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Relationship between climate change and crop productivity: Review articles

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Abstract
Climate change is one of the most factors that affect the crop productivity. The most climatic factor that affects the final yield of crops is temperature, precipitation, relative humidity, solar radiation and air pollution. Increase in temperature may lead to higher respiration rates, shorter periods of seed formation and, consequently, lower biomass production. Also higher temperatures may result in a shorter and insufficient development period; therefore, it may lead to smaller and lighter grains, lower crop yields and perhaps lower grain quality. Dry periods can badly affect plant growth but the amount of damage depends on the ability of the plant to expand its root system and how much water the soil can hold onto. High humidity, frost and hail may also damage certain crops. Excessively wet years, on the other hand, may cause crop yield reduction due to water logging. Air pollutants such as nitrogen oxides, carbon monoxide, and methane, react with hydroxyl radicals in the presence of sunlight to form tropospheric O_3, which causes oxidative damage to photosynthetic parts in all major crops.

Keywords: air pollution, climate change, crop, productivity

1. Introduction

Climate Change is a serious global environmental concern. It is primarily caused by the building up of Green House Gases (GHG) in the atmosphere. Increasing evidences over the past few decades are indicating that significant changes in climate are taking place worldwide as a result of enhanced human activities. Global Warming is a specific example of the broader term "Climate Change" and refers to the observed increase in the average temperature of the air near earth's surface and oceans in recent decades. Its effect particularly on developing countries is adverse as their capacity and resources to deal with the challenge is limited. Accumulation of green house gases in the atmosphere has its adverse effects on agriculture (Haris *et al*., 2013) [22]. Due to climate change, the spatial and temporal distribution of rainfall is expected to vary a lot (Oki, 2006) [45]. Rate of evaporation may change, leading to variations in water availability and ground water recharge (Huntington, 2005) [25]. Thus, competition for water will be a major future challenge for agriculture. Crop water requirement and the temporal and spatial changes of this important characteristic provide key information for irrigation scheduling, water resource planning and future decision making (Yang *et al*, 2013) [25]. In addition, expected changes in soil moisture may alter the amount of water available to plant roots for transpiration (Goyal, 2004) [19]. Increased concentration of green house gases especially CO2 has a direct impact on crop growth and productivity. Under elevated CO2, conditions, the stomatal conductance in most species decreases, which may result in lower transpiration per unit leaf area (Kruijt *et al*., 2008) [27] Spatial and temporal changes in precipitation and temperature will shift current agro-ecological zones (Kurukulasuriya and Mendelsohn 2008) [28] and have major impacts on the viability of both dry land subsistence (Challinor *et al*., 2007) [7] and irrigated crop production (Knox *et al*., 2010) [26]. As climate is a primary determinant of agricultural productivity, any changes will influence crop growth and yield, hydrologic balances, supplies of inputs and other components of managing agricultural systems. Climate change may be a change in the mean of the various climatic parameters such as temperature, precipitation, relative humidity and atmospheric gases composition etc. and in properties over a longer period and a larger geographical area. It can also be referred as any change in climate over time, whether due to natural variability or because of human activity.

The changing patterns of climatic parameters like rise in atmospheric temperature, changes in precipitation patterns, excess UV radiation and higher incidence of extreme weather events like droughts and floods are emerging major threats for crop production in the tropical zone (Tirado *et al*., 2010) [54].

Many developing countries are especially sensitive to climate change because they are located in the tropics, with temperatures that already compromise agricultural production (Da Cunha *et al*., 2015; Kurukulasuriya *et al.,* 2006; Mendelsohn *et al*., 2006) [29, 13], and because they have limited access to the human and physical capital that might mitigate its effects (Di Falco, 2014) [14]. These challenges are often compounded by a lack of access to new technology and to developed markets (Di Falco, 2014; Kurukulasuriya *et al*., 2006) [14, 29]. Therefore the objective of this review is to gather the information on the relationship between climate change and crop productivity.

