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Full Research Article

Vegetable Production in Changing Climate Scenario: Challenges and Mitigation

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Abstract

The major climate changes viz., increase in temperature, enhanced evapo-transpiration, uncertainty of precipitation and seasonal variability, affect vegetable production technologies particularly choice of variety, sowing time, plant protection, nutrient and water management. Reduced GHG emission may help in minimizing the changes and their effects, but this reduction should not be expected from poor and developing counties at the expense of development. The developing countries with justified financial support may mitigate and lower the emissions by effective technology transfer, investment in eco–friendly infrastructure, encouragement of biodiversity conservation and good practices. Germplasm of the major vegetable crops tolerant to high temperatures, flooding and drought has been identified and advanced breeding lines are required to be developed. Furthermore, nurient-use efficient germplasm also need to be identified. In addition, development of water-use efficient production systems is key tool to mitigate the effects of hot and dry conditions. Not all the effects are negative. Agriculture emits and traps green house gases. The beneficial effects of CO_2 enhancement on crop growth need to be exploited. Farm practices can be modified to reduce emissions and to sequester the green house gases. We need to emphasize low external input agriculture particularly organic farming. Such low or no fertilizer farming shall be subsidized to the tune of social benefits of emission reduction. In global scenario, low GHG emissions in developing countries have made it possible to sustain the high pattern of energy consumption by the industrialized countries for decades and shall continue. People in high-income countries with higher carbon emission rate can buy organic products to promote such practices. The pricing of organic vegetable should include external benefits of reducing GHG emissions so that high-income people pay for their higher emission of GHG.

Introduction

Climate change is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions or the distribution of events around that average (e.g., more or fewer extreme weather events). Climate change may be limited to a specific region or may occur across the whole Earth. Climate change also refer to the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer (IPCC,2007). It refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level**.** Climate change is one of the most important global environmental challenges. The carbon dioxide, methane, nitrous oxide, sulphur dioxide, etc. form greenhouse gas (GHG) pools in the atmosphere. A significant change in climate on a global scale will impact agriculture and consequently affect the world's food supply. The problems arise from extreme events that are difficult to predict. More erratic rainfall patterns and unpredictable high temperature spells will consequently reduce crop productivity. Environmental stresses severely affect the soil organic matter decomposition, nutrient recycling and nutrient and water availability to the plant. However the intensity and duration of environmental extremes determine the magnitude of impact on crop growth cycle, biomass accumulation and ultimately the economic yield. Climate change is projected to increase the global temperatures, causes variations in rainfall, increase the frequency of extreme events such as heat, cold waves, frost days, droughts, floods, etc with immense impact on agriculture sector.

DRIVERS OF CLIMATE CHANGE

The climate change is attributed to the change in the composition of the global atmosphere that increases mean temperature that affects the ecology in the earth and ocean. The change in the composition of the atmosphere is caused directly and indirectly by various human activities in addition to natural climate variability over time (Pant KP, 2009). The energy from the sun reaching the earth is balanced by the energy that the earth emits back to space. The cloud of greenhouse gases (GHGs) like water vapour, carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O) trap some of the solar energy that the earth releases to space (Robertson *et al*., 2000). Such GHGs have effects like a greenhouse on the earth's atmosphere and the temperature of the earth increases. Since 1750, the atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased by approximately 31 percent, 151 percent and 17 percent respectively. Current rates of increase per year are 0.5 percent for carbon dioxide, 0.6 percent for methane and 0.3 percent for nitrous oxide (IPCC, 2001). Human activities increase the GHG levels in the atmosphere by introducing new sources or removing natural sinks such as forests. A balance between sources and sinks determines the levels of greenhouse gases in the atmosphere.

There was an average increase in the mean annual temperature of earth surface by 0.06ºC per year between 1977 and 1994 (World Bank, 2007a). With predicted increases in temperatures and changes in rainfall patterns, there will be significant negative impacts on ecosystems and people's livelihoods. Specifically, there will be negative impacts on public health, forestry and biodiversity, agriculture and water resources (MoPE, 2004). As the agriculture is concerned with the food security and livelihood of the majority of the people in developing countries and under developed countries, this sector deserves immediate attention for making it environment friendly.

The temperature of the planet would increase by, at least, 2.4ºC above pre-industrial times (Liliana Hisas, 2011). Carbon dioxide (CO2) is the most important man-made greenhouse gas. In 2008, CO2 levels reached 385.2 parts per million (ppm). With current increase rates of about 0.5 percent per year, CO2 levels could reach 410 ppm in the next decade. These levels correspond to greenhouse gases (GHGs) concentrations above 490 ppm CO2-equivalent (all greenhouse gases combined). This equals a 2.4ºC increase in global temperature above pre-industrial times.

Two of the three main elements of food production –water and climate— would be most affected by climate change. Obtaining more land suitable for agricultural production is unlikely. It is therefore water availability (mainly in the form of rain, on which 80 percent of food production depends) and climate conditions which would most significantly impact food production worldwide, with both positive and negative impacts. The most significant impacts of climate change on food production would be on:

- The tropical region –the region between 30º N and S of the Equator—due to reducedwater availability and increased temperatures.
- The temperate region –between 30º and 60º N and S—due to changes in precipitation.

