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The Impact of Climate Change on Maize *(Zea mays)* Production; Assessing the Biotic and Abiotic Stress

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Abstract: ***Climate change is a global phenomenon and has adverse effects and impact on agricultural crops growth and productivity. Over the years, this has periodically reduced the harvest yields and economic value of the crops. In the context, Maize (Zea mays) was taken as a case study and it is one of the most consumed staple crops in the world and can easily be grown globally. Climate change has tremendous impact on its growth and productivity too. This paper reviews effects of Climate Variability in Relation to Biotic and Abiotic Stress, the abiotic stress which has increased due to climate change includes Drought is the most pervasive limitation to the realization of yield potential in maize, heat in which at the end of this century the growing season temperatures will exceed the most extreme seasonal temperatures recorded in the past century. Biotic stresses account for a significant proportion of maize yield losses worldwide which includes the plants diseases and insects - pests. In plants diseases, climate changes have the potential to modify host physiology and resistance, and alter both stages and rates of pathogen development. In insects - pest; increased temperature as a result of climate change can speed up the life cycle of insects leading to a faster increase in pest populations. It has been estimated that a 2°C increase in temperature has the potential to increase the number of insect life cycles during the crop season by one to five times. This paper also reviewed the strategies for mitigating climate related effects of biotic stresses and abiotic stresses on maize yields. For the biotic stresses mitigation, the following strategies and approaches were suggested, Conventional breeding, Molecular breeding, Precision and High Throughput Phenotyping. For the abiotic stresses mitigation, planting of Drought - tolerant maize seedlings could help that boost farmers' yields and incomes, in the face of climate change. In conclusion, varieties with increased resilience abiotic and biotic stresses will play an important role in adaptation and resilience to climate change. Improvedmaize seeds production and deployment, effective policies and management strategies globally will be of a great win.***

Keywords: Climate Change, Abiotic and Biotic Stress, Maize, Drought, Impact And Adaptation

1. Introduction

Climate change can be described as change in the state of the climate that can be identified by changes in the mean 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. It is also the variation in the earth's global climate or in the regional climates over time. It is change of climate which attributed directly or indirectly to human activity that alters the composition of the global atmosphere (IPCC, 2001). Climate change is a phenomenon due to emissions of greenhouse gases from fuel combustion, deforestation, urbanization and industrialization resulting variations in solar energy, temperature and precipitation. Climate change is an emerging environmental challenge to date is a natural process and has been considered through increased variability and uncertainty of precipitation.

Climate change is the global issue at present. Climate change possesses an increasing threat to the sustainability of agricultural production and livelihood strategies of poor rural people worldwide. The threat of and vulnerability to climate Change are special challenges in marginal areas. Scientific studies show that world climate is changing and it affects the overall systems in the earth. Greenhouse gases (GHGs) mainly CO2, N2O and CH4 majorly emitted from the energy sector is the major contributing agents of climate change. Emission of Carbon Dioxide (CO2) is the major element which forms more than 80% of the total GHGs. GHGs have created a greenhouse effect which subsequently altered precipitation patterns and global temperatures. The concentration of greenhouse gases in the atmosphere has increased significantly since the industrial revolution in 1750s. The amount of Carbon dioxide has been increased by 31%, Methane by 151% and Nitrous oxide by 17% (Regmi, 2004).

Increasing concentration of anthropogenic ally produced greenhouse gases which include Carbon dioxide, Methane, Nitrous Oxide, Chlorofluorocarbons and Water vapour are responsible for the changes in the climate of the Earth, and these gases block infrared radiation escaping directly from the surface to the space resulting in warming of the atmosphere.

Agriculture is sensitive to changes in climatic conditions, with outcomes affecting food security, livelihoods and economic prosperity. Climate change is a threat that, in the short term, will significantly affect the rural poor who are the most vulnerable given their limited resources and high exposure to risk. The poor in the tropics are of particular concern because some impacts of climate change e. g. water availability, droughts and floods are expected to be highly negative in the tropics and sub - tropics. Improved knowledge of such vulnerability is needed in order to design appropriate response and mitigation strategies.