2. Effect of temperature on crop productivity

Rate of plant growth and development is dependent upon the temperature surrounding the plant and each species has a specific temperature range represented by a minimum, maximum, and optimum. Analysis by Meehl *et al*. (2007) revealed that daily minimum temperatures will increase more rapidly than daily maximum temperatures leading to the increase in the daily mean temperatures and a greater likelihood of extreme events and these changes could have detrimental effects on grain yield. If these changes in temperature are expected to occur over the next 30 years then understanding the potential impacts on plant growth and development will help develop adaptation strategies to offset these impacts.

2.1 Response of crop to temperature.

Responses to temperature differ among crop species throughout their life cycle and are primarily the Phenological responses, i.e., stages of plant development. For each species, a defined range of maximum and minimum temperatures form the boundaries of observable growth. Vegetative development (node and leaf appearance rate) increases as temperatures rise to the species optimum level. For most plant species, vegetative development usually has a higher optimum temperature than for reproductive development. Faster development of non-perennial crops results in a shorter life cycle resulting in smaller plants, shorter reproductive duration, and lower yield potential. Temperatures which would be considered extreme and fall below or above specific thresholds at critical times during development can significantly impact productivity. Photoperiod sensitive crops, e.g., soybean, would also interact with temperature causing a disruption in Phenological development. In general, extreme high temperatures during the reproductive stage will affect pollen viability, fertilization, and grain or fruit formation (Hatfield *et al*., 2014) [24].

There is emerging evidence that differences exist among rice cultivars for flowering times during the day (Sheehy *et al*., 2005). Given the negative impacts of high temperatures on pollen viability, recent observations from Shah *et al*. (2011) suggest flowering at cooler times of the day would be beneficial to rice grown in warm environments. They proposed that variation in flowering times during the day would be a valuable phenotypic marker for high-temperature tolerance. As daytime temperatures increased from 30 to 35 °C, seed set on male-sterile, female fertile soybean plants decreased (Wiebbecke *et al*., 2012). This confirms earlier observations on partially male-sterile soybean in which complete sterility was observed when the daytime temperatures exceeded 35 °C regardless of the night temperatures and concluded that daytime temperatures were the primary factor affecting pod set Caviness and Fagala (1973).

Matthews *et al*. (1997) [34] simulated the impact of increased atmospheric carbon dioxide on the productivity of rice in various parts of Asia and found that on average the yields will go down by 4%. Though, there are areas where the yields would rise due to the increased global temperatures (especially in regions with cooler climate) leading to double-cropping, this would not be sufficient to compensate for the overall loss in yields in various parts of Asia, which grows the majority of rice in the world (Matthews *et al*., 1997) [34].

2.2 Effect of extreme temperature on crop productivity

Increase in temperature may lead to higher respiration rates, shorter periods of seed formation and, consequently, lower biomass production. Crop growth cycles are related to temperature and increase in temperature speeds up development. In case of an annual crop, duration between sowing and harvesting season decreases, hence this shortening of growth cycle affects productivity. Also higher temperatures may result in a shorter and insufficient development period; therefore, it may lead to smaller and lighter grains, lower crop yields and perhaps lower grain quality (i.e. lower protein levels). Again, certain weeds, diseases and pests (Ziska *et al*. 2011) [23] benefit from warming and growth of many microbial (usually fungal infection) is aggravated when warmth and moisture are available. Humidity and temperature can thus favor the growth of fungal infection and damage crops.

Temperature affects agricultural yields through various ways. Temperature also affects the rates of photosynthesis, transpiration and respiration. Increase in temperature during day increases photosynthesis (provided the temperature is maintained near the optimal range) whereas an increase in temperature during night raises the rate of respiration (Crafts-Brandner *et al.*, 2002) [11]. Another factor directly affected by the fluctuation in temperature is humidity. Increase in temperature leads to an increase in saturation vapor pressure of air. Relative humidity has remained roughly constant in recent decades over large spatial scales (Willett, 2007) [61] and is projected to change minimally in the future as well. Increase in temperature to an extreme level can directly damage plant cells.

In China, researchers reported that wheat production rates would be reduced by 3 to 10% due to a 1 °C increase in temperature during the growing period based on the historical data between 1970- 2000. The same study also reported that the increase in temperature over the last two decades would have resulted in the yields dropping by 4.5%, if not for the increased use of resources (like irrigation, fertilizers etc.,) in growing the crops (You *et al*., 2009) [65]. Experimental observations on wheat yields between 1981–2009 across China showed a wide variation in the productivity of wheat in different climactic regions. They found that the wheat yields in Northern China rose by 1–13% while a reduction of 1% to 10% was observed in Southern China (Tao *et al*., 2014) [53].

