

Participatory action research generates knowledge for Sustainable Development Goals

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New approaches to generating knowledge are needed to achieve the UN Sustainable Development Goals (SDGs). Participatory action research (PAR) builds on and expands the scientific process through engagement of scientists (ecological, agricultural, and social) with stakeholders in a systematic manner. To illustrate iterative co-learning cycles, we report on two decades of PAR in rural communities in Malawi. Novel findings include the expansion of agricultural diversity beyond agroforestry to meet farmer requirements while enhancing redundancy and supporting a broad range of functions. Insights from farmers facilitated identification of the value of intermediate growth habits (such as those of shrubs and vines) as “goldilocks” crop types that tighten nutrient cycles in mixed farming systems while providing multiple harvests of nutritious seeds and forage. This illustrates how PAR involves co-design with stakeholders and learning by doing, to meet local needs and mediate trade-offs, as well as generate knowledge that addresses SDGs.

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Meeting UN Sustainable Development Goals (SDGs; Fritz *et al.* 2019; <https://sdgs.un.org/goals>) will require greater integration of the social sciences with ecology, along with

In a nutshell:

- The UN Sustainable Development Goals are complex and involve value conflicts, requiring collaboration among ecologists, social scientists, and local communities
- Participatory action research (PAR) systematically supports researchers co-learning with stakeholders, for participant-oriented inquiry and problem solving
- Iterative cycles of “plan, act, observe, and reflect” can be used broadly in sustainable development, to identify a range of options for policy and management that meet multiple objectives
- Nature-based solutions through PAR often involve redesign of agroecosystems, to meet local needs and mediate trade-offs, as part of sustainable development
- PAR conducted in cooperation with rural communities in Malawi identified multifunctional crop diversity as a means to mediate trade-offs

increased stakeholder engagement. Agrifood systems are critical for realizing many SDGs. Research on this topic requires systematic approaches that encompass difficult trade-offs, social–ecological complexity, and uncertainties (Kremen and Miles 2012). Participatory action research (PAR) is such a knowledge generation process, one that – through a series of iterative steps – supports adaptive capacity building (Armitage *et al.* 2009), engages with stakeholders, and addresses value conflicts and uncertainty. Yet the evidence base for PAR methodology remains fragmented and is often inaccessible. Here, we draw on two decades of experience as agroecologists conducting PAR in cooperation with rural communities in Malawi, a small landlocked country in southeastern Africa (Snapp *et al.* 2010; Bezner Kerr *et al.* 2018). We explore the theory and practice of PAR in the generation of knowledge and technical options suitable for the socioeconomic and environmental conditions under which Malawian farmers operate to enhance food security and conserve ecosystem services.

The SDGs serve as a comprehensive blueprint for addressing equitable and sustainable transitions in food production and farming systems, and ecologists have much to contribute to these efforts, including systems-level understanding. The SDGs that address food security, equity, and protection of environmental services represent “wicked problems” where human values and high uncertainty need to be addressed with respect to appropriate resource conservation practices, for whom, over which time horizon, and at what cost (Defries and Nagendra 2017). Knowledge is often local, access to natural resources is highly heterogeneous, climate variability is unpredictable, and socioeconomic circumstances are context-dependent (Waldman *et al.* 2020).

Agricultural development has often focused on achieving production gains, which has led to substantial progress. For

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example, global cereal production has increased dramatically, and worldwide declines in child malnutrition have been observed (Pingali 2012). Even so, results have not been monolithic and gains have been variable, particularly in sub-Saharan Africa, despite concerted efforts to generate an African Green Revolution (Messina *et al.* 2017). Conventional research has also developed environmentally sound agricultural alternatives, such as agroforestry, but adoption of these practices has been modest (Ndlovu and Borrass 2021). Rather than engage in a dialectical comparison of conventional and alternative approaches to SDGs, we focus instead on the ways in which PAR can generate knowledge that not only integrates social and ecological science but also directly addresses the complexity of sustainable development. We also explore how PAR enhances the production of germane knowledge, which is expected to broaden the scope of adoption, for greater impact (Payne *et al.* 2019).