Analyzing climate variability and food security, reports by Intergovernmental Panel on Climate Change (IPCC, 2007) have indicated least developed countries to suffer the devastating effects of climate change and climate variability, with colossal economic impacts because it often lacks adaptive capacity. The African rain - fed agriculture compared to other parts of the world is viewed by many observers to be the most vulnerable sector to climate variability and the potential impacts of climate change on agriculture are highly uncertain. The report by World Meteorological Organization (WMO, 1996) revealed that the overall global warming is expected to add in one way or another to the difficulties of food production and scarcity. The report also stated that reduced availability of water resources would pose one of the greatest problems to agriculture and food production, especially in the developing countries. Climate variability is likely to increase under global warming both in absolute and relative terms (Katz and Brown, 1992). According to reports of Intergovernmental Panel on Climate Change (IPCC, 2007), factors such as endemic poverty, bureaucracy, lack of physical and financial capital, frequent social unrest and ecosystem degradation contribute to Africa’s vulnerability to climate variability.

The Intergovernmental Panel on Climate Change (IPCC) fourth assessment report confirmed that climate change is unequivocal. It is coming to us faster with larger impacts and bigger risks than even most climate scientists expected as recently asa few years ago. One particular worry is the disastrous consequence to agriculture and food security sectors in many parts of the world, particularly in developing countries.

Adaptation is the only option to reduce the impacts of climate change. However, before planning adaptation policies or strategies to climate change, it is important to assess the impacts of climate change at regional and local scale to have scientific evidence that would guide the formulation of such policies or strategies.

Maize (Zea mays) is a tropical grass, yet is vulnerable to climate change. More than 50 varieties of maize exist, but are generally divided into five major categories: flint corn; dent corn; flour corn; popcorn; and sweet corn. Each of the varieties of maize is based on kernel size, color, and the amount of starch within each kernel. Its temperature range is greater than for rice, especially its ability to withstand cooler temperatures. However, its growth and yields are also affected by hot temperatures over 35°C; temperatures above 35°C are considered inhibitory at whatever stage of growth. Generally, the warmer the temperature, the faster the plant completes its life cycle (phenology). In warm temperatures, rapid plant growth can lead to lower yields because the plant (stem and leaves) mature before grains completely filled. Like rice, warmer night - time temperatures reduce its yield while increasing its water demand (FAO 2013). Recent temperature trends, more frequent hot days, warmer nighttime temperatures, and generally warmer temperatures would thus negatively affect maize growth and reduce maize yields.

Water requirements for maize vary greatly depending on variety, soil and temperature, but generally it does best between 500 and 800 mm/growing season. However, yields are very sensitive to water deficits during the flowering period. Severe water deficits during that period, particularly at the time of silking and pollination, may lead to little or no yield, or to a reduction in the number of grains per cob (FAO 2013).

Maize is the third most important crop in the world after wheat and rice. World production of maize is put at 1147.6million tonnes as at 2018 (FAO, 2019). However, to meet the demands of its rapidly expanding population, an estimated 50 % increase in maize production is required over the coming decades (Wudiri and Fatoba, 1992), a goal that is made difficult by the declining natural the influence of climate change on maize production in the country, resources. Therefore, only adds to an already complex problem. For this reason, an estimation of its likely impact is vital in planning strategies to meet the increased demands for maize in the next century.

In recent years, a number of controlled - environment studies have added to our understanding of the effects of increased temperature and CO, on crop growth and development (Kimball, 1983; Bisbal, 1987; Baker et al., 1989). The use of crop simulation models is one way in which this knowledge can be extrapolated, not only outward to a region but also forward in time. And probably represent the best method we have at present of evaluating the likely effect of climate change.

