OPEN ACCESS

Global Academic Journal of Agriculture and Bio sciences

Available online at https://www.gajrc.com
DOI: 10.36348/gajab.2023.v05i04.002

ISSN:2706-8978 (P)
ISSN: 2707-2568 (O)

Review Article

Climate Change and Crop Adaptation: Its Impacts and Opportunities for Crops Production

Dr. Zewdinesh Damtew Zigene[1*]
[1]Ethiopian Institute of Agricultural Research, Wondo Genet Agricultural Research Center, Ethiopia

***Corresponding Author**
Dr. Zewdinesh Damtew Zigene
Ethiopian Institute of Agricultural Research, Wondo Genet Agricultural Research Center, Ethiopia

Article History
Received: 24.07.2023
Accepted: 26.08.2023
Published: 08.09.2023

Abstract: Climate change is the departure of a region's weather patterns from the norm or from conditions that have been historically documented as usual. The term "climate" refers to long-term weather patterns, whereas the term "climate change" refers to changes in weather patterns through time. Climate, which can refer to a county, state, continent, or the entire world, is simply the pattern of weather that prevails on average in a location. Despite rigorous analysis of weather data conducted, it is difficult to forecast the effects of climate change for a specific agricultural operation because of the numerous human and environmental elements influencing it as well as the increased variability in weather over time and across space. After more than a decade of disagreement, the scientific community has now come to the conclusion that climate change is one of the planet's most pressing environmental issues of this century. The issue has evolved from a scientific to a political and economic matter, with dire economic repercussions, according to conventional thinking. Climate change has numerous impacts on the production of crops. The productivity of crops is subjected to a variety of stress and potential yields are rarely achieved. In order to sustain crop production with present-day challenges, there have to be packages to manage stresses caused by climate change. If properly managed, some sectors such as the horticulture sector could be might benefit from the impact of climate change in terms of energy, productivity, and market advantages. This review paper, therefore, reviews the impact opportunity and challenges of climate change on the productivity of crops.

Keywords: Abiotic impact, biotic impact, climate change, crop productivity.

INTRODUCTION

Climate change is the deviation of an area's weather pattern from the average or from the historically observed normal condition. Long-term patterns of weather are referred to as the "climate and changes in weather patterns over time are defined as "climate change." Climate is essentially the average pattern of weather for a region, which could be a county, state, continent, or the entire world (California department of food and Agriculture, 2013a). The Earth's climate is in a continuous state of change - it is inherent in the dynamic nature of our planet. It changes because of the interactions between the oceans and the atmosphere, changes in the Earth's orbit, fluctuations in incoming radiation, and volcanic activity. These forces will continue to have a major influence on our future climate (Environment Agency, 2012). Due to the many human and environmental factors influencing climate change, and due to increased variability in

Citation: Zewdinesh Damtew Zigene (2023). Climate Change and Crop Adaptation: Its Impacts and Opportunities for Crops Production, Glob Acad J Agri Biosci; Vol-5, Iss- 4 pp- 68-81.

weather over time and across space, climate change effects are difficult to predict for a specific agricultural operation nevertheless, rigorous analysis of weather data conducted. After more than a decade of debate, the scientific community now agrees that climate change is one of the most critical environmental problems to face the planet this century (Daniel, 2005). The issue has shifted from a scientific to a political and economic question for which common wisdom indicates severe economic consequences. Agricultural productivity is highly dependent on the climate. Increases in temperature and carbon dioxide (CO_2) can increase productivity of crops yields in some places. But to realize these benefits, nutrient levels, soil moisture, water availability, and other conditions must also be met. The effects of climate change also need to be considered along with other evolving factors that affect agricultural production, such as changes in farming practices and technology. Therefore, this review is done to assess the impact, opportunities and challenges of climate change on crops production.

EVOLUTION OF CLIMATE CHANGE

Human societies have long been subject to disruption by climate change. In the past, most of these variations have reflected natural phenomena, from fluctuations in levels of solar radiation to periodic eruptions of volcanoes. But in future most climate change is likely to result from human actions and in particular from the burning of fossil fuels and changes in global patterns of land use. These and other developments have been increasing the atmospheric concentrations of certain gases, chiefly carbon dioxide, methane and nitrous oxide. These are called greenhouse gases (GHGs) because, accumulating in the upper atmosphere, they act like the roof of a greenhouse, trapping long-wave radiation and thus raising temperatures and provoking other forms of climatic disruption (UNFCCC, 2006).

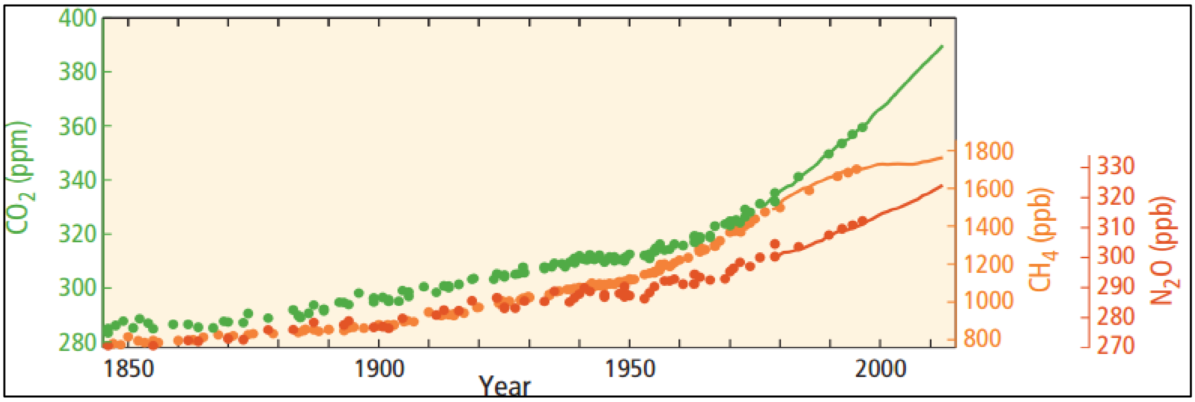

Figure 1: Global Average Green House Concentration

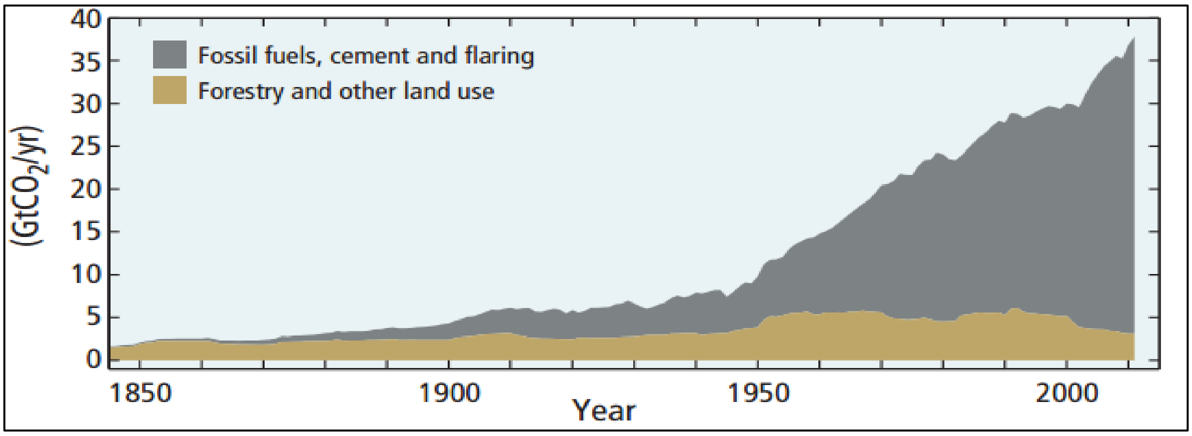

Figure 2: Global Atmospheric CO_2 Emission

The global averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06] °C[2] over the period 1880 to 2012. In addition to robust multi-decadal warming, the globally averaged surface temperature exhibits substantial decadal and interannual variability (figure 3).