Our objective is to illustrate how PAR can generate systems-level agroecological knowledge in addition to simply enhancing adaptive capacity. Specifically, we draw on our experience over two decades in Malawi with stakeholder engagement, and explore costs and benefits associated with this approach. Knowledge generated by PAR included agroecology insights and innovations that were tailored to local contexts, addressing value conflicts in a manner that mediated trade-offs. We describe how the PAR process provided key insights toward meeting SDGs, with a focus on rural communities in Malawi, which are representative of a highly agricultural context of dryland maize (*Zea mays*)-based farming that constitutes an important agrifood system across the Global South.

■ PAR: history and practice

The PAR approach involves engaging stakeholders embedded in a local context, which enhances a holistic understanding, to derive systems solutions. The theoretical framework for PAR is well developed; “learning by doing” forms the

foundation of PAR (Panel 1), and it incorporates features of adaptive co-management, which is an effective means to enhance local capacity and conserve resources. Adaptation, however, has often been localized in scope and pays limited attention to discovery (Armitage *et al.* 2009; Plummer *et al.* 2017). Experiential discovery through PAR therefore is a step beyond adaptive management, in that it is a research process involving synthesis of new knowledge and principles (Figure 1).

The PAR process is initiated with a planning step, where joint consideration of challenges and opportunities is undertaken by participants and researchers to prioritize problems that are of mutual interest and identify plausible options to address key challenges (Figure 1). This is followed by joint action to test options, and then co-observations regarding performance. Next, participants and researchers reflect on, and synthesize, findings to generate new knowledge. The process then repeats in an iterative manner for progressive learning to refine both theory and practice (Méndez *et al.* 2013; Falconnier *et al.* 2017). Although similar to citizen science, PAR involves a greater degree of engagement and concentrates on reflection, iteration, power relations, and multiple cycles of co-learning (Panel 1; Newig *et al.* 2019).

PAR has attributes that are particularly suited to sustainable development, as discussed below, and in other Global South contexts. For example, in a multiyear, multisite PAR approach, farmers in Mali were shown to benefit from enhanced learning and demonstrated considerable interest in experimenting with new practices (Falconnier *et al.* 2017). At the same time, SDGs are broad in scope, take time to manifest, and often operate at scales that are not clearly discernable, or necessarily of interest, to local stakeholders. There can be a disconnect between PAR (conducted at the community level, with individuals) and societal benefits (such as regulation of air and water quality for everyone). At the same time, a PAR approach that, for instance, concentrates on site selection, so as to be representative of communities of interest in sustainable development, holds

Panel 1. The origins of participatory action research

The participation of non-scientists in scientific endeavors has a long history, and has helped build the ecological knowledge base (Miller-Rushing *et al.* 2012). Participatory action research (PAR) builds on pioneering approaches by social scientists during the 1940s, whose goal was to partner with clients and address real-world organizational challenges (Lewin 1946). In the 1960s, PAR took on a more explicit political dimension through the active involvement of marginalized peoples in research and reflection, including raising consciousness about the roots of poverty and illiteracy (Freire 1970). The PAR approach integrates reflection, action (including research), and sharing within a “learning by doing” framework, which ensures ongoing knowledge exchange and dialogue about progress.

Not all interactions between farmers and education specialists, such as extension workers, qualify as PAR, however; what matters is the degree to which farmers can establish the agenda, participate in research, and interpret the results. Co-assessment is an essential component of an iterative process of continual learning (Ebert-May and Emery 2017). In addition, PAR explicitly considers power relations and equity, with an active role for practitioners as co-researchers (Méndez *et al.* 2017). Participation does not guarantee success, but it can increase the relevance of research and enhance adaptive capacity. There is increasing effort to have meaningful citizen engagement in research, exemplified by the growing role of stakeholder engagement and co-production of knowledge in the US Department of Agriculture Long-term Agroecosystem Research Network.