2. Impacts of Climate Change and Variability in Maize Production

2.1 Effects of Climate Variability in association with Biotic and Abiotic Stress

Crops typically encounter an increased number of abiotic and biotic stress combinations, due to global mean temperature increase or global warming, and potential climate abnormalities associated with it, which severely affect their growth and yield. Concurrent occurrence of abiotic stresses such as drought and heat has been shown to be more destructive to crop production than these stresses occurring separately at different crop growth stages. Abiotic stress conditions such as drought, high and low temperature and salinity are known to influence the occurrence and spread of pathogens, insects, and weeds. They can also result in minor pests to become potential threats in future (Duveiller *et al*., 2007). These stress conditions also directly affect plant - pest interactions by altering plant physiology and defense responses (Figure 3). Additionally, abiotic stress conditions such as drought enhance competitive interactions of weeds on crops as several weeds exhibit enhanced water use efficiency than crops.

2.2 Abiotic Stresses of Maize under the Changing Climate

Heat: By the end of this century, growing season temperatures will exceed the most extreme seasonal temperatures recorded in the past century (Battisti and

Naylor, 2009). Using crop production and meteorological records, (Thomson, 1966) showed that a 6°C increase in temperature during the grain filling period resulted in a 10% yield loss in the US Corn Belt. A later study in the same region showed maize yields to be negatively correlated with accumulated degrees of daily maximum temperatures above 32°C during the grain filling period. (Lobell and Burke, 2010) suggested that an increase in temperature of 2°C would result in a greater reduction in maize yields within sub - Saharan Africa than a decrease in precipitation by 20%. A recent analysis of more than 20, 000 historical maize trial yields in Africa over an eight year period combined with weather data showed for every degree day above 30°C grain yield was reduced by 1 % and 1.7% under optimal rain - fed and drought conditions, respectively (Lobell et al., 2011). The temperature threshold for damage by heat stress is significantly lower in reproductive organs than in other organs

Successful grain set in maize requires the production of viable pollen, interception of the pollen by receptive silks (Stone, 2001), transmission of the male gamete to the egg cell, and initiation and maintenance of the embryo and endosperm development (Schoper *et al*., 1987a). High temperature during the reproductive phase is associated with a decrease in yield due to a decrease in the number of grains and kernel weight. Under high temperatures, the number of ovules that are fertilized and develop into grain decreases.

Drought: Drought is the most pervasive limitation to the realization of yield potential in maize (Edmeades*et al*., 1993). Average annual global losses due to drought in maize range from 15% in temperate zone to 17% in tropical zone as estimated by empirical methods. A precise measurement of yield losses worldwide is not possible due to a range of occurrences of drought from individual fields to regional in extent, with severity from slight to catastrophic. Losses are greatest in parts of the world where soils and weather patterns are less favourable than US Corn Belt, which is named for its long - term suitability for growing maize at relatively low level of risk of crop failure.

Water logging: South and Southeast Asia is frequently affected by floods and water logging problems, causing production losses of 25 - 30% annually (Zaidi and Singh, 2010). Although the area of land in sub - Saharan Africa affected by water logging is lower than in Asia, it is a risk in a few areas. Water logging stress can be defined as the stress inhibiting plant growth and development when the water table of the soil is above field capacity. The diffusion rate of gases in the flooded soil could be 100 times lower than that in the air, leading to reduced gas exchange between root tissues and the atmosphere (Armstrong and Drew, 2002). As a result of the gradual decline in oxygen concentration within the rhizosphere, the plant roots suffer hypoxia (low oxygen), and during extended water logging (more than 3 days), anoxia (no oxygen) (Zaidi and Singh, 2010). Carbon dioxide, ethylene and toxic gases (hydrogen sulphide, ammonium and methane) also accumulate within the rhizosphere during periods of water logging. A secondary effect of water logging is a deficit of essential macronutrients (nitrogen, phosphorous and potassium) and an accumulation of toxic nutrients (iron and magnesium) resulting from decreased plant root uptake and changes in redox potential. Nutrient uptake is reduced as a result of several factors. Anaerobic conditions reduce ATP production per glucose molecules, thereby reducing energy available for nutrient uptake. Reduced transport of water further reduces internal nutrient transport.

Reduced soil conditions decrease the availability of key macro nutrients within the soil. Under water logging conditions nitrate is reduced to ammonium and sulphate is converted to hydrogen sulphide, and both become unavailable to most of the non - wetland crops, including maize. Availability of phosphorous may increase or decrease depending upon soil pH during water logging.

