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Effect of Climate Change on the Production and Productivity of Wheat Crop in the Highlands of Ethiopia: A Review

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ABSTRACT

Climate change is a recent challenge on crop production and productivity in the world. The objective of this paper is to review the major effects of climate change on the production and productivity of wheat in the high lands of Ethiopia. Effects of climate change on wheat would be mainly through changes in [CO_2], temperature, rainfall, length of growing period, actual growth rate and increased evapo-transpiration, which may lead to reduce yield or complete crop failure. Moreover, flower fertilization and grain set are highly sensitive to heat stress during mid-anthesis. In C_3 crops like wheat, the elevated CO_2 level is expected to increase productivity as a result of higher CO_2 diffusion through stomata leading to a higher photosynthesis rate. But, elevated [CO_2] may have negative effects on the grain-quality of wheat in terms of protein, lipids, number of mitochondria and nitrogen contents. Unlike CO_2, elevated temperature affects crop production negatively by increasing rate of respiration; hastening plant growth and development; increasing photorespiration of wheat, reducing photosynthetic efficiency due to O_2 interrupts the photosynthetic path way instead of CO_2, increasing rate of water loss by increasing evapo-transpiration and decreasing nutrient use-efficiency through increased rate of decomposition and mineralization. As a result, wheat area is forecast to be displaced by other crop types. In order to tackle this issue, major mitigation and adaptation measures for example promoting area closures and conservation agriculture-based (CA), agroforestry practices, efficient use of energy sources, etc. should be practiced and given special attention by the communities as well as the government to solve the effects of climate change on wheat production and productivity in the country.

Key words: C_3 crops, Climate change, Grain-quality, Heat stress, Photorespiration, Wheat.

Climate change refers to a change in the state of the climate that can be identified by using statistical tests by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC, 2014). A study by Brajesh and Amaranth (2011) and Zerihun (2012), noted that wheat is growing in cool environments of Ethiopian highland areas. The results of long term changes in rainfall and hotter temperatures are very sensitive to grain filling and maturity periods of wheat. Crop productivity damage in a changing climate will generally be greater in countries located closer to the equator, where temperatures already tend to be close to crop tolerance levels (Cline, 2007). In the absence of any boost from carbon fertilization, the most severely affected countries are in Africa, Latin America and South Asia (Cline, 2007), although most of the world registers a decline in agricultural productivity. If there are no beneficial effects from increased carbon dioxide, agricultural output declines almost everywhere and catastrophically closer to the equator.

Different aspects of climate change, such as higher atmospheric CO_2 concentration, increased temperature and changed rainfall all have different effects on plant production and crop yields. In combination, these effects can both increase or decrease plant production and the net effect of climate change on crop yield depends on the interactions between these different factors. The increasing temperature will increase the rate of evapotranspiration and crop water requirements, adding to the currently frequent water stress of crops (Belay, 2014). Recent, different studies have also shown that greenhouse gases such as carbon dioxide (CO_2) lead to changes in climate conditions such as temperature, precipitation, soil moisture and sea levels and results in negative impacts of future climate change entail serious damage on production of wheat crop in 2050 of Ethiopia (Zerihun, 2012). These climatic changes may be having adverse effects on ecological systems, agriculture, human health and the economy (EPCC, 2015).

The Intergovernmental Panel on Climate Change (IPCC) forecasts that during this century, there will be an increase in the average global surface temperatures by 2.8°C, with best-guess estimates of the increase ranging from 1.8 to 4.0°C (IPCC, 2007). It is obvious that these increases will be brought about by the increase in the atmospheric