Variations in temperature within a short span of time may seem critical if it by chance interferes with the different stages of development of crops. It was observed by Wheeler *et al*. (2000) [7] that a few more days of extreme temperature (greater than 32 ^{0}C) at the flowering stage of many crops candrastically reduce yield. Changes in growing conditions coupled with stress factors thus affect the growth, development and eventual yield.

Physiological processes related to growth such as photosynthesis and respiration respond to changing temperature always. But rates of crop development are often affected when the changes in temperature or the fluctuation in temperature reaches a certain level. In the short-term, high temperatures can affect enzyme mediated reactions and gene expression, whereas in the longer term, these will have their impact on carbon assimilation and eventually on growth rates and final yield. The impact of high temperatures on final yield can depend on the stages of crop development. Wollenweber *et al*. (2003) [62] stated that the plants experience warming periods as independent events and those critical temperatures of 35 ^{0}C for a short-period around anthesis had severe yield reducing effects. However, high temperatures during the vegetative stage did not seem to have significant effects on growth and development.

Various researchers have shown that global warming can have a negative impact on the yields of paddy produced around the world. Over the past century, the average global temperatures have increased by 0.5 to 0.6 °C (Hansen *et al*., 2010) [21]. The increase in temperature has resulted in increased respiration in the plant and a subsequent increase in carbon metabolism and a decrease in the yield of paddy (Zhao and Fitzgerald, 2013) [66]. The higher temperatures can also cause the flowers of the paddy to become sterile, disrupting the reproduction process. Recently, the International Food Policy Research Institute (IFPRI) reported that climate change could reduce the paddy yield by 10 to 15%, which can result in a rise in market price by 32 to 37% (Nelson *et al*., 2009) [44]. Using historic data from 1999 to 2007, the ORYZA 2000 model predicted for Malaysia that a 2 °C temperature increase could reduce paddy yields by 0.36 t ha^{-1}, which would result in a huge economic loss (Vaghefi *et al*., 2011) [55].

2.3 Effect of solar radiation on crop productivity

One of the most important factors that influence plants development is the solar radiation intercepted by the crop. The solar radiation brings energy to the metabolic process of the plants. The principal process is the photosynthetic assimilation that makes synthesize vegetal components from water, CO2and the light energy possible. A part of this, energy is used in the evaporation process inside the different organs of the plants, and also in the transpiration through the stomas. Solar radiation is the set of electromagnetic radiation emitted by the Sun. In the interception of light by a canopy, difference between the solar incident radiation and reflected radiation by the soil surface (Villalobos *et al.,* 2002) [57], is a determining factor in crop development and provides the energy needed for fundamental physiological processes such as photosynthesis and transpiration. Leaf is the principal photosynthetic functional unit; therefore its efficiency on the capture and use of solar energy determines the vegetable productivity. The area and arrangement of foliage (the canopy architecture), determine the interception of solar radiation (LI) by a crop and the distribution of irradiance among individual leaves (Loomis and Connor, 2002) [33]. Leaf area and arrangement change during the life of a crop and, by leaf movement, even during the course of a single day. Maximum crop production requires complete capture of incident solar radiation and can only be achieved with supporting levels of water and nutrients (Loomis and Connor, 2002) [33].

The productivity of a crop depends on the ability of plant cover to intercept the incident radiation, which is a function of leaf area available, the architecture of vegetation cover and conversion efficiency of the energy captured by the plant into biomass. Deficiencies in water and nutrient inputs may reduce the rate of leaf growth, reducing yield below optimum levels due to insufficient energy capture (Gardner *et al*., 1985) [17]. The efficiency of interception of a canopy corresponds to the capacity of the plant population in intercepting the incident solar radiation, which is the main factor influencing the photosynthesis and the transpiration processes (Thorpe, 1978). The efficient crops tend to spend their early growth to expand their leaf area; they make a better use of solar radiation.