2.3 Biotic Stresses of Maize under the Changing Climate:

Biotic stresses account for a significant proportion of maize yield losses worldwide. The predominant insect-pests and diseases vary across environments and a major challenge in adapting crops to climate change will be the maintenance of genetic resistance to pests and diseases (Reynolds and Ortiz, 2010). Changing climates will affect the diversity and responsiveness of agricultural pests and diseases. Studying and understanding the drivers of change will be essential to minimize the impact of plant diseases and pests on maize production.

Plant Diseases: For a disease to occur a virulent pathogen, susceptible host and favourable environment are essential (Legrève and Duveiller, 2010). All of these components are strongly coupled with environmental conditions. Global climate changes have the potential to modify host physiology and resistance, and alter both stages and rates of pathogen development. Environmental conditions controlling disease development include rainfall, relative humidity, temperature and sunlight. Changes in these factors under climate change are highly likely to have an effect on the prevalence of diseases and emergence of new diseases. For example, in Latin America tar spot complex, caused by Phyllachoramaydis, Monographellamaydis and Coniothyriumphyllachorae, was previously rare. However, recent epidemics of the tar spot complex have been recorded in Guatemala, Mexico, Colombia and El Salvador due to recent climate variability (Pereyda - Hernández *et al*, 2009). Climate change may also affect gene flow, the process through which particular alleles or individuals are exchanged among separate populations. This will increase pathogen population diversity leading to variation in host resistance, variation in pathogen virulence and new specific interactions. This has the potential to result in new diseases or pathogen emergence, and the introduction of pathogens into new ecological niches. Depending on the distribution of populations and environmental conditions that are influenced by climate change, gene flow leads to an increase in population diversity or to the introduction of a new population in new ecological niches. An important example of changes in growing season conditions being linked to outbreaks of diseases, with serious human health implications, is mycotoxins and their prevalence within maize systems. Mycotoxins are toxic secondary fungal metabolites that contaminate agricultural products and threaten food safety. Different groups of mycotoxins are produced by different fungi. A. flavus and A. parasiticus produce aflatoxin, F. verticillioides produces fumonisin, and F. graminierum produces deoxynivelanol (DON) and zearalenone (Cardwell *et al*, 2001) (Miller, 2008). Mycotoxin contamination is a serious problem with long - term consequences for human and animal health. Sub - lethal exposure to mycotoxins suppress the immune system, increase the incidence and severity of infectious diseases, reduce child growth and development, and reduce the efficacy of vaccination programs (Williams *et al*., 2004). Consumption of high doses of mycotoxins causes acute illness and can prove fatal. In 2004, more than 125 people died in Kenya from eating maize with aflatoxin B1 concentrations as high as 4, 400 parts per billion - 220 times the Kenyan limit for foods (Lewis *et al*., 2005). The maize implicated in this outbreak was harvested during unseasonable early rains and stored under wet conditions conducive to mold growth and therefore aflatoxin contamination (CDC, 2004). Previous outbreaks in Kenya and India have also been attributable to unseasonable, heavy rain during harvest (Krishnamachari *et al*,.1975) (Ngindu *et al*., 1982).

Insect - Pests: The dynamics of insect - pests are also strongly coupled with environmental conditions. Insects do not use their metabolism to maintain their body temperature, and are dependent on ambient temperature to control their body temperature. Temperature is therefore the single most important environmental factor influencing insect behaviour, distribution, development and survival, and reproduction. Insect life stage predictions are calculated on accumulated degree days, which is a function of both time and temperature. Increased temperature can speed up the life cycle of insects leading to a faster increase in pest populations. It has been estimated that a 2°C increase in temperature has the potential to increase the number of insect life cycles during the crop season by one to five times (Petzoldt and Seaman, 2005), (Bale *et al*., 2002), (Porter *et al*., 1991). The feeding rate of many arthropod vectors increases at higher temperatures, thus increasing exposure of crops to mycotoxigenic fungi thereby increasing the spread of mycotoxins (Bale *et al*., 2002), (Dowd, 1992). The increased global warming and drought incidences will favour insect proliferation and herbivory, which will likely increase the incidence and severity of insect related damages as well as aflatoxin and fumonisinmycotoxins in maize. Higher average temperatures have the potential to change the geographical distribution of crops. This may in turn result in an expansion of the geographical distribution of insect - pests and their associated pathogens (e. g. maize streak virus, corn stunt complex that are vectored by different species of leaf hoppers), resulting in a change in the geographical distribution of diseases.