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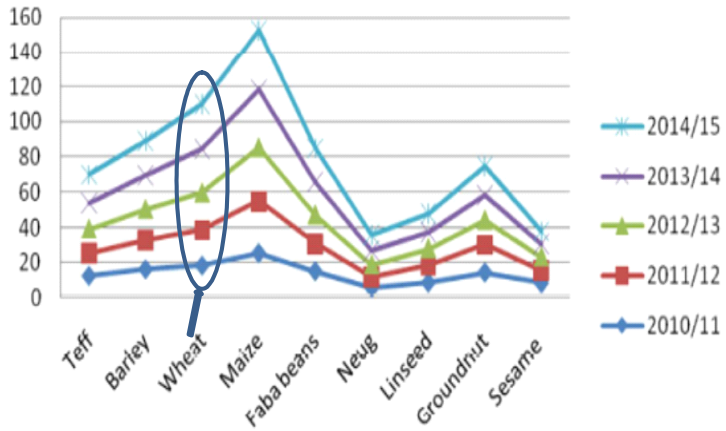
concentration of greenhouse gases. As noted by Steven *et al*. (2008), during climate change phenomenon there was more fertilizer application rates on crop lands. This leads to greenhouse gas emissions to the atmosphere. In general, warmer climate is known to negatively impact wheat production in low latitude regions in most of the developing world. On the other hand, a negative effect of elevated CO_2 on the productivity of wheat crop may be reduced tissue nutrient concentration, particularly nitrogen, which results in lower grain protein content (Hogy *et al*., 2009a, 2009b). Besides to the elevated CO_2, higher temperatures increase the rates of transpiration and crop water demand of wheat crops (Eduardo *et al*., 2013). Higher temperatures also affect grain yield of wheat crop by accelerating phenology and reducing biomass production (Van Ittersum *et al*., 2003) and negatively affects through heat stress (Fulco, 2006). Highest temperatures increase the rates of grain filling, but reduce the duration of grain filling and ultimately grain yield of wheat crop especially reducing grain quality by affecting dough making qualities (Asseng *et al*., 2011; Steven *et al*., 2008).

Climate change is a recent phenomenon for developing countries like Ethiopia and different crop types have been affected by climate change issues. Out of the crop type's wheat is one of the cool environment cereal crop types highly affected by climate change through its yield and productivity per unit area as temperature increases from its level (Brajesh and Amaranth, 2011; Zerihun, 2012; Belay, 2014). There is a large body of literature clearly indicating that there are major challenges to be faced in relation to climate change both globally and in Ethiopia. Records indicate that there has been a rise in temperature over the past decades and is projected to rise further over the coming decades both globally and nationally. The status of annual precipitation, another main climate change factor, is somewhat mixed. Both factors affect agricultural production and productivity in addition to their serious impact on human health and welfare (EPCC, 2015; Porter *et al*., 2014). In order to tackle these problems, reviewing the effects of climate change on the production and productivity of wheat crop is very essential in Ethiopian context so as to put mitigation and adaptation climate change recommendations for future wheat producing issues for Ethiopian poor farmers.

OVERVIEW OF WHEAT PRODUCTION IN ETHIOPIA

Wheat (*Triticum aestivum* L.) is the main cereal crop in the world and it is a staple food of about one third of the world's population (Ehsanullah *et al*., 2013). Ethiopia is the largest wheat producer in Sub-Saharan Africa and has a favorable wheat growing climatic environment especially in the high land areas. Predominantly grown by subsistence farmers under rain-fed conditions, wheat is one of the most important cereals cultivated in Ethiopia and it ranks fourth in area coverage after teff, maize and sorghum (CSA, 2015). Likewise, wheat ranks third as to production levels in grain production after maize and teff in Ethiopia. It is used in different forms such as bread, porridge, soup and roasted grain. In addition to the grain, the straw of wheat is an important feed for livestock, thatching roofs and bedding (White *et al*., 2001).

The average grain yield of wheat is very low in Ethiopia as compared to other growing countries of the world. This is due to many constraints one of the major problem is climate change effects on the productivity of wheat crop. Wheat production constraints include low soil fertility, grass weed infestations, waterlogging in vertisol areas and water deficits in short season areas; stripe rust (*Puccinia striiformis*) is common at higher elevations (> 2,400 m); stem rust (*P. graminis* f. sp. *tritici*) is more problematic at mid-elevations (2,000-2,400 m) (White *et al*., 2001). Out of the total grain crop area of 10,144,252.30 hectares wheat took up 1,663,837.58 hectares of the grain crop area in Ethiopia. According to Central Statistical Agency of Ethiopia (CSA) (2015), as to production 42,315,887.16 quintals of wheat grain production was obtained in Ethiopia. According to CSA (2015), with regard to estimate of wheat crop yield trend has shown an increment ranges from 20.29 to 25.43 Qt/Ha over the last four years from 2011/12 - 2014/15 (Fig 1).



Source: (CSA, 2015)

Fig 1: Trends of estimated wheat crop yield from 2010/11-2014/15 during "*Meher*" (main-rainy) season.

