Overcoming soil productivity constraints as evidenced by historic FAO crop trials to improve food security in Africa, Latin America and SE Asia

Marijn van der Velde[1],*, Linda See[1], Liangzhi You[2], Juraj Balkovič[1], Steffen Fritz[1], Nikolay Khabarov[1], Michael Obersteiner[1] and Stanley Wood[2]

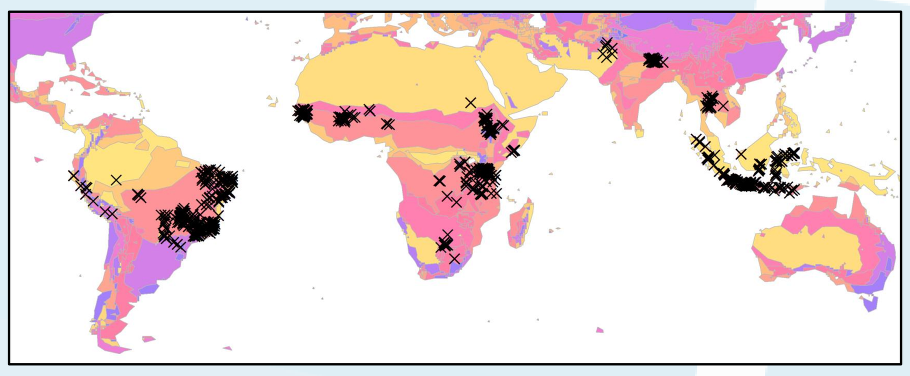
1International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1, A-2361 Laxenburg, Austria

2International Food Policy Research Institute (IFPRI), 2033 K Street, 20006, Washington, D.C., USA

Abstract

Robust assessments of attainable crop yields in Africa and South America are pivotal for projections of food security and cropland expansion. Here we present a continental and comprehensive analysis of location-specific relationships between soil productivity, N and P fertilizer inputs, and corn yields, based on historic FAO crop fertilizer trials. Mitscherlich-Baule crop response functions were fitted through experimental data for 2151 locations having at least 5 N and P input combinations to predict corn yields (the relation between experimental and modeled yields: r2=0.90, p<0.0001). Current yields were estimated with the crop response functions and current N and P inputs (Potter et al., 2010) which compared satisfactorily to regional yield statistics from IFPRI. Additional nutrient input of 10 kg N ha-1 increased yield by ~4% and ~7% in South America and Africa respectively while adding P lead to increases of ~12% and ~25%. In Africa, adding 10 kg ha-1 of N or P resulted in mean and median percentage increases of respectively ~4 and ~10% and ~10 and ~15%; effectively shifting a bulk of smallholders out of marginal productivity. If 80 kg ha-1 of N and 20 kg ha-1 of P were applied this would lead to average yield increases of 30% (maximum of 90%) and 70% (maximum of 190%) in South America and Africa respectively. Yield potentials are considerable, though lower than model-based assessments and appropriate agricultural management interventions are necessary to improve food security outlook and minimize cropland area expansion.

