REFLECTIONS ON EFFORTS GEARED TOWARD IMPROVED SOIL FERTILITY AND CROP YIELDS IN KENYA

ABSTRACT

A successful strategy aimed at enhancing productivity relies on its ability to be implemented practically in the field (farmers' field). Many research-based and promising soil fertility technologies are largely not adopted. This paper examines the impact of the research work conducted at University of Eldoret, agricultural institutes and the government projects at farm level. Precisely, this paper narrows down to research done with an aim of exploring system approaches that address soil phosphorus and its effect on increasing crop yields. Although literature registers success stories of that research work, there is slow and limited adoption rate of the output by farmers. We suggest the development and expansion of Transdisciplinary research and creation of Farmer Research Network to seek a one-size- fits-all solution for farmers to adopt technologies with proven success.

1.0. INTRODUCTION

Rapid human population growth and stagnating crop yields [1] greatly contributes to food insecurity in Sub Saharan Africa and Kenya in particular. There is a need for new and complementary solutions to improve crop yields. The ever- increasing global population is expected to be near 9.6 billion by the year 2050 [27] therefore, use of a sustainable way to improve crop yields, use of cropping systems that maximize productivity while minimizing input resources would be ideal.

In Kenya, increasing crop yields requires the additions of phosphorus and nitrogen fertilizers as well as pesticides to control destructive pests. Recently, the depletion of phosphorus (P) has received increased interest [4] as a major limiting nutrient for staple cereal crop production. The P delivered by inorganic fertilizers is derived from the rock phosphate which is a non-renewable resource [9] and is expected to be largely depleted in the next few decades [32].

Farmers are expected to benefit from new sustainable technologies or products to boost yields. Some of these technologies have been developed through participatory experiments by the government [6] , agricultural institutes and researchers at the Department of Soil Science, University of Eldoret, Kenya. The soil fertility technologies presented below are geared towards improved availability of phosphorus and have been proven effective in increasing crop nutrient and yields. However technology adoption rates have been extremely low and in some cases near absent [23] .

1.1. A review of the Fertilizer Use Recommendation Project (FURP) -Phase one; when, why and how

In 1987, the Ministry of Agriculture through the National Research Laboratories (NARL) commissioned a study in high and medium potential maize growing areas. This was done in order to make a decision as to where to establish FURP trial sites in Kenya through a survey in what was then called 'first priority sites'. A priority site is an area that was considered to have representative soils, agro ecological zone, accessible, close to a long-term rainfall station, free from rocks and boulders and termite mounds. A survey of description of the first priority sites in the various districts in Kenya was done and Uasin Gishu was included. The breakdown of soil properties referring to groupings of soil units was given. These properties included description of soils which were well drained, deep to very deep, red to dark red with friable clay. Well drained, very deep to extremely deep, dark red to dark reddish brown, friable clay with humic top soil was also described. In Uasin Gishu county (then a district), two priority sites were selected. That was Moi teachers (now University of Eldoret) near Eldoret town and Turbo forest station. Farmers' fields were not selected and it was recommended that it should be done in the future because Uasin Gishu district was vast. Areas that were not represented by the trial sites involved scattered hills and foot slopes as well as shallow soils on volcanic foot ridges. All combinations of the different soils, climate environments occurring in Uasin Gishu district were placed in Agro-Ecological Zones maps. From this study, it was recommended that N and P be applied together with organic materials. Lime was recommended but it was said to antagonize Zinc (Zn) and Copper (Cu) [6] . All fertilizer recommendations since then have been based on this report. However, this situation has changed with the release of the [8] report, based on a smaller unit of sub-county.

1.2 Green manure technologies

These technologies consist of a combination of manures with inorganic fertilizers and leguminous trees/shrubs [19] . Adoption has been minimal, largely due to the lack of immediate benefits to the farmers, despite the research and extension efforts made by the International Institute of Tropical Agriculture (IITA) and the Tropical Soil Biology (TSBF). A study done by [25] showed that combination of rock phosphates, farmyard manure, tithonia and inorganic fertilizer as sources of P, had an effect on exchangeable acidity, exchangeable aluminium, P availability in the soil and may have other benefits associated with integrated soil fertility management. The use of tithonia and Farmyard manure is negligible in implementation because of limited quantities available at the farm level to supply the recommended rates of P ha^{-1} [25] .