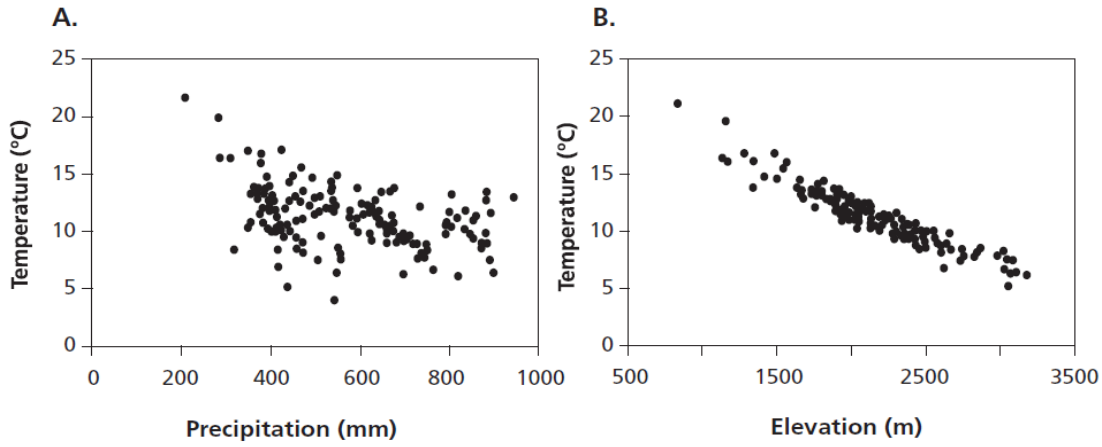
Although Ethiopia is the largest wheat producer in Sub-Saharan Africa, it is reliant on foreign wheat imports to satisfy its annual domestic demand. Therefore, the Ethiopian government through the Agricultural Growth Program is active in efforts to improve the production and productivity of wheat to increase domestic supply. Wheat in Ethiopia is primarily grown in the Amhara, Oromia, Tigray and Southern Nations, Nationalities and Peoples (SNNP) regions. The majority (59-75%) of wheat is grown in the region of Oromia, particularly the Arsi-Bale wheat belt that begins just north of Addis Ababa and extends to the southeast. Amhara region is also a major producer and these two regions accounted for 88% of domestic production. These regions account for more than 90% of national wheat production. Wheat production zones in Ethiopia lay at altitudes ranging from 1500m to 3000m. The most suitable areas for wheat production, however, fall between 1900m and 2700m in the highlands rainfall distribution is bimodal and ranges between 600mm and 2000mm (ECEA, 2008).

A review of growing season conditions for various highland research sites suggested that precipitation and minimum temperature were key determinants of potential wheat areas. Setting requirements of at least 350 mm rainfall and a minimum temperature between 6° to 11°C during the wettest quarter (three months) (White *et al*., 2001). This result also shows the lower limits of 350 mm for precipitation and 6°C for minimum temperature (Fig 2A) for wheat distribution in Ethiopia. However, the upper limit for minimum temperature proved more problematic, with about half the collection sites exhibiting minimum temperatures over 11°C and some sites having values over 15°C. Comparing minimum temperature with elevation (as estimated from the 5 km digital elevation model, not as reported with the germplasm collection data) showed that some collections came from locations well below the suggested 2,000 m limit (Fig 2B).

Because water deficits and warm night temperatures seemed to be key factors defining bread wheat production areas in Ethiopia. Potential new areas for bread wheat production were identified by assuming that technologies could be developed to allow wheat to be grown in drier or warmer environments. For drier conditions, such technologies might include more drought tolerant cultivars, supplemental irrigation from small catchments, or agronomic practices such as reduced tillage and residue retention that reduce runoff. Growing wheat under warmer conditions might require cultivars with greater heat tolerance as well as resistance to pathogens that prevail under warmer conditions (ECEA, 2008).