Solar radiation also has an important role in the processes of evaporation and transpiration. Evaporation takes place mainly from the soil surface and transpiration is the evaporation that occurs across different plant organs, mainly leaves. Because both processes are closely linked, they are often considered together (evapotranspiration). Apart from the availability of water in the surface horizons, the cultivated soil evaporation is determined mainly by the fraction of solar radiation reaching the soil surface. This fraction decreases over the growing season, and at the same time the crop canopy cover grows. The development of a crop can be divided into four stages (Allen *et al*., 1998) [2]

2.3.1 Initial Stage: The early growth of individual plants, with little plant-plant competition is very fast. As the LAI develops, there is a shade of lower leaves, so that descriptions of crop growth are based on leaf area depending on the soil surface (Gardner *et al.*, 1985) [17].

2.3.2 Crop Development Stage: LAI grows exponentially, changing the dominant component of evapotranspiration, predominating evaporation in theinitial period and the plant transpiration at the end of the stage. As the leaf area grows, the radiation intercepted by leaves increases. Mid-season stage: The late season stage runs from the start of maturity to harvest or full senescence. In the vegetative period radiation interception does not increase, starting from fruit ripening to leaf senescence.

Under no-stressed environmental conditions, the amount of dry matter produced by a crop is linearly related to the amount of solar radiation, specifically photo synthetically active radiation (PAR), intercepted by the crop. Monteith (1977) [399], demonstrated that cumulative seasonal light interception for several crops grown with adequate soil water supply was closely related to biomass production. He formalized and fully established the experimental and theoretical grounds for the relationship (RUE) between accumulated crop dry-matter and solar radiation, arguing that this approach is robust and theoretically appropriate to describe crop growth. RUE is highly dependent on the photosynthetic performance of crop canopies and can be influenced by several factors, namely, extremes temperature, water, and nutrient status. This is indicated by the variation reported in RUE among and within crop species and across locations and growing environments (Subbarao *et al*., 2005) [52].

The water deficit reduces the interception of solar radiation due to rolling up the leaves (Müller, 2001). If the water deficit is prolonged, the number and size of leaves may be reduced or the total leaf area may decrease, reducing as a result, the interception of radiation (Collinson *et al*., 1999). Soil water and the resulting plant water status play a key role in determining stomata conductance and canopy photosynthesis. Soil water deficit results in plant water deficits that lead to stomata closure and reduced photosynthesis, and results in loss of photosynthetic efficiency of the canopy and thus to a decrease in RUE (Monteith, 1977) [39].

2.4 Effect of precipitation on crop productivity

Extreme rainfall conditions characterized by droughts and floods can have devastating impacts on rural household’s engaged in agricultural production, especially in low-income regions around the world. The absence of access to financial services by these households implies that they cannot mitigate the short-run effects of adverse weather conditions. Under these circumstances, rural households use informal strategies for coping with weather related risk (Chen and Chang, 2005; Lewin *et al*., 2012; Skees *et al.*, 2002) [8, 32, 49]. However, relying on informal insurance to deal with weather variations from others in the same village or rural region is likely to be unavailable since bad weather conditions affect other neighboring households (Gudiño, 2013) [20].

Rainfall variations have devastating effects in areas where agriculture is predominantly rain fed and hence any irregularity in weather conditions has adverse welfare implications (Birhanu and Zeller, 2009) [5]. In consistency with the long-run effects in Mexico of climate change, several measures indicate that droughts have been one on the main problems affecting rural areas. Severe and sustained drought began in 1994 and continued for the past 15 years with only limited relief. Drought during this period equaled some aspects of the 1950s drought, which is the most severe drought evident in the instrumental climate record for Mexico from 1900 to 2008 (Cook, 2007; Cortez, 2006; Stahle *et al*., 2009) [9, 10, 50].

Increases in precipitation (i.e. level, timing and variability) may benefit semi -arid and other areas which have shortage of water, by increasing soil moisture. But this factor could aggravate problems in regions with excess water. Similarly a reduction in rainfall could have the opposite effect. Water stress during the reproductive period of cereal crops may be particularly harmful (Stone, 2001; Hatfield *et al*., 2011) [23, 51] while the farmers may be confused enough to determine the planting season for agriculture if there are changes in the timing of the rainy season, particularly in tropical areas. Finally, more intense rainfall events may lead to flooding and water logging of soils, which are also good reasons behind crop destruction. An atmosphere with higher CO2 concentration would result in higher net photosynthetic rates (Cure *et al*., 1986; Allen *et al.*, 1987) [12, 1]. Higher concentrations may also reduce transpiration (i.e. water loss) as plants reduce their stomatal apertures, the small openings in the leaves through which CO2and water vapor are exchanged with the atmosphere.