Fig. 1: Crop trial locations and Köppen climate zones

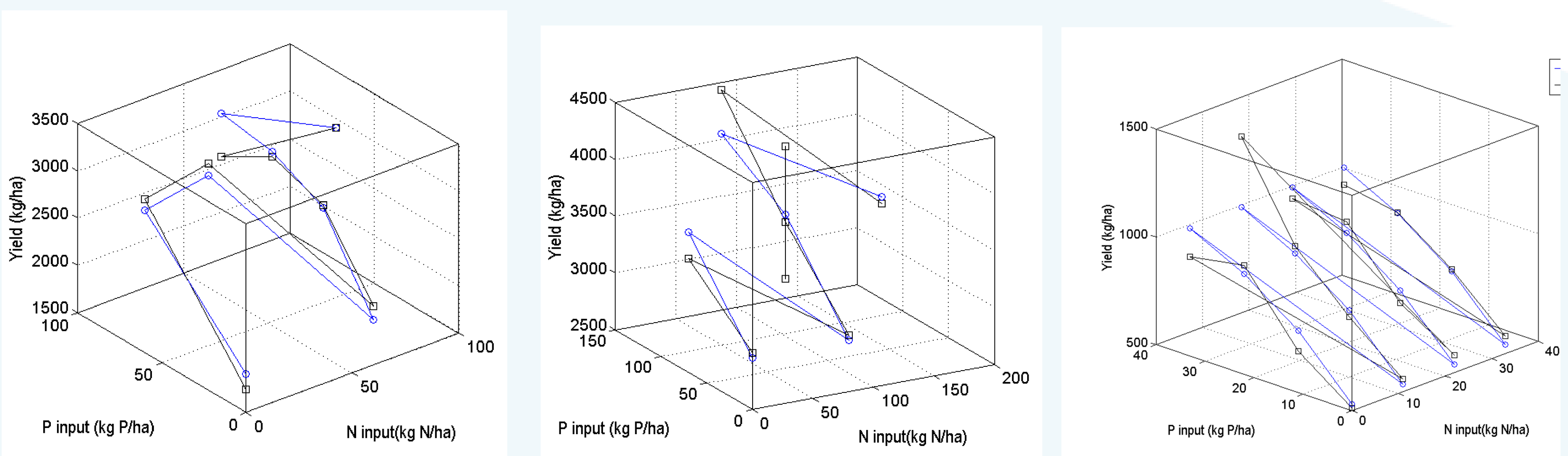


Background and Methodology

Background and approach: Fertilizers have been essential in increasing and improving global crop productivity and food security status. Nevertheless, consumption of nutrients is unequally distributed among the world's nations. The lack of fertilizer and low crop yields in large parts of the developed world, particularly Africa, is further compounded by an increasingly unsustainable nutrient consumption ratio that has lead to soil nutrient depletion. Without maintaining adequate soil fertility levels, crop yields cannot be sustained, increase over time, or respond to improved agricultural management practices. Instead, depletion of soil nutrients without replenishment leads to a vicious cycle of insufficient food production, malnutrition and hunger: Poverty drains a soil and through this reinforces itself.

Data: Recently historic FAO crop fertilizer field trials have become publically accessible (http://www.fao.org/ag/agl/agll/nrdb/). These data were collected as part of FAO's Fertilizer Programme from 1969 until 1994. The purpose behind the programme was to undertake a set of trials to determine suitable fertilizer application rates for locally grown crops and to demonstrate to as many farmers as possible, the positive effect of fertilizer application on crop yields and farm income. The information available from the trials includes crop yields (kg ha^{-1}), and application rates of the main nutrients (N, P_2O_5 and K_2O) and farm yard manure (kg ha^{-1}).

Methodology: Data on corn yields from trials with at least 5 N and P input combinations were selected for this analysis with 1316 unique experiments in Africa and South America to illustrate two contrasting cases. The Mitscherlich-Baule crop response function was used to analyze relations between nitrogen (N) fertilizer input, phosphorus-phosphate (P) fertilizer input and corn yields y_{mb}:The function allows for growth that plateaus with increasing fertilizer application, and accommodates cases of both near perfect factor substitution and near zero factor substitution (Frank et al., 1990). Application rates of farm yard manure were converted to N, P_2O_5 and K_2O application. The parameters a_2, a_3, a_4, and a_5 were obtained by minimizing the sum of squared errors for all applications in each experiment. The Nelder-Mead multidimensional unconstrained nonlinear minimization algorithm was used to minimize the objective function. The fertilizer dataset of Potter et al. (2010) was used to assign the current N and P inputs from chemical fertilizer and manure to the crop response functions.



References

Cordell, D., Drangert, J-O & White, S., 2009. The story of phosphorus: Global food security and food for thought. *Global Environmental Change* 19 (2009) 292–305.

Davidson, B., 1962. Crop yields in experiments and on farms. Nature, 194, 458-459

Lobell, D.B., Cassman, K.G. and Field, C.B. 2009. Crop yield gaps: their magnitudes, and causes. *Annu. Rev. Environ. Resourc.* 34, 179-204.