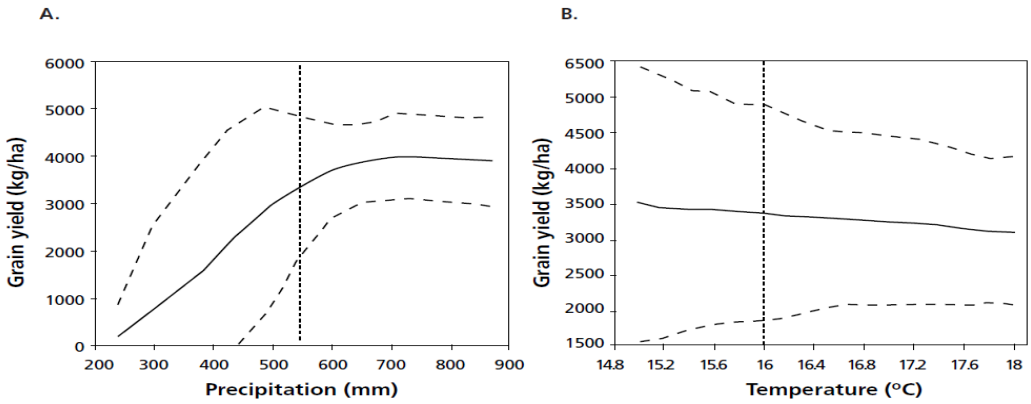
Using 10 years of weather data at Kulumsa, simulations were run to evaluate wheat yield response to precipitation and temperature (Fig 3). Reducing precipitation from the mean of 540 mm to 490 mm over the growing season decreased yields 430 kg/ha, whereas an increase of 50 mm raised yields 345 kg/ha (Fig 3A). Reducing the maximum and minimum temperatures during the growing season 1°C (for a growing season mean at Kulumsa of 16°C) increased wheat yields about 140 kg/ha (Fig 3B). This was attributable mainly to a slight delay in maturity (120 days vs 115 days for the actual weather). Increasing temperatures 1°C decreased wheat yields 130 kg/ha, whereas an increase of 2°C reduced wheat yields 270 kg/ha (White *et al*., 2001).

A recent study by Asseng *et al*. (2015), involving Kansas State University researchers found that in the coming decades at least one-quarter of the world's wheat traded will be lost to extreme weather from climate change if no adaptive measures are taken. For this study, researchers systematically tested 30 wheat crop models against field experiments from around the world that were conducted in areas where the average temperature of the growing season ranged from 15 to 32°C. The models accounted for planting dates, planting rates, temperatures and other crop management factors. With the models, researchers were able to look at the effects of temperature stresses on wheat and predict future changes based on temperature changes. Different researchers in the country found wheat yields are



Source: (White *et al*., 2001)

Fig 2: Relationships between total precipitation (A) and elevation (B) and mean minimum temperature during the wettest quarter for 180 wheat germplasm accessions collected in Ethiopia.



Source: (White *et al.*, 2001)

Note: Broken lines indicate +/- 2 standard deviations for simulations based on 10 years of weather data. The vertical lines indicate mean values over the growing season.

Fig 3: Variation in wheat grain yield at Kulumsa, Ethiopia, as simulated for changes in growing season total precipitation (A) and mean temperature (B).

projected to decrease by 6% for each °C the temperature rises if no measures to adapt to extreme weather fluctuations are taken. Researchers also found that increasing temperatures are shortening the time frame that wheat plants have to mature and produce full heads for harvest, resulting in less grain produced from each plant (Asseng *et al.*, 2011).

The critical goal of wheat crop production is to get optimum or maximum yield of interest through combination of better crop genetic, environmental and management factors. Environmental climatic factors such as temperature, moisture, radiation and CO_2 directly affect phonological and physiological processes involved in biomass and grain development of wheat crop. The increase in concentration of atmospheric CO_2 is expected to be beneficial for yield increment as a whole. Nevertheless, an increase in temperature will benefit a yield advantage from CO_2 fertilization, which is even worse when accompanied with water deficit. In Ethiopia, model predictions have shown that climate change will affect grain yield significantly and the effects are variable with crop and region types. For example predictions by EPCC (2015) showed that at national level yield of maize will increase by about 10% in the mid-century (2050), but decline by end of the century (2100). The same models predicted declining yield of wheat throughout the century (Table 1).

At regional level models projected an increase in maize yield by 48% in Amhara region in the mid-century and by 2% in Oromia region by end of the century. Nevertheless, models predicted a decreasing yield for wheat and tef with much reduction (17%) in the SNNP region in case of wheat (Table 2). Similarly using SWAT model, Mohammed (2009) predicted a 35 and 20% yield reduction in wheat by 2020 and 2050, respectively at Anjeni, North West Ethiopia. The same model predicted a yield reduction of 12 and 7% for tef in 2020 and 2050, respectively (Mohammed, 2009).