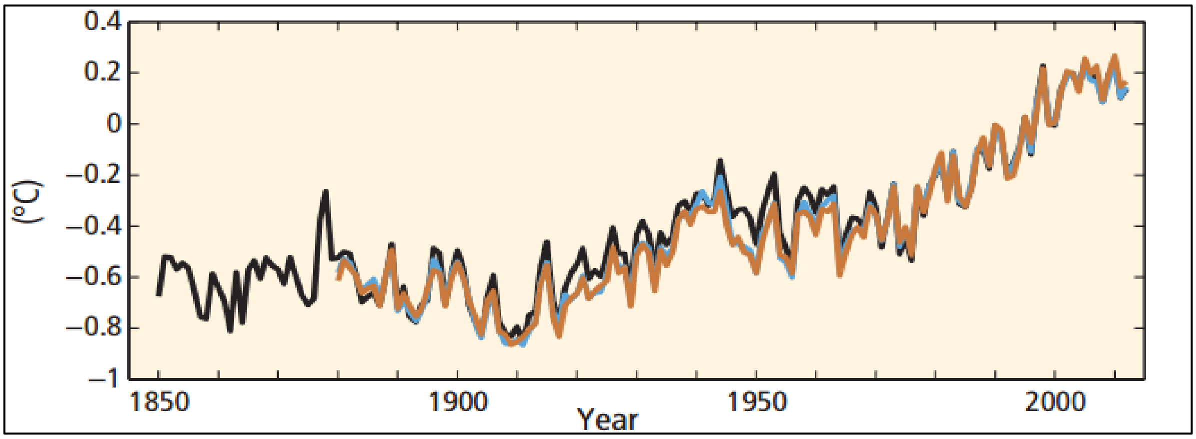

Figure 3: Global Average Combined Land and Ocean surface Temperature (source: Climate Change synthesis report, 2014)

Climate-change adaptation is increasingly on the agenda of researchers, policymakers, and program developers who are aware that climate change is real and threatens to undermine social and ecological sustainability. In agriculture, adaptation efforts focus on implementing measures that help to build rural livelihoods that are more resilient to climate variability and disaster (Gerald *et al.,* 2009). In many cases people will adapt to climate change simply by changing their behavior such as: by moving to a different location say, or by changing their occupation. But often they will employ different forms of technology, whether "hard" forms, such as new irrigation systems or drought-resistant seeds, or "soft" technologies, such as insurance schemes or crop rotation patterns. Or they could use a combination of hard and soft, as with early warning systems that combine hard measuring devices with soft knowledge and skills that can raise awareness and stimulate appropriate action (UNFCCC, 2006).

IMPACT OF CLIMATE CHANGE

Climate change and development are highly intertwined: The risks of global warming could jeopardize decades of development efforts, particularly in the poorest regions of our planet (Keller, 2009). Beyond its direct effects on weather, climate change will increase both abiotic and biotic stresses, on agricultural systems of greatest concern and largely unknown, are the influences that interactions among different types of stresses will have on crops (Gala and Fisher, 2011).

Abiotic Impact of Climate Change

Abiotic impact of climate change includes the following.

- **Drought**:- is expected to limit the productivity of over half of the earth's arable land in the next 50 years (Cattivelli *et al.,* 2008; Sinclair, 2010), and competition for water between urban and agricultural areas will compound issues of water availability (Rosegrant *et al.,* 2009).
- **Temperature:-** Influences the growth and development of all crops, shaping potential yield throughout the growing season. Temperature events higher than normal are expected to reduce cereal and grain legume yields (Hatfild *et al.,* 2011). Elevated temperatures are known to shorten the grain-filing period, and to reduce pollen viability and weight gain in grain (Boote and Sinclair, 2006; Hatfild *et al.,* 2011). Moreover, temperature changes can result in warmer, less severe winters, which sometimes allow diseases and pests to survive and overwinter, increasing the likelihood of reduced yield during the next cropping season.
- **Carbon dioxide (CO_2):-** is fundamental to crop carbohydrate production (important for crop productivity and yield) and overall plant metabolism. It is also plays an important role in climate change. Atmospheric CO_2 concentrations have risen dramatically over the past 200 years. Rising CO_2 levels will likely boost the overall productivity of many crops, although important tropical grasses like maize, sugarcane, and sorghum and some cellulosic biofuel crops don't respond as well to elevated CO_2 levels (Gala and Fisher, 2011). Increases in productivity could be offset, though, by pressures such as insect and fungal pests, ozone, and more variable precipitation, although the degree to which this occurs will depend on the physiology and biochemistry of each crop. Research shows that increased CO_2 can reduce grain protein by 4 to 13% in wheat and 11 to 13% in barley (Jablonski *et al.,* 2002; Ziska *et al.,* 2004), while increasing the carbohydrates in grain (Erbs *et al.,* 2010). Depending on the crop, micronutrients also appear to be somewhat diluted by an increase in carbohydrate in the grain. These effects are difficult to explain, and more difficult to separate from whole plant physiological changes.
- **Ozone (O_3):-** is an important greenhouse gas and agricultural pollutant. It is continues to increase

because of fossil fuel combustion (Staehelin *et al.,* 2001; Krupa *et al.,* 2000). While levels of CO_2 will rise rather uniformly around the globe, O_3 concentrations will vary regionally and exist to a greater extent around industrialized areas (Jaggard *et al.,* 2010). Crops take ozone into their leaves during photosynthesis, where the gas lowers photosynthetic rates and accelerates leaf death, affecting crop maturity and productivity (Krupa *et al.,* 2001). The rate at which crops take up O_3 depends on the O_3 concentration in the air as well as the opening and closing of the stomata or leaf pores. Present-day global yield losses due to ozone are estimated at approximately 10% for wheat and soybean, and 3–5% for rice and maize (Van Dingenen *et al.,* 2009).

Biotic Impact of Climate Change

Biotic effect on cropping systems includes weeds, insects, viruses, bacteria, and fungi. Temperature is considered the most important factor in determining how insects affect crop production and yield (Coakley *et al.,* 1999). For example, some populations of insect species, such as flea beetles, are showing signs of over-wintering because of warmer winter temperatures (Harrington *et al.,* 2001; Wolfe *et al.,* 2007). Viral, bacterial, and fungal pathogens also respond greatly to temperature, as well as humidity and rainfall. Thus, as the growing season lengthens and winters moderate due to climate change, pressures from plant, microbial, and insect pests are expected to rise due to an increased capacity for over-wintering, greater movement of organisms, and expanded adaptation zones (Gala and Fisher, 2011).

In addition, impacts of climate change on agriculture and human well-being include: - the biological effects on crop yields; the resulting impacts on outcomes including prices, production, and consumption; and the impacts on per capita calorie consumption and child malnutrition. The biophysical effects of climate change on agriculture induce changes in production and prices, which play out through the economic system as farmers and other market participants adjust autonomously, altering crop mix, input use, production, food demand, food consumption, and trade (Gerald *et al.,* 2009).

CLIMATE CHANGE AND HORTICULTURAL CROP PRODUCTION

Horticultural crops comprising of fruits, vegetables, root and tuber crops, flowers and other ornamentals, medicinal and aromatic plants, spices, condiments, plantation crops and mushrooms. Cultivation of these crops is labor intensive and as such they generate lot of employment opportunities for the rural population. Fruits and vegetables are also rich source of vitamins, minerals, proteins, and carbohydrates etc. which are essential in human nutrition. Hence, these are referred to as protective foods and assumed great importance in nutritional security of the people. Thus, cultivation of horticultural crops plays a vital role in the prosperity of a nation and is directly linked with the health and happiness of the people (Datta, 2013). Climate change has a variety of impacts on production of horticultural crops. Addressing problems of climate change is more challenging in horticulture crops compared to annual food crops. The issues of climate change and solution to the problems arising out of it requires thorough analysis, advance planning and improved management. The crop productivity is subjected to number of stresses and potential yields are seldom achieved with stress. Climate change is predicted to cause an increase in average air temperature, increases in atmospheric CO_2 concentration, and significant changes in rainfall pattern (Houghton *et al.* 2001). In order to sustain horticultural production with present day challenges there has to be packages to manage stresses caused by climate change. Climate change poses serious challenges to human and places unprecedented pressure on the horticulture industry.