Presently 10% of the earth's landmass is covered with snow, with 84.16% of the Antarctic, 13.9% in Greenland, 0.77% in the Himalaya, 0.51% in North America, 0.37% in Africa, 0.15% in South America, 0.06% in Europe. Outside the polar region, Himalaya has the maximum concentration of glaciers. 9.04% of the Himalaya is covered with glaciers, with 30-40% additional area being covered with snow. Talking of glaciers, India has 5243 glaciers covering an area of 37579 km^2 and containing 142.88 km^2 of ice. The Gangotri glacier, the source of the Ganga is receding at 20-23 miles per year. Millain glacier is receding at 30m/yr, Dukrian is retreating at 15-20m/yr. The receding of glaciers has accelerated with global warming. The rate of retreat of the gangotri glacier has tripled in the last three years. Some of the most devastating effects of glacial meltdown occures when glacial lakes overflow and the phenomena of Glacial Lake Outburst Floods (GLOFs) take place. In the Ganga, the loss of glacier meltdown would reduce July-September flows by two thirds, causing water shortages for 500 million people and 37 percent of India's irrigated land.

In the last decade, maximum temperature in the Himalayas has risen by an average of 1^0C which is causing great concern amongst the agricultural scientists. Whereas according to the study conducted by ADB, indicative predictions for 2070-2100 with reference to baseline of 1961-1990, the projected increase in summer monsoon rainfall is about 45% over northern part of the Himalayas and 15% in southern part while temperature rise is estimated at about 4^0 C across whole Himalayas. In Himalayan States, agriculture is the mainstay of around 90% population which gets its earnings from agriculture. Any change in the natural resources of the region due to climate change will have far-reaching repercussions. Climate change has also led to rain, rather than snow, falling even at higher altitudes. This also accelerates the melting of glaciers. Meantime, heavy rainfall which was unknown in the high altitude desert has become more frequent, causing flash floods, washing away homes and fields, trees and livestock. The arrival of black clouds and disappearance of white snow in the cold desert is how climate change is entering the life of the communities in cold deserts like Ladakh in J&K and Lahaul &Spiti and Kinnaur in Himachal Pradesh. They did not cause the pollution, but they are its victims. This is the direct and cruel face of climate injustice-the polluters continue to pollute, they are insulated from the impact of their own actions, others, thousands of miles away bear the brunt of greenhouse gas pollution.

Agricultural productivity can be affected in two ways: one, directly, due to changes in temperature, precipitation or CO_2 levels and two, indirectly, through changes in soil, distribution and frequency of infestation by pests, insects, diseases or weeds. Sixty five per cent of Indian agriculture is heavily dependent on natural factors such as rainfall. It is also restricted by a lack of complementary inputs and institutional support systems. In tropical Asia, India produces main crops (area)-chili, onion, eggplant, tomato, okra, cabbage, peas, cauliflower (volume)-eggplant, tomato, onion, cabbage, cauliflower, okra, peas, chili. Cropping is in two seasons: *kharif* and *rabi*. Rabi is the spring harvest season, with crops sown September to November and extending up into February and March, with most productivity in areas that receive the north-east monsoon. Crops in Tropical Asia are likely to be sensitive to an increase in maximum temperature and would be vulnerable to an increase in minimum temperature. The adverse impacts of likely water shortage on wheat productivity in India could be minimized to a certain extent under elevated CO_2 levels; these impacts, however, would be largely maintained for rice crops, resulting in a net decline in rice yields. Acute water shortage conditions combined with thermal stress could adversely affect the crops , more severely, rice productivity in India even under the positive effects of elevated CO_2 in the future.(IPCC 2001) The loss in farm-level net revenue will range between 9 and 25% for a temperature rise of 2-3.5^{0}C (Kumar and Parikh 1998). A rise in mean temperature of 2^{0}C and a 7% increase in mean precipitation will reduce net revenues by 12.3% for the country as a whole. Agriculture in the coastal regions of Gujarat, Maharashtra and Karnataka is likely to be affected negatively. Small losses are also indicated for the major foodgrain-producing regions of Punjab, Haryana, and Western Uttar Pradesh (Sanghi *et.al.*1998).

POSSIBLE IMPACTS OF CLIMATE CHANGE

CLIMATE CHANGE LIMITING VEGETABLE PRODUCTIVITY

Climate change is likely to cause environment stress and it is the primary cause of crop losses worldwide, reducing average yields for most major crops by more than 50% (Boyer 1982, Bray *et al.* 2000). The tropical vegetable production environment is a mixture of conditions that varies with season and region. Climatic changes will influence the severity of environmental stress imposed on vegetable crops. Moreover, increasing temperatures, reduced irrigation water availability, flooding, and salinity will be major limiting factors in sustaining and increasing vegetable productivity. Extreme climatic conditions will also negatively impact soil fertility and increase soil erosion. Thus, additional fertilizer application or improved nutrient-use efficiency of crops will be needed to maintain productivity or harness the potential for enhanced crop growth due to increased atmospheric CO2. The response of plants to environmental stresses depends on the plant developmental stage and the length and severity of the stress (Bray, 2002). Plants may respond similarly to avoid one or more stresses through morphological or biochemical mechanisms (Capiati *et al.* 2006). Environmental interactions make the stress response of plants more complex or influence the degree of impact of climate change.