Waithaka *et al.* (2013) using DSSAT (Decision Support System for Agro-technology Transfer) model found substantial reduction in wheat yields even where rainfall is expected to increase, presumably owing to heat stress while there will be 25% gain in maize yield in the eastern highlands at the edge of Great Rift Valley as well as in the north central highlands. The same model showed a yield reduction of rain-fed sorghum over large areas in the western and north western part of the country. As a result 5-25% yield decline is expected in the western parts of Tigray, Amhara, Oromia and SNNP as well as the whole of Benishangul Gumuz and Gambella states. Over large areas of Gambella, the yield

Table 1: Predicted change in national crop productivity of major crops in Ethiopia in response to projected climate using CGCM2, PCM and HadCM3 GCMs under the A2 and B2 emission scenarios.

Crop	Predicted % change in national production (%)	
	2050	2100
Maize	10.84	-1.14
Wheat	-6.21	-11.03
Tef	-2.43	-1.09

Source: (EPCC, 2015).

Table 2: Comparative predicted % age change in grain productivity of major cereal crops among the three major grain producing regional states of Ethiopia in response to projected climate change using CGCM2, PCM, HadCM3GCMsunder the A2 and B2 emission scenarios.

Crop	Year	Projected % age change at regional level		
		Oromia	Amhara	SNNP
Maize	2050	-1.51	47.86	-3.09
	2100	0.18	-0.21	-8.19
Wheat	2050	-7.26	-0.19	-17.04
	2100	-9.59	-12.3	-17.23
Tef	2050	-3.58	-1.93	1.89
	2100	-1.62	-0.66	-0.28

Source: (EPCC, 2015).

decline might be exceeding 25%. On the other hand, more than 25% increase in sorghum yield is expected in central Ethiopia and isolated areas in the northern part of the country (Waithaka *et al*., 2013).

CLIMATE EXTREMES AND ITS EFFECTS ON WHEAT PRODUCTION IN ETHIOPIA

Climate extremes in Ethiopia

Among the many challenges constraining Ethiopian agriculture, none is more severe than that caused by its devastating dependence on the vagaries of weather and climate. Erratic rainfall and excessive evapotranspiration due to extended dry season have been causing drastic crop yield reductions, or crop failures and decrease herbage biomass yield and carrying capacity of grazing lands (EPCC, 2015). Many reports indicate that there have been major droughts in Ethiopia over the past centuries, 15 of which, in fact, occurred in the last 50 years or so (Mahoo *et al*., 2013; Belay, 2014). It would be noted that droughts leading to major losses or suffering in human as well as loss in livestock due to shortage of water and grazing lands. This is severely aggravated when rain failures occur repeatedly (i.e., year after year) both in the short (*Belg*) and main (*Meher*) rainy seasons.

Events like flooding, hail storm and landslides as well as the periodic occurrence of pests (including insects, migratory birds and rodents) and diseases of various types also increase the vulnerability of the agricultural community as well as the national economy. All of these natural factors occur at some point in the agricultural calendar and they can be neither predictable nor easily amenable to prevention measures as might be expected (Kassa, 2014).

The impact of climate change on crop production would be mainly through change in temperature, rainfall, length of growing period, time of critical growth rate, increased evapotranspiration and hence productivity would be seriously reduced (EPCC, 2015). A range of climate change scenarios and models suggest that many parts of Ethiopia are likely to experience a decrease in the length of growing period and in some areas, the decrease may be severe (Mahoo *et al*., 2013). This impact of climate change is further aggravated by rapid population growth of Ethiopia, projected to reach close to 200 million by 2050.

Effects of climate change on wheat crop production

For wheat, an increase of 1°C average temperature during the growing season in semitropical wheat growing areas reduces the yield potential on average by 10% (Lobell *et al*., 2007; Umesh *et al*., 2015). Lobell *et al*. (2012), using nine years of data from north-western India, found that crop models underestimate yield losses from high temperature as much as 50% for some sowing dates. These results imply that warming presents an even greater challenge to wheat than implied by previous modelling studies and that the effectiveness of adaptations will depend on how well they reduce crop sensitivity to very hot days. The dominant predicted response of wheat to climate change is a reduction in yield. Knox *et al*. (2011) reviewed 17 studies from South Asia and 20 studies from Africa and found a significant (-7.2%) mean variation in wheat yield for Africa but no significant difference for Asia. According to Gbegbelegbe *et al.* (2012), different model results predicted that wheat yields in most parts of the developing world are expected to decrease due to climate change.

