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Impact of Atmospheric CO_2 Concentration and Temperature Increase on Crop Production

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***Abstract:** Two critical factors impinging on crop production in the coming days are the continued and accelerated increase in CO_2 concentration in the atmosphere and average temperature rise with spikes and locational extremes. Initial thinking that CO_2 concentration increase, being the feed of the plants, will improve crop yields. Enough evidence now exists that this is not going to be the case, most likely because the rate of increase is too fast for the adaptive capacity of the plants. Temperature increase is also going to have negative impact on crops because within the averages the changes in the extremes will be beyond the tolerance level of plants compounded by the relatively higher increase in nighttime increase in temperature compared to the daytime increase.*

1. INTORDUCTION

Green House Gas (GHG) triggered global warming and the consequent climate change is a major existential challenge we now face. Among the primary reasons of concern is that climate change will dramatically stress the existing crop production systems and severely impact the ability of the world to feed its growing and becoming richer population in the coming decades. In fact, the existing crop production systems being followed in much of the world with homogenization, high water intensity and extensive usage of agrochemicals for soil fertility and plant protection are themselves proving to be major cause of climate change.

In each crop system, there exist many climate change adaptation and mitigation options to close yield gaps and minimize the harmful environmental impacts of crop production.

2. HOW CHANGING CLIMATE IS LIKELY TO IMPACT CROP PRODUCTION?

The answer to this question is a big unknown, and that is the real problem. First of all how the climate change itself will play out over in terms of actual change is uncertain. Then there is the unknown element of how much the earth will heat up on the average, but the average will be an average of extremes with many survival level threshold limits getting crossed within the average. As there are many complex linkages and positive and negative feedback, local level changes will remain unpredictable. Some uncertainty associated with modelling the complex relationships between crop health and yields and future climate scenarios will have to accounted for in all possible solutions.

While the unknowns remain, from the perspective of impact on crop production, the following changes are to worked around for a survival solution:

3. CLIMATE CHANGE

- is going to alter long-term trends in average rainfall and temperature as also seasonal variability within the averages, with higher frequency of extreme weather events,
- is likely to shock the timing of recurring biological events and impacts on the causes of their timing with regard to biotic and abiotic stresses, and the interrelation among phases of the same or different species (phenological stages), and
- expected to increase the frequency and extent of extreme weather events (IPCC, 2012).

4. INCREASED ATMOSPHERIC CONCENTRATION OF CARBON DIOXIDE AND ITS IMPACT ON CROPS

The essential cause of global warming is the persistent increase in the concentration of certain gases in the atmosphere viz. Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O) and Fluorinated gases (essentially synthetic gases like Hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride). Each gas's effect on climate change depends on its abundance or concentration in the atmosphere and its time stability in the atmosphere. The effect of increasing concentration of Carbon Dioxide on crops is by far the dominant cause for concern and action..

CO_2 concentration in the atmosphere has seen a constant rise in the last 60 years, from about 315 ppm in 1960 to just short of 400 ppm in 2015. This level could rise to anywhere around 600 ppm by 2050 under current projections. Carbon dioxide levels today are higher than at any point in at least the past 800,000 years. While the elevated level of CO_2 is a problem, this is compounded by the fact that the rate of increase of concentration is going up every decade. In the 1960s, the growth rate of concentration of atmospheric carbon dioxide was roughly 0.6 ± 0.1 ppm per year. This has gone up four times to about 2.3 ppm per year as of 2015. This annual rate of increase over the past 60 years is about 100 times faster than previous natural increases. Such an accelerated change of concentration atmospheric carbon dioxide is way beyond the adaptive and absorptive capacity of plants (and in fact all living beings)

As per current research higher CO_2 concentration would mean higher rates of photosynthesis resulting in increased physical growth along with lower water intake and poorer tissue concentrations of nitrogen and protein. The effect will, however, be different on different crops and will be different on the same crop depending on its production location in terms of soil and atmospheric conditions.

5. DIFFERENCES AMONG C3 AND C4 PLANTS IN RESPONSE TO CO_2 LEVEL RISE

Among crops species, the higher CO2 concentration impact will neither be uniform nor stable. The effects of elevated CO_2 are not uniform. About 85 percent of the plant species on the planet utilize C3 photosynthetic process (rice, wheat, soybeans and all trees). The other two physiologically distinct photosynthetic processes being C4 and CAM. C4 plants include sugarcane, corn (maize), sorghum, millets, and most tropical and sub-tropical grasses.

As per current research, increased concentration of CO_2 in the atmosphere will increase speed of the photosynthesis will increase in C3 plants, along with reduced water uptake because of lower stomatal conductance and transpiration. This means that plants absorb less water and nutrients and that their biomass becomes less nutritious. Thus higher growth because of elevated CO_2 will come at the cost of lower nutritional content proteins, minerals and trace elements like zinc and iron in leaves, stems, roots, fruits and tubers of C3plants (Taub et al., 2008; Loladze, 2017). A big negative however will be carbon protein imbalance in the plant insidious aspect associated with the nutritional quality of crops is that, in addition to humans, also insect pests will have to compensate by eating more to meet their nutritional needs (Hatfield et al., 2011).

