Article 13

Enhancing sustainable agriculture through farmer research networks: a pathway to co-learning and innovation

Philip C Stevenson, Angela G Mkindi, Yolice LB Tembo and Steven R Belmain

[Profile: <Phil Stevenson.jpg>]

Phil is the Priority Leader for Trait Diversity and Function at the Royal Botanic Gardens, Kew where he is also a Natural Environment Research Council (NERC) Merit Researcher. He leads research projects in the Biological Chemistry group on the plant chemistry of biological interactions, especially between plants and insects (eg pollinators and pests), identifying useful agricultural traits in crops and non-crop plant taxa for sustainable agriculture and harnessing ecosystem services to improve food systems and address global challenges around food security and biodiversity. His research is funded through grants from the Biotechnology and Biological Sciences Research Council, NERC, Innovate UK, McKnight Foundation and the National Science Foundation (USA). Phil also holds a position as Professor of Plant Chemistry, Natural Resources Institute, and is a Fellow of the Royal Entomological Society (FRES) and a Fellow of the Royal Society of Chemistry (FRSC). He is a group member of the Department for Environment, Food & Rural Affairs Pollinator Advisory Steering Group, on the Advisory Board of the All Party Parliamentary Group on Bees & Pollinators and on the Sustainability advisory board for Brentford Football Club.

[profile: <Angela Gerald Mkindi.jpg> – crop a little if possible]

Angela is a lecturer and researcher in the department of Sustainable Agriculture, Biodiversity and Ecosystem Management at the Nelson Mandela African Institution of Science and Technology in Arusha, Tanzania, working on sustainable crop pest management and improving livelihoods through agroecological approaches to food production including use of natural plant products and conservation biological control. She has a PhD in sustainable pest management and is an awardee of African Women in Agricultural Research and Development.

[Profile: <Yolice Tempo.jopg>]

Yolice is a distinguished academic affiliated with the Lilongwe University of Agriculture and Natural Resources in Malawi, where significant contributions to the field of agroecology and pest management have been made over the past decade. With a focus on sustainable agricultural practices, Tembo's research emphasises the integration of ecological principles into pest management strategies, particularly in the context of smallholder farming systems in East Africa.

[Profile: <Steven-Belmain.jpg>]

Steven is Professor Ecology and Research Leader for the Centre for Sustainable Agriculture for One Health at the Natural Resources Institute (NRI). His research in the field of applied ecology specialises in the sustainable management of vertebrate and invertebrate pests cutting across fields of behavioural and chemical ecology, ecosystem services and agroecology. In 2019, Steven's work contributed to a Queen's Anniversary Prize for the University of Greenwich on Smart Pest Control. His collaborative *research projects have been conducted in 40 countries across Europe, Africa and Asia, involving multidisciplinary teams to understand environmental parameters and human behaviour with a view to developing ways of changing behaviours that reduce risk of pathogen spill-over, crop damage and stabilizing habitat biodiversity.*

Abstract

Smallholder farming communities face numerous challenges in securing food production sustainably, often stemming from poor levels of adoption, or uptake, of researcher-led interventions and innovations. Farmer research networks (FRNs) have emerged as a promising approach to address these challenges by involving farmers in the research process through co-development and implementation of research, fostering collaboration, and facilitating knowledge sharing through extended networks. FRNs offer an opportunity to promote agroecological practices and this has been demonstrated through the evaluation and adoption of botanical pesticides. Through this approach FRNs have been an effective route for smallholders to reduce synthetic pesticide use, promoting more sustainable farming practices, and enhancing community resilience. Future potential opportunities for FRNs include enabling farmers to adopt interventions that optimise the contribution of natural enemies for pest control and pollination services by improving agricultural landscapes, expanding the cultivation of useful plants for pest management, and conducting research with FRNs on beneficial insects and soil health.

Key words: Smallholder, Sustainable Intensification, Farmer Research Network, Botanicals, Field Margins

Introduction

Smallholders are defined by the Food and Agriculture Organization of the United Nations (FAO) as farmers who manage holdings of up to 10 ha. Globally, there are over 570 million farms and around 80 percent of these are smallholdings of less than 2 ha (HLPE, 2013) producing around one third of the world's food. This illustrates how important smallholders are to global food security but also shows how poor yields are, so it is not surprising that these smallholders are some of the poorest farmers in the world (Ritchie, 2021; Lowder *et al*, 2016). Like all farmers, food production by smallholders is challenged by multiple biological and abiotic constraints. Of these, insect pests present one of the most important challenges, because they are diverse and unpredictable, yet insect damage is frequent, highly visible and potentially devastating. The benefit of effective control is also highly visible, making it an attractive aspiration for farmers over other agronomic activities, but pest management is still largely dependent on synthetic pesticides (Stevenson *et al*, 2017). Our work has focussed on plant-based products for pest control because they are more sustainable and as effective as synthetic pesticides (Mkenda *et al*, 2015); can be produced by farmers themselves, reducing reliance on market availability; have commercial potential (Mkindi *et al*, 2017) and are as economically viable as synthetic pesticides (Mkindi *et al*, 2021).