Impact of Climate Change on Horticulture

There are two major parameters of climate change that has far reaching implications on agriculture in general and horticulture in particular. Which are more erratic rainfall patterns and unpredictable high temperature spells which will consequently reduce crop productivity. Latitudinal and altitudinal shifts in ecological and agro-economic zones, land degradation, extreme geophysical events, reduced water availability, rise in sea level and salinization are also postulated effects of climate change (FAO, 2004).

According to Datta, (2013), climate change will have many impacts on horticulture and a few examples are given below.

1. A study conducted at IISR, Calicut using GIS models have shown that many areas presently suitable for spices would become unsuitable in another 25 years. There would be new areas which are presently unsuitable, become highly suitable for cultivation of spices. This will be applicable in other horticultural crops.
2. Production timing will change due to rise in temperature. Due to rise in temperature, photoperiods may not show much variation. As a result, photosensitive crop will mature faster.
3. The winter regime and chilling duration will reduce in temperate regions affecting the temperate crops.

4. Pollination will be affected adversely because of higher temperature. Floral abortions, flower and fruit drop will be occurred frequently.
5. The requirement of annual irrigation will increase and heat unit requirement will be achieved in much lesser time.
6. Higher temperatures will reduce tuber initiation process in potato, reduced quality in tomatoes and pollination in many crops.
7. Coastal regions can expect much faster percolation of sea water in inland water tables causing more salinity.
8. Suitability and adaptability of current cultivars would change.
9. Changes in the distribution of existing pests, diseases and weeds, and an increased threat of new incursions.
10. Increased incidence of physiological disorders such as tip burn on mango.
11. Increase in pollination failures if heat stress days occur during flowering.
12. Increased risk of spread and proliferation of soil borne diseases as a result of more intense rainfall events (coupled with warmer temperatures).

Climate Change Opportunities for Horticulture

Horticultural crop production may be benefited from the outcome of climate change (Fact sheet, (2011). The following are some of the opportunities.

Energy: - Reduced requirement for greenhouse heating and therefore reduced energy costs. In the case of high energy, crops can utilize waste heat and CO_2 from other industries and heat or power from biomass boilers.

Productivity: **-** There may be possible increase in yields due to more carbon dioxide available for growth and canopy development (but the effect will be limited by availability of water and nitrogen). Earlier spring growth due to milder winters, shorter seed dormancy periods and subsequent earlier germination and earlier and quicker ripening are also the benefits.

Increased carbon dioxide could increase growth (dependent on other factors) and can reduce need for water, making plants more water efficient. It also reduced frost damage as frosts become milder and less frequent. However, increased temperature can cause plants to close their stomata to conserve water, with prolonged high temperatures reducing photosynthesis and ultimately damaging the crop.

Markets: - The global impacts of climate change are likely to affect other countries more severely, but enabling farmers of the other country to take advantage of the chance to supply new markets and investigate new crops more suitable to the changing climate.

Climate change Challenges for Horticulture

As described in Fact sheet, (2011) climate change has effects on the following:

- **Productivity:-** Efficient and accurate irrigation and water use are crucial to maintain competitive advantages for growers but climate change will result in: low spring and summer rainfall that could reduce yields and increase the need for irrigation; Increased autumn and winter extreme rainfall incidents could increase soil erosion and soil saturation, and increase options for winter water storage; Some crops may be badly damaged by high temperatures particularly brassicas e.g. cauliflower and broccoli; fruit mineral production and composition could be affected; variability and increasing unreliability of water supplies will occur; Warmer winters and reduced frosts will weaken verbalization, potentially reducing yields in some crops; variability and increased uncertainty about the number of soil workable days will occur.
- **Pests and Diseases: -** Climate change will result in: incidence of new pests, diseases and weeds; possible increase in mycotoxin risk due to changes in fungal growth; larger surviving and breeding of diseases and weeds due to high temperature. This could create more resilient populations and more of a management problem for farmers.
- **Energy: -** in case of climate change there will be: reduced demand for heating but increased demand for ventilation in hot weather and increasing problems with shading for glasshouse crops; increased requirement for refrigeration in transport and storage of some crops.
- **Extreme Events: -** More incidences of flooding and drought and the resultant erosion; wind damage to infrastructure (especially glasshouses); increasing unpredictability of weather; variability and increased uncertainty of water supply for irrigators will be occurred.

PHYSIOLOGICAL RESPONSE OF PLANTS TO CLIMATE CHANGE

Plants are grouped in to ´C3`, ´C4` and ´CAM` plants according to their photosynthetic metabolic pathways. Around 95 % of the world plant biomass grouped in ´C3` plant species (e.g. wheat, rice, fruits & vegetables), C4 (e.g. maize or corn, sugarcane & sorghum) and CAM (e. g. Pineapple). These divisions into groups largely based on the enzymes involved in photosynthetic fixation of CO_2, namely Rubisco, PEP carboxylase and to some extent carbonic anhydrase, which are significantly different in their response to

CO$_2$ enrichment (Fantahun, 2013). The process of photorespiration rate is high in C$_3$ plants and the relative proportion of CO$_2$ and O$_2$ inside the leaf determines the rate of photorespiration. In contrast, PEP carboxylase in C4 plants not inhibited by O$_2$ and thus photorespiration is negligible. PEP carboxylase also has a higher effective affinity for CO$_2$ than Rubisco in the absence of O$_2$. Therefore, we would expect higher atmospheric CO$_2$ concentrations to increased photosynthesis and growth of C$_3$ plants but not to the same extent, if any, in C4 plants (Bolin *et al.,* 1989).

Over the past 800,000 years, atmospheric [CO$_2$] changed between 180 ppm (glacial periods) and 280 ppm (interglacial periods) as Earth moved between ice ages. From pre-industrial levels of 280 ppm, [CO$_2$] has increased steadily to 384 ppm in 2009, and mean temperature has increased by 0.76 ^{C} over the same time period. Projections to the end of this century suggest that atmospheric [CO$_2$] will top 700 ppm or more, whereas global temperature will increase by 1.8–4.0 ^{C}, depending on the greenhouse emission scenario (IPCC, 2007). There is growing evidence suggesting that many crops, notably C$_3$ crops, may respond positively to increased atmospheric [CO$_2$] in the absence of other stressful conditions (Long, Ainsworth, Rogers, & Ort, 2004), but the beneficial direct impact of elevated [CO$_2$] can be offset by other effects of climate change, such as elevated temperatures, higher tropospheric ozone concentrations and altered patterns of precipitation (Easterling *et al.,* 2007).

The temperature response of crop growth and yield must be considered to predict the [CO$_2$] effects (Morison & Lawlor, 1999; Polley, 2002; Porter & Semenov, 2005; Ziska & Bunce, 1997). The threshold developmental responses of crops to temperature are often well defined, changing direction over a narrow temperature (Porter & Semenov, 2005). High temperatures reduce the net carbon gain in C$_3$ species by increasing photorespiration; by reducing photorespiration, [CO$_2$] enrichment is expected to increase photosynthesis more at high than at low temperatures, and thus at least partially offsetting the temperature effects of supra-optimal temperatures on yield (Long, 1991; Polley, 2002). Therefore, yield increases at high [CO$_2$] should occur most frequently in regions where temperatures approximate the optimum for crop growth. Conversely, in regions where high temperatures already are severely limiting, further increases in temperature will depress crop yield regardless of changes in [CO$_2$] (Polley, 2002). In fact, results of mathematical modeling suggest that, in mid- to high-latitude regions, moderate to medium local increases in temperature (1–3o^{C}), along with associated CO$_2$ increase and rainfall changes, can have beneficial impacts on crop yields, but in low-latitude regions even moderate temperature increases (1–2o^{C}) are likely to have negative impacts on yield of major cereals (Easterling *et al.,* 2007). Thus, climate change may impair food production particularly in developing countries, most of which are located in tropical regions with warmer baseline climates (Tubiello & Fischer, 2007).