A study conducted by the International Center for Agricultural Research in the Dry Areas (ICARDA), a simulation activity of the impact of a regionally downscaled changing climate on wheat growth and yield under rainfed, Mediterranean conditions using the CropSyst cropping systems simulation model (Stockle *et al*., 2003). CropSyst was calibrated to historic, multiyear data sets on crop growth, biomass accumulation, nitrogen uptake and water use of major wheat varieties grown at ICARDA headquarters in the north of Syria. Subsequently, researchers analyzed the impact of climate change considering the future periods 2011–2030, 2046–65 and 2080–99 as provided by 15 GCMs within the framework of the IPCC climate change studies (IPCC, 2007) and quantified possibilities for mitigating the negative impact of climate change by means of application of supplemental irrigation (Sommer *et al*., 2011). Warmer temperatures and more frequent exposure to high temperature events are major drivers of yield loss with climate change. In wheat, this can be mainly attributed to more rapid crop development, reduction of wheat reproductive phase and reproductive failure and drastic reduction of grain number and yield by heat stress.

Effects of elevated CO_2 on wheat yield

There is considerable on-going debate concerning the effects of elevated CO_2 on crop growth and yield. Whilst there is a clear mechanistic basis for a direct CO_2- induced stimulation of C_3 photosynthesis, the scale of the response observed in the field has been much less than expected based on greenhouse studies only (Leakey *et al*., 2009). A meta-analysis of Free-Air CO_2 Enrichment (FACE) experiments gave a general trend towards increases in wheat yield (15%) under elevated CO_2, but these increases were not statistically significant (Ainsworth and Long, 2005). Elevated CO_2 concentrations may have negative effects on the grain quality of wheat crop interms of protein content and alters wheat grain lipids and doubled the number of mitochondria in wheat leaves, lower seed nitrogen concentration and decreases grain and flower protein (Fentahun, 2013).

By 2050 atmospheric CO_2 levels are expected to be around 550 ppm. In C_3 species like wheat, the elevated CO_2 level is expected to increase productivity through the improvement of CO_2 diffusion through stomata and a consequent effect on photosynthesis. However, a complex of interactions can arise among plant development, growth and environment variables. Plants that have acclimated to high CO_2 and grown new leaves over time (with typically fewer and smaller stomata) do not show the same high photosynthesis rates as a normal plant will under short

periods of exposure (Leakey *et al*., 2009; Parry and Hawkesford, 2010). Consequently, the observed increases in yield have been only in the order of 10 to 20% for crops like wheat, when grown in open-top chambers with elevated CO_2.

Analysis of impact of elevated CO_2 on yield of wheat in India using CropSyst model showed increases in yield up to 2°C rise in temperature at doubled (375 to 750 ppm) CO_2 condition. The increased growth response with increasing CO_2 concentration was attributed to greater tillering and more grain-bearing panicles due to increased net assimilation rate and canopy net photosynthesis under elevated CO_2 concentration. The photosynthetic acclimation to elevated CO_2 concentration in wheat occurred because of down regulation of Rubisco, through limitation imposed on Rubisco gene expression, as a consequence of sugar accumulation in the leaves (Pandurangam *et al*., 2006). In an another study in central India, Naidu and Varshney (2011) reported that the negative effect of drought and weeds on wheat yield under rising temperatures can be ameliorated by the elevated CO_2 levels of 550±30 ppm compared to ambient (370±20 ppm) CO_2.

Effect on length of wheat growing period (LGP)

A study by EPCC (2015) reported that an increase in temperature, as a manifestation of climate change affects duration of crop growth by slowing or hastening growth and development. Under cool climatic condition, for instance, the process of crop growth is slow and takes longer time to finish life cycle from germination to senescence. Slow growing process during vegetative phase allows the wheat crop to have more photosynthetic time to accumulate more assimilates. Wheat crop will also have time at grain filling stage to translocate assimilates from source to sink to produce heavy size grains and thereby high yield. Conversely, under warm temperature conditions, the rate of internal metabolic process is higher with hastened growth and development resulting in early maturity. As a result, wheat crops will have less time for vegetative growth to produce enough assimilates and also shorter time to mobilize assimilates to fill their sink at grain filling stage which results in small size and shriveled seeds at harvest.