Crops that utilize the C4 variant of photosynthesis are expected to prove more stable in response to higher CO_2 concentration. C4 crops like sugarcane, corn (maize), sorghum, millets with presence of RUBISCO enzyme as the differentiating factor, are able to increase the carbon dioxide concentration in their leaves before the photosynthesis begins. Since CO_2 concentrations are already high within the bundle sheath cells, increased concentrations of carbon dioxide in the atmosphere will not have the growth enhancing effect on C4 plants. Affect on yield of C4 plants will also be less under reduced soil moisture conditions (Simpson, 2017). Overall, C 4 plants are expected to remain more tolerant to CO_2 concentration increase.

6. IMPACT OF TEMPERATURE RISE ON CROP PRODUCTION

The first primary consequence of increase in the concentration of GHG is warming as manifest by rise in global average temperature. Temperature rise to the extent of about 1^o Celsius has already happened in the last 150 years, but the next 1o degree warming can happen in less than 40 years if the current indications of levelling of greenhouse gas (GHG) emissions is maintained. This rise could be much faster and higher in case the GHG gas emissions growth is the same as of the last 50 years. Some areas are going to see more than double the 2^o Celsius average warming. Further, there are going to be many kinks and spikes on both sides of the average temperature increase, like higher day time and much faster nighttime temperatures besides change in the intensity and frequency of heat and cold waves, all within a general warming trend.

Although the response to temperature changes is going to be species specific, the temperature sensitivity of most crops is at the reproductive and grain-filling/fruit maturation stage (Hatfield et al., 2011). Temperature change from the normal will affect the photosynthetic activity and the phenological and morphological patterns of crops.

Studies and captured results of past impacts under temperature change situations are our best guide for assessing the possible response to temperature increases. Based on phenological studies spread over at least a 10 year period the following broad observations can be derived:

- A 1^{o} Celsius increase in average temperature is expected to reduce the yield of major food and commercial crops by 5 to 10 per cent as the plants will have to use more energy for maintenance respiration rather for growth if the temperature increase happens during the growing season (Lobell and Field, 2007; Hatfield et al., 2011).
- As the maturation period is going to shrink if consistently exposed to higher temperatures higher reproductive failure will lower yield (Hatfield et al., 2011, Craufurd and Wheeler, 2009).
- Temperature sensitivity of photosynthesis is higher in C3 plants compared to C4 plants (Lipiec et al., 2013).
- The merging trend clearly shows a decline in the amount of winter chill in the temperate areas with variations in the length of the thermal growing season. For growth of vegetative and reproductive organs of the temperate perennials a certain length of time of chilling hours during dormancy is essential before active growth resumes. Declining winter chill will have an impact on the yield and output of temperate perennial crops like apples, cherry and grapes through effects on bud break, flower quality, potential to set fruit and vegetative growth. (Atkinson, et al 2013)
- Temperature change, mostly on the higher side, during the grain filling and fruit maturation stage of the plant will impact theit nutritional value. This will affect the the market value of the crops negatively as under higher temperatures the plants will use higher sugars in the respiration process leaving less sugar in the harvested product. (Hatfield and Prueger, 2015).
- A average increase in temperatures as a consequence of global warming hides a critical fact that within this average the night time temperature is rising 1.4 times the daytime temperature increase. The duration of the warming at night will be longer and spread across a wider area. This nighttime temperature increase is accompanied by increase atmospheric vapor pressure deficit (VPD). The combined impact of increase in nighttime temperature and nighttime evaporative demand is additive and will reduce yields and quality traits. Peng, S. et al. (2004),
- Multiple studies clearly indicate a drop in yields because of negative impact of much faster rising night temperature on rice (Oryza sativa) Chilean quinoa (Chenopodium quinoa), and cotton (Gossypium hirsutum) among others. In wheat a 1°C increase in night temperature during the seed-fill period resulted in a yield drop of 6 per cent among winter wheat varieties and 4-7 per cent drop in spring wheat and rice [(Welch, J.R. et al. (2010), Bahuguna, R.N. et al. (2017), García, G.A. et al. (2015), García, G.A. et al. (2016), Lesjak, J. and Calderini, D.F. (2017), Loka, D.A. and Oosterhuis, D.M. (2010)]
- For most crops photosynthesis the optimum temperature range is 20-30 ^{o} Celsius. In terms of heat tolerance, higher daytime temperatures are well tolerated during vegetative growth phase. (Wahid et al., 2007). However, yields have been observed to have dropped in cases of day time temrpatures exceeding 30-34^{o} Celsius (FAO, 2016b).
- Studies have clearly established permanent damage to plants and even stored seeds under extended exposure to temperatures above 37 degree Celsius, this is especially true if the average temperature increase is over a short time period with plants unable to adapt (Wahid et al., 2007).

7. CONCLUSION

For all practical purposes a tipping point is already here when the adaptive capacity of the plants and the ability of the scientists to continually bring in improved/higher tolerant varieties is proving to be insufficient to the negative impact of changes the climate change is forcing on the crops. Major changes in crop production practices will have to be put in place for maintaining the current level and expected increase in requirements of food and non-food crops.

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