The result from experiments done on wild grass species shows that under elevated CO$_2$ condition both C$_3$ and C$_4$ species show increase in the total plant biomass by 44% and 33%, respectively. The increased in C$_3$ species was greater in tiller formation whereas in C$_4$ was greater in leaf area. Net CO$_2$ assimilation rates (A), that means (flux of CO$_2$ between leaf and atmosphere through photosynthesis) increased in both C$_3$ and C$_4$ species with 33% and 25% respectively. While, stomatal conductance (Gs) (the ability of CO$_2$ entering, or water vapor exiting through the stomata) decreased for C$_3$ and C$_4$ species by 24% and 29%, respectively (Wand *et al.,* 1999).

Many simulation results showed that increased biomass production were observed in both C$_3$ and C$_4$ plants under elevated [CO$_2$]; although the enhancement of shoot production by elevated CO$_2$ varied with temperature and precipitation. In C$_3$ species, the response of NPP to increased temperatures was negative under dry and ambient CO$_2$ condition, but was positive under wet and doubled CO$_2$ condition; whereas, the responses of NPP of C$_4$ species to elevated CO$_2$ was positive under all temperature and precipitation levels particularly at high precipitation level (Chen *et al.,* 1996). Plant growth in elevated atmospheric CO$_2$ has shown to be less vulnerable to drought, maintaining higher growth rate on drought condition than plants under lower CO$_2$. Elevated CO$_2$ also enhances plant resistance to heat, frost stresses, likely reflecting greater concentrations of membrane stabilizing sugars in the tissues and it induces greater nutrient deficiency, and as observed in several studies it leads to accumulation of secondary carbon rich chemicals such as tannins (Niinemets, 2010).

Physiological Responses of Field Crops to Climate Change

Elevated [CO$_2$] leads plants to produce a larger number of mesophyll cell, chloroplasts, longer stems and extended length, diameter and number of large roots, forming good lateral root production with different branching patterns; in some agricultural food crops, resulting in increasing root to shoot ratios under elevated [CO$_2$] (Qaderi & Reid, 2009). The potential of crop productivity increased under an increased in local average temperature range of 1-

30^c, but it decreased above this range (IPCC, 2007), probably the reason could be low vernalization, shortened phenological phases decrease in photosynthesis rate, and increased transpiration. (Qaderi & Reid, 2009). Elevated CO_2 have a positive effect on some annual C_3 field crops, such as soybean, peanut, and rice cultivars, etc. Growth and development accelerated throughout the vegetative phase, and before flowering stage started seven days earlier, which contributed to the higher grain yield and change in the chemical composition of the rice grain (Uprety *et al.,* 2010). Some studies also show that a reduction in maize (C_4 species) yield occurred under elevated [CO_2] condition due to shortened growing period and a yield reduction also recorded in some experiment on winter wheat (C_3 species) due to an effect on vernalization period (Alexadrov & Hoogenboom, 2000). Whereas an increase in the yield of spring wheat with 8-10% was observed when water was no limiting; similarly, a cotton crop exposed to free–air CO_2 enrichment (FACE) was stimulated and show increased about 48 % of harvestable yield and 37 % of biomass under elevated (550 ppm) [CO_2] level (Easterling and Apps, 2005). The difference in responses in different ecosystems to elevated CO_2 might be due to difference in water, soil, nutrient availability and temperature variation (Chen *et al.,* 1996).

Physiological Responses of Forest Trees to Climate Change

Different processes in plants or forest ecosystems and their interaction with climate variability is complex, due to different response of physical, biological, and chemical processes. An increase in the ambient CO_2 concentration could reduce the opening of stomata required to allow a given amount of CO_2 to enter in the plant that might reduce transpiration of the trees. These could increase the efficiency of water use by forest plants and increase productivity to some extent (Bolin *et al.,* 1989). Trees are capable of adjusting to a warmer climate, although the response expected from species are different and the effect on photo inhibition and photorespiration are more difficult to generalize (Saxe *et al.,* 2001). As forest trees are characterized by the C_3 photosynthetic path way their productivity and demand for nutrient is highly affected by atmospheric CO_2 concentration and temperature. The total productivity expected from trees (especially from trees with indeterminate growth) growing under elevated CO_2 is larger than estimated in crops (Lukac *et al.,* 2010). Estimated increased production from trees is higher than crops only achieved especially if the combination of absorption and increased nutrient use efficiency is attained (Tylianakis *et al.,* 2008). However, the long-term response of forest to rising level of [CO2] is still uncertain.

The current over all response of trees is positive and results from a review of 49 papers on effects of elevated CO_2 on different tree species shows that net primary production (NPP, photosynthesis minus plant respiration) on average increased with 23 % at an elevated CO_2 concentration of 550 ppm as compared with 370 ppm (Norby *et al.,* 2005). Whereas, enhanced in temperatures can lead to heat and more water logging stress in bogs and cause more severe heat, drought and photo-inhibition stress periods in temperate bog and forest ecosystems (Niinemets, 2010).

Response of Photosynthesis and Plant Respiration Processes to Climate Change

Respiration can be highly affected by temperature (Atkin *et al.,* 2005), and its rate is determined by status of carbohydrate and supply of adenylate (enzyme catalyzing the conversion processes). The sucrose content of the tissue can govern the capacity of mitochondrial respiration (Farrar & Williams, 1991), and mitochondrial respiration plays a great role in growth and survival of plants (Atkin *et al.,* 2005). One would expect at least a short period increases in respiration rate from parts of plants those show increased growth and assimilation due to elevated [CO2], that is source leaves, individual sink tissue (fruit, seed, steam, root etc.) and total sink tissue. Nevertheless, a few reports concluded that long term treatment with increased concentration of CO_2 resulted in declined whole-plant respiration (Farrar & Williams, 1991). Whereas, result of a few other experiments show that a short-term increase in temperature on plants growing in cold climate areas such as Arctic have resulted in greater potential impact on plant respiration than in plants growing in warmer areas (tropics) (Atkin & Tjoelker, 2003). One of the reasons might be that tropical plants more acclimate to higher temperatures than the Arctic cold area plants.

Photosynthesis is intimately tied to climatic conditions, both directly and indirectly. While light absorption is independent of temperature, the subsequent steps in converting light into chemical energy respond to temperature in complex ways. In C_3 plants, the uptake of CO_2 by Rubisco is the first step in photosynthetic CO_2 assimilation, and Rubisco is not saturated with CO_2 at normal intercellular CO_2 concentrations. Both $_{CO2}$ and O_2 also compete for access to the active sites on Rubisco, with increasing CO_2 favouring carboxylations at the expense of oxygenations, so that an increasing proportion of reducing and phosphorylation potentials can be channeled towards CO_2 fixation (Farrar & Williams, 1991). Indirect effects of climate change may ultimately be even more important. Plants require an aqueous medium in their cells, and photosynthetic function is impaired when plant water status falls below critical values. Plants could maintain an aqueous internal environment by closing their stomata and minimizing water loss by fully surrounding their leaves by a cuticular epidermis that allows only minor rates of water loss. However, stomatal closure would also prevent the diffusive entry of CO_2 into photosynthesizing cells. On-going water loss is therefore an inevitable cost of the need to maintain an open diffusion path for CO_2 to enter photosynthesizing leaves (Kirschbaum, 2004).