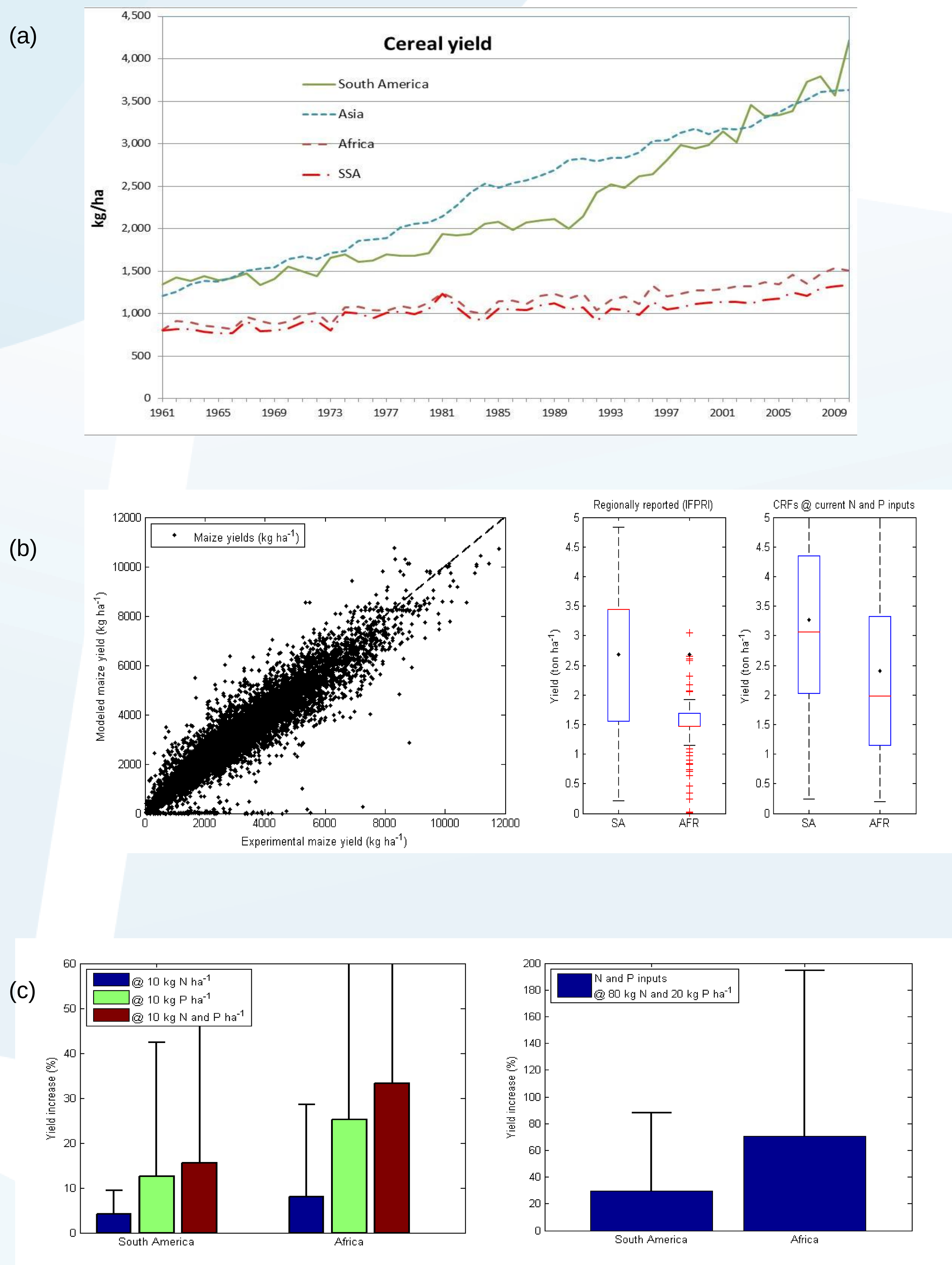
Frank, M.D., Beattie, B.R. and Embleton, M.E. 1990. A comparison of alternative crop response models. *American Journal of Agricultural Economics*, 72(3), 597-603.

Nelson, G. C., M. Rosegrant, A. Palazzo, I. Gray, C. Ingersoll, R. Robertson, S. Tokgoz, T. Zhu, T. Sulser, C. Ringler, S. Msangi, L. You. 2010. Food security, farming, and climate change to 2050. IFPRI Research Monograph. International Food Policy Research Institute (IFPRI), Washington, USA. DOI: 10.2499/9780896291867.

Results

- In contrast to previous crop productivity assessments for Africa and South America, our study allows farm input management interventions to be directly based on small scale on-the-ground observations accounting for both site-specific conditions, as well as reflecting variability in soil conditions and climates.
- Furthermore, the study provides yield gaps that are realistically attainable as the assessment is based on farmers' field trials.
- We showed the importance of phosphorus for closing yield gaps in Africa. The P deficiency reflects soil P supply problems that are of widespread concern in highly weathered tropical soils notorious for low levels of available P and exhibit a strong P fixation capacity. Combined with the fact that P reserves are likely to become exhausted during the next 50-200 years (Cordell et al., 2009), this paints a bleak picture indeed. Nevertheless, if recycling programs were put in place for animal and human excreta some of these effects might be mitigated.
- Achieving trend-growth in crop productivity through sufficient and balanced nutrient applications can partly offset negative climate change impacts on food security in Africa.
- Crop field trials might be considered costly by some but provide essential and hard-won insights, that when analyzed comprehensively, have the potential, through better formulated policies and agreements, to reward the global society with improved food security status for many.

Fig. 1: Results (a) Cereal yield development (b) measured, modelled and reported yields (c) yield increases @ N and P nutrient inputs and yield increase @ global average inputs.



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* Corresponding author: Marijn van der Velde
ESM IIASA
Schlossplatz 1, A-2361 Laxenburg, Austria
Phone : +43 2236 807-451
E-Mail: velde@iiasa.ac.at