HIGH CO_2 CONCENTRATION

Higher concentration of CO2 and carbon fertilization (increased availability of the carbon to the crops) increase plant photosynthesis and thus crop yields (Rosenzweig and Hillel, 1998). Enhanced photosynthesis increase the yield of C3 crops wheat, rice and soybean (Potato, Carrot, Beans) , but not of the C4 crops such as sugarcane and maize (Cabbage, Cauliflower, Turnip, Broccoli) (Cline, 2008). Higher CO_2 levels will affect both plants, pathogens and diseases. Higher CO_2 with higher humidity will result in denser canopies which will favour many pathogens like *Phytophthora, Alternaria* and *Botrytis*. Soilborne pathogens will be more serious as high CO_2 conc. will result in lower plant decomposition. Higher CO_2 conc. Can also result in higher fungal spore production. However, increased CO_2 can also result in physiological changes in the host that can result in resistance in the hosts against the pathogens.

Effect of increased CO_2 under controlled environment

• Elevated CO_2 at 550 ppm improved the bulb size and yield of onion.

• Tomato plants grown at 550 ppm CO_2 environment produced 24% more fruits.

• The quality (carotene, starch and glucose content) and tuber yield of sweet potatoes increased.

• Increased Carbon: Nitrogen ratios in the leaves of plants or in other aspects of leaf chemistry, possibly changing herbivore nutrition

HIGH TEMPERATURE STRESS

Temperature limits the range and production of many crops. In the tropics, high temperature conditions are often prevalent during the growing season and, with a changing climate, crops in this area will be subjected to increased temperature stress.

➢Analysis of climate trends in tomato-growing locations suggests that temperatures are rising and the severity and frequency of above-optimal temperature episodes will increase in the coming decades (Bell *et al.* 2000).

➢Vegetative and reproductive processes in tomatoes are strongly modified by temperature alone or in conjunction with other environmental factors (Abdalla & Verkerk 1968).

➢High temperature stress disrupts the biochemical reactions fundamental for normal cell function in plants. It primarily affects the photosynthetic functions of higher plants (Weis & Berry 1988).

➢High temperatures can cause significant losses in tomato productivity due to reduced fruit set, and smaller and lower quality fruits (Stevens & Rudich 1978).

➢Pre-anthesis temperature stress is associated with developmental changes in the anthers, particularly irregularities in the epidermis and endothesium, lack of opening of the stromium, and poor pollen formation (Sato *et al.* 2002).

➢In pepper, high temperature exposure at the pre-anthesis stage did not affect pistil or stamen viability, but high post-pollination temperatures inhibited fruit set, suggesting that fertilization is sensitive to high temperature stress (Erickson & Markhart 2002).

➢Hazra *et al.* (2007) summarized the symptoms causing fruit set failure at high temperatures in tomato; this includes bud drop, abnormal flower development, poor pollen production, dehiscence, and viability, ovule abortion and poor viability, reduced carbohydrate availability, and other reproductive abnormalities.

➢In addition, significant inhibition of photosynthesis occurs at temperatures above optimum, resulting in considerable loss of potential productivity.

➢Increased temperature during growing season can reduce yields, because crops speed through their physiological development producing less grain. Faster plant growth and modifications of water and nutrient budgets in the farm (Long, 1991) will render existing farming technology unsuitable. Change in crop physiology will make traditional practices inappropriate.

➢The higher temperature also increases the process of evapo-transpiration and decreases soil moisture availability.

DROUGHT STRESS

Unpredictable drought is the single most important factor affecting world food security and the catalyst of the great famines of the past (CGIAR 2003). The world's water supply is fixed, thus increasing population pressure and competition for water resources will make the effect of successive droughts more severe (McWilliam 1986). Inefficient water usage all over the world and inefficient distribution systems in developing countries further decreases water availability. Water availability is expected to be highly sensitive to climate change and severe water stress conditions will affect crop productivity, particularly that of vegetables. In combination with elevated temperatures, decreased precipitation could cause reduction of irrigation water availability and increase in evapo -transpiration, leading to severe crop water-stress conditions (IPCC 2001).

➢Vegetables, being succulent products by definition, generally consist of greater than 90% water (AVRDC 1990). Thus, water greatly influences the yield and quality of vegetables; drought conditions drastically reduce vegetable productivity.

➢Drought stress causes an increase of solute concentration in the environment (soil), leading to an osmotic flow of water out of plant cells. This leads to an increase of the solute concentration in plant cells, thereby lowering the water potential and disrupting membranes and cell processes such as photosynthesis.

➢The timing, intensity, and duration of drought spells determine the magnitude of the effect of drought.

SALINITY STRESS

Vegetable production is threatened by increasing soil salinity particularly in irrigated croplands which provide 40% of the world's food (FAO 2002). Excessive soil salinity reduces productivity of many agricultural crops, including most vegetables which are particularly sensitive throughout the ontogeny of the plant.