As global warming progress, there will be increased evaporation from the earth's surface and from plants. Even a 1 °C temperature increase would increase the amount of evaporation from the earth. As well, increased temperatures result in more concentrated, heavy rainfall, and crops show decreased rainfall use efficiency in such circumstances. Snowfall, which results in stored water resources, also decreases with higher temperatures, and snow melts more rapidly. Together, these factors could combine to increase drought in the major agricultural regions the mid-latitude continents. This could significantly restrict the world's food supply. In dry areas, water moves from subsurface to surface layers of the soil. Therefore, when capillary water reaches the ground or irrigation water evaporates, the soluble salts that dissolved into the water in the lower layers are concentrated in the surface soil layer. As a result, salt accumulates at the soil surface, where it negatively affects or prevents plant growth. Theoretically, the increase in the number of strong tropical storms is because of increased evaporation the energy source for tropical storms due to the rise in the temperature of the ocean's surface (Emanuel, 1987) [15].

Walsh (2004) [58] indicated that the tropical cyclone intensity will increase by 5–10% around 2050, along with increased peak rainfall rates of approximately 25%. More recent climate model predictions are that the number of cyclones will decrease by approximately 30% under global warming, but their duration will be longer (Oouchi *et al.*, 2006) [46]. Therefore, low-lying areas could be at high risk because of longer tropical storms and increased sea levels.

The millet yield increased by 6% after drought (lower limit of soil water availability) and 8% after heat simulation (increased from 27 °C to 29 °C). Drought and heat tolerance together showed an increase in millet yield which amounts to 14% under climate change. Furthermore, millets also possess the ability to grow in hilly terrain and mountainous regions where cultivation of other cereals is difficult (Rasul *et al*., 2018) [47]. This shows that millets possess the potential to be a vital crop that could grow with limited nitrogen input in drought, high-temperature and hilly regions around the world. This is one crop that clearly has the potential to reduce the carbon footprint as it has the least global warming potential, and at the same time is resistant to the global warming effects such as increased frequency in droughts and increased average temperatures.

In the United States, global warming has resulted in an average 2.5% decrease in maize yield in the period from 1970 to 1999, and precipitation modeling reported that by the 2050s, corn yields are projected to decrease further by 20 to 50% depending on the current emission scenarios (Leng, and Huang, 2017). Water supply is also a vital factor for maize production. Studies revealed that from 1999 to 2002, the average yield of maize grown under irrigation (12.44 t ha^{-1}) was 16.5% higher than when cultivated under non-irrigated condition (10.68 t ha^{-1}) Nagy (2003) [3]. The yields of maize grown under two irrigation systems, raised bed and drip irrigation systems were compared (Amin *et al*., 2015) [3]. The results showed that compared to the drip irrigation system, the raised bed irrigation system was beneficial for increasing the plant height, biological yield, and grain yield by 1%, 5%, and 21%, respectively.

Water is one of the most important factors for proper growth, balanced development, and high yields of wheat. Two cultivars of winter wheat (Baviaans and 14SAWYT306) were cultivated with three irrigation durations or schedules with the control case having no irrigation. The three schedules were irrigation up to development of the stem extension, irrigation from stem extension up to physiological maturity, and irrigation throughout the growth of the crop (Ngwako, and Mashiqa, 2013). The results showed that irrigation treatments significantly increased grain yield compared to no irrigation treatment for both cultivars. Compared with no irrigation, irrigation throughout the growth period increased the number of tillers, number of grains per spike, grain yield, harvest index, and grain protein by 20.58%, 26.07%, 42.72%, 16.71%, and 3.31%, respectively.