Botanically diverse field margins also influence pest regulation in smallholder farming systems by providing food, refuge and nesting for natural enemies of pests (Karimi *et al*, 2024; Obanyi *et al*, 2023, 2024), although this is not always with favourable outcomes (Karp *et al*, 2018). The integration of botanical pesticides with natural pest regulation is feasible (Ochieng *et al*, 2022) because plant metabolites are less harmful to beneficial insect communities than synthetic pesticides. Tembo *et al* (2018), for example, field tested six pesticidal plants and showed that treatments often resulted in good insect control albeit less effective than synthetic pesticide treatments, but crop yields were comparable across the two approaches. However, numbers of beneficial arthropods were very low in treatments using synthetic pesticides but were similar to the untreated controls in plots treated with pesticidal plants. Crop pest management using pesticidal plants could therefore be easily incorporated into integrated pest management. However, knowledge gaps exist for farmers in adopting new sustainable approaches to pest management and the exploitation of nature-based solutions (Mkenda *et al*, 2019). Enabling farmers to use new approaches effectively requires collaboration across multiple stakeholders, from scientists to farmers.

The botanical pesticides promoted in the farmer research networks described here are chemically well characterised, which is important in understanding spatial and temporal variations in efficacy (Mkindi *et al*, 2019). Plant metabolites are non-persistent compared with synthetic molecules, which may help explain their lower impacts on beneficial insects (Tembo *et al*, 2018). A knowledge of compounds in botanicals also informs safer use which cannot be assumed simply because plant materials are natural (Coats, 1994; Trumble, 2002), while the tendency for bioactive metabolites to be non-persistent reduces the risk of exposure for consumers. Essential oil-based products, for example, have very low persistence under field conditions because they are volatile (Isman, 2006), while non-volatile plant compounds are less persistent than synthetic compounds owing to being unstable and ultraviolet (UV) labile. Rotenoid residues on olives, for example, have a half-life of just 4 days (Cabras *et al*, 2002). However, the use of botanicals must always prioritise safety and mitigate the potential hazards by minimising exposure.

Contemporary approaches to the development of improvements in smallholder farming are often challenged by poor adoption. These approaches are typically researcher led and may not effectively address the unique needs, and contexts, of smallholder farmers if the options available are limited. As a result, interventions aimed at enhancing production or pest management sustainably may not be widely embraced or may not align with the priorities of farmers and are unlikely to deliver economic or environmental benefits (Richardson *et al*, 2022; Nelson *et al*, 2016; Herrman *et al*, 2013). Farmers, however, still need support to help in the transition away from farming practice that relies on synthetic inputs. This can be achieved through the farmer research network (FRN) approach.

Understanding farmer research networks

FRNs represent a paradigm shift in agricultural research and development, emphasising the active participation of farmers in the entire research process, from development to implementation. These networks bring together farmers who represent the social and biophysical diversity of their communities to co-create research agendas, engage in rigorous research, and foster collaboration and knowledge sharing. By focusing on understanding biophysical and social variations within farming communities, FRNs democratise research and promote the adoption of sustainable agricultural practices tailored to local contexts. In recognising the diversity of needs and context, FRNs offer approaches to focus on indigenous people, women and youth, as well as other traditionally excluded stakeholders (Richardson *et al*, 2022).

Promoting agroecology through FRNs, a case study: Kilimanjaro, Tanzania

FRNs prioritise ecological, health, social and economic goals, with a specific focus on meeting the needs of smallholders. These networks recognise and learn from diverse knowledge systems, catalysing new ways of collaboration between scientists and a range of stakeholders. By emphasising agroecological approaches, such as the use of plant-based pesticides as alternatives to synthetic chemicals for managing insect pests in crops, FRNs can increase engagement and, ultimately, the adoption of sustainable farming practices (Belmain *et al*, 2022).