It has been shown in many experimental studies that C_3 photosynthesis responds strongly to CO_2 concentration, with photosynthesis typically increasing by 25–75% for doubling atmospheric CO_2 concentration (Kimball, 1983; Cure and Acock, 1986; Drake, 1992; Luxmoore *et al.,* 1993; Drake *et al.,* 1997; Urban, 2003). There are fewer reports for C_4 plants, but those available suggest only minor responses to increasing CO_2 concentration (Pearcy *et al.,* 1982; Morison and Gifford, 1983; Drake, 1992; Polley *et al.,* 1992). Recent work has also shown sustained growth increases for plants fumigated in “free air CO_2 enrichment” (FACE) experiments. This has been observed in wheat fields (Garcia *et al.,*1998) and in largely undisturbed forests (Herrick and Thomas, 2001; Gunderson *et al.,* 2002). These responses are consistent with theoretical understanding of the effect of CO_2 concentration on photosynthesis at the leaf and stand level (McMurtrie *et al.,* 1992; Long *et al.,* 1996).

ADAPTATION TO CLIMATE CHANGE

According to dictionaries the term adaptation refers to make more suitable (to fit some purpose) by modifying or altering and it indicates both the process of adapting and the condition of being adapted. In ecology, adaptation indicates change in an organism´s physiology, behavior or other characteristics that increase the fitness to the environment, related to genetic changes. In social science, cultural adaptation refers to adjustment by individuals and to the collective behavior of socio-economic systems. Cultural adaptation also include changes in cognitions (e.g. risk perceptions), which are socially constructed and negotiated (Grothmann & Patt, 2003). Adaptation to climate change refers both making use of the ecological adaptation and its relation to the environment by ecosystem management and the change in social behavior to reduce the impacts of climate change. Thus, adaptation to climate change is the process through which people reduce the adverse effects of climate on their health and well-being, and take advantage of the opportunities that their climatic environment provides (Smit *et al.,* 2000; Glick *et al.,* 2009). The term “adaptation” has been used since the early 1990´s in the climate change context. No specific single definition is given to it, but most definitions reflect that climate adaptation involves “initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects” (Glick *et al.,* 2009). Another definition of adaptation involves adjustment to enhance the viability of social and economic activities and to reduce their vulnerability to climate, including its current variability and extreme events as well as long-term climate changes (Smit *et al.,* 2000). Natural resource conservationist propose the following definition “climate change adaptation for natural systems is a management strategy that involves identification, preparation for, and responses to expected climate change in order to promote ecological resilience, maintain ecological function, and provide necessary elements to support biodiversity and sustainable ecosystem services”. In general the term climate change adaptation can be concluded by the following phrases; “climate change safe guards”, “preparing for warming world”, “protecting wild life and natural resource from warm” and “coping mechanisms”(Glick *et al*, 2009).

Importance of Climate Change Adaptation

Adaptation is important in the climate change issue in two ways; one relating to the assessment of impacts and vulnerabilities, the other is to the development and evaluation of response options (Grothmann & Patt, 2003). The danger and seriousness of climate change can be changed or reduced through practicing different kinds of adaptation measures, and adaptation is crucial in policymaking and planning strategies. During planning, considering different weather events and climate variables and collecting required information is important to prepare in advance and to decide the kind of measures, how and under what conditions adaptation practices can be performed (Smit *et al.,* 2000). Adaptation to climate variability aims to reduce vulnerability or increase resilience (improving ability to tackle and recover quickly from observed or expected climate change difficulties and weather events). Adaptation of physical, ecological and human systems include a change in social and environmental processes, and practices, enabling reduce potential damage or finding new opportunities. Adaptation includes anticipatory and reactive actions, to expected change in temperature and climate variations and extremes. In practice, it should be on-going processes, which reflect many stresses. For example, crop and livelihood diversification, seasonal climate forecasting, and many activities including community based disaster risk reduction, water storage, and supplementary irrigation etc. Individuals undertake some adaptation measures and others may be planned and implemented by government on behalf of the society (Adger *et al.,* 2007). Extreme weather events are already affecting agricultural systems around the world. Therefore, adaptation to climate change is more urgent than ever, given both the climate risks facing agriculture and the increasing opportunity costs of failing to address entrenched resource degradation and poverty associated with underinvestment and misinvestment in agriculture (Padgham, 2009). Adaptation should be well integrated with livelihood priorities and development goals if it is to succeed.

Approaches of Climate Change Adaptation in Agriculture

Agriculture is highly sensitive to even minor climate variations, and have an impact on agricultural output even for a single growing season, so ongoing climate change can affect long-term agricultural productivity and food security (Stalked *et al.,* 2006). Climate change impacts on crops affect human health, largely through potential for mal nutrition and as a result, few studies have estimated millions of peoples are at risk of hunger (Warren, 2011). Using different crops, physical land improvement to control soil erosion, improving water holding capacity of the soil, improving water use and sources, making a change in cultural practices in order to maintain nutrient and soil, adjusting timing of different farm activities are some adaptation strategies in agriculture (Stalked *et al.,* 2006). According to CSSA, 2011 and Gala and Fisher, 2011, generally there are two primary approaches exist for adapting climate change in agriculture: 1) improving existing crop cultivars and developing new crops, 2) devising new cropping systems and methods for managing crops in the field.

Strategies for Improving Existing Cultivars and Developing New Crops

(i) ***Develop New Crops*****:-**New crops will likely play a key role in maintaining and increasing agricultural production. Domestication began only 5,000 to 12,000 years ago for our oldest crops such as maize, wheat, potatoes, and sorghum, while blueberries and wild rice were domesticated more recently (Harlan, 1991). Today, some scientists are crossing wild, perennial relatives of crops such as maize, millet, rice, sorghum, sunflower and wheat with their annual, domesticated counterparts, additionally; a growing interest in bioenergy has also encouraged the domestication and breeding of C4 grasses, including switch grass, and Miscanthus (Bransby *et al.,* 2010). Domestication and breeding of new crops is a long-term solution, requiring many years of effort before formal testing can be performed.

(ii) Integrate Beneficial Traits into Existing Crops Through use of Germplasm Collections, Related Datasets, and Breeding:- Historically, crop scientists have identified and selectively adapted crops to exhibit desirable traits that allow crops to achieve optimum yields while withstanding stresses, such as drought, heat, and water logging. To support continuous improvement of germplasm that can be used to develop cultivars adapted to climate change, there is a need to acquire, preserve, evaluate, document, and distribute plant genetic resources for a wide range of crops and their wild relatives. Additionally, well-preserved information can allow scientists to employ modern biotechnology methods to screen crop traits—these advances are already changing how germplasm banks are used. Expanded use of these resources and methods will help researchers more quickly identify adaptive traits, represented by genes or groups of genes, which contribute to stress resistance (CSSA, 2011).

(iii) Identify Crop Germplasm that Tolerates Drought, Heat, and Water-logging:- yield drops when crops experience drought, excessive heat, or surplus water deviating from the optimum for growth during key stages, including pollination, flowering, and filing periods, when carbohydrates and nutrients assimilate inside grain, tubers, or fruit. Multiple molecular markers can be statistically associated with some of these traits to allow selection to be performed without testing in the breeding environment. Cultivars are now being developed which are tolerant to excess heat during pollination for cowpea and corn, and flooding early in the growing season for soybean and rice (Hall, 2004; VanToai *et al.,* 2010; Bailey-Serres *et al.,* 2010). Maize hybrids are now being developed that have a better synchronization of pollination and flowering under heat and water stress (Ribaut *et al.,* 2009). Cultivar differences for heat tolerance exist in some crops such as rice, cowpea, and peanut, but knowledge about the effects of extremely high temperatures is very limited because diverse germplasm has not been extensively screened.