3. Solutions for Mitigating Climate Related Effects of Biotic Stresses and Abiotic Stresses on Maize Growth and Production

Breeding for disease and insect resistance requires an understanding of parasite biology and ecology, disease cycles and drivers influencing the evolution of plant - pathogen interactions, because unlike abiotic stresses, biotic stress resistance is influenced by genetic variability in the pest/pathogen population. As a result of the evolving pest/pathogen populations and the changes in fitness favouring new pathotypes/biotypes, improving resistance to biotic stresses has been a long - term focus of agricultural researchers. The long - term success of conventional and molecular breeding for disease or insect - pest resistance will depend on a more in-depth and clear understanding of: (i) the nature of the pathogen/insect - pest, and diversity of virulence in the populations; (ii) the availability, diversity and type of genetic resistance; (iii) availability of suitable sites (hot spots), screening methodologies/protocols for generating adequate disease/insect-pest pressures and tracking resistance; (iv) selection environments and methodologies for rapidly generating multiple stress resistant inbred lines, and their use in hybrid or variety development. Significant progress has been made over the decades in the identification of stable genetic resistance for major maize diseases (Dowswell *et al*., 1996). However, the population structure of most maize pathogens remains inadequately characterized. Also, concerted efforts are required to widely test the available sources of resistance in multiple and relevant environments to expose them to a wide spectrum of pathogen strains and to facilitate identification of the most suitable resistance genes/alleles for use in the breeding programs (Engelen, 2002). Research at CIMMYT is focused on multi-location phenotyping of a common set of 500 maize inbred lines for some prioritized diseases, namely GLS (gray leaf spot), TLB (Turcicum leaf blight), MSV (maize streak virus), and ear rots, across more than 15 locations in Sub - Saharan Africa, Latin America and Asia.

This will help identify stable sources of resistance to key diseases and identify key phenotyping sites for future research. Using a common set of genotypes across environments will also provide the ability to monitor and detect emergence of new pathogen strains that will be registered as shifts in disease pressure and emerging new diseases, and how the environmental characteristics impacts pest biology and prevalence. CIMMYT has also developed several insect-pest resistant populations, inbred lines, and varieties, especially for the stem borers and post - harvest insect pests (weevils and grain borers) through projects such as Insect Resistant Maize for Africa (IRMA). In addition, several inbred lines have been developed combining resistance to stem borers and storage pests.

3.1 Breeding approaches for resilience to climate change biotic stresses

3.1.1. Conventional breeding

During the period of 1982 to 1994, the yield growth rate as a result of conventional breeding was 1.2 % worldwide (Duvick and Cassman, 1999). In temperate maize, breeding based on multi - - -location trials under different weather conditions has resulted in increased grain yields at a rate of 73 kg - - -1 ha - - -1 yr - - -1 under mild stress (Duvick, 1997). In tropical maize, conventional breeding has resulted in gains of up to 144 kg ha - - -1 yr - - -1 under drought stress (Edmeades *et al*., 1999). However, in the face of climate change, it is essential that breeding pipelines are improved to meet the needs of future generations. In conventional drought breeding, the application of proven breeding methodologies in managed stress screening has been attributed to the significant gains in grain yield under drought stress (Bänziger *et al*., 2006). Up scaling training and application of these methodologies across projected drought prone environments will play a key role in the continued development of drought adapted maize. A similar approach will be required for additional abiotic and biotic stress expected to increase under future climates.

