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Abiotic Stresses Forced Challenges in Agriculture Under Future Climate

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Introduction

Much of the world's agricultural biodiversity is found in environments marginal for agricultural production. It is in such environments where management of high levels of diversity can become a central part of the livelihood management strategies of farmers and the survival of their communities. Abiotic stress can be termed as the negative impact of environmental factors on the organisms in a specific situation. It is a natural phenomenon that occurs in multiples and interdependent, and its impact varies across the sectors of agriculture. Abiotic stress is the primary cause of crop loss worldwide, reducing average yields for most major crop plants by more than 50%. Drought and salinity are becoming particularly widespread in many regions, and may cause serious salinization of more than 50% of all arable lands by the year 2050 (Wang 2003). Environmental stresses such as erratic and insufficient rainfall, extreme temperatures, salinity, alkalinity, aluminium toxicity, acidity, stoniness and others limit yield and productivity of many cultivated crop plants. Not only are such problems serious today, it seems they are inevitably worsening.

Climatic variability is the biggest challenging factor that affects agriculture in India and elsewhere. Drought, salinity, extreme temperatures and oxidative stress are interconnected and affect the water relations of a plant on the cellular as well as whole plant level causing specific as well as unspecific reactions (Beck *et al.*, 2007). This leads to a series of morphological, physiological, biochemical and molecular changes that adversely affect plant growth and productivity (Wang *et al*,. 2003). Forecasting climate change is imperfect, complex, important, and often controversial. While disputes remain, the consensus foresees accelerating increases in average annual temperature and changes in precipitation coupled with increasingly erratic intra-annual weather patterns. Stemming from these two primary dimensions of climate change (higher averages and more volatility) are melting glaciers and ice caps, rising sea levels and more frequent and more severe extreme weather events. Some of these changes will likely be shared globally - most places will get hotter - but other changes will vary geographically. For agriculturally important agro-ecological zones, higher level forecasting of daily weather extremes (frosts, the intensity and form of precipitation, extreme temperature, etc.) is crucial but even more demanding.

Organized research and innovation have been central to agricultural policy for nearly two centuries, often with the goal of increasing output per unit of land, water, labour or other input. More recently, reducing the negative environmental spill over effects of agriculture as joined improving crop yields and other simple productivity indicators as a research pursuit. With a growing global population, with especially rapid population growth in some of the poorest places, with improved diets for the poor an imperative, and with evident local environmental impacts, agricultural innovation has never been more important. Climate issues add to this already challenging agenda. In this paper, we tried to link the impact of future climate on influencing the various abiotic stressors, and the policy decision to be taken to avoid, adopt and mitigate those climatic vagaries.

Impact of climate change

Climate has obvious and direct effects on agricultural production. The effects of agriculture on GHG emissions are also large. Agriculture is a major part of the global economy and uses substantial fossil fuel for farm inputs and equipment. Animal agriculture also releases substantial GHGs in the form of nitrogen and methane. Furthermore, and probably more importantly, land clearing and preparation releases carbon from the living biomass that is removed from the land. The 2010 World Development Report draws on analysis of the Intergovernmental Panel on Climate Change (IPCC, 2007) to calculate that agriculture directly accounts for 14 percent of global GHG emissions in CO_2 equivalents and indirectly accounts for an additional 17 percent of emissions when land use and conversion for crops and pasture are included (World Bank, 2009). Regional disparities around the global average impact are substantial. India and Africa are projected to see reductions of agricultural output by 30% or more (Cline, 2007). Given that agriculture's share in global GDP is about 4 percent, these figures suggest that agriculture is highly GHG intensive. The climate implications of agricultural production and practices have broadened the agricultural agenda over recent years to include responses to climate issues, and the climate change agenda has similarly subsumed agricultural production as both a contributor to climate change and, through adjustment in practices, a potential mitigating force.

Innovation constraints in many developing countries stem from deeper problems in the agricultural sector. More generally, developing countries are vulnerable to climate change because they depend heavily on agriculture, they tend to be relatively warm already, they lack infrastructure to respond well to increased variability, and they lack capital to invest in innovative adaptations. Concerns about mitigating and adapting to climate change are now renewing the impetus for investments in agricultural research and are emerging as additional innovation priorities. In the coming decades, the development and effective diffusion of new agricultural technologies will largely shape how and how well farmers mitigate and adapt to climate change. This adaptation and mitigation potential is nowhere more pronounced than in developing countries where agricultural productivity remains low; poverty, vulnerability and food insecurity remain high; and the direct effects of climate change are expected to be especially harsh. Creating the necessary agricultural technologies and harnessing them to enable developing countries to adapt their agricultural systems to changing climate will require innovations in policy and institutions as well. In this context, institutions and policies are important at multiple scales. Impediments to the development, diffusion and use of relevant technologies can surface at several levels - from the inception and innovation stages to the transfer of technologies and the access to agricultural innovations by vulnerable smallholders in developing countries.

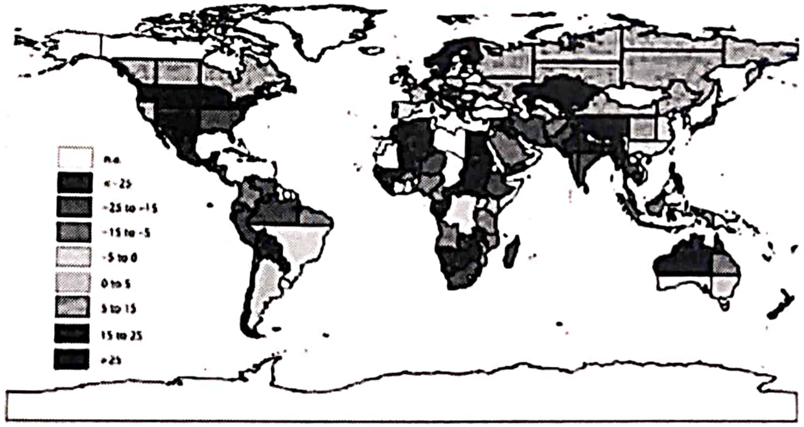

Figure 1. Projected impact of climate change on 2080 agricultural production assuming a 15% carbon fertilization benefit (*Source*: Cline 2007).