➢According to the United States Department of Agriculture (USDA), onions are sensitive to saline soils, while cucumbers, eggplants, peppers, and tomatoes, amongst the main crops of AVRDC - The World Vegetable Center, are moderately sensitive. In hot and dry environments, high evapo-transpiration results in substantial water loss, thus leaving salt around the plant roots which interferes with the plant's ability to uptake water.

➢Physiologically, salinity imposes an initial water deficit that results from the relatively high solute concentrations in the soil, causes ion-specific stresses resulting from altered K^+/Na^+ ratios, and leads to a build up in Na^+ and Cl^- concentrations that are detrimental to plants (Yamaguchi & Blumwald 2005).

➢Plant sensitivity to salt stress is reflected in loss of turgor, growth reduction, wilting, leaf curling and epinasty, leaf abscission, decreased photosynthesis, respiratory changes, loss of cellular integrity, tissue necrosis, and potentially death of the plant (Jones 1986; Cheeseman 1988).

FLOODING DANGER TO VEGETABLES

Vegetable production occurs in both dry and wet seasons. However, production is often limited during the rainy season due to excessive moisture brought about by heavy rain. Most vegetables are highly sensitive to flooding and genetic variation with respect to this character is limited, particularly in tomato.

➢In general, damage to vegetables by flooding is due to the reduction of oxygen in the root zone which inhibits aerobic processes. Flooded tomato plants accumulate endogenous ethylene that causes damage to the plants (Drew 1979).

➢Low oxygen levels stimulate an increased production of an ethylene precursor, 1-aminocyclopropane-1-carboxylic acid (ACC), in the roots. The rapid development of epinastic growth of leaves is a characteristic response of tomatoes to water-logged conditions and the role of ethylene accumulation has been implicated.

➢The severity of flooding symptoms increases with rising temperatures; rapid wilting and death of tomato plants is usually observed following a short period of flooding at high temperatures (Kuo *et al.* 1982).

ADAPTATION TO CLIMATE CHANGE

“Adaptation is needed as we are already committed to some degree of climate change regardless of mitigation efforts. Developing adaptation actions is essential if we are to reduce our vulnerability to climate change**”**

Potential impacts of climate change on agricultural production will depend not only on climate *per se*, but also on the internal dynamics of agricultural systems, including their ability to adapt to the changes (FAO 2001). Success in mitigating climate change depends on how well agricultural crops and systems adapt to the changes and concomitant environmental stresses of those changes on the current systems. Farmers in developing countries of the tropics need tools to adapt and mitigate the adverse effects of climate change on agricultural productivity, and particularly on vegetable production, quality and yield. Current, and new, technologies being developed through plant stress physiology research can potentially contribute to mitigate threats from climate change on vegetable production. However, farmers in developing countries are usually small-holders, have fewer options and must rely heavily on resources available in their farms or within their communities. Thus, technologies that are simple, affordable, and accessible must be used to increase the resilience of farms in less developed countries.

1. Assist farmers in coping with current climatic risks-weather services, agro-advisories, insurance, community banks for seed and fodder

2. Intensify food production systems-technology and input delivery systems, market links

3. Improve land and water management-technologies for resource conservation and use efficiency

4. Enable policies and regional cooperation-incentives to farmers for resource conservation and use efficiency, pricing of resources, credit for transition to adaptation technologies

5. Strengthen research for enhancing adaptive capacity-varieties, resource conservation technologies, pest surveillance -for improved assessments: mechanism for collection and dissemination of weather, soil, water and agricultural data

Concrete Actions To Address The Impacts Of Climate Change On Food Production Include:

REDUCE GHG EMISSIONS

Reducing GHG emissions is the first and most important step. Efforts so far have been numerous, but unsuccessful. The annual meetings among world leaders and negotiators at the United Nations Framework Convention on Climate Change (UNFCCC) failed to produce a formal agreement to reduce GHG emissions. Global GHG emissions have already exceeded the levels projected by the IPCC as the safe upper limit, which would increase the global temperature by 1ºC. Thus, currently, global GHG emissions are steadily increasing to a level which would be dangerous –more than 2ºC.

The IPCC concluded that developed countries as a group –responsible for almost 50 percent of the global GHG emissions—would need to reduce their emissions by 2020 in the range of 25 to 40 percent below 1990 levels.

The commitments made through the Copenhagen Accord (2009) were reaffirmed by the Cancun Agreements (2010). No formal agreement, however, was reached to reduce GHG emissions. Also, consensus was reached by industrialized countries to provide $30 billion for the period 2010-2012 and to jointly mobilize $100 billion per year by 2020 to assist developing Countries with expected decrease in production: India, Brazil, Egypt, Nigeria, Russian Federation, Ukraine, Italy, Argentina, France, Germany, Romania, South Africa, Mexico, Hungary and Serbia.

ADAPT TO CLIMATE CHANGE

The implementation of measures to cope with climate change, including two main categories:

➢**Adjusting practices and processes** –concrete measures for **cropping systems,** include, among others:

✓Altering inputs such as varieties and/or species to those with more appropriate thermal time and/or with increased resistance to heat shock and drought, altering fertilizer rates to maintain quality consistent with the climate and altering amounts and timing of irrigation and other water management practices.

✓Altering the timing and relocating crops and livestock activities.

✓Wider use of technologies to 'harvest' water, conserve soil moisture (e.g., crop residue retention) and to use water more effectively in areas with rainfall decreases.