3.1.2. Molecular breeding

Molecular breeding offers the ability to increase the speed and efficiency of plant breeding (Whitford *et al*., 2010). Molecular breeding is a general term used to describe modern breeding strategies where DNA markers are used as a substitute for phenotypic selection to accelerate the release of improved germplasm. Currently, the main molecular breeding schemes are marker assisted selection (MAS), marker assisted backcrossing (MABC), marker assisted recurrent selection (MARS) and genome - --wide selection (GWS),

Molecular marker - --assisted breeding relies on the identification of DNA markers that have significant association with expression of specific target traits. The use of molecular techniques within breeding pipelines is widely, and successfully, employed within the private sector (Eathington *et al*., 2007) and with greater emphasis in the public sector.

3.1.3. Precision and High Throughput Phenotyping

Breeding progress relies on genetic variability for the trait of interest (e. g. grain yield under drought stress), high selection intensity through screening a large number of genotypes and high broad - --sense heritability for the trait of interest. Improved phenotyping platforms will provide the foundation for the success of conventional, molecular and transgenic breeding. Yield is a function of many processes throughout the plant cycle thus integrative traits that encompass crop performance over time or organization level (i. e. canopy level) will provide a better alternative to instantaneous measurements which only provide a snapshot of a given plant process (Araus et al., 2008). Many new phenotyping tools based on remote sensing are now available including non - --destructive measurements of growth - --related parameters based on spectral reflectance (Marti et al., 2007) and infrared thermometry to estimate plant water status (Jones et al., 2009).

3.2 Approaches for resilience to climate change abiotic stresses.

3.2.1 Drought - tolerant maizevarieties

Maize is one of the most important crops in Africa, supporting the sustenance and livelihoods of over 300 million people. Maize is also at severe risk due to climate change. Droughts and temperature increases could reduce global maize yields up to 30 percent by 2030, according to the International Maize and Wheat Improvement Center (CIMMYT). To address this, CIMMYT undertook major R&D programs to develop drought - tolerant maize varieties with support from the Bill & Melinda Gates Foundation. The Drought Tolerant Maize for Africa program successfully developed hundreds of new varieties that boost farmers' yields and incomes, directly improving millions of lives.

For example, farmers in Zimbabwe who used drought - tolerant maize in dry years harvested up to 1, 300 pounds more per 2.47 acres — a surplus worth $240 and enough to feed a family of six for nine months. The success of improved maize varieties in Africa provides a model for developing climate - resilient maize in other vulnerable regions and improving less researched crops such as beans, plantains and potatoes.

3.2.2 Improved agronomic management and Crops management

Improved agronomic management can improve soil quality and make cropping systems more resilient to changing environmental conditions. Conservation agriculture, based on minimum tillage, crop residue retention and crop rotation, can improve infiltration and reduce evaporation compared to practices involving conventional tillage and zero tillage without retention of adequate levels of crop residue (Verhulst *et al.*, 2010). The reduction in tillage and increased carbon input in conservation agriculture result in more stable aggregates (Bronick and Lal, 2005). Residue cover prevents aggregate breakdown, and thus crust formation, which is caused by direct raindrop impact as well as by rapid wetting and drying of soils (Le Bissonnais, 1996). In addition, the residue cover slows down runoff, giving the water more time to infiltrate.

4. Conclusion

Different types and varieties with increased resilience abiotic and biotic stresses will play an important role in adaptation to climate change. While this challenge is immense, the advancement in molecular and phenotyping toolscombined with the vast accumulated knowledge on mechanisms responsible for yield loss will provide a solid foundation to achieve increases in productivity within maize systems.

Adaptation to climate change requires cross-disciplinary solutions that include the development of appropriate germplasm and mechanism to facilitate to farmers access to germplasm. Seed production and deployment, effective policies and management strategies at the country, regional and international levels will all be required to ensure that the technologies reach the intended beneficiaries and make the desired impacts. Smallholder and subsistence farmers will suffer more of the impacts of climate change resulting from small farm sizes, low technology, low capitalization, and diverse non - climate stressors will tend to increase vulnerability Farmers have a long record of adapting to the impacts of climate variability. Technologies for the development of improved germplasm, however the first step in the process of reducing the impact of climate changes on Maize growth and production.

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