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A comprehensive review on climate change effects on agriculture: Response of plants in growth, productivity, and physiological attributes under climate change conditions

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Abstract

Assessing the impacts of climate change will be a vital task in developed as well as in developing countries because of many interdependent physical, biological and chemical processes are ongoing in earth and agricultural systems. These processes can be affected by change in climate, causing an effect on natural resources (water resources, forest products, etc.), on biodiversity, ecosystem services and on plants in general, some positive and on others negative effects, such as, altering biophysical relationship, shrinking of habitats, desertification and general shift in natural world. Warming directly affects rate of plant respiration, photosynthesis, and other biogeochemical processes. For instance, enhanced CO_2 concentration can increase photosynthetic rate especially for plants growing under warm and dry condition such as C3 plants. Naturally, plants have their own mechanism to tolerate a certain level of increased temperature. As soil temperature increase, the decomposition rate of organic matter will increase, and then nutrient mineralization and availability for plants uptake become increased at presence of sufficient water if other conditions are unchanged. This Working Paper provides an overview of projected climate change impacts on agriculture, crop growth, production, physiological and biochemical function of plants and suitability across the world.

Keywords: climate changes, ecosystem services, plant growth, productivity, land use change

1. Introduction

Current and predicted pattern of global climate change are a major concern in many areas of socio- economic activities, such as agriculture, forestry, etc., and is a major threat for ecosystem function (Lepetz *et al.*, 2009) [15]. Climate change is a result from emission of greenhouse gases (e.g. CO_2, CH_4, & N_2O, etc.) in the past century that will cause atmospheric warming (IPCC, 2007) [14]. The effects have become particularly obvious over the last 30 years in the natural environment and it will affect all level of life, from the individual, population species community and ecosystem (Lepetz *et al.*, 2009) [15]. The main issue that every country, private sector, institutions, etc. must face is how to adjust the future changes in climate that will occur. Agriculture is one of the sectors, which are both sensitive to global warming (e.g. through, atmospheric temperature, precipitation, soil moisture, sea level and humidity) and contributes to climate change. In response to changes in climate, through practicing adaptation options it is important to protect both market and non market benefits from damages (Auger & Suwanraks, 1999) [12]. A report from Intergovernmental panel on climate change (IPCC, 2007) [14] shows that CO_2 released from agriculture to large extent comes from microbial decay or burning of plant residue and organic matter.

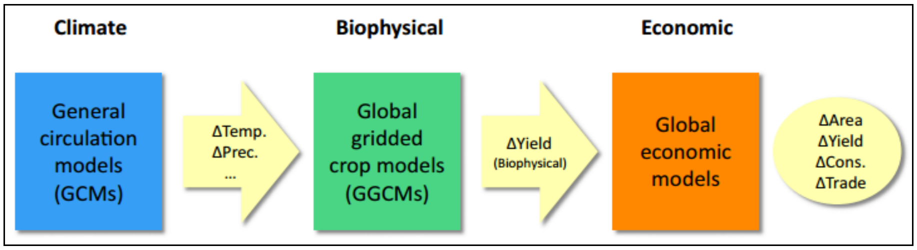

Fig 1: The impact modeling chain from climate through to crop and economic effects, Temperature; Precipitation; consumption

CH_4 produced during fermentation of organic material, emitted from ruminant animals, stored manure and rice farming under flooded condition, etc. N_2O generated by microbial transformation of nitrogen in soil, manures and often, enhanced where there is high availability of N, particularly under wet condition (Smith *et al.*, 2007). The production of greenhouse gases from agriculture is complex and heterogeneous, but active management of agricultural system can give possibilities for mitigation (IPCC, 2007) [14]. Even though plants have their own natural mechanisms to tolerate some level of untoward conditions, physiological responses of plants under climate change condition are highly determined by the limiting factors of a particular site of plants growth. For example, increasing temperature may also increase vapor pressure deficit (VPD) of the air, and increase transpiration rates that may result in adverse effects, especially on dryer sites (Boyd, 2010) [6]. Hence, the first aim of this study is to assess the level of impacts of climate change on plant production, biodiversity and different ecosystem services, and to understand the responses of plants to change in climate conditions. The second aim is to study different ways of protecting agriculture against environmental damages caused by climate change.