✓Water management to prevent water-logging, erosion and nutrient leaching in areas with rainfall increases.

✓Provide appropriate shelter for cattle and other livestock for improved productivity.

✓Diversifying income by integrating other farming activities such as livestock raising.

✓Monitoring weather and climate and running risk management systems, to provide early alert advisories, as well as using seasonal climate forecasting to reduce risks and adverse effects on food production and quality.

The benefits of adaptation vary with crops and across regions and temperature changes; however, on average, they provide approximately a **10 percent yield benefit** when compared with yields when no adaptation is used.

• Effective planning for adaptation to climate change –deliberate, planned measures to 'mainstream' climate change into policies, to create and strengthen favorable conditions for effective adaptation and investment in new technologies and infrastructure.

➢**Change dietary habits**

Trends in food consumption for the last two decades may change by 2020 to cope with the decrease in food production due to climate change. To maintain a balanced and healthy diet, and sustain the shares of food sources, some of the changes in dietary habits may include:

• Cereal consumption for food may shift to roots and tubers (e.g.: potatoes, sweet potatoes)

• The consumption of alternative sources of protein may increase, in particular of legumes (e.g.: beans, lentils)

➢**Policy-based adaptation –**

Options can either involve adaptation activities such as developing infrastructure or building the capacity to adapt by changing the decision-making environment under which management-level adaptation activities occur.

Effective planning and capacity building for adaptation to climate change could include:

• To change their management, enterprise managers need to be convinced that the climate changes are real and are likely to continue. This will be assisted by policies that maintain climate monitoring and communicate this information effectively.

• Managers need to be confident that the projected changes will significantly impact on their enterprise. This could be assisted by policies that support the research, systems analysis, extension capacity, and industry and regional networks that provide this information.

• There needs to be technical and other options available to respond to the projected changes. Where the existing technical options are inadequate to respond, investment in new technical or management options may be required (e.g., improved crops) or old technologies revived in response to the new conditions.

• Where there are major land use changes, industry location changes and migration, there may be a role for governments to support these transitions via direct financial and material support, creating alternative livelihood options.

• Developing new infrastructure, policies and institutions to support the new management and land use arrangements by addressing climate change in development programs, and enhanced investment in irrigation infrastructure and efficient water use technologies, among others.

• The capacity to make continuing adjustments and improvements in adaptation by understanding what is working, what is not and why, via targeted monitoring of adaptations to climate change and their costs and effects.

MITIGATION OF CLIMATE CHANGE BY AGRICULTURE

We are searching for effective approaches to improve energy efficiency and minimize GHG emissions from agriculture sector.

Carbon sequestration in crops, pastures and trees and trapping carbon is soil can reduce atmospheric carbon. Similarly, substituting fossil fuels with renewable energy in crop and livestock production can reduce GHG emissions. Thus, the agriculture can reduce atmospheric greenhouse gases. Soil organic carbon (SOC) pool is the largest among terrestrial pools and the restoration of SOC pool in arable lands represents a potential sink for atmospheric CO2 (Jarecki *et al*., 2005). Restorative management of SOC includes using organic manures, adopting legume based crop rotations and converting plough till to conservation till system. When land is ploughed, soil carbon gets oxidized and become atmospheric carbon dioxide (Takle and Hofstrand, 2008). Minimum till farming practices provide a great potential for the future sequestration of atmospheric carbon and building soil organic matter while also minimizing soil erosion and reducing production costs. However, the carbon trapped in the soil is reversible and it gets released to the atmosphere after some years.

Restoration of SOC in arable lands represents a potential sink for atmospheric CO2 (Lal and Kimble, 1997). Strategies for SOC restoration by adoption of recommended management practices include conversion from conventional tillage to reduced tillage, increasing cropping intensity by eliminating summer fallows, using highly diverse crop rotation, introducing forage legumes and grass mixtures in the rotation cycle, increasing crop production and increasing carbon input into the soil (Lal, 1999; Desjardins *et al*., 2001; Hao *et al*., 2002). The potential to sequester carbon varies considerably between crop type, crop rotation and the amount of fertilizer necessary for crop growth. Crop characteristics like species, productivity, canopy structure, root physiology and root function and pattern affect soil organic carbon (Chan and Heenan, 1996). Change in farming practices to the emission reducing ones can offer great potential to reduce the problem of climate change. Burning crop residues is clearly a climate unfriendly practice.

ENHANCING VEGETABLE PRODUCTION SYSTEMS

Various management practices have the potential to raise the yield of vegetables grown under hot and wet conditions of the lowland tropics. AVRDC-The World Vegetable Center has developed technologies to alleviate production challenges such as limited irrigation water and flooding, to mitigate the effects of salinity, and also to ensure appropriate availability of nutrients to the plants.

Strategies include modifying fertilizer application to enhance nutrient availability to plants, direct delivery of water to roots (drip irrigation), grafting to increase flood and disease tolerance, and use of soil amendments to improve soil fertility and enhance nutrient uptake by plants.