2.5 Effect of air pollution on crop productivity

Air pollutants such as nitrogen oxides, carbon monoxide, and methane, react with hydroxyl radicals in the presence of sunlight to form tropospheric O_3, which causes oxidative damage to photosynthetic machinery in all major crop plants (Wilkinson *et al*., 2012) [60]. Aerosols from air pollution can also cause harm. These pollution-related impacts are incredibly dangerous in agricultural areas, but the danger of tropospheric Ozone can also be a problem across continents. In fact, tropospheric O_3concentrations above pre-industrial levels are currently found in most agricultural regions of the globe (Van Dingenen *et al*., 2009) [56]. There are effects due to interaction between O_3 and elevated CO_2. For example, reduced stomatal conductance under elevated CO_2 will reduce O3uptake by crop plants, thereby limiting damage to the plant and maintaining biomass production (McKee *et al*., 1997) [35]. However, empirical evidence is mixed regarding the ability of elevated CO_2 to reduce the impact of O_3 on final yields (McKee *et al*., 2000) [36]. However, a higher stomatal conductance implies more uptake of O_3, increasing the sensitivity of more recent varieties to O3damage (Biswas *et al*., 2008) [6].

To achieve high yields, crops must be protected from pests, diseases, and weeds. Of the total cropping area worldwide, crop yield is decreased by 10–20% by weeds (Mirrabelli *et al*., 2005). Many C4weeds are found in arable C3crops and many C3weeds in arable C4crops. Therefore, under high temperatures and increased atmospheric CO2 concentrations, weed damage to arable C4crops in tropical and subtropical semiarid areas is predicted to increase. It is likely that global warming will result in pests and diseases that are currently found in low-latitude regions spreading to high-latitude regions. Bacteria and fungi are the main causal agents of plant diseases, and their optimal growth temperatures are approximately 25 °C and above 30 °C, respectively. Temperature also affects the growth of insects, with higher temperatures increasing their growth rate. Therefore, continued warming is expected to increase damage to crops from bacteria, fungi, and insects.

2.6 Effect of relative humidity on crop productivity

Relative humidity is the ratio of actual water vapor content to the saturated water vapor content at a given temperature and pressure expressed in percentage (%).Maximum RH is in the equatorial region due to high evaporation and decreases towards poles up to 30° N and S due to subsiding air mass. It is increases in poles due to low temperature. Relative humidity (RH) directly influences the water relations of plant and indirectly affects leaf growth, photosynthesis, pollination, occurrence of diseases and finally economic yield. The dryness of the atmosphere as represented by saturation deficit (100-RH) reduces dry matter production through stomatal control and leaf water potential.

Water is a primary factor controlling plant growth. Xiao *et al*. (Xiao *et al*., 2000) [63] stated that, when water was applied at 0.85, 0.70, 0.55 or 0.40 ET (evapotranspiration) to cotton plants grown in pots, there was a close relationship between plant development and water supply. The fruit bearing branches, square and boll numbers and boll size were increased with increased water supply. Barbour and Farquhar (2000) reported on greenhouse pot trials where cotton cv. CS50 plants were grown at 43 or 76% relative humidity (RH) and sprayed daily with abscisic acid (ABA) or distilled water. Plants grown at lower RH had higher transpiration rates, lower leaf temperatures and lower stomatal conductance. Plant biomass was also reduced at the lower RH. Within each RH environment, increasing ABA concentration generally reduced stomatal conductance, evaporation rates, superficial leaf density and plant biomass, and increased leaf temperature and specific leaf area.

Until now, optimization of the greenhouse environment has been achieved mainly by focusing on the productivity and visual plant quality of flower crops; keeping quality has been given less attention. This is particularly the case with respect to air humidity. The effect of air humidity on the keeping life of flower crops is little known, with one exception: in cut roses, humidity control (avoiding high humidities) as a means of improving keeping quality is nowadays strongly advocated in the greenhouse industry in Scandinavia (Mortensen and Fjeld, 1998) [42].

Very high or very low RH is not conducive for high grain yield. Under high humidity, RH is negatively correlated with grain yield of maize. The yield reduction was 144 kg/ha with an increase in one per cent of mean monthly RH. Similarly, wheat grain yield is reduced in high RH. It can be attributed to adverse effect of RH on pollination and high incidence of pests. Increasing the humidity from about 700 to 200 Pa VPD has been found to increase the leaf area and dry weight of agricultural plants such as wheat and sugar beet (Ford and Thorne, 1974).