A recent study on maize in the Central Rift Valley of Ethiopia using two crop simulate on models (DSSAT and WOFOST) under various climate change scenarios predicted a reduction of maize growth duration by 14-33 days by 2050 compared to the present, due to higher temperature and variable rainfall conditions (Kassie *et al*., 2014). Another study in the Tigray Regional State indicated a decrease in the LGP by 14–26 days in 2030s (Gebre *et al*., 2014).

Effect on wheat photosynthesis and respiration processes

Increased carbon fertilization of crops is reported to affect crop production positively especially in C_3 species. Increased CO_2 concentration increases yield by increasing rate of photosynthesis, leaf area index and accumulation of non-structural carbohydrates, biomass and decreasing stomatal conductance and transpiration loss of water (Gready *et al*., 2013; Chauhan *et al*., 2014). You and Ringler (2010) projected 8-10% increase in agricultural growth domestic product (GDP) of Ethiopia due to fertilization of 482-532 ppm CO_2 by 2050. On the other hand, elevated CO_2 negatively affects crop production by decreasing the carbon to nitrogen ratio (Chauhan *et al*., 2014). Unlike CO_2, elevated temperature affects crop production negatively by increasing rate of respiration; hastening plant growth and development; increasing photorespiration of wheat crops and reduces photosynthetic efficiency due to O_2 affects the photosynthetic path way instead of CO_2; increasing rate of water loss by increasing evapo-transpiration and decreasing nutrient use-efficiency through increased rate of decomposition and mineralization.

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). 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 [CO_2], that is source leaves, individual sink tissue (fruit, seed, stem, root etc.) and total sink tissue. On the other hand, result of a few other experiments show that a short-term increase in temperature on plants growing in cold climate areas have resulted in greater potential impact on plant respiration than in plants growing in warmer areas (tropics) (Atkin and Tjoelker, 2003).

Respiration is necessary for many processes in living organisms; for instance, it is crucial for maintenance of photosynthesis activity, mainly because of the energy demands of sucrose synthesis. Moreover, 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 65% of the total CO_2 released to the atmosphere (Atkin *et al*., 2005). For a majority of plants, growth in relation to temperature at initial stage on base (low) temperature, there is no active plant growth. As temperature increase rapid and optimal growth will come up, as it reaches to maximum tolerable temperature, the rate remain constant or starts to decline following rise in temperature (Heidorn, 2003). The rates of photosynthesis and respiration processes initially increase over a temperature range followed by a flat response after which it starts to decrease. However, the responses of photosynthesis and respiration differ. For example the light saturated photosynthesis reaction rate of C_3 crops such as wheat is at maximum at a temperature range of about 20-32°C, while crop respiration increase over a temperature range of 15-40°C followed by a decline (Atkin *et al*., 2005).

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. Following increased temperature to a certain level, the rate of photosynthesis is also increased but not as much as respiration. That indicates the amount of CO_2 produced from increased respiration is faster than the amount of O_2 released from increased photosynthesis (Asseng *et al*., 2015). Temperature affects photosynthesis through altering the activities of enzymes, electron transport and leaf temperature (leaf-to air vapor pressure difference) can influence the stomatal conductance. As evaporation increases, stomata tends to close to reduce water loss through transpiration, following this stomata closure reduction in CO_2 assimilation rate occur due to less rate of CO_2 supply to chloroplast, this is indirect temperature response (Asseng *et al*., 2015).

Wheat diseases and pests in a changing climate

According to Asseng *et al*. (2015), a survey study was carried out by international researchers in China; there is a risk that severity of epidemics of some wheat diseases may increase within the next ten to twenty years due to the impacts of climate change. The study was shown to establish a link between weather and the severity of epidemics of fusarium ear blight on the wheat crops. This weather-based model was then used to predict the impact on severity of the disease of future weather scenarios for the period from 2020 to 2050. During severe epidemics, wheat crop losses can be as much as 60%. The weather plays a big part in the development of the disease on the wheat crops so that the incidence of the disease is determined by temperature and the occurrence of wet weather at the flowering or anthesis of the wheat crops. Different weather-based model developed in different research areas were used to predict how climate change may affect the wheat crops, it was predicted that wheat flowering dates will generally be earlier and the incidence of the ear blight disease on the wheat crops will substantially increase (Asseng *et al*., 2015).