WATER-SAVING IRRIGATION MANAGEMENT

The quality and efficiency of water management determine the yield and quality of vegetable products. The optimum frequency and amount of applied water is a function of climate and weather conditions, crop species, variety, stage of growth and rooting characteristics, soil water retention capacity and texture, irrigation system and management factor (Phene 1989). Too much or too little water causes abnormal plant growth, predisposes plants to infection by pathogens, and causes nutritional disorders. If water is scarce and supplies are erratic or variable, then timely irrigation and conservation of soil moisture reserves are the most important agronomic interventions to maintain yields during drought stress.

There are several methods of applying irrigation water and the choice depends on the crop, water supply, soil characteristics and topography. Application of irrigation water could be through overhead, surface, drip, or sub-irrigation systems. Surface irrigation methods are utilized in more than 80% of the world's irrigated lands yet its field level application efficiency is often 40-50% (von Westarp 2004).

To generate income and alleviate poverty of the small-holder farmers in developing countries, AVRDC-The World Vegetable Center and other institutions promote affordable, small-scale drip irrigation technologies developed by the International Development Enterprises (IDE). Drip irrigation delivers water directly to plants through small plastic tubes. IDE states that water losses due to run-off and deep percolation are minimized and water savings of 50-80% are achieved when compared to most traditional surface irrigation methods. Crop production per unit of water consumed by plant evapo-transpiration is typically increased by 10-50%. Thus, more plants can be irrigated per unit of water by drip irrigation, and with less labor.

In Nepal, cauliflower yields using low-cost drip irrigation were not significantly different from those achieved by hand watering; however the long-term economic and labor benefits were greater using the low-cost drip irrigation (von Westarp 2004). The water-use efficiency by chili pepper was significantly higher in drip irrigation compared to furrow irrigation, with higher efficiencies observed with high delivery rate drip irrigation regimes (AVRDC 2005).

For drought tolerant crop like watermelon, yield differences between furrow and drip irrigated crops were not significantly different; however, the incidence of Fusarium wilt was reduced when a lower drip irrigation rate was used. In general, the use of low-cost drip irrigation is cost effective, labor-saving, and allows more plants to be grown per unit of water, thereby both saving water and increasing farmers' incomes at the same time.

PRECISION FARMING TECHNOLOGIES TO IMPROVE VEGETABLE PRODUCTION:

Precision farming technologies can play an important role in the changing climate scenario. Precision farming involves application of right amount of input at right place and at right time thereby minimizing spatial and temporal variabilities in a micro climate. The main components of PF are Global

Positioning System, Geographical Information System, Remote Sensing, different type of sensors and whole lot of computer attached gizmos. Precision farming has focused on the development of techniques that primarily aid the conventional farming system i.e. tilling the field and other practices and it has the potential of changing agriculture dramatically in the 21st century. Precision farming is based on information technology, which enables the producer to collect information and data for better decision making. It is a pro-active approach that reduces some of the risks and variables common to agriculture. It is more environmentally sound and is an integral part in sustaining natural resources.

CULTURAL PRACTICES THAT CONSERVE WATER AND PROTECT CROPS

Various crop management practices such as mulching and the use of shelters and raised beds help to conserve soil moisture, prevent soil degradation, and protect vegetables from heavy rains, high temperatures, and flooding. The use of organic and inorganic mulches is common in high-value vegetable production systems. These protective coverings help reduce evaporation, moderate soil temperature, reduce soil runoff and erosion, protect fruits from direct contact with soil and minimize weed growth. In addition, the use of organic materials as mulch can help enhance soil fertility, structure and other soil properties.

• Rice straw is abundant in rice-growing areas of the tropics and generally recommended for summer tomato production. The benefits of rice straw mulch on fruit yield of tomato have been demonstrated in Taiwan (AVRDC 1981).

• In India, mulching improved the growth of eggplant, okra, bottle gourd, round melon, ridge gourd, and sponge gourd compared to the non-mulched controls (Pandita & Singh 1992).

• Yields were the highest when polythene and sarkanda (*Saccharum* spp. and *Canna* spp.) were used as mulching materials. In the lowland tropics where temperatures are high, dark-colored plastic mulch is recommended in combination with rice straw (AVRDC 1990).

• Dark plastic mulch prevents sunlight from reaching the soil surface and the rice straw insulates the plastic from direct sunlight thereby preventing the soil temperature rising too high during the day. During the hot rainy season, vegetables such as tomatoes suffer from yield losses caused by heavy rains. Simple, clear plastic rain shelters prevent water logging and rain impact damage on developing fruits, with consequent improvement in tomato yields (Midmore *et al.* 1992).

•Fruit cracking and the number of unmarketable fruits are also reduced. Elimination of flooding and rain damage, as well as the reduced air temperature, was responsible for the higher yields of the crops grown under plastic shelters. Another form of shelter using shade cloth can be used to reduce temperature stress. Shade shelters also prevent damage from direct rain impact and intense sunlight. Planting vegetables in raised beds can ameliorate the effects of flooding during the rainy season.

• Yields of tomatoes increased with bed height, most likely due to improved drainage and reduction of anoxic stress. Additive effects on yield were observed when tomatoes were planted in raised beds with rain shelters.