The CO_2 fertilization effect

CO_2 is an essential plant 'nutrient', in addition to light, suitable temperature, water and chemical elements such as N, P and K, and it is currently in short supply. Higher concentrations of atmospheric CO_2 due to increased use of fossil fuels, deforestation and biomass burning, can have a positive influence on photosynthesis (Fig. 2) under optimal growing conditions of light, temperature, nutrient and moisture supply. Biomass production can increase, especially of plants with C_3 photo-synthetic metabolism above and even more below ground.

Plants are classified as C_3, C_4 or CAM according to the products formed in the initial phases of photosynthesis. C_3 plants: cotton, rice, wheat, barley, soybeans, sunflower, potatoes, most leguminous and woody plants, most horticultural crops and many weeds; C_4 plants: maize, sorghum, sugarcane, millets, halophytes (i.e., salt-tolerant plants) and many tall tropical grasses, pasture, forage and weed species; CAM plants (Crassulacean Acid Metabolism, an optional C_3 or C_4 pathway of photosynthesis, depending on conditions): cassava, pineapple, opuntia, onions and castor. C_3 species respond more to increased CO_2; C_4 species respond better than C_3 plants to higher temperature and their water-use efficiency increases more than for C_3 plants. There are some indications that enhancements can decline over time ('down-regulation').

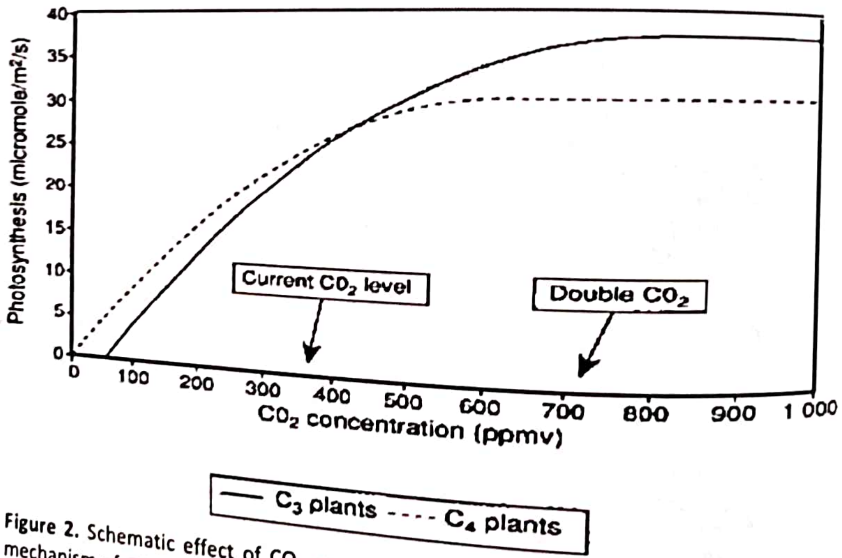

Figure 2. Schematic effect of CO_2 concentrations on C_3 and C_4 plants. The main mechanism of CO_2 fertilization is that it depresses photo-respiration, more so in C_3 than in C_4 plants

A total of 10 to 20% of the approximate doubling of crop productivity over the past 100 years could be due to this effect and forest growth or regrowth may have been stimulated as well. Further productivity increases may occur in the coming century, in the order of 30% or more where plant nutrients and moisture are adequate. Higher CO_2 values would also mitigate the plant growth damage caused by pollutants such as NO_x and SO_2 because of smaller stomatal openings. Higher percentages of starch in grasses improves their feeding quality, implying less need for feed mixes when silaging.

Effect on quality

According to the IPCC's "The importance of climate change impacts on grain and forage quality emerges from new research. For rice, the amylose content of the grain—a major determinant of cooking quality—is increased under elevated CO_2. Cooked rice grain from plants grown in high-CO_2 environments would be firmer than that from today's plants. However, concentrations of iron and zinc, which are important for human nutrition, would be lower. Moreover, the protein content of the grain decreases under combined increases of temperature and CO_2. Studies using FACE have shown that increases in CO_2 lead to decreased concentrations of micronutrients in crop plants. This may have knock-on effects on other parts of ecosystems as herbivores will need to eat more food to gain the same amount of protein. Studies have shown that higher CO_2 levels lead to reduced plant uptake of nitrogen (and a smaller number showing the same for trace elements such as zinc) resulting in crops with lower nutritional value. This would primarily impact on populations in poorer countries less able to compensate by eating more food, more varied diets, or possibly taking supplements. Reduced nitrogen content in grazing plants has also been shown to reduce animal productivity in sheep, which depend on microbes in their gut to digest plants, which in turn depend on nitrogen intake.

Major Abiotic Stressors Influence the Crops Growth and Production

Abiotic stresses occurring during production can either be the primary cause (direct) for disorders that exhibit themselves during postharvest handling and storage practices or they can influence the postharvest handling and storage practices or they can influence the susceptibility of a fruit or vegetable to postharvest conditions that cause abiotic stresses resulting in disorders (indirect). It is important to characterize the relationship between pre harvest abiotic stresses occurring during production and postharvest abiotic stresses that the fruit or vegetable is exposed after harvest and during storage and distribution, since the solution to these different problems will be best resolved by focusing on pre harvest or postharvest abiotic stress amelioration, respectively.

Drought

Aberrant monsoon lead to moisture deficit which may affect the agricultural scenarios. Water stress refers to the situation where cells and tissues are less than truly turgid. It occurs whenever the loss of water in transpiration exceeds the rate of absorption. When plants are unable to absorb enough water to replace that lost by transpiration, water stress develops in the plant system. The results may be wilting, reduction in photosynthesis, disturbances in physiological processes, cessation of growth, or even death of the plant or plant parts. In fact water stress practically affects every aspect of plant growth, modifying the anatomy, morphology, physiology, and biochemistry which are related with decrease in turgor, water potential and osmotic potential. The occurrence of drought conditions during production of fruit and vegetable crops is becoming more frequent with climate change patterns (Whitmore 2000; Kumar *et al.*, 2013). The existing literature provides some insight which may lead to better understanding and perhaps also encourage future research. Water stress during the production phase of some fruits and vegetables may affect their physiology and morphology in such a manner as to influence susceptibility to weight loss in storage. There have been both positive effects reported for field water deficits (stress) in tree fruits and root vegetables. Timing of a water stress event can also be very important in determining response to postharvest abiotic stress response. Therefore it is critical to avoid water stress until the fruit has reached maximum size in order to minimize incidence of chilling-induced injury in storage. Water stress, particularly at the tuber forming stage, can also lead to a higher susceptibility of potatoes to postharvest development of black spot disorder.