1.3. Rock phosphate technologies (PREP – PAC)

Non-acidulated rock phosphate could be used as an alternative source for P. Several studies have been conducted in Western Kenya on the effects of rock phosphate on cereal and legume yields. A patented PREP - PAC [24 : 30] was designed at the Department of Soil Science in 1997, University of Eldoret which by then was still Moi University. PREP – PAC is designed to replenish the fertility of soils on seriously depleted patches that are widespread on smallholder farms. It consisted of repackaging of inputs in small, affordable quantities, which may be an avenue to attract smallholder farmers to use nutrient inputs. Positive economic returns to investment from PREP-PAC inputs was reported by [37] . PREP-PAC consists of 2 kg Minjingu Rock Phosphate (MPR), 0.2 kg Urea, 120 g food legume seed, rhizobial innoculant (Biofix) packed with lime pellets to raise the pH of the inoculated seed environment and gum Arabic sticker to hold the innoculant onto the surface of the seed. Several other works citing the promising effect of MPR on soil fertility replenishment [18; 20] has been documented, however, adoption by farmers is negligible due to the unavailability of rock phosphate locally and its extra cost incurred when imported from the neighboring Uganda and Tanzania. Furthermore, the use of rock phosphate often does not translate to an immediate increase in production depending on the initial level of soil fertility. Phosphate rock (PR) is a very important finite resource but its applications have adverse environmental implications. It contains hazardous elements that could be transferred to the soil through the application of fertilizers, especially after long term use. [7] . Leaching or runoff losses from PR should be minimized because this resource may be depleted in the near future.

1.4. Bio fertilizers

To satisfy crop nutritional requirements, P is usually added to soil as chemical P fertilizer. However, rock phosphate is expected to be depleted in the near future [32] and synthesis of chemical P fertilizer is highly energy intensive with long-term impacts on the environment in terms of eutrophication, soil fertility and carbon footprint. Moreover, plants only use a small amount of the added P, 75–90% of it is precipitated by metal–cation complexes, and rapidly becomes fixed in soils. Such environmental concerns have led to the search for a sustainable way of P nutrition of crops. In this regard, Phosphate-Solubilizing Microorganisms (PSM) is percieved as best eco-friendly means for P nutrition of crops in a sustainable manner [36] . Many studies have evaluated either combined and/or sole use of mycorrhizal and rhizobial inoculants on various legumes. Improved crop yields have been reported ([14; 15 and 16] with adequate available phosphorus. From these studies, it was recommended that continued evaluation of biofertilizers and dissemination of results to smallholder farmers be done. The rate of adoption of this technology has been low despite the bio inoculants being affordable. Poor adoption could probably be due to short duration viability of microorganisms and poor dissemination of research outcomes to smallholder farmers.

1.5. The maize legume intercrop technology (“MBILI’’)

In this technology, there is a spatial arrangement of one maize line followed by two legume lines [35] . Apart from the beneficial interaction (biological nitrogen fixation-BNF) legumes, can mobilize fixed forms of soil P through the secretion of organic acids such as citrate and malate and other P mobilizing compounds from their roots ([26] . Among other beneficial effects brought about by legumes, is the production of hydrogen gas (H_2) as a by-product of BNF which greatly affects the composition of the soil microbial population, further favoring the development of plant growth-promoting bacteria [1] and Vesicular Arbuscular Mycorrhiza a fungus. When cereal roots forms associations with this fungus, extensive root system is developed which has the capacity to utilize the solubilized P from the legume intercrop. In essence, this technology improves the P use efficiency in the soil.

This technology is the only one which has been largely adopted. This is probably because during planting the maize is planted first by a male farmer either by use of a planter or by hand. Because the legumes are perceived to be a ``female’’ crop, the legumes are planted afterward with strict instruction from the male farmer that they should be planted in between the rows of maize to avoid competition for nutrients [12] . With that given, the female farmer plants, the legumes between the maize lines with little fertilizer and both the crops do well. In this technology, gender roles influence its adoption This technology has also worked in Malawi where gender differentiation is very important for farmer interest with legumes [13; 28].