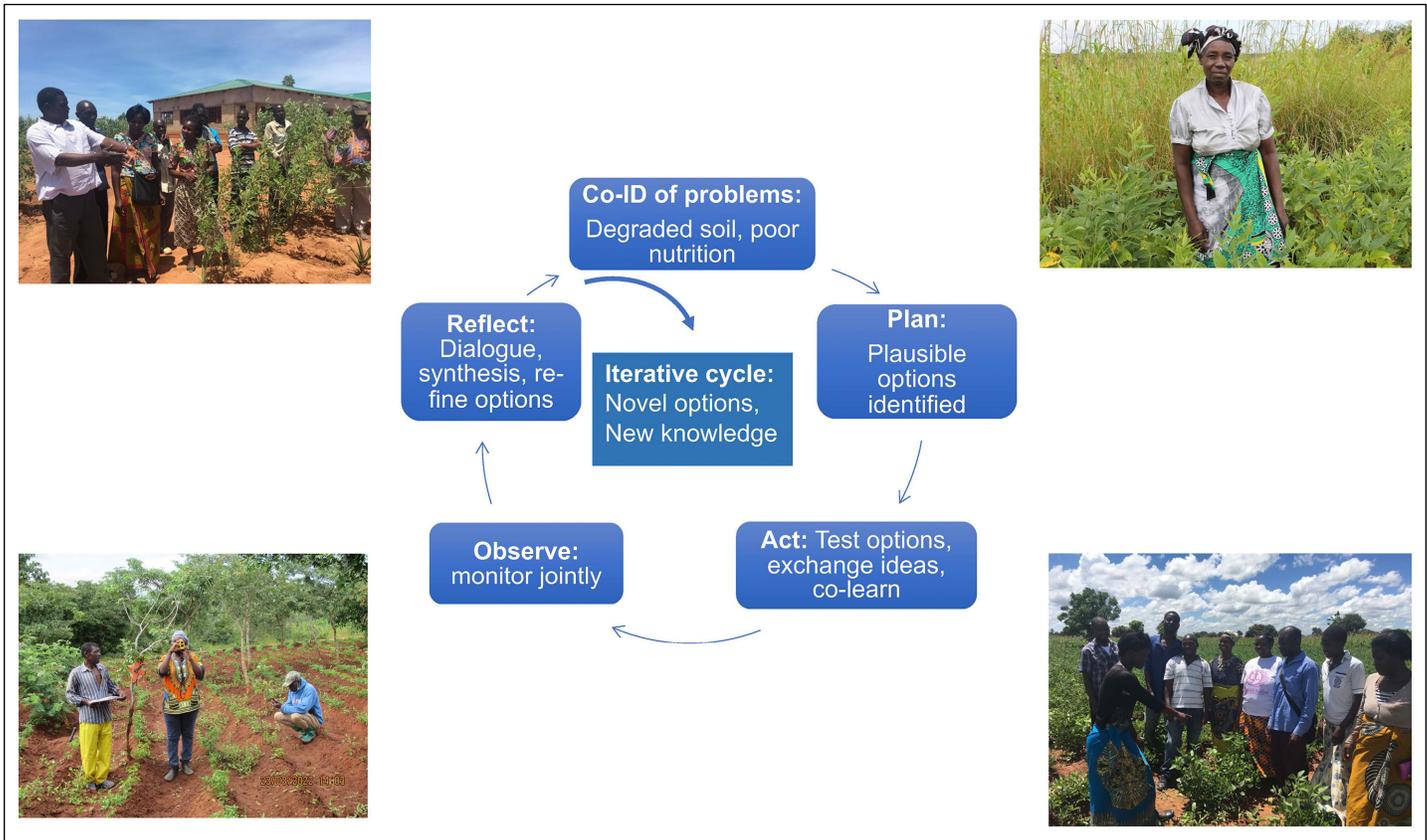


Figure 1. Iterative steps involved in participatory action research (PAR) implemented in selected Malawian communities: Ekwendeni (northern Malawi) as well as Dedza and Ntcheu (central Malawi). Knowledge sharing and dialogue are important aspects that engage the broader community, where PAR supports progressive learning over time through an iterative process. Image credits: Soil, Food and Healthy Communities.

promise to address SDG challenges like food security and environmental security in a manner that is gender-aware and inclusive (Table 1).

Timelines involved in the application of PAR will vary depending on the stakeholders involved and the environmental context. In addition, iterative cycles of “plan, act, observe, and reflect” require time: building relationships between stakeholders and ecologists, social scientists, and other actors may take several years or longer, and conducting participant inquiry over the agricultural cycle requires sufficient time as

well. The length of crop and livestock production cycles varies by agroecosystem, ranging from short crop cycles common with irrigation and bimodal precipitation to long cycles associated with mixed tree–crop systems or transhumance (seasonal movement of livestock between summer and winter pastures) that involves sizeable livestock migrations. The PAR literature includes many multiyear studies, illustrating that a substantial investment of time is generally required to carry out this research approach. Here, we report on a long-term PAR experience in Malawi as a means of exploring the richness associated