The FRN for Ecological Pest and Disease Management is a programme of farmer-directed research supported by the McKnight Foundation's Global Collaboration for Resilient Food Systems. It has focused on smallholder farmers of northern Tanzania on Kilimanjaro to evaluate and support the adoption of pesticidal plants and other ecosystem services such as flowering field margins in pest management. Over 100 lead farmers have directly benefitted from training and facilitated meetings and activities working in collaboration with scientists and researchers from the Nelson Mandela African Institution of Science and Technology (NM-AIST), Royal Botanic Gardens, Kew and the University of Greenwich. A third component of this FRN programme is networking, which has facilitated collaboration with Floresta Tanzania, an organic agriculture NGO. This collaboration has enabled the number of participating lead farmers to increase to over 250. Each lead farmer who works with the FRN research team then shares that knowledge back home with dozens more farmers, meaning the FRN has potential to reach thousands of farmers.

Pest management by smallholders is still dependent on the application of synthetic pesticides but is often limited to just a few major crops. For many minor crops, pest management is often not practised at all because the benefit to cost is too low for the investment in synthetic pesticides. Benefit–cost ratio is an indicator of the relative economic performance of treatments with a ratio of more than one indicating economic viability (Aziz *et al*, 2012). Amoabeng *et al* (2014) reported a benefit–cost ratio of between 10 and 14 when using botanical pesticides for insect pest control on cabbages on smallholdings in Ghana. The net income benefit of pest control using botanicals compared with untreated fields was up to USD 4400/ha. In a similar study, Amoabeng *et al* (2021) measured economic benefits of botanicals across three seasons with benefit–cost ratios as high at 40:1, while Mkindi *et al* (2021) reported economic benefits of using extracts of field margin weeds to control pests with some showing an increased rate of return compared with the synthetic pesticide.

Many approaches to the development of novel interventions do not consider farmers' diversity or context-specific practices. To address this, our FRN is helping farmers discover the benefits of sustainable pest management through co-development of context-specific research activities that farmers undertake themselves as well as testing applications used more widely in the farming community, and which are identified as priorities by the farmers. Our activities have offered a dynamic farming approach for smallholders in Kilimanjaro, where maize, common bean and a variety of vegetables are among the major crops cultivated, while farmers also grow coffee and bananas. Evaluation of pesticidal plants for insect pest management on these crops has been undertaken with FRNs in on-farm experiments on fixed-size (5 m^2) plots of each treatment and crop followed by the application of treatments and controls. An example of some recent data (Figure 1) shows that on common bean synthetic pesticides had the strongest effect on pests but as expected from our earlier work, also had a major effect on beneficial insects, while beans treated with botanicals had significantly lower pest numbers than untreated plants but importantly the numbers of beneficial insects were high (Figure 1).