General Overview of Climate Change

Global warming and climate change is largely attributed to emission of GHGs from natural or anthropogenic sources and changes in albedo. As global mean temperature rise, it causes positive or negative effects on different processes and activities in earth systems (IPCC, 2007) [14]. These effects may affect ecosystem services, biodiversity, plant growth, effects on physiological attributes and productivity. According to FAO (2007) [9] and Minura, (2010) climate change impacts classified into two broad categories; 1. Biophysical impacts: indicates the physical impacts caused by climate change directly in physical environment; example, drought and flooding, causes an effect on physical environment such as a) effects on quality and quantity of crops, forest. Change in natural resources quality and quantity of soil, land and water resources. c) Increased weed and insect pest challenges on crops field due to climate change. d) Many annual crops, brief sequences of hot temperatures can greatly reduce seed set, and hence crop yield). 2. Socio economic impacts: following the first biophysical impacts on environment there will be a secondary effect on socio economic systems. For Example, decline in yield and production, reduced marginal GDP from agriculture sector, fluctuation of world market price, and change in geographical distribution of trade regimes, due to shortage of food in quality and quantity the number of people in hunger and risk increased.

Causes for climate change

Due to increasing world population and industrial development there is an increased emission of Green house gases. Use of fossil fuels, deforestation, burning and decay of biomass, etc., leads to seriously higher atmospheric CO_2 concentration, which currently is around 388 ppm and predicted to increase to approximately 470 – 570 ppm until year 2050 (IPCC, 2007) [14]. The level of absorption, scattering and emission of radiation with in the atmosphere, ocean and at the earth surface highly affected by the amount of concentration of atmospheric GHGs, aerosols, soli type and moisture, vegetation and land cover, solar radiations. They are a cause for alteration of energy balance within the climate system and are driver of climate change (Root *et al*., 2005). In addition the concentration and lifetime of greenhouse gases (GHGs) in the atmosphere depends on the rate of chemical reactions in the atmosphere (faster or slower). For instance, CH_4 primarily removed by reacting with hydroxyl radicals to form water and CO_2 within its lifetime of 12 years. The global warming potential of CH_4 is 72 times higher than CO_2 over a period of 20 years and 25 times higher over a period of 100 years. However, since the current concentration of CH_4 in the atmosphere is much lower, compared to the level of CO_2 the total warming effect of CO_2 is higher (Smith *et al*., 2007).

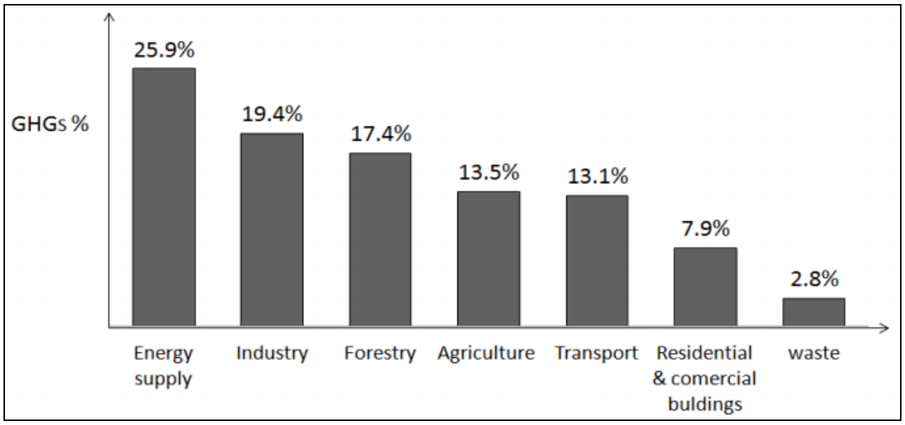

Fig 2: The main sectors, which take part in global anthropogenic GHGs emission: source IPCC synthesis report (2007) [14].