Temperature extremes

Susceptibility to high (heat injury inducing) or low (chill injury inducing) temperatures is known to be reduced by prior exposure of the sensitive fruit or vegetable to low ambient temperatures. However, if the pre harvest temperature leads to chilling induced injury in the field, then susceptibility to postharvest chilling injury can be increased. Therefore, the level of the pre harvest temperature extreme will be a determinant as to if the exposure will have positive or negative effects on postharvest stress sensitivity. Extreme high temperatures can occur in the field and apple fruit exposed to direct sunlight can reach in excess of 40 °C. High temperatures during the late season (leading up to harvest) can enhance susceptibility of apples to superficial scald which develops in storage.

High temperature

Extreme high temperatures can occur in the field and apple fruit exposed to direct sunlight can reach in excess of 40 °C. High temperatures during the late season (leading up to harvest) can enhance susceptibility of apples to superficial scald which develops in storage. Sun scald of grapes, soft nose of mango, sun burn in papaya and citrus are mostly related to high temperature. Fruit cracking in pomegranate and litchi is associated with temperature aberrations coupled with fluctuation in moisture.

Low temperature

When plant tissue temperatures fall below critical values, sensitive perennial crops such as grapevines and tender tree fruits can suffer irreversible cold injury, causing malfunction or death of plant cells.

Frost/ temperature inversions

In clear sky and minimum wind, radiational cooling forces temperature inversions to occur where air temperatures 10-20 m above the field are at least 2 - 3°C warmer than at 1 m above ground. For formation of inversions, wind speeds must be less than7 km/h; for inversions to break up, wind speeds mustbe greater than 7 km/h. This is because the wind mixes the air above the field with the air at ground level. This is like a house furnace fan mixing air throughout a house to keep air temperatures more uniform. When that fan is off, air stratification can occur with colder, heavier air settling in the basement, while warmer, lighter air rises and remains upstairs.

Cold wave

The prolonged cold spell causes large-scale damage to agricultural and horticultural crops. The damage to fruit plantations is so severe that many a times farmers up root their well-established orchards. Crop yields were lower by 10 to 40 per cent in wheat, 25 per cent in gram, 50 to 70 per cent in mustard and 60 to 95 per cent in *aonla* compared to a normal year. The orchards of mango, litchi, guava, ber and kinnow in Punjab were hit resulting in reduced size or poor quality of the fruit. The plant mortality in mango varieties was highest in Dashehari, followed by Amrapali and least in Langra with 18 to 48 per cent flowering damage in parts of Jammu, Punjab, Haryana, Chandigarh and Himachal Pradesh. The mortality rate in papaya ranged from 40 to 83 per cent in the Shiwalik region, plains of Uttar Pradesh, Bihar and the northeast.

Heat waves

Three or more consecutive days of unusually high maximum and minimum temperatures for the location and time of year. A heatwave is a run of unusually hot days but what constitutes a heat wave will differ from region to region given the normal temperatures for that area. Inland areas can expect to be normally hotter than areas closer to the coast. Heat-wave intensity is classified as low, severe or extreme based on the actual temperatures and the previous 30 days' temperatures.

Fruit is less likely to set if heat waves occur during blossoming. There are no precise threshold temperatures or periods for reduced pollination because it is a complex interaction between bee activity and the availability of viable pollen and receptive stigmas. Sunburned fruit is caused by combined high air temperature and solar radiation. Sunburn typically occurs in the afternoon on the western side of trees and is often worse where cool, cloudy weather is suddenly followed by a change to hot, sunny conditions. This problem is becoming more common with the increased frequency of heatwaves. An early sign of fruit sunburn is white, tan or yellow skin. Severe sunburn results in dark brown to black sunken patches on the fruit surface. Browning associated with sunburn is likely when the fruit surface reaches 46–49°C. Skin necrosis occurs at 52°C. Air temperature provides a reasonable estimate of sunburn risk. It is normally 10 to 18°C lower than fruit surface temperature. Cherry doubling is caused by temperatures above 35°C after harvest when buds for the following year's crop are initiated. It is unclear how many days at this temperature are needed but heat waves almost certainly increase the risk. In grapes, hot and dry summers typically result in early harvests of mature fruit and abundant robust wines. Heat waves often associate with lower-yield harvests.

Hailstorm

Hailstorms are the result of four atmospheric factors which are characterised as strong convective instability creating strong updrafts, abundant moisture at low levels feeding into the updrafts, strong wind shear aloft, usually veering with height, enhancing updrafts and some dynamical mechanisms that can assist the release of instability such as air flow over mountain ridges. The typical mechanism of hail formation in a thunderstorm is that when the ground is heated during the day by the sun, the air close to it gets heated as well. Hot air, being less dense and lighter than cold air, rises and cools. As it cools, its capacity for holding moisture decreases. When the rising, warm air has cooled so much that it cannot retain all of its moisture, water vapour condenses, forming puffy-looking clouds. The condensing moisture releases heat of its own into the surrounding air, causing the air to rise faster and give up even more moisture.

The development of hailstones typically occurs 5 to 7 km/hr above the earth's surface. As a thunderstorm moves along, it may deposit its hail in a long narrow band (often several kilometers wide and about 5-10 kilometers long) known as a hail-streak or hail-swath. Its size and shape depend on how fast the storm is moving and how strong the updrafts are inside the storm. A typical hail-streak is about 1.5 km wide and 8 km in length. However, these may vary from a few acres to large belts, about 16 km wide and 160 km long. Most storms that produce hail generate one or two hail-streaks during their lifetime. The volume of hail reaching the ground falls at a speed of about 40 m/sec, and is usually less than 10 per cent of the volume of rain produced by a thunderstorm.

