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Efficient Fertilizer Consortium

The Global Fertilizer Challenge: Future Directions for Efficient Fertilizer Research

SUMMARY REPORT
FFAR EFFICIENT FERTILIZER CONSORTIUM
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An uneven use of fertilizers around the world has resulted in nutrient surpluses in some regions and severe shortages in others[1]. Efforts to optimize fertilizer inputs to increase crop production efficiency and reduce environmental impact is complicated by a diversity of plant, nutrient, soil and climatic factors[2,3]. Fertilizer technologies aimed at increasing nutrient use efficiency in cropping systems have the potential to achieve production goals while reducing nutrient losses to the environmental. Here we discuss the status of enhanced efficiency and novel fertilizer products and the rigorous methods needed to assess their efficacy, safety and environmental impact.

Enhanced Efficiency & Novel Fertilizers

Enhanced efficiency fertilizers (EEFs) have been produced for over 50 years and come in a variety of different forms, including slow-release, controlled-release and stabilized nitrogen (urease and nitrification inhibitors). There is evidence that, if used appropriately, these EEFs can support optimum crop yields while reducing nitrate leaching, ammonia volatilization and nitrous oxide emissions[4]. Despite the promising evidence, EEFs are only a fraction of the fertilizer market, primarily due to higher costs[5] and concerns around the use of non-biodegradable plastics in some coatings[6]. Guidance on how to best use EEFs within the 4R fertilizer management framework[7] is needed. Rapidly emerging novel fertilizer products include biofertilizers, nanofertilizers and other "smart fertilizers" claim to adapt the timing of nutrient release to plant demand via plant signaling or bioactivation by soil microorganisms (Figure 1).

Figure 1. Three categories of fertilizer products for increasing nutrient use efficiency and availability.

Biofertilizers contain one or more strains of microorganisms that colonize the soil or plant and mobilize or transform nutrients into plant-available forms[8]. There is limited evidence that these products maintain or increase crop yield at lower P or N rates consistently and effectively[9,10], and research documenting the environmental impact, positive or negative, of biofertilizers is scarce[8]. While there are promising results from controlled laboratory experiments[11], rigorous field-scale evaluation is sorely needed to understand performance in working agricultural fields[8,12,13]. The ability to reduce synthetic fertilizer inputs and biologically increase nutrient availability, particularly in developing countries with low fertilizer access, would help address multiple Sustainable Development Goals.

Nanofertilizers are either nutrient sources which claim to enhance nutrient uptake due to the small size and high surface area of the fertilizer molecules[14,15] or fertilizer coatings to control the release of nutrients[16]. The agronomic and environmental impact of nanofertilizers is poorly understood[17]; a systematic understanding of their mechanisms is needed before they can safely be used.

Scientific Evaluation of Novel Fertilizer Technologies

Many promising novel fertilizers are on or entering the market, however their agronomic and environmental impacts are poorly understood. This is largely due to a lack of rigorous scientific evaluation to assess their efficacy, safety and environmental impact under a range of field conditions. To improve our understanding and enable confident adoption of novel products, a rigorous evaluation framework is needed, including minimum data standards, standard protocols and proper controls (Figure 2).

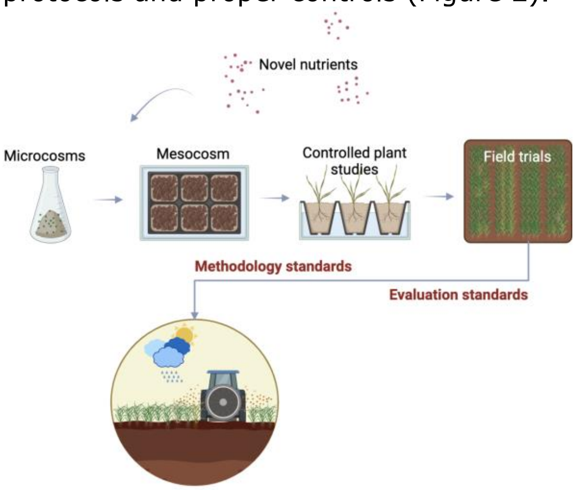

Figure 2. The evaluation of novel fertilizer products and practices pipeline.