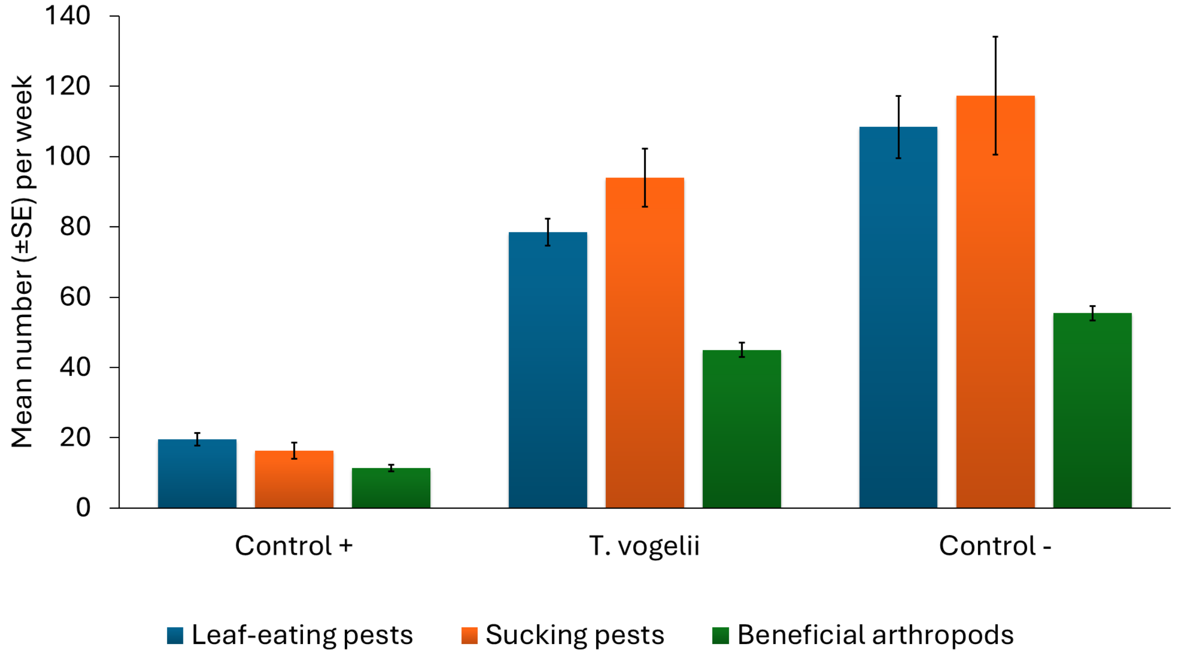

Figure 1. Farmers (n = 50) involved in a farmer research network evaluating the impact of synthetic and botanical pesticides on numbers of beneficial and pest insect species on a common bean crop

Again, in responding to farmers' research interests, our FRN experiments have also evaluated the efficacy of different application methods for plant extracts with some better-resourced farmers using knapsack sprayers, while other less well-resourced farmers apply extracts using brushes and buckets (Figure 2). Our data indicate that spraying onto plants was more effective than other applications such as using a brush or a watering can which can be less targeted and wasteful. Furthermore, yields were significantly higher with sprayed applications of plant-based extracts than of synthetic pesticides, which concurs with our earlier controlled trials and may be explained in part by control of pests but also that extracts of *Tephrosia vogelii* and other botanicals can act as foliar feeds (Mkindi *et al*, 2020).

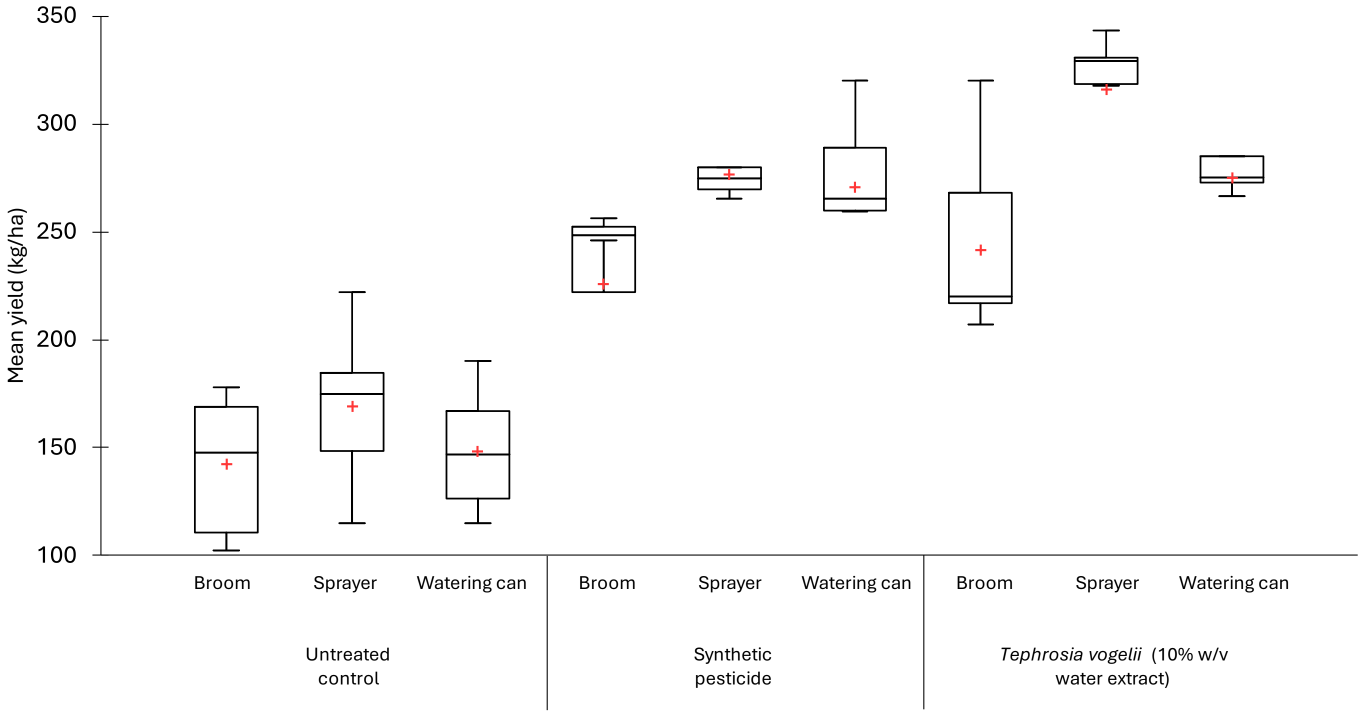

Figure 2. Yield of common beans according to different pesticide treatment application methods carried out by farmers (n = 100) involved in a farmer research network