IMPROVED STRESS TOLERANCE THROUGH GRAFTING

Grafting vegetables originated in East Asia during the 20th century and is currently common practice in Japan, Korea and some European countries. Grafting, in this context, involves uniting of two living plant parts (rootstock and scion) to produce a single growing plant. It has been used primarily to control soil-borne diseases affecting the production of fruit vegetables such as tomato, eggplant, and cucurbits. However, it can provide tolerance to soil-related environmental stresses such as drought, salinity, low soil temperature and flooding if appropriate tolerant rootstocks are used.

• Grafting of eggplants was started in the 1950s, followed by grafting of cucumbers and tomatoes in the 1960s and 1970s (Edelstein 2004).

• Romero *et al.* (1997) reported that melons grafted onto hybrid squash rootstocks were more salt tolerant than the non-grafted melons. However, tolerance to salt by rootstocks varies greatly among species, such that rootstocks from *Cucurbita* spp. are more tolerant of salt than rootstocks from *Lagenaria siceraria* (Matsubara 1989).

• Grafted plants were also more able to tolerate low soil temperatures. *Solanum lycopersicum* x *S. habrochaites* rootstocks provide tolerance of low soil temperatures (10°C to 13°C) for their grafted tomato scions, while eggplants grafted onto *S. integrifolium x S. melongena* rootstocks grew better at lower temperatures (18°C to 21°C) than non-grafted plants (Okimura *et al.* 1986).

DEVELOPING CLIMATE-RESILIENT VEGETABLE

Improved, adapted vegetable germplasm is the most cost-effective option for farmers to meet the challenges of a changing climate. However, most modern cultivars represent a limited sampling of available genetic variability including tolerance to environmental stresses. Breeding new varieties, particularly for intensive, high input production systems in developed countries, under optimal growth conditions may have counter-selected for traits which would contribute to adaptation or tolerance to low input and less favorable environments. Superior varieties adapted to a wider range of climatic conditions could result from the discovery of novel genetic variation for tolerance to different biotic and abiotic stresses.

Genotypes with improved attributes conditioned by superior combinations of alleles at multiple loci could be identified and advanced. Improved selection techniques are needed to identify these superior genotypes and associated traits, especially from wild, related species that grow in environments which do not support the growth of their domesticated relatives that are cultivated varieties. Plants native to climates with marked seasonality are able to acclimatize more easily to variable environmental conditions (Pereira & Chavez 1995) and provide opportunities to identify genes or gene combinations which confer such resilience.

➢ VARIETIES TOLERANT TO HIGH TEMPERATURES

- The heat tolerant tomato lines were developed using heat tolerant breeding lines and landraces from the Philippines (*e.g.* VC11-3-1-8, VC 11-2-5, Divisoria-2) and the United States (*e.g.* Tamu Chico III, PI289309) (Opena *et al.* 1989). However, lower yields in the heat tolerant lines are still a concern.
- The fruit set of CL5915 ranges from 15% - 30% while there is complete absence of fruit set in heat-sensitive lines in mean field temperatures of 35^{o}C. Genetic studies at AVRDC - The World Vegetable Center indicated that heat tolerance in CL5915, based on fruit set and fruit number per cluster, is controlled by additive and dominant effects (Hanson *et al.* 2002).
- The average heritability for fruit set is 0.26. However, bimodality of fruit set distribution and recovery of tolerant lines in early backcross generations suggests that only a few major genes and modifiers may control the heat tolerance trait (Opena *et al.* 1990, 1992).
- Germplasm evaluation for heat tolerance at AVRDC - The World Vegetable Center conventionally relied upon field screening during the hot and humid season, with measurement of fruit set and yield. Generally less than 1% of the screened lines or accessions exhibit a high level of heat tolerance (Villareal *et al.* 1978). Although field screening is effective, the accuracy and speed of the process could be improved through the use of molecular markers.

➢ VARIETIES TOLERANT TO DROUGHT AND WATER-USE EFFICIENCY.

Plants resist water or drought stress in many ways. In slowly developing water deficit, plants may escape drought stress by shortening their life cycle (Chaves & Oliveira 2004).

- Tissue tolerance to severe dehydration is not common in crop plants but is found in species native to extremely dry environments (Ingram & Bartels 1996).
- Genetic variability for drought tolerance in *S. lycopersicum* is limited and inadequate. The best source of resistance is from other species in the genus *Solanum*.
- The Tomato Genetics Resource Center (TGRC) at the University of California, Davis has assembled a set of the putatively stress tolerant tomato germplasm that includes accessions of *S. cheesmanii*, *S. chilense*, *S. lycopersicum*, *S. lycopersicum* var. *cerasiforme*, *S. pennellii*, *S. peruvianum* and *S. pimpinellifolium*. *S. chilense* and *S. pennelli* are indigenous to arid and semi-arid environments of South America. Both species produce small green fruit and have an indeterminate growth habit. *S chilense* is adapted to desert areas of northern Chile and often found in areas where no other vegetation grows (Maldonado *et al.* 2003), has finely divided leaves and well-developed root system and has a longer primary root and more extensive secondary root system than cultivated tomato (O'Connell *et al.* 2007).
- Drought tests show that *S. chilense* is five times more tolerant of wilting than cultivated tomato. *S.pennellii* has the ability to increase its water use efficiency under drought conditions unlike the cultivated *S. lycopersicum* (O'Connell *et al.* 2007). It has thick, round waxy leaves, is known to produce acyl-sugars in its trichomes, and its leaves are able to take up dew (Rick 1973).
- Transfer and utilization of genes from these drought resistant species will enhance tolerance of tomato cultivars to dry conditions, although wide crosses with *S. pennellii* produce fertile progenies, *S. chilense* is cross-incompatible with *S. lycopersicum* and embryo rescue through tissue culture is required to produce progeny plants.