Frost

Frost occurs when water vapour in the air freezes upon contact with an object that has a surface temperature below 0°C. It is commonly seen as ice crystals on tree branches, grass stems, and car windscreens.

Radiant frost: It occurs at night in cold temperatures when heat radiates into the atmosphere and leaves the ground and ambient air cooler. It most commonly occurs under clear skies with little or no wind. Clear skies encourage heat radiation, and windless nights encourage cold air to settle which increases the frost risk, particularly in low lying areas. Drought years are conducive to radiant frost due to the lack of cloud cover and the increased difference between day and night time temperatures.

Advection frost: Forms when a mass of very cold air moves over an area, replacing the warmer air in that area. It is not affected by cloud cover. It occurs more often, possibly due to the southward movement of the subtropical ridge of high pressure zones. There are more southern highs bringing air masses from further south than in the past. This air is very cold and leads to widespread frost.

When plant tissues freeze, ice crystals form and rupture cell walls. The resulting dead tissue leads to the familiar water-soaked and scorched appearance of frosted plants. Late heavy frosts during spring can kill fruitlets at any stage of development. The severity of the damage varies with the phenological stage and type of fruit tree affected. The duration of exposure to frost and the rate of tissue defrosting also influence the amount of damage. Developing fruit can withstand relatively low temperatures early in the season, but become more susceptible to frost damage (GRDC 2014). Fruitlets which are killed, shed early in the season. Fruit can also suffer sub-lethal damage which distorts growth during maturation and makes it unmarketable. This damage is often expressed as banded areas of russetted, corky growth or constricted bands leading to misshapen fruit. Severe, late frosts can also kill the buds responsible for the following year's crop and have an ongoing effect on orchard productivity.

Light

It would be considered logical to assume that effects of exposure to high light are difficult to dissociate from effects exposure to high temperatures. However, research has shown that low light in the preharvest interval reduced susceptibility of apples to developing superficial scald in cold storage and, in contrast, high ambient temperatures resulted in increased susceptibility. In the case of ambient low light, when lettuce is grown under low light which is sub-optimal for photosynthetic activity, shelf life of fresh cut lettuce (i.e. lettuce subjected to mechanical stress) is much shorter than lettuce produced under optimal light conditions. Tomato size is smaller when the crop is grown under ambient low light levels, such as in the early spring season in northern latitudes and since surface area to volume ratio is greater in smaller fruits, susceptibility to postharvest desiccation stress would increase. Low light also results in lower levels of ascorbate in many greenhouse-grown fruits and vegetables, which would render them less fit to deal with postharvest stresses since ascorbate contents are generaly directly proportional to relative levels or stress tolerance.

Salinity

The coastal system, made up of waters from the sea and other estuaries, is highly coupled. As a result, local meteorological processes,such as precipitation, evaporation, wind events, and direct inflows of fresh-water through stream flow and runoff, strongly influence the salinity, water quality, and circulation of coastal waters. Long-term changes in sea surface temperature, sea-level rise, hurricane severity and frequency, and other more recently discovered phenomena, such asa rise in ocean acidification, are expected to occur as a result of natural and anthropogenic global climate variability. Annual wet season/dry season pattern causes noticeable changes in the regional sea surface salinity, most pronounced in the coastal zone near the river mouths and along the onshore edges.

Tomatoes grown under high salinity will produce smaller fruit with higher soluble solids. Smaller fruit will have higher surface area to volume ratios, hence greater susceptibility to postharvest water loss (i.e. desiccation stress). Firmness declines in tomatoes grown under 3 and 6 dS m^{-1} salinity levels were increased by 50 to 130%, respectively, at two weeks holding at 20 °C compared with control fruit.

Plant nutrition

Climate change impacts on soil fertility and crop nutrition in developing countries leads to the opening of Pandora's Box. 963 million people on our planet are underfed or malnourished including a 10% increase over the last 3 years due to rising food costs (FAO 2009). Demand for food continues to increase while per capita arable land area dedicated to crop production continues to shrink because of population growth, urbanization and soil degradation. From the supply side, this imbalance is largely driven by edaphic constraints that result from inherently low soil fertility and/or soil degradation from unsustainable farming practices. Under tropical and sub-tropical climate, wide spread deficiency of N and P occurs. Acidification of soil leads to K, Ca, Mg deficiency and toxicity of Al and Mn.

Table 1. Climate interactions with plant nutrition

Process	Climate variable	Nutrient affected
Transpiration driven mass flow	CO_2, RH, Rain, Temp	NO_3, SO_4, Ca, Mg, Si
Root growth and architecture	CO_2, drought, temp	P, K
Root symbiosis	CO_2, drought, temp	N, P, Zn
Root exudates	CO_2	Al tox, metal uptake, P
Tissue dilution	CO_2	Stress responses, nutrient cycling, nutritive value
Growth responses	CO_2, drought, temp	N, P: "no clear pattern"

Drought highly impacts the plant nutrition. Water dependent diffusion and mass flow of nutrients to the roots slows with increasing soil moisture deficit. Impaired root growth decreases the capture of less mobile nutrients such as phosphorus. Drought inhibits N-fixation in legume crops and disrupts N cycling by soil bacteria. Conversely, high intensity rainfall events can be a major source of erosion leading to loss of nutrient (N) rich top soil and surface broadcast fertilizer. Waterlogged soils become hypoxic which slows the O_2 dependent active transport of nutrients, lead to change in soil redox status resulted to Mn, Fe and Al toxicity. Waterlogging also leads to N losses through denitrification when nitrate is used as alternative electron acceptor in the absence of oxygen. High temperatures that result in extreme vapor pressure deficits, may reduce mass flow of nutrients by triggering stomatal closure.

Arguably, rising global CO_2 increases yield and decreases water use by crops, and this is often presented as one positive of atmospheric change with the expense of quality. CO_2 levels will likely reduce the levels of zinc, iron, and protein in wheat, rice, peas, and soybeans. In addition to wheat, rice, peas, and soybeans, which all use a form of photosynthesis known as C_3, Myers and his colleagues studied corn and sorghum, which use C_4 photosynthesis, a faster kind. They found relatively little effect of CO_2 enrichment on the nutritional value of the C_4 crops.