Table 1. Global challenges and UN Sustainable Development Goals (SDGs) are presented as addressed through conventional and participatory action research (PAR)

Challenges (SDGs)*	Agricultural development research	PAR principles	PAR-generated principles and practice
Food security (1, 2, 5, 12, 13, 15)	Early maturing crops; agroforestry	Functional diversity	“Goldilocks” growth habit: semi-perennial multipurpose crops
Nutrition (2, 3, 5, 12)	Diversity in crops; diversity in diet	Functional redundancy	Missing redundancy: doubled-up legumes
Soil (1, 2, 12, 13, 15)	Integrated nutrient management; conservation agriculture	Slow processes	Coupled carbon and nutrients: compost

Notes: the principles and practices presented are based on long-term research involving smallholder farming communities in Malawi. Research topics in agricultural development are listed, along with agroecology principles that were the premise at the start of the PAR process, and the refined principles and practices generated through PAR iterative cycles of co-learning. *SDGs addressed in this research process include: (1) No Poverty, (2) Zero Hunger, (3) Good Health and Well-being, (5) Gender Equality, (12) Responsible Consumption and Production, (13) Climate Action, and (15) Life on Land.

with engagement of multiple communities and a diversity of agroecosystems.

■ Malawi context

The PAR experience discussed here involves smallholder agricultural communities in Malawi. Ranking near the bottom of many UN development indicators, Malawi is a highly rural society dependent on rainfed agriculture, with about one-third of households being self-sufficient and nearly half being net buyers of maize, the country's staple food crop. Most farms are small (0.4–1.1 ha), and rising land inequity is reflected in the disparity between prominent landlessness and a growing number of large-scale farms. For over a decade, Malawi has made considerable investments in subsidy programs for fertilizers and hybrid seed, an approach that has generally been heralded as a success (Sanchez *et al.* 2009), although not all agree (Chinsinga 2015; Messina *et al.* 2017). It is a model of sustainable agriculture that has been followed by many countries, supported by conventional research that has focused on developing the best components and combinations of technologies and policies (Table 1). However, consideration of end-user engagement, or whether a given approach is suitable for the local context, has largely been neglected. Most studies on sustainable agricultural development in Malawi have reported patterns similar to those highlighted in Reich *et al.* (2021), which described an overwhelming reliance on crop yield and economics as performance metrics. However, Reich *et al.*'s (2021) systematic literature review found only moderate use of environmental metrics and little use of metrics relating to social or human conditions. This underscores the limited attention that has been given to the full complement of SDGs, including equity and ecosystem services, along with livelihoods, food security, and incomes.

The Malawi context offers a unique opportunity to synthesize lessons from the PAR process with work carried out over two decades, from 1999 to 2014 in northern Malawi and from 2012 to 2021 in central Malawi. This experience involves hundreds of communities and farmer networks, and several interdisciplinary teams with diverse expertise (eg soils, extension, agricultural economics, geography, agronomy, community nutrition, gender and health development; Snapp *et al.* 2010, 2018; Bezner Kerr *et al.* 2019). Many of the Malawian communities that participated in the PAR process have reported improvements in child nutrition, food security, environmental services, and adaptation to a variable climate (Snapp *et al.* 2010; Bezner Kerr *et al.* 2011).

■ The PAR process in Malawi

Communities were initially selected by the interdisciplinary teams in a purposeful manner so as to include villages with high incidence of poverty and malnutrition. In northern Malawi, this involved consultation with Ekwendeni Hospital

staff who were also members of the research team, as well as with village leaders familiar with the region. In central Malawi, selection was instead based on a stratified randomized process, including assessment of environmental status (marginal to mesic) and food security (poor to moderate), followed by random selection of seven communities that represented a gradient of conditions.

The PAR process began with community introductions (Figure 1), including a series of meetings over the initial year of engagement, during which researchers and communities identified priority topics where interests overlap (prioritization of challenges and associated SDGs are listed in Table 1). Insufficient food production, family nutrition, and soil degradation were the issues most consistently prioritized across the communities. The next step in the process involved community-based selection of farmers to participate in the PAR process. In northern Malawi, farmer–researcher partnerships (linked to farmer-to-farmer exchanges) were formed, and in central Malawi a similar network approach involved a design that included researcher-led and farmer-led trials (Snapp *et al.* 2019a). Researchers discussed equity and representation concerns with communities and asked that farmer network nominees include both female and male farmers, as well as those with diverse backgrounds and economic status (Bezner Kerr *et al.* 2007).