(iv) Identifying Crop Germplasm for Tolerance to Pathogens, Insects, and Nematodes:- Under climate change and climate variability the interactions between crops, pests, and pathogens will likely be complex and are currently poorly understood (Gregory *et al.,* 2009). There is a need for concerted efforts to screen crop germplasm for susceptibility to many pest organisms. Such screening, coupled with molecular marker tools, will assist plant breeders in dealing with current and future pest outbreaks, and support producers by providing them with new cultivar options at a faster pace, and provide greater food security.

Strategies for Devising New Cropping Systems and Methods for Managing Crops in the Field

New management systems are now being developed to increase crop resilience toward climatic stresses. Since not all regions are predicted to experience the same agricultural vulnerabilities to climate change, mitigation and adaptation strategies will vary. Appropriate, site-specific cropping system management practices can help alleviate the effects of abiotic and biotic stresses on crop productivity and yield. Crops are planted in sequences or rotations depending on their purpose, tolerance to prevailing temperatures and weather extremes, and economic return. Each crop has an impact on the successive crop planted. Because agriculture will not experience the same vulnerability to climate change in all regions, site-specifi cropping systems and management practices are needed that match yield potential with inputs, soil fertility, and the range of climate variability in each area (CSSA, 2011).

(i) **Use Crop Models in Decision-Making:-** Crop models integrate important information about processes, and allow scientists to estimate the impact of changes in crop genetics, and crop and soil management methods. Models can also be used to compare crop management strategies, helping producers weigh both economic and environmental considerations as they make decisions about crop varieties, cropping dates, and management practices (Jones *et al.,* 2003).

(ii) **Apply Remote Sensing and Precision Agriculture Technologies:-** Remote sensing using both satellite and on-the-go field scanners can reduce the resources needed to measure crop characteristics like cover, leaf greenness, growth rate, and biomass across a broad range of cropping systems and environments. This information then allows researchers to assess the effectiveness of modifications in cropping systems, and can help producers make precision agriculture production decisions at the field scale. These tools will be of great use in understanding the effects of a changing environment at the field scale, and the appropriate agronomic methods needed to respond to such changes.

(iii) **Monitor Crop Condition:-** Short- and long-term monitoring of factors such as pathogens, changes in field conditions, crop productivity, and weather patterns is essential for building an information base on which future decisions and innovations can draw from. Remote sensing of crop, weather, and pest conditions, for example, can be used by farmers for adaptive management or by governments as an early warning signal for climate based food security crises.

(iv) **Optimize Water-Use Efficiency:-** With climate change, water supplies are expected to become threatened in certain regions of the world, but water management strategies, such as drip irrigation, can conserve water and protect vulnerable crops from water shortages.

(v) **Optimize Land Use:-** Intensifying yields sustainably on existing arable land uses land more efficiently and avoids bringing new land into production. Higher yields have also been shown to reduce greenhouse gas emissions, thus helping minimize agriculture's contribution to climate change (Burney *et al.,* 2010).

Mechanisms of Crops to Adapt Climate Chang

Adaptation of crops to the challenges of climate change will involve exploiting the continually developing technologies, resource and the expertise of science base. Throughout history, farmers have adopted new crop varieties and adjusted their practices in accordance with changes in the environment. But as global temperature continues to rise, the pace of environmental change will likely be unprecedented. More frequent and intense precipitation events, elevated temperatures, drought, and other types of damaging weather are all expected to impact crop yield and quality (Hatfild *et al.,* 2011), making the challenge of feeding the world people exceedingly difficult. An understanding of the physiological capacity of plants to respond to climate change is essential to predict future species distributions and population dynamics and to implement successful conservation strategies (Wikelski and Cooke 2006; Chown and Gaston 2008; Williams *et al*. 2008). Plants have the capacity to adapt to changing environmental conditions both by phenotypic plasticity within a life span and by microevolution over a few life spans. Higher plants are sessile and therefore cannot escape from abiotic stress factors. They are continuously exposed to different abiotic stress factors without any protection. On the other hand animals are mobile and can escape the direct harsh conditions. The immobile nature of plants needs more protection. This enabled them to develop unique molecular mechanisms to cope with different stress factors. However, variations do exist in tolerance mechanisms among plants. Certain morphological features of some plants however, make them avoid stress factors. But it may not be the case in all plants. The only option for plants is to alter their physiologies, metabolic mechanisms, gene expressions and developmental activities to cope with the stress effects. Therefore, plants possess unique and sophisticated mechanisms to tolerate abiotic stresses (Madhava *et al.,* 2006). Some of the abiotic stress tolerance includes; activation of signaling factors, altered gene expression, accumulation of compatible solutes, synthesis of stress proteins, enhanced antioxidative metabolism, Ion homeostasis and compartmentation, facilitated membrane transport, accumulation of polyamines, adjustment of hormonal balance.

CONCLUSION

Industrialization and unmanaged utilization of resources results in higher rate of GHG emissions and accumulations in the atmosphere, which might result in effects many years later. In addition, population growth, urbanization and industrialization will result in a higher demand of renewable and non-renewable natural resources. Even though, currently there is a gap between availability and demand of increased population interests, there is a need to consider a more careful utilization of natural resources. Activities of filling the gap must be by reducing emission and protecting the coming generation, and make them beneficial. Our adaptation practices need technologies and suitable policy options as main tools, thus, preparation of guidelines and technology options has to be, socially acceptable, environmentally sustainable and effectively applied. Moreover, forming continuous awareness about climate change and adaptation issue might help to make the communities more participatory in all processes of adaptation. Finally, it is crucial to use different effective conservation strategies to maintain species, genetic diversity, and ecosystem services, and to proceed with research on different plant species to investigate their response to climate variability, and to identify which species will be most restricted in range and which will be most endangered and how they can be protected from extinction.

REFERENCES

- Adger, W.N., Agrawala, S., Mirza, M.M.Q., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smitand, B., Takahashi, K. (2007). Assessment of adaptation practices, options, constraints and capacity. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 717-743.
- Agricultural Development under Changing Climate: Opportunities and Challenges for Adaptation. Joint Discussion Paper, Agriculture and Rular Development & Environment Departments. 198pp.
- Alexandrov, V. A., & Hoogenboom, G., (2000). Vulnerability and Adaptation Assessments of Agricultural Crops under Climate Change in the Southeastern USA; *theor. Appl. Climatol., 67,* 45-63.
- Atkin, O. K., & Tjoelker, M. G. (2003). Thermal acclimation and the dynamic response of plants respiration to temperature: TRENDS in Plant Science 8 No. 7, TX 77843-2135.
- Atkin, O. K., Bruhn, D., Hurry, V. M., and Tjoelker, M. G. (2005). The hot and the cold: unraveling the variable response of plant respiration to temperature: *Functional Plant Biology, 32,* 87-105.
- Bailey-Serres, J., Fukao, T., Ronald, P., Ismail, A., Heuer, S., & Mackill, D. (2010). Submergence tolerant rice: SUB1's journey from landrace to modern cultivar. *Rice*, *3*(2), 138-147.
- Bolin B., Döös B. R., Jager J., & Warrick R. A. (1989). The Green House Effect climate change and Ecosystems: SCOPE 29 International Council of Scientific Union. Great Britain.
- Boote, K.J., and Sinclair, T.R. (2006). Crop Physiology: Signifcant Discoveries and Our Changing Perspective on Research. *Crop Sci., 46,* 2270.
- Bransby, D. I., Allen, D. J., Gutterson, N., Ikonen, G., Richard, E., Rooney, W., & van Santen, E. (2010). Engineering advantages, challenges and status of grass energy crops. *Plant biotechnology for sustainable production of energy and co-products*, 125-154.
- Burney J.A., Davis, S.J., and Lobella, D.B. (2010). Greenhouse gas mitigation by agricultural intensifiation. *PNAS. 107,* 12052-12057.
- California Department of Food and Agriculture. (2013). Climate Change Consortium for Speciality Crops Impact and Strategies for Resillience. 76pp.
- Cure, J. D., & Acock, B. (1986). Crop responses to carbon dioxide doubling: a literature survey. *Agricultural and forest meteorology*, *38*(1-3), 127-145.
- Chen, D. X., Hunt, H. W., & Morgan, J. A. (1996). Responses of a C3 and C4 perennial grass to CO2 enrichment and climate change: comparison between model predictions and experimental data. *Ecological Modelling*, *87*(1-3), 11-27.
- Chown, S. L., & Gaston, K. J. (2008). Macrophysiology for a changing world. *Proceedings of the Royal Society B: Biological Sciences*, *275*(1642), 1469-1478.
- Coakley, S. M., Scherm, H., & Chakraborty, S. (1999). Climate change and plant disease management. *Annual review of phytopathology*, *37*(1), 399-426.
- CSSA. (2011). Position Statement on Crop Adaptation to Climate Change. Crop Science Society of America, Madison, WI 16pp.
- Ackerberg, D., Caves, K., & Frazer, G. (2005). Structural identification of production functions.
- Datta, S. (2013). Impact of climate change in Indian horticulture-a review. *International Journal of Science, Environment and Technology*, *2*(4), 661-671.
- Drake, B. G., Gonzàlez-Meler, M. A., & Long, S. P. (1997). More efficient plants: a consequence of rising atmospheric CO_2? *Annual review of plant biology*, *48*(1), 609-639.
- Drake, B. G. (1992). A field-study of the effects of elevated CO2 on ecosystem processes in a Chesapeake Bay wetland. *Australian Journal of Botany*, *40*(5), 579-595.
- Easterling, W., & Apps, M. (2005). Assessing the consequences of climate change for food and

