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INTEGRATED AGRICULTURE

Beyond fertilizer for closing yield gaps in sub-Saharan Africa

Adopting new models for sustainable and profitable agriculture in sub-Saharan Africa requires a comprehensive evaluation of fertilizer use in terms of agronomic performance, economic implications, the integration of crops and livestock, and policy recommendations.

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Numerous factors interact and result in the yield gaps in sub-Saharan Africa, although none have been studied more than mineral fertilizer[1–3], particularly N-based fertilizer, from the micro to landscape scales. In the quest to close yield gaps, recommended fertilizer application rates are often informed by fertilizer response trials or simulation models based on these. However, this is not the only information farmers need. Farmers function in complex worlds, where information needs to be contextualized by considering the total cost of fertilizer application (purchase, transportation and labour) and how this cost relates to increased yields and crop prices. In this context, recommended fertilizer rates may render crop production unprofitable. What is viable and possible is quite different in the real world, especially for resource-poor small-scale farmers.

In this issue of *Nature Food*, Bonilla-Cedrez et al.[4] contribute to these debates by contextualizing fertilizer and grain prices as constraints on food production in sub-Saharan Africa. Using a modelling approach based on large, spatial data sets, they illustrate the interplay between fertilizer prices, yield gains per kg of N per ha, and associated increases in income owing to grain prices. They demonstrate the varied geospatial response of maize to fertilizer caused by the physical environment, which is further nuanced by the prices of fertilizer and grain. They found that farmers can double maize yields in many areas, but the economic incentives may be weak. The relationship between yield and profit is not linear and changes over time. The contribution from their work is the value-cost ratio (VCR), the ratio between the benefit of fertilizer use (grain price × increase in yield) and the fertilizer cost, which provides a simple analysis of the relative return on fertilizer. Applying fertilizer to healthy soils, with high water

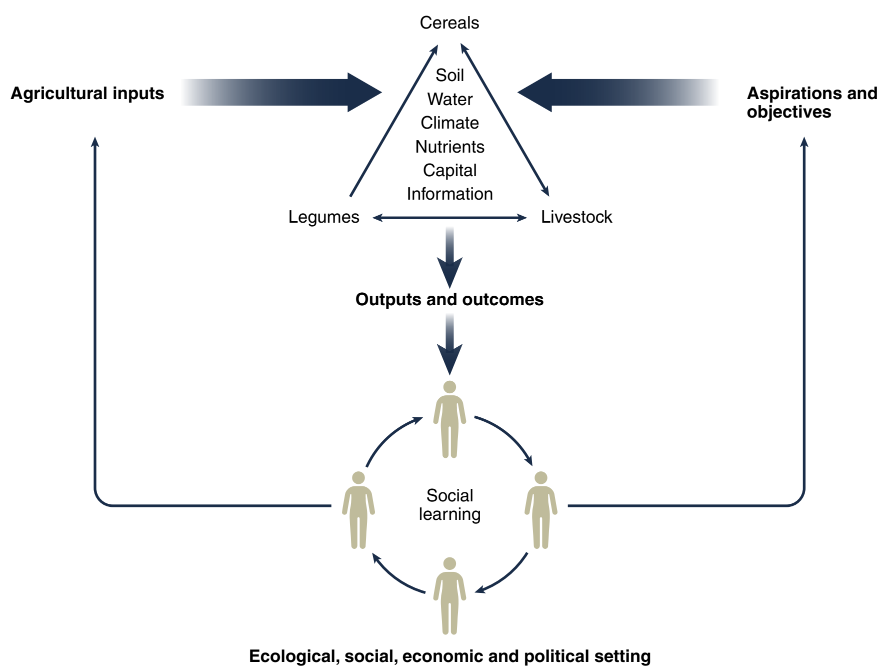

Fig. 1 | Farmers' mental models determine on-farm decision making and investment strategies. Mental models are a function of many interacting factors and are adapted on the basis of reflection and social learning. The factors contributing to mental models include (1) the larger biophysical and social environment, market access and the policy environment; (2) their aspirations and multiple objectives, for instance, personal and cultural motives for using specific crops or livestock, food security, market-oriented production, or reducing a range of risks; and (3) the technologies and strategies used, the inputs available and investments made. These factors determine multiple decisions and, eventually, production outputs, returns from the market and the extent to which personal aspirations and objectives are met. We suggest that there are strong feedbacks between reflection and social learning that will influence future aspirations and objectives on the one side and investment strategies on the other. Such learning processes may well improve production systems beyond what fertilizer recommendations will achieve.

and nutrient-holding capacities, results in higher returns, whereas returns are low in poor soils, especially where fertilizers are expensive[3,5]. Economic yield gaps in West Africa are low as compared to western Ethiopia and Kenya and parts of southern Africa. Hence, these authors suggest using spatially targeted fertilizer recommendations to account for fine-scale variation in soil fertility. For instance, in Ethiopia, wheat responded differently to fertilizer application along the catena and over relatively short distances[6]. Hence, while yield gap analysis is a practical approach to evaluate agronomic performance, economic implications and policy recommendations at higher levels of aggregation, this does not mean it is applicable at the farm level.