Calcium is also been suggested as a putative signalling molecule involved in the development of cross tolerance to abiotic stresses. Therefore the role of preharvest calcium nutrition is postharvest stress resistance may be complex, and dependent on whether the fruit or vegetable is also exposed to environmental abiotic stresses. In carrots, deficiency in potassium is associated with greater weight loss (desiccation stress) in storage. Improved potassium nutrition has also been shown to reduce susceptibility of potatoes to internal bruising in response to mechanical stresses imposed during postharvest handling. Relatively high preharvest nitrogen is often associated with poor postharvest quality of many fruits and vegetables. In regards to affecting susceptibility to postharvest stress, applying higher than recommended levels of pre harvest nitrogen for a specific crop have been linked to storage discoloration susceptibility in both cabbage and potato. In contrast nitrogen deficiency or lower than recommended nitrogen application rates will most often results in increased vitamin C content in many fruits and vegetables. Vitamin C content has been tightly linked with storage life potential which is likely a consequence of the importance of this antioxidant nutrient in forestalling oxidative injury that leads to quality losses in storage.

Agricultural Technologies for Climate Change Mitigation & Adaptation

The core challenge of climate change adaptation and mitigation in agriculture is to produce

(i) more food, (ii) more efficiently, (iii) under more volatile production conditions, and (iv) with net reductions in GHG emissions from food production and marketing. Producers will grapple with these growing demands and shifting incentives amidst more volatile production conditions. Agricultural technologies will play a central role in enabling producers to meet these core challenges. Because agriculture is inseparably linked to climate and feedback runs in both directions, most agricultural technologies have direct or indirect climate linkages. Most new technologies change the use of farm inputs, often in ways that alter the impact of weather on production and of production on carbon emissions. While most agricultural technologies therefore have climate implications, there are a handful of current and emerging technologies with particular relevance to developing country agriculture and climate change.

New Traits, Varieties & Crops

Increasing agricultural productivity requires technological advances in crop yields. In contrast to developed counties, which have seen dramatic yield gains in the past century through investments in agricultural innovation and operate close to the technological frontier, much of developing country agriculture is far from this frontier. Profitable adaptation and farmer adoption of suitable varieties and crops could spark substantial yield gains. These productivity gains could confer a substantial mitigation benefit in the form of foregone land conversion or even reversion of some sensitive lands to grass or forests. Since land use changes, including deforestation and conversion to agricultural production account for 17% of global CO_2 emissions (World Bank, 2009), productivity gains represent a significant mitigation mechanism in agriculture. New varieties and traits can also lead to less intensive use of other inputs such as fertilizers and pesticides and the associated equipment.

In addition to increasing productivity generally, several new varieties and traits offer farmers greater flexibility in adapting toclimate change, including traits that confer tolerance to drought and heat, tolerance to salinity (e.g., due to rising sea levels in coastal areas), and early maturation in order to shorten the growing season and reduce farmers' exposure to risk of extreme weather events. These promising new traits and varieties, which are mostly still in development,can emerge from traditional breeding techniques that leverage existing varieties that are well suited to vagaries of the local production environment as well as from more advanced biotechnology techniques such as marker assisted selection and genetic modification.

In many places, new traits and varieties for the crops, farmers have traditionally cultivated will confer sufficient scope for adaptation. In other places, shifting to a totally different mix of crops will be required to cope with dramatic changes in rainfall or temperature, and cropping systems will fundamentally change as a result. Even if adaptation does not imply an entirely new mix of crops, many producers will benefit from new crops and varieties as they diversify their production portfolios as a means of stabilizing their revenue or local production of basic foods in the face of more volatile conditions. These diversification benefits will be important because many households and many regions will continue to produce their own food even decades from now, when transportation, communication and financial infrastructure has penetrated many areas that are currently poor and remote.

Climate change will also lead to new pest and disease pressures. The nuances of temperature changes e.g. higher low temperatures and fewer freezes - could shorten dormant periods, speed pest and disease growth and change the dynamics of these populations and their resistance. Crops, varieties and traits that are resistant to pests and diseases will improve producers' ability to adapt to climate change. To the extent that these varieties reduce the need for pesticides, they also reduce carbon emissions by decreasing pesticide demand as well as the number of in-field applications. Breakthroughs in nitrogen use efficiency could substantially mitigate emissions in agriculture. The mitigation potential of new crops and varieties extends to direct carbon sequestration and perhaps to second generation biofuel crops. There are several second generation biofuel crops (i.e., beyond sugar cane and maize) that appear promising as fuel sources (e.g., miscanthus,). The damage to fruit trees was relatively more in low-lying areas where cold air settled and remained for a longer time on ground. But temperate fruits such as apple, peach, plum and cherry gave higher yield due to extended chilling. One of the best way to reduce the impact of the cold wave is to go in for proper selection of fruit species and varieties as per the site conditions. Apart from that, wind breaks or shelter belts should be provided. There should be frequent irrigation, smoking, covering young fruit plants with thatches or plastic sheets.

For the development of traits and varieties that help to mitigate and adapt to climate change, agricultural biotechnology stands out as an especially promising set of tools. While it remains controversial in some policy arenas and public fora, agricultural biotechnology has produced dramatic improvements in yield and reductions in production costs and input use intensity. Many of the promising traits and varieties discussed above owe their existence to biotechnology, including genetically modified crops with pest resistance (Bt) and herbicide tolerance (Roundup Ready) and conventionally bred varieties that benefit from breeding tools such as marker selection and tissue culture.