forest resources: a view from the IPCC. *Increasing climate variability and change: Reducing the vulnerability of agriculture and forestry*, 165-189.

- Easterling, W. E., Aggarwal, P. K., Batima, P., Brander, K. M., Erda, L., Howden, S. M., ... & Tubiello, F. N. (2007). Food, fibre and forest products. *Climate change*, *2007*, 273-313.
- Environment Agency. (2012). Climate change impacts on water for horticulture available at www.environment-agency.gov.uk
- Erbs, M., Manderscheid, R., Jansen, G., Seddig, S., Pacholski, A., & Weigel, H. J. (2010). Effects of free-air CO2 enrichment and nitrogen supply on grain quality parameters and elemental composition of wheat and barley grown in a crop rotation. *Agriculture, ecosystems & environment*, *136*(1-2), 59-68.
- Fact sheet. (2011). Farming Future, Climate change series focus on horticulture 4p.
- Amedie, F. A. (2013). Impacts of climate change on plant growth, ecosystem services, biodiversity, and potential adaptation measures. *MasterThesis. Program Study of Biological and Enviromental Science, University of Gothenberg, Sweden*.
- FAO. (2004). Impact of climate change on agriculture in Asia and the Pacific. Twenty seventh FAO Regional Conference for Asia and the Pacific. Beijing, China, 17-21 May 2004.
- Farrar, J. F., & Williams, M. L. (1991). The effects of increased atmospheric carbon dioxide and temperature on carbon partitioning, source-sink relations and respiration. *Plant, Cell & Environment*, *14*(8), 819-830.
- Gala, C. B., and Fisher, M. (2011). Crops Adaptation to Climate Change. CSA news, 6p.
- Garcia, R. L., Long, S. P., Wall, G. W., Osborne, C. P., Kimball, B. A., Nie, G. Y., ... & Wechsung, F. (1998). Photosynthesis and conductance of spring-wheat leaves: field response to continuous free-air atmospheric CO2 enrichment. *Plant, Cell & Environment*, *21*(7), 659-669.
- Nelson, G.C., Rosegrant, M.W., Koo, J., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Msangi, S., Palazzo, A., Batka, M., Magalhaes, M., Valmonte-Santos, R., Ewing, M., and Lee, D. (2009). Climate Change: Impact on Agriculture and Costs of Adaptation. International Food Policy Research Institute Washington, D.C. 30pp.
- Glick P., Staudt A., & Stein B. (2009). A New Era for Conservation: Review of climate change adaptation literature: National Wildlife Federation.
- Gregory, P. J., Johnson, S. N., Newton, A. C., & Ingram, J. S. (2009). Integrating pests and pathogens into the climate change/food security debate. *Journal of experimental botany*, *60*(10), 2827-2838.
- Grothmann, T., & Patt, A. (2003). Adaptive Capacity and Human Cognition: prepared for presentation at the Open meeting of the Global Environmental Change Research Community, Montreal, Canada, 16.
- Hall, A. E. (2004). Breeding for adaptation to drought and heat in cowpea. *European Journal of Agronomy*, *21*(4), 447-454.
- Harlan, J.R. (1991). Crops and Man. ASA, Madison, WI.
- Harrington, R., Fleming, R. A., & Woiwod, I. P. (2001). Climate change impacts on insect management and conservation in temperate regions: can they be predicted?. *Agricultural and Forest Entomology*, *3*(4), 233-240.
- Hatfield, J. L., Boote, K. J., Kimball, B. A., Ziska, L. H., Izaurralde, R. C., Ort, D., ... & Wolfe, D. (2011). Climate impacts on agriculture: implications for crop production. *Agronomy journal*, *103*(2), 351-370.
- Houghton, J. T., and IPCC Working Group, I. (2001). Climate Change: The Scientific Basis : Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge; New York: Cambridge University Press.
- IPCC. (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Core Writing Team, R.K. Pachauri and A. Reisinger (ed.)]. IPCC, Geneva, Switzerland.
- Jablonski, L. M., Wang, X., & Curtis, P. S. (2002). Plant reproduction under elevated CO2 conditions: a meta-analysis of reports on 79 crop and wild species. *New Phytologist*, *156*(1), 9-26.
- Jaggard, K. W., Qi, A., & Ober, E. S. (2010). Possible changes to arable crop yields by 2050. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1554), 2835-2851.
- Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., ... & Ritchie, J. T. (2003). The DSSAT cropping system model. *European journal of agronomy*, *18*(3-4), 235-265.
- Keller, M. (2009). Climate Risks and Development Projects. Assessment Report for a Community-Level Project in Guduru, Oromiya, Ethiopia, 35pp.
- Kimball, B. A., 1983 Carbon dioxide and agricultural yield: an assemblage and analysis of 430 prior observations. Agronomy Journal 75, 779–788.
- Kirschbaum, M. U. F. (2004). Direct and Indirect Climate Change Effects on Photosynthesis and Transpiration. Plant Biology, 6 (2004), 242–253.
- Krupa, S., McGrath, M. T., Andersen, C. P., Booker, F. L., Burkey, K. O., Chappelka, A. H., ... & Zilinskas, B. A. (2001). Ambient ozone and plant health. *Plant Disease*, *85*(1), 4-12.
- Long, S. P. (1991). Modification of the response of photosynthetic productivity to rising

temperature by atmospheric CO2 concentrations: has its importance been underestimated?. *Plant, Cell & Environment*, *14*(8), 729-739.