Plan

In year 1, communities, farmers, and researchers planned together and identified a set of plausible options to be evaluated through the “action step” of on-farm experimentation in year 2. A long dry season with negligible food production, few crop options, and limited access to resources by women emerged as proximate causes in many of these discussions. Option identification criteria were those that addressed root causes, were locally relevant, and were ecologically sound. Researchers proposed options derived from field experimentation and literature reviews, whereas farmers proposed options based on their own observations and, in some cases, ideas generated during visits to other communities. Attention was paid to choosing crop varieties and tree species that were of interest to farmers, particularly women farmers.

Act

Initially, on-farm experimentation focused largely on agricultural diversification. This involved plant species with divergent life histories (eg rapidly maturing crops like peanut [*Arachis hypogaea*] and bean [*Phaseolus vulgaris*]) in addition to perennial agroforestry species (*Tephrosia vogelii* and *Gliricidia sepium*) (Figure 2). Planting of trees was proposed as a means to ameliorate soil fertility and provide fuelwood, with many farmers involved in PAR having the opportunity to review agroforestry experiments through visits to nearby research stations and other communities. Researchers

presented species and crop–tree mixture arrangements that appeared promising based on their performance in previous studies, and that required only modest labor relative to other agroforestry systems (Beedy *et al.* 2010).

Action steps initiated in year 2 included maize–legume intercrops, maize–tree systems, and maize-based rotational sequences with inputs of fertilizer or compost that were evaluated via researcher-led on-farm trials, farmer-led trials, and farmer experimentation with various options in farmer-to-farmer networks. Over years 3–10, a broad range of species and management options were assessed (development and refinement of the evaluated options are described in the “Reflect” and “New knowledge generated through PAR” sections below).

Observe

Performance evaluations were conducted yearly by farmers and researchers. Evaluations often included monitoring of yield, yield variability, field security, and profitability, along with assessments of soil characteristics such as organic matter content, nutrient status, pH, and texture (Snapp *et al.* 2018). Farmer performance criteria often included income, labor requirements, and grain quality attributes (Bezner Kerr *et al.* 2019). Farmers noted if varieties produced harvestable crops early, under drought conditions, or on degraded soils (Snapp *et al.* 2019b). The metrics used in the PAR process were based on the five domains – productivity, economic, environmental, human, and social – described in the Sustainable Intensification Assessment Framework Online Toolkit (<https://sitoolkit.com/the-five-domains>). Tools employed to document performance criteria included household surveys, field-based surveys of practice and farmer preference, focus groups, and yield cuts and soil sampling conducted in the field, along with economic gross margin analysis.

Reflect

Researchers conducted analyses to summarize performance indicators such as yields, food quality, soil properties, economics, and farmer rankings, that were chosen by farmers and researchers to assess technologies trialed on-farm. Feedback about findings was solicited at community meetings, which were usually held at the end of each growing season. Farmers’ insights and observations in relation to performance data were documented through focus group discussions, short surveys, and voting exercises, many of which were conducted in conjunction with field visits to facilitate experiential learning and assessment. Performance data were presented in the form of figures on posters, using symbols (such as bags of maize) and visualization tools (such as radar charts) to present multiple indicators on one graph (Figure 3).

Social trade-offs and challenges were discussed via interactive media (such as drama performances). The reflection process led to a redesign of systems with farmers to expand



Figure 2. Value conflicts and trade-offs are key aspects of wicked problems, which participatory action research is well-suited to address. Illustrated here are crop diversification options where trade-offs are associated with crop growth habits. (Bottom image) Short-statured annual crops are excellent producers of food but feature limited aboveground vegetation and belowground rhizospheric activity to regenerate soil fertility. (Top image) Agroforestry perennials provide soil regeneration services but no food products. (Middle image) An intermediate plant type often referred to as the “goldilocks option” includes semi-perennials (such as shrubs or vines) that produce food over several years while also promoting soil fertility. Genetic and agronomic improvement efforts have almost entirely overlooked semi-perennial plant types as a means to address food–soil trade-offs. Image credits: Soil, Food and Healthy Communities.