Agriculture and climate change

Agriculture contributes to climate Green house gases emission and highly affected by change in climate parameters. In an intensive farming, we expect high greenhouse gases emission because of using high amount of inputs and chemicals, due to these changes of human activity natural divers and climate change impacts varies accordingly in different part of the world. Vulnerability to climate change depends not only on physical and biological responses but also on socio economic characteristics. Low- income population especially those who cultivate crops under rain fed and non- irrigated agriculture systems in dry lands, arid and semi-arid areas highly affected by severe hard ship due to climate change (Grasty, 1999) [12].

Plant Responses 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, Saccharum officinarum & 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. CO_2 together with other minerals can activate Rubisco by binding at a non-catalytic site on the enzyme protein. The process of photorespiration rate is high in

C3 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 C3 plants but not to the same extent, if any, in C4 plants (Bolin, 1989) [5]. The result from experiments done on wild grass species shows that under elevated CO_2 condition both C3 and C4 species show increase in the total plant biomass of 44% and 33% respectively, the increased in C3 species was greater in tiller formation whereas in C4 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 C3 and C4 species with 33% and 25% respectively, while, stomatal conductance (the ability of CO_2 entering, or water vapor exiting through the stomata) decreased for C3 and C4 species by 25% and 30%, respectively (Wand *et al*., 1999) [28]. Many simulation results indicated that increased biomass production were observed in both C3 and C4 plants under elevated CO_2; although the enhancement of shoot production by elevated CO_2 varied with temperature and precipitation.

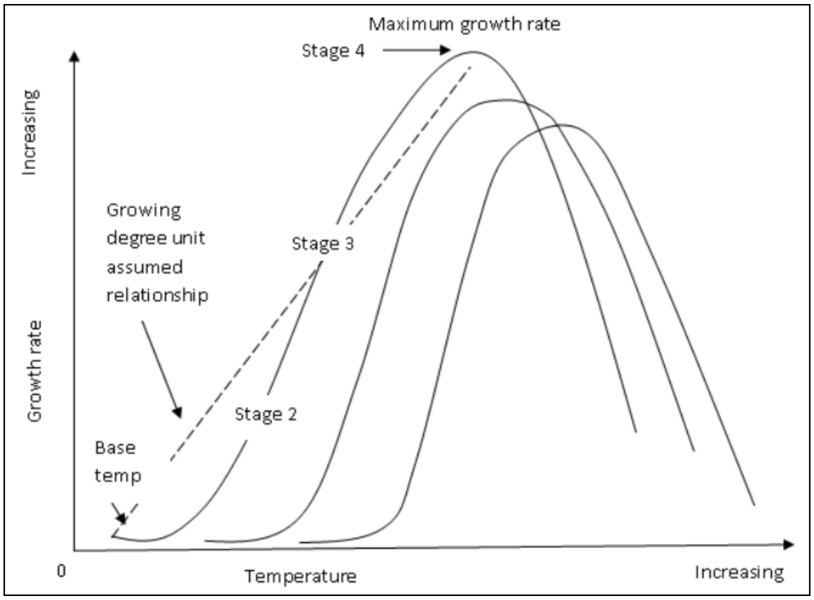

Fig 3: Changes in the rate of crop development as a function of temperature, Source: modified from Heidorn (2003). The three curves in the Figure indicate that optimal temperature range differs and depends on the species and crop type.

(Chen *et al*., 1996) [7]. 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) [16].

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) [21]. The potential of crop productivity increased under an increased in local average temperature range of 1-3ºC, but it decreased above this range (IPCC, 2007) [14], probably the reason could be low vernalization, Shortened phonological phases decrease in photosynthesis rate, and increased transpiration. (Qaderi & Reid, 2009) [21]. Elevated CO_2 have a positive effect on some annual C3 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) [26]. Some studies also show that a reduction in maize (C4 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 (C3 species) due to an effect on vernalization period (Alexadrov & Hoogenboom, 2000) [1]. 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) [8]. 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) [7].