Adoption of Soil and Moisture Conservation Techniques

Some of the basic methods to collect and conserve water are; harvesting of rain water, harvesting of water from snow melting, development of catchment area and storing runoff water for recycling, check dams and construction of waterways. Contour cultivation, contour trip cropping, mixed cropping, tillage, mulching, zero tillage, are some of the agronomical measures for the *in-situ* soil moisture conservation. Mechanical measures like contour bunding, graded bunding, bench terracing, vertical mulching etc. also need to be followed for effective soil and moisture conservation in dry lands. Another technology for efficient utilization of runoff is water harvesting recycling. Rainwater harvesting includes collecting runoff water into dug out ponds or tanks in small depressions, gullies and into storage dams of earth or masonry structures. Rain water harvesting is possible in areas having rainfall as little as 500 to 800 mm. Depending on the rainfall and soil characteristics, 10-50 % of the runoff can be collected in farm pond. Surface run off thus collected in a farm pond can be used to provide protective irrigation in the period of prolonged dry spell. Trench planting (0.5-1.0 m) is recommended for ber, *aonla* and custard apple to conserve moisture. The trenches collect rain water along with silt and organic matter and thus promote tree growth. Planting in trenches is common for pineapple under dry conditions. contouring, contour bunds, sloping area land technology (SALT), contour drains, graded bunding, terraces, broad bed furrow system for raising crop and conservation of water, contour Furrow, stabilisation structures, curved land ploughing for intensive land preparation; soil conservation and water retention through use of vegetation, live check of bamboo pieces and loose boulders are some of the other agronomical measures used to conserve moisture.

Water Management & Irrigation

In the midst of increasing urban and environmental demands on water, agriculture must improve water use efficiency generally. Adding climate change to this mix only intensifies the demands on water use in agriculture. With hotter temperatures and changing precipitation patterns, controlling water supplies and improving irrigation access and efficiency will become increasingly important. Climate changes will burden currently irrigated areas and may even outstrip current irrigation capacity due to general water shortages, but farmers with no access to irrigation are clearly most vulnerable to precipitation volatility.

Across the Middle East and North Africa, Central Asia and Southern Africa, water availability is projected to decline dramatically with climate change and population growth in the next several decades. It is no exaggeration that the future of agriculture in these regions hinges primarily on improving the efficiency of existing irrigation systems and, where profitable, extending irrigation infrastructure. Drip irrigation systems are important on farmers' fields, but inefficiencies in delivery (e.g., canal construction and maintenance) are often more glaring than field-level inefficiencies in application (e.g., flood versus drip irrigation).

In places with limited access to irrigation, well timed 'deficit irrigation' can make a substantial difference in productivity. With dwindling water supplies, such deficit irrigation techniques will become increasingly important. In non-irrigated areas, water conservation and waterharvesting techniques may be farmers' only alternative to abandoning cultivation agriculture all together. Drip irrigation has proved its superiority over other conventional method of irrigation, in horticulture due to precise and direct application of water in root zone. A considerable saving in water, increased growth, development and yields of fruits and vegetables and control of weeds, saving in labour under drip irrigation are the added advantages. Drip irrigation can be adopted in fruit crops and also to all vegetable crops including closed spaced crops like onions and beans. The saving in water is to the tune of 30-50 % depending on the crop and season.

The following methods may be adopted under limited water conditions to save water:

(a) **Water Saving Irrigation Method**: Under limited water situations, water-saving irrigation methods like alternate furrow irrigation or widely spaced furrow irrigation and drip irrigation systems can be adopted. Studies conducted on methods of irrigation in capsicum, tomato, okra and cauliflower indicated that adopting alternate-furrow irrigation and widely-spaced furrow irrigation saved 35 to 40 per cent of irrigation water without adversely affecting yield.

(b) **Mulching Practices in Vegetable Production** - The technique of covering the soil with natural crop residues or plastic films for soil and water conservation is called mulching (Suresh Kumar *et al.*, 2012). Mulching can be practiced in fruits and vegetable crops using crop residues and other organic material available in the farm. Recently plastic mulches have come into use due to the inherent advantages of efficient moisture conservation, weed suppression and maintenance of soil structure. Wide variety of vegetables can be successfully grown using mulches. In addition to soil and water conservation , improved yield and quality, suppression of weed growth , mulches can improve the use efficiency of applied fertilizer nutrients and also use of reflective mulches are likely to minimize the incidence of virus diseases. For vegetable production generally polyethylene mulch film of 30 micron thick and 1 to 1.2 m width is used. Generally raised bed with drip irrigation system is followed while laying the mulch film.

Depending upon situation and availability of water, this technology can be used for fruits and vegetable crops. The cost of initial establishment is lower compared to drip system. Further in summer the sprinkling of water helps in reducing the microclimate temperature and increasing the humidity, thereby improving the growth and yield of the crop. The water saved is to the tune of 20 to 30 per cent.

Other Production Inputs

Improvements in crop yields per unit of land are crucial as an alternative to extensive conversion of grassland and forestland to crops. Therefore practices or technologies with potential to increase the intensity of land use can yield mitigation benefits. This may even include application of additional fertilizer or pesticide inputs, where the "first round" GHG implication may not look favorable. There are, however, other amendments such as biochar, a charcoal soil amendment, that may offer both improved soil fertility and serve as a carbon sink (Lehmann, *et al.*, 2006). Similarly, herbicides and other inputs that reduce competition from weeds can improve productivity and thereby serve to mitigate GHG emissions associated with bringing additional land under cultivation. Furthermore, since potential cropland in different regions has very different capacities to sequester carbon, shifting crops to the land with the least negative carbon implication may have net GHG benefits. This may mean farming dry regions under irrigation which allows use of land that otherwise would not contribute to mitigation.

Application of foliar nutrition: The foliar application of nutrients during water stress conditions helps in the better growth by quick absorption of nutrients. The spraying of K and Ca induces drought tolerance in vegetable crops. Spraying of micronutrients and secondary nutrients improves crop yields and quality. Anti-transpiration coatings have been shown to be effective for maintaining quality through control of water loss. Anti-transpirants are chemicals which when sprayed on plants form a film which increases the diffusion resistance of water from stomata and thus reduces transpiration losses of water. Several chemicals have been successfully used like Acropyl in grapes, polycot in banana and kaolinite (3-8%) in different fruit plants. The energy input can be reduced by increasing plant reflectivity by using effective chemicals like zinc oxide, kaolinite, chalk etc alone or in combination with other anti-transpirants. These chemicals are used to reduce temperature on plant parts. Film forming compounds like wiltpruf, mobileaf, clear spray, vapour gard and folicoat can be used to reduce transpiration and water loss. Water loss can also be restricted by applying chemicals which facilitate stomatal closure. Some of these are; phenyl mercuric acetate (PMA), Decenyl succinic acid (DSA), Atrazine and Sodium azide.