1.6. National Accelerated Access to Input Acquisition Program (NAAIAP)

National Accelerated Access to Input Acquisition Program [8] in Kenya, carried out soil sampling and analyses nation-wide after which later-on fertilizer recommendations for various crops grown in selected counties were developed. However, there is limited information on crop nutrients requirements, characteristics of soils and high level of variation in soil properties experienced across many sub-counties where soils were sampled. Today, farmers have not fully adopted the recommendations because some of the inputs recommended are beyond their reach either financially, in the amounts required or even availability of the formulation recommended. For example, the use of manure at the rate of 6 t ha^{-1} is difficult to implement due to limited quantities available at the farm level, not to mention the likely physical effects on the soil.

Other projects like International Phosphate (IMPHOS) carried out research between 2010 and 2012 and published a paper of their findings [17] from which recommendations that liming materials should be combined with conventional Diammonium Phosphate (DAP) and manures to improve the soil fertility. Once more, lack of involvement of all stakeholders hindered adoption of this technology. Further, many farmers are not well endowed with resources so they could not implement the recommendations. [8] , however, discouraged the use of DAP in Uasin Gishu County due to its acidifying effects on the soil. Such conflicting information warrants an in-depth review of soil test results for farm-specific recommendations coupled with appropriate dissemination method.

Participatory experiments preceded by proven success in greenhouse trials often do capture farmers' preferences for different technologies, but they do not necessarily answer why farmers actually adopt those technologies, or not. As such, the outcomes of participatory evaluation cannot be taken as automatically predictive for future adoption. The looming food insecurity poses questions for scientists who have to work round the clock to find answers to constraints of food security. One of the question to be asked is did we find a solution to the farmer's problems to warrant adoption of a technology?

2.0. SUGGESTED STRATEGY

Having shown that the failure by the traditional extension approaches to improve on technology adoption, scientists should strategize on how to communicate these technologies to farmers or use a new suggested approach like the transdisciplinary process and creation of Farmer Research Networks (FRN) to reach out to the farmers.

A transdisciplinary process is a reflexive approach that addresses societal problems by means of interdisciplinary collaboration as well as collaboration between researchers and non-researchers. Its aim is to enable mutual learning process between science and society [34] . This process brings scientific knowledge to the farmers by creating researcher and farmer to farmer networks [21] . The extension officers are among stakeholders and they play a role in disseminating the information to farmers. Transdisciplinary processes utilize knowledge from theory and practice to generate socially robust solutions for sustainable development [33] . The process complements other forms of science-society cooperation such as contract-based research, public participation, participatory research [11] . Farmer Field Schools or Farmer Research Networks [21] . In Africa, and specifically, Kenya the transdisciplinary process is a relatively new concept. This process was initially used in Europe and was suggested first by [10] for the African context. In this context, the process aims at enabling a mutual learning process between scientists and farmers. The transdisciplinary process has been used with success for some disciplines such as higher education[2] , Landscape Management [39] and the emerging Sustainability Science [38] . In the recent past, the transdisciplinary process has become a tool of corporate sustainability in management science [31] . In the United States (US) and other parts of the world, TD has not been used for long but similar approaches like the community based participatory research are used. This method was applied in Uasin Gishu, Kenya in 2014 [22] and [3] . It aimed at farmers' participation in a transdisciplinary process including extension officers and local scientist to construct farm specific fertilization strategies based on farm specific soil testing. This method also aimed at construction of cooperative strategies for purchasing fertilizer involving farmers, traders and financial institution in a timely manner.

A brief presentation of results showed that the farmers who participated in a transdisciplinary process and tested their soils had better crop yields. Usually the farmers in Uasin Gishu region produce about 4.5 t dry maize/ha without soil testing, independent of their participation in a transdisciplinary process. A qualified soil test with differentiated soil testing recommendations increases the yield by about 1.5 t dry maize/ha. Participating in a transdisciplinary process provides an additional surplus of about 1 t dry maize/ha yield. Economically, this is a highly attractive result; given that soil testing costs around 20 USD, a surplus of 1 t dry maize returns approximately 330 USD and farms' sizes have been about 2.8 ha. The development of this method in Kenya has been a mid-sized transdisciplinary process that aims to improve smallholder farmers' participation in the agricultural value chain; providing soil testing-based, farm-specific fertilization strategies. The development and application of this study included (1) a multi-stakeholder discourse including the key actors of the smallholder farmers' crop cycle; (2) an interdisciplinary process in which a science team from agro science collaborated with a socioeconomic team; and (3) the facilitation of a mutual learning experience between key stakeholders and scientists.