Climate change effects on Photosynthesis and plant respiration processes

Respiration can be highly affected by temperature (Atkin *et al*., 2005) [3], 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) [10], and mitochondrial respiration plays a great role in growth and survival of plants (Atkin *et al*., 2005) [3]. 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 CO_2, that is source leaves, individual sink tissue (fruit, seed, steam, root etc.) and total sink tissue. 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 impact on plant respiration than in plants growing in warmer areas. (Atkin & Tjoelker, 2003) [2]. Respiration is essential for many processes in living organisms; it is significant for maintenance of photosynthesis activity, mainly because of the energy demands of sucrose synthesis. Furthermore, it plays a role in determining the carbon budget of individual plants and the concentration of CO_2 in the atmosphere; it contributes up to 70% of the total CO_2 released to the atmosphere (Atkin *et al*., 2005) [3].

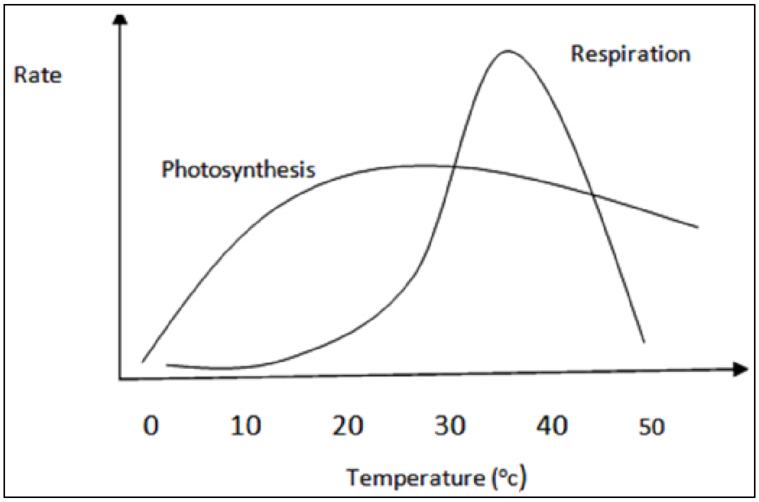

Fig 4: Changes in the rate of photosynthesis and respiration of (C3) crops as a function of temperature (Porter & Semenov, 2005) [19]. Photosynthesis is a process, undertaken in green plant cells to produce sugar molecules, by the uptake of CO_2 from the atmosphere, sun light energy and water, and during the process oxygen released. Whereas, respiration is a process of oxidation of food or breakdown of sugars and production of energy for maintenance, reproduction, and growth etc., which is undertaken in all living organisms at day and night time by the uptake of O_2 and release of CO_2 and energy.

Atkin *et al*., (2005) [3] proposes that higher CO_2 does not on average change the temperature sensitivity of dark Rind roots, leaves or shoots. In most plants as temperature increase with optimal range, the rate of respiration as well as the rate of metabolism increased, because increased respiration results with higher energy available, that means as long as nutrients are available the metabolism processes within the plant will also increase. Increased temperature to a certain level, the rate of photosynthesis is also increases but not as much as respiration. That indicates the amount of CO_2 produced from increased respiration is quicker than the amount of O_2 released from increased photosynthesis. Temperature affect photosynthesis through changing the activities of enzymes, electron transport and leaf temperature can influence the stomatal conductance. As evaporation increases, stomata inclines to close to reduce water loss through transpiration, following this stomata closure reduction in CO_2 assimilation rate take place due to less rate of CO_2 supply to chloroplast, this is indirect temperature response. Temperature also affects photosynthetic metabolism directly showing a alter in the activity of ribulose-1,5- carboxylase oxygenase (Rubisco) processes related with the regeneration of Rubisco’s substrate, rubulose-1,5- bisphosphate (RuBP) through the Calvin cycle (Lloyd & Farquhar, 2008). Climatic variability affects crop growth and yield via linear and non-linear response to weather variables and exceeding of well-defined crop thresholds, particularly, temperature (Porter & Semenov, 2005) [19]. At low temperatures, the reaction processes become slower, temperature can indirectly affect plant morphology, growth, roots turn over etc., if it is both beyond and under the optimum level for the plants. In addition, soil moisture, availability of nutrient and minerals together with other processes will play an important role in plant growth and development. Enhanced CO_2 and anthropogenic Nitrogen can directly increase short-term plant growth rates and change plant chemistry (C:N ratio and concentration of carbon-based compounds often increase), these physiological changes can affect a range of biotic interactions involving plants. As an example of plant responses, C3 plants often derive a competitive advantage following nitrogen deposition and C4 plants can derive a competitive benefit from increasing temperatures (Tylianakis *et al*., 2008) [24]. Long-term ecosystem responses to elevated CO_2 may ultimately depend on nitrogen availability to plants and on the ability of plants to use nitrogen more efficiently under elevated CO_2 condition (Norby *et al*., 2001) [17]. In addition, larger supply of photosynthesis to mycorrhizal fungi shown to occur under elevated CO_2 (Lukac *et al*., 2010). Nutrient up take by tree is an active process supported by enzyme activity, and is highly dependent on temperature. Several authors claim that nutrient uptake increases with rising temperature, but similar to enzymatic processes, the rate of uptake increases only until a threshold temperature reached. A period of increased soil and air temperature; whether it is gradual or rapid hot and in which stage of the growing seasons, is also an important condition and has a potential factor in the uptake of nutrient. Because of their longevity, trees have developed physiological mechanisms to deal with such disruption and are able to store and re - mobilized nutrients. However, repeated seasonal stress might exhaust this capacity for nutrient storage, with detrimental effects for tree health in the long-run (Lukac *et al*., 2010). Increased decomposition rates of leaf litter could result in more readily mineralized nutrients available to the plants, which likely would increase photosynthetic carbon gain in nutrient limited systems (Boisvenue & Running, 2006) [4].