At a global scale, pests and diseases attribute to an average yield loss of 18% and 16%, respectively in major crop species (IPCC, 2014). Climate change will alter potential losses to many pests and diseases as changes in temperature can result in geographic shifts through changes in seasonal extremes. Although, evaluation of climate change impacts on crop pests and diseases is difficult, owing to lack of long-term data sets, some studies highlight the potential impact of climate on crop diseases and pests (EPCC, 2015).

A current study by EPCC (2015) observed that wheat rust risk, a major threat to wheat production in Ethiopia in recent years, has been observed to respond to ENSO (Eli No and Southern Oscillation). Changes in climate are expected to affect the geographic range of specific species of insects and diseases for a given crop growing region. Climate change may also influence the migration of agronomic and invasive weeds species which possess characteristics that are associated with long-distance seed dispersal and it has been suggested that these species may migrate rapidly with increasing surface temperatures (IPCC, 2014).

Effect on suitable production area of wheat in Ethiopia

One of the major expected effects of climate change on crop production in Ethiopia is relocation of suitable area of production for different crops. Under warming scenarios, plant species are forced to relocate growing areas to remain within optimal thermal zone (Mekasha *et al*., 2013). As species relocate habitat area, there may be net gain or loss of area of adaptation and production. In line with this, EPCC (2015) showed that by 2020 the major cereal crops of Ethiopia such as maize, teff, sorghum and barley will loss over 14, 11, 7 and 31% of their current suitable area of production, respectively. For maize, tef and barley this will be expected to increase to over 18, 11 and 37% by 2050, respectively. This indicates that C_4 species (maize, sorghum, millet and tef), which are originated in warm tropical environments will reach near to their upper limit of maximum temperature tolerance and a small increase in temperature over the present maxima will displace them from their current adaptation area and hence the areas used to be planted to these crops will be out of production (at least for the crops mentioned including wheat).

Apart from C_4 crops, C_3 species, which are adapted to cool temperature, will be most affected by projected climate change. This is because C_3 crops like barley and wheat are grown over small areas in the highlands and relocation of growing areas upward along altitudinal gradient will further reduce suitable area available for the crops due to the natural decline in area available, with increase in altitude. As a result, wheat is also expected to lose significant area of its current production including where rainfall is expected to increase (Waithaka *et al*., 2013).

CONCLUSION

Wheat is increasingly being pushed into more high land areas due to higher climate change effects and replaced by other crops like maize and tef in Ethiopia. In the near future, wheat cultivated land is shrinking and instead other crops that are tolerant to high temperature and little moisture requiring crops can be more progressively covered the wheat areas of the country. Under a climate change scenario, more carbon dioxide concentration has positive influence on the productivity of wheat crop since a C_3 crops need high level of carbon dioxide compensation point. Besides to this, different researchers found that the effects from climate change and its increasing temperatures on wheat will be more severe than once projected and are happening sooner than expected and there is wheat yield decreasing trend in the country. Researchers said increases in the average temperature are problematic; a bigger challenge is the extreme temperatures that are resulting from climate change. Increasing temperature for C_3 crops like wheat brings inactivation of the nature of the enzyme Rubisco and evapotranspiration loss becomes very high, finally the photosynthetic products were affected negatively. This results in poor yield harvest due to fast growth, immature

grains and the seed contains poor nutrient qualities like proteins, lipids and carbohydrates. Therefore, changes in genetics and crop management can minimize some of these yield losses. Rising temperatures reduce not only wheat yields but also unknown diseases and pests' outbreak and strictly that attack wheat crops in Ethiopia. Therefore, Ethiopian farmers especially in the highlands must participate how to adapt the future changes in climate that will occur. In response to changes in climate, through practicing adaptation options it is important to protect wheat crop yields from damages. Examples of such adaptive responses are improved water management (irrigation), improved crop varieties and other adjustments in agricultural practices that could counteract the effects of climate change should be addressed by governments and farmers.

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