Some farmers in our FRN chose to experiment with different soaps and surfactants, with some assessing liquid soap as a surfactant and extractant to include in botanical extracts, while others used hard clothes soap bars. Again, the choices were dependent on context, such as affordability and availability of materials. Some farmers tested combinations of plants to determine if a more complex mixture of potentially bioactive metabolites in these plants might have greater efficacy, while others compared bioactive plant extracts at different concentrations with different frequencies of application; in both cases to save time and money.

Other data generated through our FRNs have included insect damage on maize, common beans and vegetables; disease severity and germination percentage on common beans – the latter in relation to a bean anthracnose management experiment which considered crop yield for an intercrop of maize and common beans (Mkindi, NM-AIST personal communication). Broadly, these concur with those from earlier studies undertaken on experimental farms by trained scientists and under controlled conditions (Belmain *et al*, 2022, and references therein).

Our results also reveal that different pest management challenges have a range of solutions in diverse farming systems that can be resolved through FRNs. For example, while *T. vogelii* is an effective pest management option for common bean aphids, the results from experiments designed and run by FRNs show that, when used as a foliar spray, it is not as effective on common bean anthracnose disease (Kushaha *et al*, 2024). Similar findings from these FRNs have shown that pyrethrum, while effective in fall armyworm management, inhibits seed germination when used as a seed treatment to control seed-borne bean anthracnose (Mkindi, NMAIST personal communication).

By ensuring flexibility in the activities and approaches used, this FRN has witnessed stronger farmer engagement in sustainable pest management than our previous researcher-led initiatives. We anticipate that this approach will inspire wider adoption of a range of sustainable pest management options which can be effective for different smallholder food systems and can ultimately provide reliable alternatives to the use of synthetic pesticides.

Context-specific approaches can inspire diversity in the use of plants, practices and cropping systems, alongside recognising the value and importance of biodiversity occurring in agricultural systems. This is exemplified by farmers on the slopes of Kilimanjaro, Tanzania, who have transitioned from initially using pesticidal plants in experimental bean crops, to now using them on a diversity of crops and some even on livestock, which previous work has validated (Mvumi *et al*, 2021, and references therein). Some farmers have also adopted a business approach, including preparing and selling semi-processed pesticidal plant products and seeds to fellow community members and researchers, which has led to the development of local commercialisation.

Achievements and future directions

FRNs have made significant strides in promoting the use of plant extracts for pest control, reducing synthetic pesticide use, and commercialising organic produce and botanicals along with a host of other practises (Richardson *et al*, 2022). Moving forward, FRNs aim to optimise the use of natural enemies for pest control, expand the propagation of useful plants, conduct research on the impact of pesticides on beneficial insects, and improve formulations of botanicals. Additionally, future research will explore the relationship between field margins, biodiversity and crop resilience to pests, as well as the impact of farming practices on soil health and beneficial insects.

The implementation of FRNs has yielded tangible outcomes among participants and their networked communities, such as the widespread and routine use of plant extracts for pest control, reduced reliance on synthetic pesticides, and increase in the commercialisation of organic inputs and produce. Based on sound evidence that the farming community has collected, farmers are able to make direct observations on the benefits, and trade-offs, achieved through changing their farming practices. As described by Mkindi *et al* (2021), FRN group discussions highlighted that one of the key benefits observed was improved health of their families, while enabling improved pest control with reduced harm to ecosystem services (Table 1). FRN members directly attributed this to a reduction in their exposure to synthetic pesticides. This kind of evidence suggests that FRNs can increase adoption of innovations and have broader benefits for people.

[Table 1 near here]

Conclusion

Farmer research networks represent a promising approach to enhancing sustainable agriculture through co-learning and innovation. By actively involving farmers in the co-development of the research and process, promoting collaboration and facilitating knowledge sharing, FRNs have the potential to drive positive change in smallholder farming communities. As these networks continue to evolve and expand, they will play an essential role in advancing agroecological practices, reducing synthetic pesticide use, and promoting community resilience in the face of environmental challenges.

Acknowledgements

We thank the McKnight Foundation Global Collaboration for Resilient Food Systems (Grant number 20-034) for financial support.

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