Nitrogen management in two maize systems of the Tanzanian highlands: approaching the balance of food and environmental objectives

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In sub-Saharan Africa (SSA), cropland intensification with increasing fertilizer nitrogen (N) and organic input is needed to secure food production. However, integrated assessment of yield and N loss in response to different N management is lacking, largely constrained our ability to design an environmentally-friend crop production system. In two sites of the Tanzanian highlands (Iringa, sandy Alfisols; Mbeya, clayey Andisols), we quantified maize yield, NO_3^- leaching, and N_2O emission, for up to four years (2013–2017), under the treatments of increasing N rates (0–150 kg N ha^{-1}) and in combination with maize stover incorporation (~2 Mg C ha^{-1}). Iringa was lower in yield and N_2O emission, and higher in NO_3^- loss, as compared to Mbeya (0.8–2.4 vs. 1.8–4.2 Mg grain ha^{-1}, 0.16–0.67 vs. 0.24–1.6 kg N_2O-N ha^{-1}, and 19–54 vs. 13–31 kg NO_3^--N ha^{-1}). The responses of averaged yield, NO_3^- loss, and N_2O emission to only N input were well described by quadratic, exponential growth, and linear pattern, respectively, in both sites (R^2 = 0.963–0.998, P = 0.006–0.098). Despite the general well fittings, yield and NO_3^- leaching showed large inter-annual variations in Iringa but not Mbeya. When the combined inputs (fertilzier-N plus stover) were involved in describing the response patterns, yield tended to be slightly reduced, NO_3^- loss was negligibly affected, and N_2O emission was markedly raised. We therefore define the optimal N range based on the sole N input scenario, and at N rates where the difference between yield and NO_3^- loss (after normalized into a same scale) reached maximum, provided that the fertilizer-induced N_2O emissions were low across N rates and sites (0.15–0.40% vs. 1% of the IPCC Tier 1 estimate). Optimal N range occurred at ~100 kg N ha^{-1} in Iringa, higher than that (~75 kg N ha^{-1}) in Mbeya, but produced less grain (2 vs. 3.4 Mg ha^{-1}); such optimal N rate may not be practical for local farmers in Iringa. Lower yield and higher NO_3^- loss in Iringa, coupled with large inter-annual variations, suggest that the maize systems are "leaky and fragile" as compared to that of more "fertile and resilient" in Mbeya. Cropland intensification in SSA should prioritize regions with "fertile and resilient" maize systems like in Mbeya, and future research is needed to address the secondary constraints (e.g., micronutrients) on the yield in addition to N input; while for "leaky and fragile" systems like in Iringa, recovery of the soil health is needed before a satisfying response of yield to the N management can be obtained.

Keywords: Sub-Saharan Africa, Soil type, Maize yield, Nitrate leaching, Nitrous oxide emission, Stover incorporation

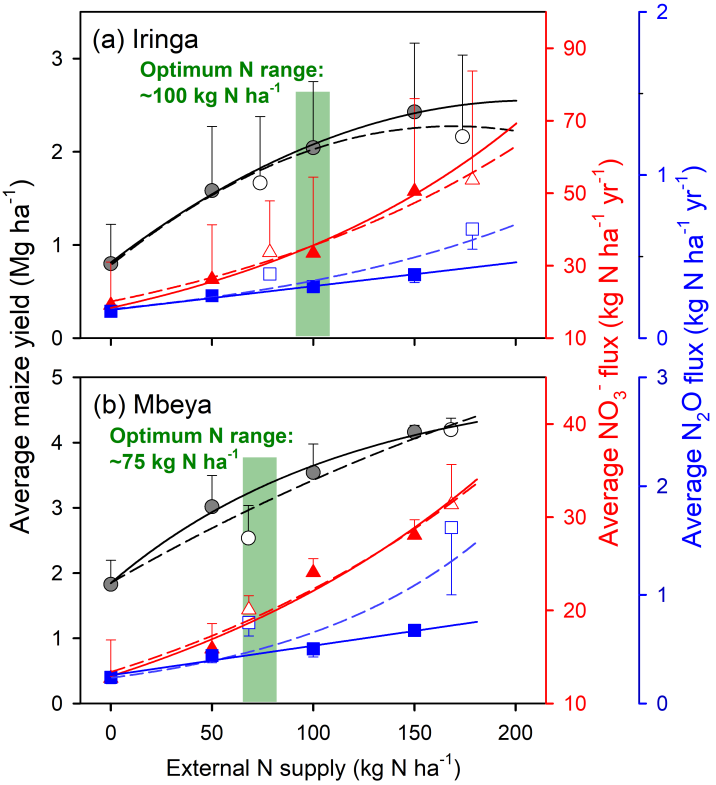

Figure Average maize yield (Mg ha^{-1}), NO_3^- flux (kg N ha^{-1} yr^{-1}), and N_2O flux (kg N ha^{-1} yr^{-1}) in response to external N input (i.e., fertilizer-N or fertilizer-N plus straw) in Iringa (a) and Mbeya (b) sites of Tanzania. Solid lines are fitted for sole N input (four N rates), while dash lines are fitted for all external N input (six N rates). Optimum N rates were determined under the sole N input scenario, and as the N rates where the difference between yield and NO_3^- flux (after normalized into a same scale) reaches maximum.