Climate variables and productivity

According to suggestion of fourth assessment report of IPCC, (2007) [14] The overall impacts of higher temperatures on crop responses at the plot level, without considering changes in the frequency of extreme events, moderate warming may benefit in crop and pasture productivity in temperate regions, while it may reduce productivity in tropical and semi-arid regions. Modelling studies indicate small beneficial effect in temperate Corresponds to local mean temperature increases in 1-3ºC with association of an increased in CO_2 and rainfall changes. In contrast, models show that tropical regions show a negative yield impacts for major crops with moderate rise in temperature (1-2ºC), but further warming projected in all regions in the end of twenty-first century results in the increased on negative impacts (Tubiello *et al*., 2008). Due to impacts of climate change, agricultural productivity directly affected in developed and developing world (Alexandrov & Hoogenboom, 2000) [1]. Climate plays a major role in determining the yield level by increasing or reducing in global perspective from temperate to tropics. Many experiments show that CO_2 is a limiting factor, in which higher concentration of CO_2 enhances photosynthesis and crop growth, modifying water and nutrient cycles (Tubiello *et al*., 2008), these responses found to hold even for plants grown under different stressful conditions. Despite related to generalization of the law of limiting factors when other environmental factors such as water shortage, less light, shortage or excess of minerals, very high or very low temperature limit yield, then CO_2 concentration will have little or no effect. However, in certain stressful environments the relative photosynthetic response of plants to CO_2 enrichment is actually increased (Bolin *et al*., 1989) [5]. For most crops, growing under elevated CO_2 conditions both quality and total yield shows improved (more ear of plant per m). The increased CO_2 induce and makes an increase in the grain weight and according to the observation, it was greater under average phosphorus treatment compared to higher phosphorus level. This influence of CO_2 and phosphorus supply was attributed to increase in the number of cells within endosperm, which is the result of enhanced rate of cell division during grain development or by greater amount of grain filling during ripening phase (Uprety *et al*., 2010) [26]. However, it has also been shown that elevated CO_2 concentrations may have negative effects on the grain quality from wheat in terms of protein content (Pleijel and Uddling, 2012) [18], it alters wheat grain lipids and doubled the number of mitochondria in wheat leaves, lower seed nitrogen concentration and decreases grain and flower protein (Qaderi & Reid, 2009) [21].