Minimum standards support consistency in experimental design and data collection and allow for more accurate and meaningful results on a broader scale beyond an individual field[18,19]. In the case of evaluating novel fertilizers, these minimum standards should include the types of data to be collected, including management, soil, weather, crop, nutrient use and loss, economic and methodology data. While a variety of minimum data standards have been developed, there are none specific to agronomic and environmental performance of fertilizers.

The inclusion of well-defined, proper controls and a range of application rates are essential to interpret the results of any fertilizer experiment. For fertilizer product research, at least two types of controls should be considered: (1) a treatment without any fertilizer added, and (2) a treatment with a conventional fertilizer product provided at the equivalent nutritional levels as the alternative source. If fertilizer timing or placement differs between fertilizer sources, additional controls should also be considered[19].

The evaluation of novel fertilizer products must follow robust and acceptable protocols. These may include soil, plant, water and atmospheric measurements and laboratory analyses. Industry-standard protocols developed by the scientific community will lead to proper verification of and confidence in new products entering the market.

The Efficient Fertilizer Consortium

To spur innovation, the Foundation for Food & Agricultural Research recently formed the Efficient Fertilizer Consortium, a multi-stakeholder collaboration to invest in the development of common protocols, the engagement of a global network of independent research locations, the evaluation of standardized results through systematic reviews and meta-analyses and the support of pre-competitive research on novel fertilizer types and/or modes of action. The consortium aims to increase standardized testing of and expand access to enhanced efficiency and novel fertilizer products, ensure food security and reduce the environmental impacts from fertilizer use.

This report is a summary of the white paper prepared by Tai McClellan Maaz.