It was not difficult to establish learning on an equal footing with traders and banks, although these stakeholders presumably took action only if they face a market win–win situation. We were able to include key stakeholders who worked with but had not made it their focus to work for the poor, as we believe that the intention is to frame and to change the system in ways that allow poor smallholder farmers to benefit. We also believe that this became possible because scientists were not perceived as political activists but rather as intermediaries [29] whose intention was to support all stakeholders.

The transdisciplinary process worked surprisingly well and was promoted by the democratic, cooperative societal environment in the Uasin Gishu setting and by the strong commitment of local stakeholders, researchers, and the international transdisciplinarians who continuously stressed a structured, systematic, method-driven facilitation of the process. The transdisciplinary process certainly provide socially robust solutions for key stakeholders to improve fertilization and thus increase the yields of smallholder farmers.

We also propose the use of Farmer Research Network combined with innovations in Information and Communication Technology as a strategy for matching diverse options and contexts in smallholder agriculture[21] . Developments in ICTs now bring within reach the prospect of large-scale participatory research, which would enable the integration and up-scaling of improved crop genetics and management, as well as other types of agricultural technologies and options.

3.0. CONCLUSION

We suggest the development and expansion of Transdisciplinary research and creation of Farmer Research Network to seek a one-size- fits-all solution for farmers to adopt technologies with proven success.

REFERENCE

1. Angus J.F., Kirkegaard J.A., Hunt J.R., Ryan M.H., Ohlander L., P. M. B. (2015). Break crops and rotations for wheat. *Crop and Pasture Science*, *66*, 523–552.
2. Brundiers, K., Wiek, A., & Redman, C. L. (2010). Real-world learning opportunities in sustainability: from classroom into the real world. *International Journal of Sustainability in Higher Education*, *11*(4), 308–324. https://doi.org/10.1108/14676371011077540
3. Chebet, A., Ruth, N., Nekesa, O. A., Ngetich, Wilson., K. J., & Scholz, R. W. (2018). Efforts Toward Improving Maize Yields on Smallholder Farms in Uasin Gishu County , Kenya , through Site-specific , Soil-testing-based Fertiliser Recommendations : A Transdisciplinary Approach Efforts Toward Improving Maize Yields on Smallholder Farms in U. *East African Agricultural and Forestry Journal*, *00*(0), 1–13. https://doi.org/10.1080/00128325.2018.1443413
4. Cordell, D. and W. S. (2015). Tracking phosphorus security: Indicators of Phosphorus vulnerability in the global food system. *Food Security*, *7*, 337–350.
5. FAO. (2016). *Food and agricultural organisation ststistics*. Rome, Italy.
6. FURP,(1994). *fertilizer use recommendation project* (Vol. 1–22). Nairobi, Kenya.
7. Fayiga, A. O., & Nwoke, O. C. (2016). Phosphate rock: origin, importance, environmental impacts, and future roles. *Environmental Reviews*, *24*(4), 403–415. https://doi.org/10.1139/er-2016-0003
8. NAAIAP, (2014). summarized fertilizer recommendations per sub county. In *National Accellerated Agricultural Access to Inputs Access Program*. Ministry of Agriculture livestock and Fisheries.
9. Gemenet, D. C., Leiser, W. L., Beggi, F., Herrmann, L. H., Vadez, V., Rattunde, H. F. W., … Haussmann, B. I. G. (2016). Overcoming Phosphorus Deficiency in West African Pearl Millet and Sorghum Production Systems: Promising Options for Crop Improvement. *Frontiers in Plant Science*, *7*(September), 1–10. https://doi.org/10.3389/fpls.2016.01389