the types of options tested, in an iterative process. Efforts to increase agricultural diversity provided an example of trade-offs and highlighted differences in value prioritization among stakeholders, and among the multidisciplinary researchers. During years 2–5, farmers and researchers primarily tested diversification options that involved the use of either early maturing crops (super annuals) or mixed tree–crop systems (perennials). These options addressed sustainable development challenges such as food security under drought (super annuals), and soil fertility and water regulation (perennials), but success was variable for both

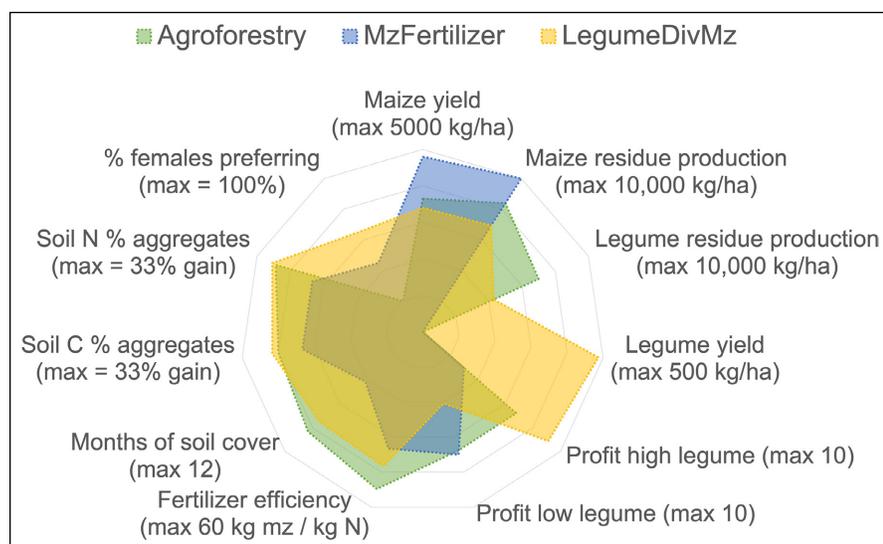


Figure 3. Participatory action research conducted on three system options: agroforestry, fertilized maize (MzFertilizer), and legume-diversified maize (LegumeDivMz). System performance indicators are shown, with the highest value along each axis appearing in parentheses. The indicators address the sustainability domains of environment (soil cover, soil aggregates, and fertilizer efficiency), profit (high and low legume-to-maize price ratios), productivity (yield and residue production for both maize and legumes) and social (female farmer rating). The radar chart illustrates trade-offs across domains for agricultural system options (adapted from Snapp *et al.* [2018]).

approaches, depending on the location. In some communities, particularly in the north, the early maturing crop varieties tested did not meet food quality or storage requirements desired by farmers (Snapp *et al.* 2019b).

During the reflection phase, agroforestry perennials were often critiqued for requiring excess labor, creating food deficits during the so-called hunger season (the resource-limited time of year for farmers, after planting but before the harvest), and having insufficient income potential (Figure 2). Soil fertility benefits were observed, but persistent trade-offs were found in terms of limited returns relative to labor and land requirements, and there was no evidence that these lessened over time, counter to initial hypotheses. Women farmers in particular strongly critiqued agroforestry interventions (Figure 3). Thus, use of tree-crop mixed systems was discontinued in most communities by year 5, based on farmer feedback during the reflection phase and greater understanding of the trade-offs involved.

The reflection phase of PAR facilitated the balancing of pragmatism of current constraints with the vision to reimagine agroecosystems. This is especially relevant to addressing SDGs. Through research cooperation with farmers and their communities, it was possible to support the expansion of options beyond current constraints. For example, in the initial 4 years of the PAR process in Malawi, communities found it challenging to grow long-lasting, soil-fertility enhancing shrubs such as pigeonpea (*Cajanus cajan*) or vines such as climbing beans because livestock browsing damaged the late-season seed pods thereof. In this region, domestic goats were allowed to roam unattended after the

maize crop harvest, a practice that impeded crop diversification. To deter goats from feeding, fencing and guards were implemented, but with limited success. In year 5, farmers chose to locate some PAR trials far from livestock, to better assess crops with prolonged growth habits. Seed, leaf and forage yield, soil fertility benefits, and (in the case of pigeonpea) fuelwood were monitored in the absence of grazing. Social change in livestock control practices requires motivation and engagement, and community participation from the start helped to mediate this challenge (Zulu *et al.* 2018).