Farmers deal with multiple integrated crops and livestock and narrow profit margins. It is critical to enable the rehabilitation of exhausted soils and to intensify agriculture at fine scales without complex input recommendations. Fertilizer investment for one crop may not reflect broader contributions from other crops and livestock in integrated farming systems. Yields are also affected by interactions between different crops in mixed systems and their ability to build soil fertility. Therefore, Guilpart et al.[7] recommend investigating yield gaps, calculated from the energy returns per ha, by adjusting entire cropping systems' spatial and temporal arrangements. However, other factors, such as applying organic fertilizer and planting legumes to build healthy soils, are not considered in yield gap analysis and the VCR, but they can provide a more cost effective way of improving soil fertility and yield for resource-poor farmers on poor soils. Moreover, it is not easy to account for environmental and economic risk management strategies in fertilizer recommendations.

Support services should provide information that strengthens the mental models that drive farmers' decision making rather than only conveying recommendations based on linear thinking (Fig. 1). Parry et al.[8] demonstrate that irrigators develop complex mental water and nutrient management models on the basis of simple soil moisture and nutrient measurements, experimentation and social learning, and develop locally effective production systems according to market demand and profitability. Similarly, Dessie et al.[9] stress the importance of social learning in soil conservation.

Agricultural intensification should be strengthened by complementary practices that will improve soil health over and above fertilizer application. Integrated cereal–legume–livestock systems may be an effective strategy as they fix nitrogen, tighten nutrient cycles and minimize losses. Converting non-edible biomass into high-value animal products builds household capital and increases income, which farmers often use to subsidize crop inputs. This illustrates the value of tighter ecological and economic integration of the different enterprises within farming systems. Nutrient and biomass losses can be further minimized by retaining by-products as inputs for production, thus allowing farmers to sell more value-added products. Working towards circular production and food systems will retain nutrients and biomass while generating more revenue. Profitable production systems will allow small-scale farmers to buy nutritious food and invest in strategic inputs. But this requires new ways of thinking and the selection of strong leverage points within these complex systems[10].

High-level analysis may not aid the synthesis of technologies and institutions needed for sustainable and profitable agriculture at the local scale but, if linked to lower levels, can spur local learning, experimentation and innovation. Hence, science should develop technologies that help farmers to measure soil fertility, estimate yields and calculate farm profitability, while policy makers should facilitate the development of vibrant input and output markets. Such pull strategies would be more effective than fertilizer recommendations that create despondency and apathy towards closing the yield gap. ❐

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References

1. Beza, E., Silva, J. V., Kooistra, L. & Reidsma, P. *Eur. J. Agron.* **82**, 206–222 (2017).
2. Mueller, N. D. et al. *Nature* **490**, 254–257 (2012).
3. van Dijk, M. et al. *Agric. Syst.* **183**, 102828 (2020).
4. Bonilla-Cedrez, C., Chamberlin, J. & Hijmans, R. J. *Nat. Food* https://doi.org/10.1038/s43016-021-00370-1 (2021).
5. van Dijk, M. et al. *Agric. Syst.* **154**, 90–99 (2017).
6. Amede, T. et al. *Renew. Agric. Food Syst.* https://doi.org/10.1017/S1742170519000504 (2020).
7. Guilpart, N., Grassini, P., Sadras, V. O., Timsina, J. & Cassman, K. G. *Field Crops Res.* **206**, 21–32 (2017).
8. Parry, K. et al. *Int. J. Water Resour. Dev.* **36** (Suppl), S199–S223 (2020).
9. Dessie, Y., Wurzinger, M. & Hauser, M. *Int. J. Sustain. Dev. World Ecol.* **19**, 258–267 (2012).
10. van Rooyen, A. F. et al. *Int. J. Water Resour. Dev.* **36** (Suppl), S171–S198 (2020).

Competing interests

The authors declare no competing interests.