10. Hurni, (1999). Sustainable management of African and Asian mountains. *Ambio*, *28*(5), 382–389.
11. Hansmann, R. (2012). Environmental Literacy in Science and Society: From Knowledge to Decisions. By Roland W. Scholz. Cambridge University Press: New York, USA, 2011; Hardback, 631 pp; ISBN 978-0-521-19271-2; Paperback, ISBN 978-0-521-18333-8. *Sustainability*, *4*(12), 863–865. https://doi.org/10.3390/su4050863
12. Kamanga, B. C. G., Kanyama-Phiri, G. Y., Waddington, S. R., Almekinders, C. J. M., & Giller, K. E. (2014). The evaluation and adoption of annual legumes by smallholder maize farmers for soil fertility maintenance and food diversity in central Malawi. *Food Security*, *6*(1), 45–59. https://doi.org/10.1007/s12571-013-0315-3
13. Kerr, R. B., Snapp, S., Chirwa, M., Shumba, L., & Msachi, R. (2007). Participatory research on legume diversification with Malawian smallholder farmers for improved human nutrition and soil fertility. *Experimental Agriculture*, *43*(4), 437–453. https://doi.org/10.1017/S0014479707005339
14. Majengo, C. O., Okalebo, J. R., Etich, W. N. G., Mburu, M. W., Mutua, S., Mutegi, E., & Pypers, P. (2013). Effectiveness of promising commercial bio-fertilizers on soybean production in Bungoma county , western Kenya, *11*(October), 827–830.
15. Masso C., Mukhongo R.w., Thuita M., Abaidoo R., Ulzen J., K. G. et al. (2016). Biological innoculants for sustainable intensification of agriculture in Sub Saharan Africa smallholder farming systems. In Lal R., Kraybill D., Hansen D.o., Singh B.R., MOSOGOYA T., Eik L. O., (Eds) Climate change and multidimensional sustainability in A. *Springer, Dordrecht*.
16. Mburu, M. W. (2012). *Performance of soybeans innoculated with a range of commercial microbial products under different soils of Bungoma county,Western Kenya.*
17. Ndung'u - Magiroi K.W., Koech M.N., Okalebo J.R., Othieno C.O., Koech A.K., O. M. et al. (2010). Upscaling the use of efficient and affordable soil fertility replenishment practices for smallholder farmers in Western Kenya. In *second RUFORUM biannual meeting*. Entebbe,Uganda.
18. Ndung'u K.W., Okalebo J.R., Othieno C.O., Kifuko M.N., Kipkoech A.K., and K. L. N. (2006). Residual effectiveness of Minjingu phosphate rock and improved fallows on crop yield and financial returns in Western Kenya. *Experimental Agriculture*, *42*, 323–336.

19. Nekesa A., Okalebo J.R., K. J. (2007). Adoption of leguminous trees/shrubs, compost and farmyard manure as alternatives to improving soil fertility in Trans-Nzoia district, Kenya. in Bationo A., Kihara J., Kimetu J., (eds) Advances in intergrated soil fertility management in Sub Saharan Arica: *Springer, Dordrecht*.

20. Nekesa, O. A. (2007). *Effect of Minjingu phosphate rock and agricultural lime on maize, groundnuts and soybean yields and financial returns in Western Kenya*.

21. NELSON, R., COE, R., & HAUSSMANN, B. I. G. (2016). Farmer Research Networks As a Strategy for Matching Diverse Options and Contexts in Smallholder Agriculture. *Experimental Agriculture*, 1–20. https://doi.org/10.1017/S0014479716000454

22. Njoroge, R., Birech, R., Arusey, C., Korir, M., Mutisya, C., & Scholz, R. W. (2015). Transdisciplinary processes of developing, applying, and evaluating a method for improving smallholder farmers' access to (phosphorus) fertilizers: the SMAP method. *Sustainability Science*, *10*(4). https://doi.org/10.1007/s11625-015-0333-5

23. Okalebo, J. R. (2011). *the African green revolution and role of partnerships in East Africa. In Bationo A., Waswa B., Okeyo J., Maina F., Kihara J., (Eds) innovations as key to green revolution in Africa*. *Springer*.

24. Okalebo, J. R., Othieno, C. O., Woomer, P. L., Karanja, N. K., Semoka, J. R. M., Bekunda, M. A., … Mukhwana, E. J. (2006). Available technologies to replenish soil fertility in East Africa. *Nutrient Cycling in Agroecosystems*, *76*(2–3), 153–170. https://doi.org/10.1007/s10705-005-7126-7

25. Opala, P. A., Okalebo, J. R., & Othieno, C. O. (2012). Effects of Organic and Inorganic Materials on Soil Acidity and Phosphorus Availability in a Soil Incubation Study. *ISRN Agronomy*, *2012*(July 2008), 1–10. https://doi.org/10.5402/2012/597216

26. Hocking, P.J (2001). Organic acids exuded from roots in phosphorus uptake and aluminium tolerance of plants in acid soils. *Advanced Agronomy*, *74*, 63–97.