■ New knowledge generated through PAR

Implementation of PAR improved understanding of the crop diversity deficit on farms in Malawian communities, including the small proportion of land available to grow legumes and the limited availability of diverse plant genotypes. These constraints contributed to poor farm function and led to increased fertilizer dependence, soil degradation, and insufficient dietary diversity (Bezner Kerr *et al.* 2011; Mhango *et al.* 2013).

Agroforestry and drought-tolerant varieties were initially considered as promising options (Holden and Fisher 2015; Ndlovu and Borrass 2021). Consequently, researchers focused on identifying labor-conserving agroforestry species such as *T vogelii*, which can be established from seed directly instead of the more time-consuming and burdensome option of planting seedlings. Yet in many communities, technology-based options that were assumed to be profitable and appropriate failed to meet local requirements and farmer expectations. Farmer assessments highlighted that, even in years 3 or 4 (after trees were well established), food production was insufficient, soil fertility gains were highly variable, and the agroforestry systems required onerous, time-sensitive labor for establishment, pruning, and residue incorporation. Over time, new alternatives were identified, including greater reliance on crop types with growth habits like shrubs and vines, which have often been overlooked for use in sustainable agriculture development (Figure 3). The new options sparked innovations in management practice so as to enhance perennial features of these crops while maintaining food production (eg ratooning – harvesting the aboveground portion of a plant while leaving roots and growing shoot apices intact – to encourage branching for fodder, soil improvement, and a second food crop; Roge *et al.* 2016). Together, through PAR, farmers and researchers identified a broad range of mixed farming systems that featured redundancy (eg two legumes) and functional diversity (eg mix of legumes, cereals, and cucurbits).

Other trade-offs were associated with modern, early maturing varieties that did not always store well or taste as expected (Snapp *et al.* 2019b). For instance, early harvest maize varieties were promoted for drought resilience, but they sometimes contributed to a seasonal food deficit. Working closely with the communities for several years, researchers and farmers eventually identified novel crop varieties and practices that included mixed plantings, ratoons, and compost amendments. Although in some cases refinement required 4 or more years, the redesigned cropping systems – over time – produced large quantities of high-quality, easy to store, and marketable food products. This outcome increased food security and improved nutrition in communities in northern Malawi where PAR projects have been ongoing for over a decade (Bezner Kerr *et al.* 2019). The improved practices and associated design principles (Panel 2) included “intermediate goldilocks” features, which not only generated local benefits but also could be incorporated into nature-based solutions and agroecology more broadly.

Diversity in plant options, including expanding the range of potential growth habit types, was co-identified as a top priority in many communities. In partnership with researchers, farmers identified the need to mediate known trade-offs in agroforestry through expanded testing of food-producing shrubs and vines, including pigeonpea, climbing beans (eg *Mucuna pruriens*), and pumpkins (eg *Cucurbita moschata*). One unique innovation was the application of a doubled-up legume rotation, to rehabilitate soil and provide nutritious food, planted in succession with a maize crop (Smith *et al.* 2016; Snapp *et al.* 2018). The doubled-up legume system intercropped two legumes with complementary growth habits, such as peanut or soybean (*Glycine max*), planted as an understory with pigeonpea, a slow-growing shrub. This mediated trade-offs to some degree, as farmers unable to devote land to agroforestry systems could instead adopt

doubled-up legumes to tighten nutrient cycles and enhance cropping system resilience. Officially promoted by the Government of Malawi in 2016, this approach has since spread to neighboring countries.

Soil management that recoupled carbon with nutrient cycles was a key focus of co-learning. Farmers were at times close observers, pointing out subtle changes in soil color and tilth, such as the presence of minuscule black flecks of decomposing legume residues. Compost production innovations included weedy biomass that was cut and carried to augment compost quality, and a fertilizer-augmented compost-making process called Mbeya composting (Ngwira *et al.* 2013). Overall, composting was a farmer-preferred strategy for addressing rainfall variability and insufficient soil fertility in central Malawi, whereas incorporation of compost and legume residue was the preferred option in northern Malawi (Bezner Kerr *et al.* 2007; Wellard *et al.* 2012).