Discussion

Following climate change and climate variability in different studies and by referring some related literature, I suggest two important effects of warming and elevated CO_2 on especially valid for agricultural system: 1) Plants and in already warm areas will become less productive and the production of plants in cold areas may increase when exposed to higher temperature. 2) Increased CO_2 concentration may have a positive effect on plant growth. Higher temperature can make an obstacle on crop growth, the rise in temperature shorten the growth period due to early flowering and fruit-bearing, and seeds might not fully develop because of decrease in nourishment sent to the seed due to increased respiration. In addition, elevated temperatures at the flowering stage of some plants (e.g. rice) makes the plant spikelet sterile. In the case of Japanese rice, the anther will have difficulties to tear when the air temperature is over 34ºC, thus global warming should in some areas be consider as a threat for food security (Furuya, & Kobayashi, 2010) [11]. However, higher temperature can directly stimulate root and microbial metabolic activities and respiration that indirectly can have an impact on soil respiration through making a change in plant growth, because of enhanced CO_2level and warming stimulate export of carbohydrates to the roots (Wan *et al*., 2007) [27].

Lukac *et al*., (2010) also mention that, increasing temperature will speed up the release of nutrients locked up in the mineral soil fractions and thus potentially stimulate growth, however decreasing soil moisture that may be a result of higher temperatures may limit this process. Currently it is not well know which the net effect of increasing temperatures are as many processes are involved and some will be affected positively and some negatively, e.g. photosynthetic rate, respiration, photorespiration and volatile organic compound (VOC) production. Although, it is quite clear that an increased temperature in some hot area can cause a reduced photosynthetic rate due to overheating effect closure of stomata during drought stress. These all together may reduce the general growth and development of the plants (Prieto *et al*., 2009) in particularly in warm areas. Research suggests that for some crops, such as rice, the benefit of CO_2may decline quickly as temperature warm beyond optimum photosynthetic levels, however crop plant growth may benefit relatively more from CO_2enrichment in drought conditions than in wet conditions (Easterling, & Apps, 2005) [8]. Increasing the concentration of CO_2 leads to normally to positive impacts on crop growth (Furuya & Kobayashi, 2010) [11]. According to Hardy, (2003) [13] this suggestion is partly supported by the following statement: enhanced CO_2 in general shows an increasing photosynthetic rate in individual plant; nevertheless, this increased productivity does not necessarily benefit plants, in the condition where several kinds of species grown together, due to increased competition, availability of nutrient diminish. Any benefit of enhanced atmospheric CO_2 and overall, the effects of CO_2 enhanced atmosphere on community of vegetation are complex and not well understood. Study by Wan *et al*. (2007) [27] shows that an elevated CO_2 concentration can stimulate not only plant growth, but also stimulate the allocation and availability of carbon substrate supply at the ground below soil level as an input of substrate for different soil microbial activities and plant root system. Therefore, it might be possible that enhanced CO_2 rise, air warming and variation of precipitation will likely have an interactive and complex effect on plant soil process. Increased CO_2 content in the atmosphere is expected to increase the yield of many agricultural crops by 5 to 15%; however, CO_2 fertilization in climate impact model is an uncertain factor (Roos *et al*., 2010) [22]. Study by Uprety *et al*., (2010) [26], shows that due to elevated CO_2 concentration the increased in the yield was based on the improvement in the development of the number of grain. Moreover, elevated CO_2 under high nitrogen availability brought about higher starch content in wheat grain due to an increased in carbohydrate translocation from the source (leaf, and steam) to sink (grain). Elevated CO_2 alters litter quality, with significant decreases in its nutrient content, which means less nutrients per unit mass, coupled with slower litter deposition under elevated CO_2; therefore, nutrient availability may be reduced in the long-run and thus counteracting the positive effects of increased CO_2 concentrations, at least in nutrient poor systems (Lukac *et al*., 2010). There are two basic counter measures regarding climate change, mitigation and adaptation (Mimura, 2010). Mitigation includes different measures, undertaken to reduce GHGs emission and increasing absorption of GHGs, which already emitted, and adaptation indicates different potential measures to protect the adverse effects of climate change. According to IPCC (2007) [14], all societies have inherent abilities to deal with certain variations in climate, yet adaptive capacities are unevenly distributed, both across countries and within the societies. Adaptation of agricultural and forest system is very complex, because of external and internal factors , e.g. temperature, humidity, light, water availability, photosynthesis, and especially genotypic factors, as discussed above will play a major role (Ulukan, 2008) [25]. 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.

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