy precipitation events increases. Climate records indicate that frequency of extreme events is occurring and climate models suggest this trend will continue (44).

Similar to temperature, precipitation variability presents greater challenges to the agricultural community than does the change in average precipitation values. Adapting to extended periods of excessively wet or dry conditions, for example, is much more difficult than adapting to average changes in availability of water necessary for plant processes. Water dynamics are a bit more manageable than temperature in that water must infiltrate soil, be retained in the soil, and then be absorbed by the plant root and transpired by the crop plant. Water availability is not only rainfall dependent, but significantly influenced by soil surface conditions influencing infiltration rates, soil water evaporation losses, and soil profile properties impacting water retention and plant root growth. These conditions, favorable or unfavorable, are often the result of soil management practices used by the farmer. Further plant genetic improvements have helped crop plant survival during quite severe water stress conditions (24). Survival is critical to withstand water deficit stress, however Sinclair (24) argues that crop survival alone is insufficient to meet rising global demand for food. Adaptations that will foster production to continue when plants are under substantial water stress must be the geneticist's goal, a rather daunting task.

Adding to this challenge, nutrient uptake is impeded by soil water deficit. Nutrients enter plant roots in solution, roots must contact soil particles and/or water films for nutrient transfer to occur from soil to roots, and roots shrink when plant turgor pressure is reduced from water deficit reducing the root to soil contact interface (45). Genetics fostering plant survival is one part of the drought and heat stress production puzzle. Soil conditions promoting required transfer of water and nutrients to the root surface is also vital to maintaining production under water stress conditions. Our ability to enhance nutrient transfer and uptake under water deficient conditions is without a doubt limited and a mechanistic process that likely will remain limiting under water deficit conditions. Nonetheless, favorable soil quality will enhance infiltration, reduce evaporation losses, favor root growth, improve water retention and support crop plant survival and production during stress periods.

Improving fertility of nutrient deficient and/or pH limiting soils will be imperative for enhancing productivity of soils in vast regions of the globe and especially Sub-Saharan Africa where native fertility is inherently low (46) and where agricultural expansion has considerable potential (3). Increasing nutrient availability will help improve crop production, particularly under favorable weather conditions. Increasing production in regions currently producing well below their potential such as that occurring in many underdeveloped countries (3) will become increasingly important in addressing local and world food needs. Unfortunately, most climate models predict that significant land areas for which production increases could occur under current weather conditions will experience an increasingly challenging climate for crop production in the coming decades (47). This again highlights the importance of managing the soil resource base to both enhance production potential and to improve crop plants tolerance of stress periods that are likely to occur with increasing frequency.

A combination of observation and model projections elevate the confidence level of predicting increasing frequency of heavy precipitation events. Such events can be devastating for humans and infrastructure required for their survival. Less often addressed is the impact of the very heavy rainfall events on soil degradation. As mentioned previously, soil productivity of vast areas have been reduced, and in some areas totally lost, due to soil degradation associated with salinization and soil erosion. A climate with increasing frequency of heat and drought and extreme rainfall events will accelerate both processes, especially if soils are not managed for both crop production and soil sustainability. Meeting these dual goals will become increasingly difficult as meeting these goals on a degraded soil is much more difficult than meeting them on high quality, productive soils. Montgomery (48) indicates current conventional agriculture practices globally result in erosion rates an order of magnitude greater than soil regeneration rates. In Iowa, USA, an area equivalent to 25% of row crop production in the state eroded at a rate 20 – 100 times the estimated soil renewal rate in 2007 (49), a year with quite typical rainfall patterns. Degradation pressure on soils worldwide is not likely to decrease; recent trends and climate models suggest the contrary.

Climate change, soil degradation and crop productivity interaction

Production potential differs dramatically between soils as soil properties important for crop growth vary spatially across the landscape and even more so between regions. Temporal variation in soil productivity also exists, but is less frequently addressed as it tends to be more subtle than spatial variability. Fertility, soil erosion, soil salinization and/or soil organic matter content vary with time for most farmed soils; in most situations agriculture practices degrade rather than improve soil properties that affect productivity (50, 15). Causes of yield loss vary for the different degradation processes and can be basically classified as those that damage the plant soil water relationship, reduce or inhibit root growth (inhibiting water and nutrient uptake), and/or reduce soil nutrient content. Nutrients can be added as either organic or inorganic fertilizers, if available, to supplement lost fertility, however fertilizers are not always available or may be too costly for farmer purchase. Nonetheless, compensation for nutrient loss can be addressed with technology. Degradation of physical conditions through erosion, salinization, or depletion of soil organic matter critically affects soil-plant-water relationships, has much longer term impacts, and is much more difficult to correct.

The impact of climate extremes, especially rainfall, on land degradation is likely to increase with increasing frequency of these events (51, 52), and does so disproportionately to rainfall amount. That is, soil erosion increases by a factor of about 1.7 times that of rainfall increase (52). As mentioned earlier, with rising global demand and increased emphasis on maximizing agricultural production, soils in many regions will very likely become more vulnerable to degradation processes, especially soil erosion from more frequent and stronger storms.

For rain-fed conditions, production is highly dependent on weather (or climatic conditions). In fact, literature addressing climate change impacts on crop production almost exclusively focuses on air temperatures, changing rainfall, and/or rising CO_2 concentration. A critical relationship missing in the literature is that of addressing climate change impacts on crop production with degraded or degrading soils. The combination of increased production demands, higher temperatures and more variable precipitation will increase the need for soil conditions that can meet increased demand for nutrients, and especially water. Genetic improvements can help reduce stress impacts on yield losses, however as yield and food/feed quality is linearly related to transpired water (24) and nutrient uptake, soils must be able to infiltrate water, retain water, and release water to growing plant roots to meet plant needs. Soil degradation inhibits each of these processes. One of the most critical challenges soil scientists face is that of maintaining, or increasing, quality of soils under intensive agricultural management. Failure to meet this challenge will have impact of immense magnitude.

Conclusions.

Rising food prices, periodic food shortages, political stress associated with high food price and availability, and increasing concern over our ability to meet rising global demand for agricultural commodities should be a wake-up call for all people associated with agriculture. Concurrently, soil and water resources, absolutely necessary for agricultural production, are being degraded while a changing and likely less hospitable climate foretells additional looming challenges that agriculture will face. The overall critical role soils play in addressing global demands under a changing climate must receive greater recognition and attention. Sustainably managing soils for high productivity will support complimentary agricultural sciences, such as crop breeding and genetics, striving to increase agricultural productivity under future conditions. However, if soils cannot meet the demands placed on them by crops that they support, for example supplying necessary water and nutrients to meet the growing production potential, other agriculture production advances designed to increase and/or stabilize productivity will not be realized. Soil Science will play an increasingly critical role in agriculture’s future.

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