Production Management & Practices

Production techniques may be as important as production technologies in climate change adaptation and mitigation. One such technique stands out in particular: ***conservation or reduced tillage agriculture***. This technique aims to build up organic matter in soils and create a healthy soil ecosystem by not tilling the soil before each planting. Seeds are planted using seed drills that insert seeds to a precise depth without otherwise disturbing the soil structure. By increasing the organic matter in soils, conservation agriculture improves the moisture capacity of the soil and thereby increases water use efficiency. The practice also reduces carbon emissions by reducing tilling, although it also requires more sophisticated pest and disease control because the system is not 're-booted' at each planting. An array of other production management practices and technologies could similarly improve farmers' mitigation and adaptation to climate change, including equipment and information that enables more precise application of inputs, especially fertilizer. The key challenge is to assure that such practices do not reduce yields so that the demand for additional land offsets the benefits from on field sequestration.

The basic principles of conservation agriculture are soil cover, particularly through retention of crop residues on the soil surface as mulch or cover crops; a minimum level of soil disturbance, e.g., reduced or zero tillage practices; and sensible, profitable crop rotations. Soil moisture can be conserved through mulching either with black polythene or locally available mulches, growing cover crops or inter-culturing in the orchards to check soil erosion and runoff rain water. If area around tree basin remains covered with mulches, like grass mulch (10-12 kg/basin) and black polythene mulch (100 micron) throughout the growth period, it helps in conserving the soil moisture, saving water for more critical stages during summer and reduced the weed population by 60% with grass mulch and 100% with black polythene mulch. The polythene mulch maintained 29% more soil moisture compared to un-mulched trees on soil available water content basis. Surface-applied mulches provide several benefits to crop production by controlling evaporation from the soil surface, heat energy and nutrient status in soil, buffering drastic changes in soil temperature. Soil temperature, especially at the surface layer is reported to be important for the translocation of photo-assimilates. Straw mulch ameliorates environmental stresses and improves the product quality and safety.

Wind breaks, hedges and intercropping: To overcome the adverse effect of high temperature and dry winds, tall growing trees need to be planted all along the boundary of the farm. Windbreaks help to deflect and to filter through the wind current thereby reducing the velocity of wind resulting lower displacement of wind around tree and cause reduction in transpiration and evaporation. The orientation of windbreak should more or less be at right angles to the prevailing winds. It is believed that the windbreak is effective for a distance equivalent to 3 to 4 times of tree height. *Acacia tortalis*, *Cassia siamea* and *Prosopis julifera* are some of the useful tree species suitable as wind break under less water conditions. Inter cropping of vegetable crops of the area can be practiced in orchards during summer months. Maize/Sorghum can be grown all along the border of the plot to mitigate the effect of desiccating winds. Crop rotation, cover crops, strip cropping, mulching (Suresh Kumar *et al.* 2011), contour hedge row intercropping system are used to conserve moisture.

Use of Plant Growth Regulators

Foliar sprays of 50 mMIAA, GA_3, or benzyl amino purine (BAP) partially counteracted the effect of water deficit on photosynthesis and transpiration. Growth regulator applications can also potentially enhance stress resistance, particularly for fruits and vegetables which are prone to show accelerated ripening or senescence in response to drought stress. Accelerated ripening or senescence is most often mediated by ethylene production in response to the stress. As consequence anti-ethylene products such as aminovinylglycine (AVG) and 1-methylcyclopropene (1-MCP) could be used to mitigate drought stress. While foliar cytokinin (CK) application can prevent ABA-induced photosynthetic limitation, the effects can be transient and of little consequence in the long term. Paclobutrazole (10 mg/ lit) is used to avoid moisture stress in mango. Accelerated ripening or senescence is most often mediated by ethylene production in response to the stress. As consequence anti-ethylene products such as aminovinylglycine (AVG) and 1-methylcyclopropene (1-MCP) could be used to mitigate drought stress. Other growth hormones, such as methyl jasmonate (which promotes leaf senescence), can enhance chilling resistance in avocado, grapefruit, bell peppers and zucchini squash. Abscisic acid has been demonstrated to reduce chilling-induced injury in some crops (Wang 1993).

Beneficial microbes

Microbial activity in soils is stimulated by the release of carbon-rich material in the form of root border cells, and/or the selective exudation of specific sugars, carboxylic acids, or amino acids that encourage the development of cultivar-specific, plant-beneficial, microbial communities. Some of these microorganisms benefiting from the availability of fresh energy are also capable of enhancing plant growth and development, which are generally called as Plant growth promoting (PGP) rhizosphere microorganisms. Plant growth-promoting rhizobacteria (PGPR) and fungi (mycorrhizae) can facilitate plant growth directly by facilitating the uptake of nutrients from the environment, by influencing phytohormone production (e.g. auxin, cytokinin, or giberallin), and/or by enzymatic lowering of plant ethylene levels. In addition to facilitating the growth of plant, these microorganisms can protect plants from the deleterious effects of flooding and drought.

The beneficial plant-microbe interactions in the rhizosphere are the primary determinants of plant health and soil fertility. Rhizobacteria include mycorrhization helper bacteria (MHB) and plant growth promoting rhizobacteria (PGPR), which assist AMF to colonize the plant roots. Synergistic positive interactions have been reported between AMF and plant growth-promoting bacteria (PGPB) such as nitrogen fixers, fluorescent *pseudomonad's* and sporulating *bacilli*. The most common bacteria in the mycorrhizosphere are *Pseudomonas*. Some extremely mycorrhizal dependent plants, including grapes, citrus, melons, oaks and pines may quite literally starve to death in soils that lack this helpful fungi. These benefits of mycorrhizal symbioses in vegetables, fruits and tree species, both agronomically by increased growth and yield as well as ecologically by improved fitness, indicate that mycorrhizal plants are often more competitive and better able to tolerate environmental stresses.

