The Impact of Climate Change on Water and Nitrogen Deficits for Maize in East & Southern Africa

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INTRODUCTION

Warming temperatures and altered precipitation are expected to affect yields of maize in East and Southern Africa where water and nitrogen (N) deficits already severely restrict yield. This study asked, what is the expected impact of climate change on water and N deficits on maize in East and Southern Africa? It examined the potential benefit of water and N to reduce the negative effects of climate change.

METHODS

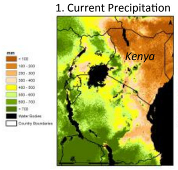
Coupled climate and the CERES Maize model (DSSAT v.4.0) were calibrated for the region, and point and spatial modeling were conducted using a locally adapted hybrid maize. Historical climate datasets (observed and WorldClim) and four GCMs (HadCM3, ECHAM, CCSM, and CSIRO) downscaled to 6 km were used (Olson et al. 2009; Moore et al 2014; Alagarswamy et al 2015). Spatial and point crop-climate simulations of maize using historical and future climate with one of the GCMs, HadCM3, are presented.

RESULTS

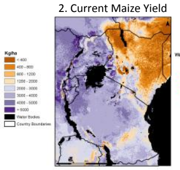
WATER DEFICITS UNDER CURRENT CLIMATE CONDITIONS

Perhaps the most important yield limiting factor in the region is water. In Kenya, for example, 80% of the country is too dry for crop production (Map 1). Yields under rainfed conditions are thus highly differentiated (Map 2) from no yield in semi-arid hot zones, to low yield across savanna areas and in the cold Highlands, and high yields in mid-elevation wetter zones. Water deficits (Map 3) mostly mirror yields, confirming the critical nature of water.

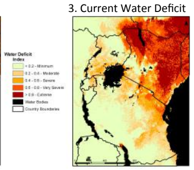
1. Current Precipitation



2. Current Maize Yield

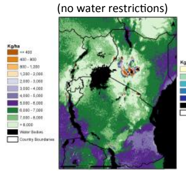


3. Current Water Deficit

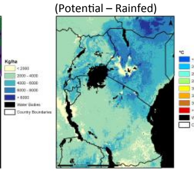


Compare the yield under rainfed conditions (Map 2) with yield grown with *no* water or N constraints, or potential yield (Map 4). The difference is the yield gap, reflecting where irrigation would provide the largest benefit (Map 5). The gap is highest in moderate temperature, dry areas. In hotter or colder areas, the gap is smaller.

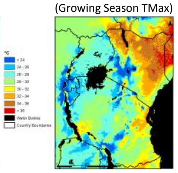
4. Current Potential Yield (no water restrictions)



5. Current Water Yield Gap (Potential – Rainfed)



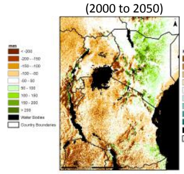
6. Current Temperature (Growing Season TMax)



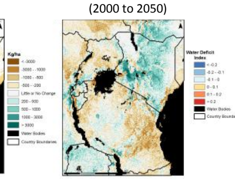
WATER DEFICITS UNDER FUTURE CLIMATE CONDITIONS

HadCM3 projects season temperatures increases of between 1.2° and 3.5° C by 2050. This would raise maize water demand, worsen water deficits and reduce yields in water-limited areas. In the Highlands, however, maize yields would improve because the warmer temperatures would moderate the current cold. Tea and coffee, however, would suffer. HadCM3, like many GCMs, projects increasing precipitation in Kenya, and yields there would rise though still be very low (Maps 7, 8, 9). HadCM3 and other GCMs may not fully incorporate the drying effects of the warming Indian Ocean (Williams and Funk 2011).