■ Conclusions

Challenges associated with PAR include the need to build and maintain relationships among researchers and stakeholders; the investment required in communication, education, and documentation of co-learning; and the inherent variability of research conducted under real-world conditions. One consequence is that publication of scientific findings and completion of doctoral projects associated with PAR-based approaches to achieve SDGs are typically associated with extensive time lags (Newig *et al.* 2019). However, we contend that the high upfront costs to invest in relationship building and learning across disciplines are a worthwhile trade-off for enhanced relevance to societal problems.

PAR prioritizes empowerment of marginalized communities, utilizing diverse knowledge and building long-term partnerships to support transformational change at local, regional, and national levels (Méndez *et al.* 2013). Through selection of sites that are representative of SDG challenges and a focus on systematic engagement of social and natural scientists with community perspectives and co-learning, PAR is an approach that can improve research performance at various scales. It has broad relevance for SDG challenges, including harnessing insights of farmers and researchers for redesigning processes that mediate trade-offs. The research findings reported here provided new redesign options, including diversity in growth habits, redundancy through legume–legume systems, and coupled carbon–nitrogen cycling practices. This was particularly relevant to the context of cereal-based smallholder farming systems in southeastern Africa, to simultaneously address food security and environmental security.

Ecologists, in collaboration with social scientists, are searching for socially sound as well as biologically sound options for sustainable farming systems. This is key to meeting SDGs. Through PAR, human condition and social-science questions can be addressed along with biological and environmental

Panel 2. Agroecology principles tested and refined through participatory action research that directly address value conflicts and mediate trade-offs

- **“Goldilocks”** options involve the use of species with intermediate growth habits between annual crops and agroforestry trees. Examples include pigeonpea and other food-producing shrubs and vines, with traits that promote both environmental (soil improvement) and provisioning (food and fuel) services.
- **Diversification with species and mixtures** enhances **functional diversity** and **redundancy**. A doubled-up legume system intercropped complementary growth types such as pigeonpea and peanut in a successional rotation with maize, a high nutrient-demanding crop.
- **Re-coupled carbon and nutrient cycles** in production systems require close attention to maintain slow biological processes in soils, reduce nutrient losses, and regulate pests.

science questions, as illustrated in this Malawian case study. The PAR-generated findings reported here have relevance beyond the sub-Saharan Africa context because they provide novel insights into the development of nature-based solutions that meet local needs, a critical requirement for rural communities in many parts of the globe.

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■ Data Availability Statement

No data were collected for this study.

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Vagrant harlequin ducks feed on a buffet of blennies

Typically found in eastern Russia, northern North America, Greenland, and Iceland, harlequin ducks (*Histrionicus histrionicus*) breed near whitewater rivers and spend the winter on rocky coastlines, where they feed on invertebrates and small fishes (*Ecology* 1986; doi.org/10.2307/1939078). Despite their temperate and subarctic distribution, two vagrant female harlequin ducks were observed in the Corpus Christi Ship Channel near the Port Aransas Jetty (Port Aransas, TX) in February 2022, representing only the third known confirmation of the species in Texas. The ducks remained in the channel for several days and were observed feeding on Molly Miller blennies (*Scartella cristata*), a common cryptobenthic fish with a wide distribution along tropical and subtropical coastlines. The dredged shipping channel connects the Gulf of Mexico to a ~380-km-long estuarine system and directly flows into the Mission-Aransas Estuary, a highly productive marine environment important for commercial fishing and wintering diving waterbirds.

During the winter, harlequin ducks forage along rocky intertidal zones with wave exposure (*Estuar Coast Shelf S* 2019; doi.org/10.1016/j.ecss.2019.04.024). Thus, the rock piles and strong tides in the shipping channel may have provided the ducks' only suitable feeding habitat in a system dominated by soft sediments and limited water movement. With their exceptional diving abilities in harsh environments, the sea ducks had access to an ample buffet of blennies, which were evidently unprepared for this skilled predator. Although these hardy ducks exhibit high site fidelity and are of low conservation concern globally, they face habitat loss and population declines in eastern North America. Vagrants are often accidentals, but the harlequin ducks' journey may have been intentional (*Biol Conserv* 2018; doi.org/10.1016/j.biocon.2018.06.006); disturbances to their wintering habitat in Maine or eastern Canada could drive bold individuals to search for alternative feeding grounds. Will habitat loss incur novel trophic interactions, particularly involving migratory birds?



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