Hail control mechanisms

Artificial hail control is an important measure in disaster prevention and mitigation. Cloud seeding for hail suppression is based on the cloud microphysical concept in which seeding is postulated to reduce hail severity. The natural and artificial ice crystals compete for the available super-cooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If sufficient nuclei are introduced into the new growth region of the storm, then the hailstones will be small enough to melt completely before reaching the ground. Another concept is to create shock waves which can prevent the formation and growth of hail by melting altogether. Shockwaves are produced using hail guns/cannons. The super-cooled water situated on the external layer of hailstone is transformed from liquid state to solid state. Therefore the hail nuclei are not able to melt anymore and remain at a small size which thus minimise the damage when they hit the ground. Nowadays, acetylene or butane gas is used to generate hail disruptive shockwaves this allows the emission of a more powerful shockwaves with higher continues to 1 frequency. It is be reiterated that hail control mechanisms cannot eliminate hail completely but the cloud seeding can be beneficial.

Protective screens termed as anti-hail nets above the crop can be appropriately utilised especially for high value crops. The hail climatology, microclimatic effects of the cover, its durability properties and installation cost are useful in evaluation of the merit of such screens. These anti-hail nets are not effective against strong hail storms. Tree shelterbelts can markedly reduce hail damage in their immediate vicinity since hails are usually associated with strong winds. Some hail is intercepted directly by the trees protecting crops immediately downwind. The trees also create a change in the air flow so that the area in the lee of them is particularly sheltered with hail deflected laterally. Wind speeds will also be less in the lee of the shelter so the total hail kinetic energy, which results both from the vertical fall speed of the hail and the wind speed will be less.

Use of mechanization in agriculture during extreme weather events

Wind machines can raise air temperatures around plants by about a third to half the temperature inversion difference. One protection method is to use wind machines in orchards of high value crops.Wind machin are tall, fixed-in-place, engine-driven fans that pull warm air down fron at least 15 m above ground during strong temperature inversions, blowin it down and out, pushing away and replacing cold air near target crop This raises air temperatures around cold-sensitive perennial crops suc as grapes.

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1. Reduce heat loss from the surface
2. Stir the air and break up the temperature inversion layer
3. Add heat to maintain the temperature above the danger level.

Marketing & Supply Chains

Post harvest GHG emissions per unit of consumption mainly depen on efficiencies of transport (rail versus road, ocean shipping versus lan shipping, and large loads versus small loads) rather than distanc traveled. Improvements in transportation efficiency are therefore a important to reducing agriculture's GHG emissions as they are to othe sectors of the global economy.

Post harvest losses represent one of the single greatest sources of inefficiencies in food production worldwide and therefore one of the best opportunities for effectively improving crop productivity. These losses - which are due to poorly timed or executed harvesting, exposure to rain, humidity and heat, contamination by microorganisms, and a host of other sources of damage and deterioration - often get far less attention than they deserve. Half or more of the total harvest of some crops can be lost post harvest. Investments in improved harvesting, processing, storage, distribution, and logistics technology and necessary training investments can pay off as well as improved crop yields in terms of gains to consumers and the climate. As climates become hotter and precipitation more erratic, the potential for postharvest losses may increase and thus improved transport and storage become even more important.

Innovative and improved postharvest management strategies

Simple modifications to postharvest handling systems can sometimes result in significant reduction in stress exposure and consequently result in storage and/or shelf life extension. One of the most successful strategies is the application of plastic film packaging or wraps to prevent desiccation, resulting in significant improvements and shelf life and quality of many fruits and vegetables. In many cases, modified atmosphere packaging is considered to largely control humidity around product and thus prevent moisture loss of fresh-cut and whole fruits and vegetables. Also, anti-transpiration coatings have been shown to be effective for maintaining quality through control of water loss (Baldwin 2003). In regards to maintaining water content on the retail shelf, the application of misting systems can 'recharge' the vegetable and in so doing maintain quality over longer durations at less than ideal storage temperatures.

Future Perspectives

☐ The best policy and institutional responses will enhance information flows, incentives and flexibility

☐ Policies and institutions that promote economic development and reduce poverty will often improve agricultural adaptation and may also pave the way for more effective climate change mitigation through agriculture.

☐ Existing technology options must be made more available and accessible without overlooking complementary capacity and investments

- Adaptation and mitigation in agriculture will require local responses, but effective policy responses must also reflect global impacts and inter-linkages.

Conclusion

Agriculture has unique role in development. It is our primary source of food, has significant potential for mitigation of global GHG emissions, and is particularly sensitive to climate change. Almost certainly, climate change will be severe in most developing countries and will directly and, in some cases, dramatically hurt agricultural production in these countries. Yet, development cannot be taken for granted and the dual burden of climate change adaptation and mitigation may make economic transformation more difficult. As climate change affects input availability, especially water in many places, input use efficiency must increase with these productivity demands. Carbon emission polices may simultaneously encourage or force producers to recognize GHG emissions as an important and costly "input" in production processes and open new opportunities and incentives for on farm GHG mitigation. It is a fool's errand to attempt to fully catalogue in any comprehensive way agricultural technologies with potential for climate change mitigation and adaptation over the next seven decades. If history is any guide, the most important such technologies have yet to be developed or even conceived.

Innovations in agriculture have always been important and will be even more vital in the context of climate change. Thoughtful policy responses that encourage the development and diffusion of appropriate agricultural technologies will be crucial to enabling an effective technological response. A careful balance of institutional change and wise investments is required to deal with both the demands of climate change and the demands of improving lives of the poor. As we consider implications of and responses to climate change, continuing concerns for improvements in nutrition, food security, food safety, local environments and rural communities must not be neglected. Agricultural development efforts cannot be diverted even while recognizing the importance of climate change and the interaction between climate and other agricultural issues. Given the reliance of the poor on agriculture and the sensitivity of agriculture to climate change, impending climate changes will almost certainly hit (currently) developing countries and vulnerable populations within these countries hardest. While this reality seems to make the development process more complex, it should also stimulate greater urgency in addressing rural poverty and vulnerability. These twin imperatives of climate change - greater complexity and greater urgency - are important to keep in mind when formulating policies and institutions aimed at improving climate change adaptation and mitigation in agriculture.

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