27. Parnell, J. J., Berka, R., Young, H. A., Sturino, J. M., Kang, Y., Barnhart, D. M., & DiLeo, M. V. (2016). From the Lab to the Farm: An Industrial Perspective of Plant Beneficial Microorganisms. *Frontiers in Plant Science*, *7*(August), 1–12. https://doi.org/10.3389/fpls.2016.01110

28. Pircher, T., Almekinders, C. J. M., & Kamanga, B. C. G. (2013). Participatory trials and

farmers’ social realities: Understanding the adoption of legume technologies in a Malawian farmer community. *International Journal of Agricultural Sustainability*, *11*(3), 252–263. https://doi.org/10.1080/14735903.2012.738872

29. Pohl, C., Rist, S., Zimmermann, A., Fry, P., Gurung, G. S., Schneider, F., … Urs, W. (2010). Researchers’ roles in knowledge co-production: Experience from sustainability research in Kenya, Switzerland, Bolivia and Nepal. *Science and Public Policy*, *37*(4), 267–281. https://doi.org/10.3152/030234210X496628
30. Rutto, E.J., Okalebo J.R., OthienoC., Kipsat M., B. A. (2011). Effectiveness of “‘PREP-PAC’” soil fertility replenishment product on performance of diversified maize - legume intercrops in Western Kenya. In Bationa A., Waswa B., Okeyo J., Maina F., Kihara J., (EDs) innovations as key to the green revolution in Africa. *Springer, Dordrecht*.
31. Schaltegger, S., Beckmann, M., & Hansen, E. G. (2013). Transdisciplinarity in Corporate Sustainability: Mapping the Field. *Business Strategy and the Environment*, *22*(4), 219–229. https://doi.org/10.1002/bse.1772
32. Scholz, R.W., Ulrich A. E., Eilitta M., and R. A. (2013). sustainable use of Phosphorus : afinite resource. *Total Environment*, *46*, 799–803.
33. Scholz R.W., Amit H.R., Brand F.s., Hellums D.T., Ulrich A.E. (2014). *Sustainable phosphorus management.A global transdisciplinary roadmap.* (1st ed.). Dortrecht Heidelberg New York London: Springer.
34. Scholz R.W. (2000). Mutual learning as a basic for Transdisciplinarity. In RW Scholz, Haberli A., Bill and Welti (eds) Transdisciplinarity: Joint problem- solving among science, technology and society. Workbook II: Mutual learning sessions, 13–17.
35. Thuita M.N., Okalebo J.R., Othieno C., Kipsat M., N. A. (2011). Economic returns of the ’ “MBILI”’intercropping compared to conventional systems in Western Kenya. In bationo A., Waswa B., Okeyo J., Maina F., Kihara J., (Eds) Innovations as key to the green revolution in Africa. *Springer, Dordrecht*.
36. Vandana U.K., Chopra A., Bhattacharjee S., M. P. B. (2017). Microbial fertilizer. A tool for sustainable agriculture. In Panpatte D., Jhalla Y., Vyas R., Shellat H. (Eds) Microorganisms for a green revolution. Microorganisms for sustainability. *Springer , Singapore*, *6*.
37. Woomer, P. L., Okalebo J.R., Maritim H.K., Obura P.A., Mwaura M.F., Nekesa P., M. E. J.

(2003). PREP-PAC: A nutrient replenishment for smallholders in Western Kenya. *Agriculture, Ecosystems and Environment*, *100*, 295–303.

38. Yarime, M., Trencher, G., Mino, T., Scholz, R. W., Olsson, L., Ness, B., … Rotmans, J. (2012). Establishing sustainability science in higher education institutions: Towards an integration of academic development, institutionalization, and stakeholder collaborations. *Sustainability Science*, *7*(SUPPL. 1), 101–113. https://doi.org/10.1007/s11625-012-0157-5
39. Naveh, Z., (2005). Epiloque: Towards a transdisciplinary science of ecological and cultural landscape restoration. *Restoration Ecology*, 228–234.