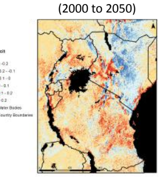
7. Change in Precipitation (2000 to 2050)



8. Change in Yield (2000 to 2050)

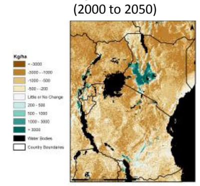


9. Change in Water Deficit (2000 to 2050)

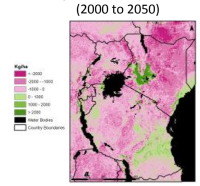


The full impact of climate change is revealed in projected declines in potential yield by 2050 (Map 10). The warming will lower yield even under optimal water and nutrient conditions, due to shorter times to maturity and hot temperatures. The benefits to irrigation, the yield gap due to water, would thus shrink as well (Map 11).

10. Change in Potential Yield (2000 to 2050)



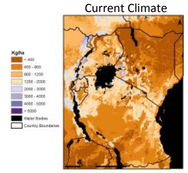
11. Change in Yield Gap due to Water (2000 to 2050)



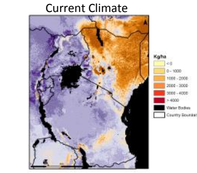
NITROGEN DEFICITS UNDER CURRENT CLIMATE CONDITIONS

The second important limitation to maize yield in this region is plant nutrients. This study focused on N. The benefits to N application are large across the region (Maps 12, 13 and 14). Only in the cold Highlands with their volcanic soil, or in dry or hot areas, is the N yield gap small and N fertilizer would not provide much benefit.

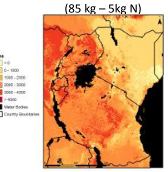
12. Yield with 5kg N Current Climate



13. Yield with 85kg N Current Climate



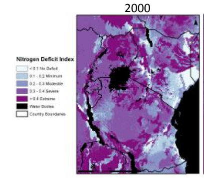
14. Nitrogen Yield Gap (85 kg – 5kg N)



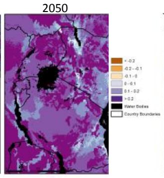
NITROGEN DEFICITS UNDER FUTURE CLIMATE CONDITIONS

Under current climate conditions, most of the region suffers from N deficits (Map 15). In the future, the N deficit is not expected to change in relatively in cool areas, but it will worsen across most of the region (Maps 16, 17). This indicates that in future, N fertilizer will not be able to raise yields as much it currently does.

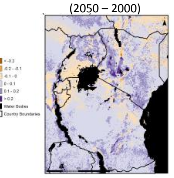
15. N Deficit 2000



16. N Deficit 2050



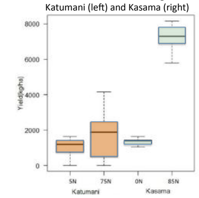
17. Change in N Deficit (2050 – 2000)



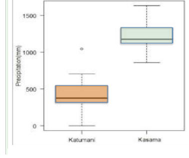
NITROGEN AND CLIMATE VARIABILITY

To example the potential of N to reduce expected worsening precipitation variability, an analysis was conducted of two sites– one hot and dry (Katumani, Kenya) and the other cool and wet (Kasama, Zambia) (Box Plots 1, 2). Even with low N, yield variability was higher in the dry site. A large N application resulted in a 64% yield increase in the dry site, and a much higher 450% increase in the wet. Improvements in inter-annual yield variability also varied by rainfall—again the wetter Kasama benefited more from the N application than Katumani.

1. Yield under low and high N Katumani (left) and Kasama (right)



2. Growing season precipitation Katumani (left) and Kasama (right)



CONCLUSION

- The region has highly variable yield responses to water and N under current and future climates, which calls for locally adapted management recommendations.
- Most maize growing areas are already water limited, and climate change change is expected to worsen water deficits. Unfortunately yield benefits to supplemental water will decline in the future due to hotter temperatures.
- Nitrogen is also very limiting, and yield benefits to N applications are high. However, the yield benefits to N will shrink in the future as water deficits worsen.
- N fertilizer application is likely to most benefit wetter, cooler areas where temperatures remain under 40° C.

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