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References

1. Mueller, N. D., Gerber, J. S., Johnston, M., Ray, D. K., Ramankutty, N., & Foley, J. A. (2012). Closing yield gaps through nutrient and water management. Nature, 490, 254–257. https://doi.org/10.1038/nature11420
2. Giller, K. E., Tittonell, P., Rufino, M. C., van Wijk, M. T., Zingore, S., Mapfumo, P., Adjei-Nsiah, S., Herrero, M., Chikowo, R., Corbeels, M., Rowe, E. C., Baijukya, F., Mwijage, A., Smith, J., Yeboah, E., van der Burg, W. J., Sanogo, O. M., Misiko, M., de Ridder, N., … Vanlauwe, B. (2011). Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. Agricultural Systems, 104(2), 191–203. https://doi.org/10.1016/j.agsy.2010.07.002
3. Morris, T. F., Murrell, T. S., Beegle, D. B., Camberato, J. J., Ferguson, R. B., Grove, J., Ketterings, Q., Kyveryga, P. M., Laboski, C. A. M., McGrath, J. M., Meisinger, J. J., Melkonian, J., Moebius-Clune, B. N., Nafziger, E. D., Osmond, D., Sawyer, J. E., Scharf, P. C., Smith, W., Spargo, J. T., … Yang, H. (2018). Strengths and limitations of nitrogen rate recommendations for corn and opportunities for improvement. Agronomy Journal, 110(1), 1–37. https://doi.org/10.2134/AGRONJ2017.02.0112
4. Lam, S. K., Wille, U., Hu, H. W., Caruso, F., Mumford, K., Liang, X., Pan, B., Malcolm, B., Roessner, U., Suter, H., Stevens, G., Walker, C., Tang, C., He, J. Z., & Chen, D. (2022). Next-generation enhanced-efficiency fertilizers for sustained food security. Nature Food, 3, 575–580. https://doi.org/10.1038/s43016-022-00542-7
5. Timilsena, Y. P., Adhikari, R., Casey, P., Muster, T., Gill, H., & Adhikari, B. (2015). Enhanced efficiency fertilisers: A review of formulation and nutrient release patterns. Journal of the Science of Food and Agriculture, 95(6), 1131–1142. https://doi.org/10.1002/jsfa.6812
6. Chen, J., Lü, S., Zhang, Z., Zhao, X., Li, X., Ning, P., Liu, M., 2018. Environmentally friendly fertilizers: A review of materials used and their effects on the environment. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2017.09.186
7. Fixen, P. E. (2020). A brief account of the genesis of 4R nutrient stewardship. Agronomy Journal, 112(5), 4511–4518. https://doi.org/10.1002/AGJ2.20315
8. O'Callaghan, M., Ballard, R. A., & Wright, D. (2022). Soil microbial inoculants for sustainable agriculture: Limitations and opportunities. Soil Use and Management, 38(3), 1340–1369. https://doi.org/10.1111/sum.12811
9. Schütz, L., Gattinger, A., Meier, M., Müller, A., Boller, T., Mäder, P., & Mathimaran, N. (2018). Improving crop yield and nutrient use efficiency via biofertilization—A global meta-analysis. Frontiers in Plant Science, 8. https://doi.org/10.3389/FPLS.2017.02204
10. Leggett, M., Newlands, N. K., Greenshields, D., West, L., Inman, S., & Koivunen, M. E. (2015). Maize yield response to a phosphorus-solubilizing microbial inoculant in field trials. The Journal of Agricultural Science, 153(8), 1464–1478. https://doi.org/10.1017/S0021859614001166
11. Kaminsky, L. M., Trexler, R. V., Malik, R. J., Hockett, K. L., & Bell, T. H. (2019). The inherent conflicts in developing soil microbial inoculants. Trends in Biotechnology, 37(2), 140–151. https://doi.org/10.1016/J.TIBTECH.2018.11.011
12. Raimondi, G., Maucieri, C., Toffanin, A., Renella, G., & Borin, M. (2021). Smart fertilizers: What should we mean and where should we go? Italian Journal of Agronomy, 16(2). https://doi.org/10.4081/IJA.2021.1794
13. Compant, S., Samad, A., Faist, H., & Sessitsch, A. (2019). A review on the plant microbiome: Ecology, functions, and emerging trends in microbial application. Journal of Advanced Research, 19, 29–37. https://doi.org/10.1016/J.JARE.2019.03.004
14. Derosa, M. C., Monreal, C., Schnitzer, M., Walsh, R., & Sultan, Y. (2010). Nanotechnology in fertilizers. Nature Nanotechnology, 5(2), 91. https://doi.org/10.1038/nnano.2010.2
15. Husted, S., Minutello, F., Pinna, A., Tougaard, S. Le, Møs, P., & Kopittke, P. M. (2023). What is missing to advance foliar fertilization using nanotechnology? Trends in Plant Science, 28(1), 90–105. https://doi.org/10.1016/j.tplants.2022.08.017
16. Mastronardi, E., Tsae, P., Zhang, X., Monreal, C., & DeRosa, M. C. (2015). Strategic role of nanotechnology in fertilizers: Potential and limitations. In M. Rai, C. Ribeiro, L. Mattoso, & N. Duran (Eds.), Nanotechnologies in Food and Agriculture. https://doi.org/10.1007/978-3-319-14024-7_2
17. White, J. C., & Gardea-Torresdey, J. (2021). Nanoscale agrochemicals for crop health: A key line of attack in the battle for global food security. Environmental Science and Technology, 55(20), 13413–13416. https://doi.org/10.1021/ACS.EST.1C06042
18. Slaton, N. A., Lyons, S. E., Osmond, D. L., Brouder, S. M., Culman, S. W., Drescher, G., Gatiboni, L. C., Hoben, J., Kleinman, P. J. A., McGrath, J. M., Miller, R. O., Pearce, A., Shober, A. L., Spargo, J. T., & Volenec, J. J. (2022). Minimum dataset and metadata guidelines for soil-test correlation and calibration research. Soil Science Society of America Journal, 86(1), 19–33. https://doi.org/10.1002/saj2.20338
19. Eagle, A. J., Christianson, L. E., Cook, R. L., Harmel, R. D., Miguez, F. E., Qian, S. S., & Ruiz Diaz, D. A. (2017). Meta-analysis constrained by data: Recommendations to improve relevance of nutrient management research. Agronomy Journal, 109(6), 2441–2449. https://doi.org/10.2134/AGRONJ2017.04.0215