➢ VARIETIES TOLERANT TO SALINE SOILS AND IRRIGATION WATER

Attempts to improve the salt tolerance of crops through conventional breeding programs have very limited success due to the genetic and physiologic complexity of this trait (Flowers 2004). In addition, tolerance to saline conditions is a developmentally regulated, stage-specific phenomenon; tolerance at one stage of plant development does not always correlate with tolerance at other stages (Foolad 2004). Success in breeding for salt tolerance requires effective screening methods, existence of genetic variability, and ability to transfer the genes to the species of interest. Screening for salt tolerance in the field is not a recommended practice because of the variable levels of salinity in field soils. Screening should be done in soil-less culture with nutrient solutions of known salt concentrations (Cuartero & Fernandez-Munoz 1999). Most commercial tomato cultivars are moderately sensitive to increased salinity and only limited variation exists in cultivated species.

- Genetic variation for salt tolerance during seed germination in tomato has been identified within cultivated and wild species. A cross between a salt-sensitive tomato line (UCT5) and a salt-tolerant *S. esculentum* accession (PI174263) showed that the ability of tomato seed to germinate rapidly under salt stress is genetically controlled with narrow-sense heritability (*h*2) of 0.75 (Foolad & Jones 1991).
- Several studies indicate that salt tolerance during seed germination in tomato is controlled by genes with additive effects and could be improved by directional phenotypic selection (Foolad 2004).
- In pepper, salt stress significantly decreases germination, shoot height, root length, fresh and dry weight, and yield. Yildirim and Guvenc (2006) reported that pepper genotypes Demre, Ilica 250, 11-B-14, Bagci Carliston, Mini Aci Sivri, Yalova Carliston, and Yaglik 28 can be useful as sources of genes to develop pepper cultivars with improved germination under salt stress.
- Related wild tomato species have shown strong salinity tolerance and are sources of genes as coastal areas are common habitat of some wild species. Studies have identified potential sources of resistance in the wild tomato species *S. cheesmanii*, *S. peruvianum*, *S pennelii*, *S. pimpinellifolium*, and *S. habrochaites* (Flowers 2004, Foolad 2004, Cuartero *et al.* 2006).

CLIMATE-PROOFING THOUGH GENOMICS AND BIOTECHNOLOGY

Increasing crop productivity in unfavorable environments will require advanced technologies to complement traditional methods which are often unable to prevent yield losses due to environmental stresses. In the past decade, genomics has developed from whole genome sequencing to the discovery of novel and high throughput genetic and molecular technologies. Genes have been discovered and gene functions understood. This has opened the way to genetic manipulation of genes associated with tolerance to environmental stresses. These tools promise more rapid, and potentially spectacular, returns but require high levels of investment. Many activities using these genetic and molecular tools are in place, with some successes. National and international institutes are re-tooling for plant molecular genetic research to enhance traditional plant breeding and benefit from the potential of genetic engineering to increase and sustain crop productivity (Pena & Hughes 2007)

CONCLUSIONS

The major effects of climate change can be summarized as increase in temperature, weather variability, evapo-tranpiration and uncertainty of precipitation. This will affect vegetable production technologies particularly choice of variety/breed, sowing time, disease/pest management and water management. It is shown that savings in GHG emissions by the poor should not be expected at the expense of development. Yet, other savings by developing countries can be increased by technology transfer, investment in better infrastructure, and efforts for modernization, all of which require financial support. Encouragement to conservation and good practices would result in lower emissions. Far from free riding, low GHG emissions in developing countries have made it possible to sustain the high pattern of energy consumption by the industrialized countries for decades in the past, at present and in the future too. Germplasm of the major vegetable crops which are tolerant of high temperatures, flooding and drought has been identified and advanced breeding lines are required to be developed.

Efforts are also underway to identify nitrogen-use efficient germplasm. In addition, development of production systems geared towards improved water-use efficiency and expected to mitigate the effects of hot and dry conditions in vegetable production systems are top research and development priorities. Climate change affects crop production practices and yields. Negative effects are projected to be more prominent than the positive effects. Agriculture emits and traps green house gases. Farm practices can be modified to reduce emissions and to sequester the green house gases. The agricultural practices to reduce emissions should be pragmatic and cost-effective. The emissions reductions should be sector wide covering crop and livestock production, food processing enterprises, farm yard manure management, composting of crop residues, agro-forestry and pasture management. We need to emphasize low external input agriculture particularly organic farming. Such low or no fertilizer farming shall be subsidized to the tune of social benefits of emission reduction from such practices. People in high-income countries with higher carbon emission rate should buy organic products from less developed countries to promote such practices. The pricing of such organic vegetable should include the external benefits of reducing carbon dioxide emissions so that high-income people pay for their higher emission of the green house gases.

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