In a range of agricultural plants, humidity has no effect at levels ranging from 500 to 1500 Pa VPD, but at higher VPD levels some reductions in photosynthetic rate can be observed (Rawson and Begg, 1977; Leach, 1979). On the contrary, increase in RH during panicle initiation to maturity increased grain yield of sorghum under low humidity conditions due to favorable influence of RH on water relations of plants and photosynthesis. With similar amount of solar radiation, crops that are grown with irrigation gives less yield compared to those grown with equal amount of 'water as rainfall. This is because the dry atmosphere, which is little affected by irrigation, independently suppresses the growth of crops. The growth of several foliage pot species is generally found to be little affected when VPD is decreased from 1000 to 400 Pa (Mortensen and Gislerùd, 1990) [41]. Decreasing VPD from 900 to 100±200Pa in Begoniahiemalis and poinsettia, however, strongly enhances leaf size and plant height. Transpiration is decreased by 50-60%, but nutrient concentrations in the leaves are little affected (Gislerùd *et al.*, 1986; Mortensen, 1986) [40].

3. Summary

The effects of climate change on crop production are complex, and are a combination of increased CO_2 concentrations in the atmosphere, higher temperatures, fluctuations in rainfall and solar radiation, and pests and diseases. Its effect particularly on developing countries is adverse as their capacity and resources to deal with the challenge is limited. Accumulation of greenhouse gases in the atmosphere has its adverse effects on agriculture. Due to climate change, the spatial and temporal distribution of rainfall is expected to vary a lot, rate of evaporation is change, leading to variations in water availability and ground water recharge. Due to this competition for water will be a major future challenge for agriculture. The major climatic factors that affect crop productivities are temperature change, rain fall, air pollution, solar radiation and relative humidity.

Temperature affects agricultural yields through various ways. Temperature affects the rates of photosynthesis, transpiration and respiration. Increase in temperature during day increases photosynthesis (provided the temperature is maintained near the optimal range) where as an increase in temperature during night raises the rate of respiration. Increase in temperature may lead to higher respiration rates, shorter periods of seed formation and, consequently, lower biomass production. Also higher temperatures may result in a shorter and insufficient development period; therefore, it may lead to smaller and lighter grains, lower crop yields and perhaps lower grain quality (i.e. lower protein levels). High temperatures affect crops directly by increasing the rate at which they lose water (their evaporation rate), in the same way that high temperatures make us sweat.

One of the most important factors that influence plants development is the solar radiation intercepted by the crop. The productivity of a crop depends on the ability of plant cover to intercept the incident radiation, which is a function of the leaf area available, the architecture of vegetation cover and conversion efficiency of the energy captured by the plant in biomass. Water stress and nutrition reduce LAI to a smaller size and greater leaf senescence. The smaller size of LAI agrees with light capture and thus crop growth, decreasing the efficiency of radiation. The measurement of radiation intercepted by a crop for formation of leaf area is an important factor in monitoring crops, water relations studies, and nutrition and in crop simulation models.

Increases in precipitation (i.e. level, timing and variability) may benefit semi -arid and other areas. Precipitation (rainfall) is the primary source of soil moisture, and rainfall amount is probably the most important factor determining the crop yield. A change in climate can cause an increase or a decrease in the amount of precipitation which falls. Dry periods can badly affect plant growth but the amount of damage depends on the ability of the plant to expand its root system and how much water the soil can hold onto. High humidity, frost and hail may also damage certain crops. Excessively wet years, on the other hand, may cause crop yields to fall. The soil becomes waterlogged and the plant roots rot in the excess water. Intense bursts of rainfall may also damage young plants, both because of the hard impact of the rain drops on the tender plants and because heavy rain can cause soil erosion.

As climate change have contrasting effect in different part of the world, it mainly affect the developing world, causing variability in precipitation, solar radiation, temperature,[CO2] humidity etc, it leads to increased infestation of disease, insect, pest and dispersal of weed, which may affect food production and productivity. When the ambient factors affecting growth will become beyond the tolerance of the plant species, it will have a negative effect on their reproduction, life cycle and eventually extinct of the species from natural ecosystem.

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