- Long, S. P., Osborne, C. P., & Humphries, S. W. (1996). Photosynthesis, rising atmospheric carbon dioxide concentration and climate change. *Scope-scientific committee on problems of the environment international council of scientific unions*, *56*, 121-159.
- Long, S. P., Ainsworth, E. A., Rogers, A., & Ort, D. R. (2004). Rising atmospheric carbon dioxide: Plants FACE the future. *Annual Review of Plant Biology, 55,* 591–628.
- Lukac, M., Calfapietra, C., Lagomarsino, A., & Loreto, F. (2010). Global climate change and tree nutrition: effects of elevated CO2 and temperature: Tree physiology [0829-318X] Lukac yr. 30, 1209 -1220.
- Luxmoore, R. J., Wullschleger, S. D., and Hanson, P. J. (1993). Forest responses to CO2 enrichment and climate warming. *Water, Air, and Soil Pollution, 70,* 309–323.
- Madhava K.V. R., Raghavendra, A.S., Janardhan. K. R. (2006). Physiology and Molecular Biology of Stress Tolerance in Plants. Springer, The Netherlands pp 351.
- McMurtrie, R. E., Comins, H. N., Kirschbaum, M. U. F., and Wang, Y.P. (1992). Modifying existing forest growth models to take account of effects of elevated CO2. *Australian Journal of Botany, 40*, 657–677.
- Morison, J. I. L., and Gifford, R. M. (1983). Stomatal sensitivity to carbon dioxide and humidity*. Plant Physiology 71*, 789–796.
- Morison, J. I. L., & Lawlor, D. W. (1999). Interactions between increasing CO2 concentration and temperature on plant growth. *Plant, Cell and Environment, 22,* 659–682.
- Niinemets, Ü. (2010). Responses of forest trees to single and multiple environmental stresses from seedlings to mature plants: past stress history, stress interactions, tolerance and acclimation: *Forest Ecology and Management 2 6 0,* 1623-1639.
- Norby R.J., Delucia E. H, Gielen B., Calfapietra C., Giardina C. P., King, J. S., Ledford J., McCarthy, H.R., Moore J.P., Ceulemans R., Angelis P. De, Finzil A.C., Karnosky D.F., Kubiske M.E., Lukac M., Pregitzer K.S., Scarascia-Mugnozza G. E., Schlesinger W. H., and Oren R. (2005). Forest response to elevated CO2 is conserved across a broad range of productivity. *PNAS, 102,* 18052-18056.
- Pearcy, R. W., Osteryoung, K., and Randall, D. (1982). Carbon dioxide exchange characteristics of C4 Hawaiian Euphorbia species native to diverse habitats. *Oecologia, 55,* 333–341.
- Polley, H. W., Norman, J. M., Arkebauer, T. J., Walter-Shea, E. A., Greegor D. H. Jr., and Bramer, B. (1992). Leaf gas exchange ofAndropogon gerardii Vitman, Panicum virgatum L. and Sorghastrum nutans (L.) Nash in a tallgrass prairie. *Journal of Geophysical Research, 97,* 18837–18844.
- Polley, H. W. (2002). Implications of atmospheric and climate change for crop yield. *Crop Science, 42,* 131–140.
- Porter, J. R., & Semenov, M. A. (2005). Crop responses to climatic variation. Philosophical Transactions of the Royal Society B: *Biological Sciences, 360,* 2021–2035.
- Qaderi, M. M., & Reid D. M. (2009). Crop Responses to Elevated Carbon dioxide and Temperature (chp1), In Singh S. N., (ed.), Climate Change and Crops, *Environmental Science and Engineering*, DOI 10.1007/978-3-540-88246-6 1, Springer-Verlag Berlin Heidelberg.
- Ribaut, J.M., Betrán, F.J., Monneveux, P., and Setter, T. (2009). Drought tolerance in maize. p. 311–344. In S.C. Hakeand J.L. Bennetzen (ed.) Hand book of maize: its biology. Springer, Netherlands.
- Rosegrant, M. W., Ringler, C., & Zhu, T. (2009). Water for agriculture: maintaining food security under growing scarcity. *Annual review of Environment and resources*, *34*, 205-222.
- Sinclair, T.R. (2010). Precipitation: The Thousand-Pound Gorilla in Crop Response to Climate Change. p. 179–190. In D. Hillel and C. Rosenzweig (ed.) Handbook of Climate Change and Agroecosystems: Impacts, Adaptation, and Mitigation. World Scientifi Books.
- Saxe, H., Cannell Melvin G. R., Johnsen O., Ryan, M. G., and Vourlitis G. (2001). Tree and forest functioning in response to global warming. *New Phytologist, 149,* 369-400.
- Smith, S. D., Huxman, T. E., Zitzer, S. F., Charlet, T. N., Housman, D. C., Coleman, J. S., ... & Nowak, R. S. (2000). Elevated CO2 increases productivity and invasive species success in an arid ecosystem. *Nature*, *408*(6808), 79-82.
- Staehelin, J., Harris, N. R., Appenzeller, C., & Eberhard, J. (2001). Ozone trends: A review. *Reviews of Geophysics*, *39*(2), 231-290.
- Stalker, P. (2006). Technologies for Adaptation to Climate Change; (UNFCCC): Bonn, Germany.
- Tubiello, F. N., & Fischer, G. (2007). Reducing climate change impacts on agriculture: Global and regional effects of mitigation, 2000–2080. *Technological Forecasting and Social Change*, *74*(7), 1030-1056.
- Tylianakis J. M., Didham R. K., Bascompte J., & Wardle D.A. (2008). Global change and spices interactions in terrestrial ecosystems. *Ecology Letters, 11,* 1351-1363.
- Unfccc. (2006). Technologies for Adaptation to climate change. Adaptation, Technology and

science programme of the Unfccc secretariat. climate change secretariat (Unfccc) Bonn, germany 40p.

- Uprety D. C., Sen S., & Dwivedi, N. (2010). Rising atmospheric carbon dioxide on grain quality in crop plants: physiol Mol Biol Plants.
- Urban, O. (2003). Physiological impacts of elevated CO2 concentration ranging from molecular to whole plant responses. Photosynthetica, 41, 9–20.
- Van Dingenen, R., Dentener, F. J., Raes, F., Krol, M. C., Emberson, L., & Cofala, J. (2009). The global impact of ozone on agricultural crop yields under current and future air quality legislation. *Atmospheric Environment*, *43*(3), 604-618.
- VanToai, T. T., Hoa, T. T. C., Hue, N. T. N., Nguyen, H. T., Shannon, J. G., & Rahman, M. A. (2010). Flooding tolerance of soybean [Glycine max (L.) Merr.] germplasm from Southeast Asia under field and screen-house environments. *Open Agric. J., 4,* 38–46.
- Wand, S. J. E., Midgley, G. F., Jones, M. H., & Curtis, P. S. (1999). Responses of wild C4 and C3 grass (Poaceae) species to elevated atmospheric CO2 concentration: A meta-analytic test of current theories and perceptions. Global Change Biology, 5, 723–741.
- Warren, R. (2011). The role of interactions in a world implementing adaptation and mitigation solutions to climate change: phil. *Trans. R. Soc. A 369,* 217-241.
- Wolfe, D. W., Ziska, L., Petzoldt, C., Seaman, A., Chase, L., & Hayhoe, K. (2008). Projected change in climate thresholds in the Northeastern US: implications for crops, pests, livestock, and farmers. *Mitigation and adaptation strategies for global change*, *13*, 555-575.
- Wikelski, M., & Cooke, S. J. (2006). Conservation physiology. *Trends in Ecology & Evolution*, *21*(1), 38-46.
- Williams S.E., L.P. Shoo, J.L. Isaac, A.A. Hoffmann, and G. Langham. 2008. towards an integrated framework for assessing the vulnerability of species to climate change. *Plant Biology, 6,* 2621–2626.
- Ziska, L. H., & Bunce, J. A. (1997). Influence of increasing carbon dioxide concentration on the photosynthetic and growth stimulation of selected C_4 crops and weeds. *Photosynthesis Research, 54,* 199–208.
- Ziska, L. H., Morris, C. F., & Goins, E. W. (2004). Quantitative and qualitative evaluation of selected wheat varieties released since 1903 to increasing atmospheric carbon dioxide: can yield sensitivity to carbon dioxide be a factor in wheat performance? *Global Change Biology*, *10*(10), 1810-1819.