A farmer inspects her maize crop, grown using a 'push–pull' approach.

THE 'PUSH–PULL' FARMING SYSTEM: CLIMATE-SMART, SUSTAINABLE AGRICULTURE FOR AFRICA/ICIPE/GREEN INK LTD, UK

Natural solutions for agricultural productivity

Scientists are pursuing sustainability strategies for intensifying production to tackle food security and environmental crises. **By Michael Eisenstein**

On paper, the global agriculture sector has done an admirable job of keeping pace with a growing population. According to the United Nations' Food and Agriculture Organization, agricultural output per person has increased by 50% since 1960 – impressive, considering the number of mouths to feed has more than doubled.

But the reality is messier. Many people, including those in high-income nations, lack reliable access to nutritious food. And food security is an ongoing struggle for people in poorer regions. Even transient disruptions can have far-reaching consequences. One article[1] described the global food supply as being "on a razor's edge" – weather events or natural disasters in one part of the world can cause the price of grain everywhere to spike by more than 50%.

"Globally, we have to increase food production by 60%, and in some areas we have to increase by 100%," says P. V. Vara Prasad, a crop ecophysiologist at Kansas State University, Manhattan.

Over the past 50 years, producers increased agricultural output in much of the world through the 'green revolution'. But this revolution has been environmentally harmful, relying heavily on chemical pesticides and fertilizers that have inflicted lasting damage on the soil and water supply. Natural biodiversity has been sacrificed to create vast monoculture fields. And in many low-income nations, survival depends on coaxing greater productivity from existing plots as more and more people scramble for limited resources, says Bernard Vanlauwe, a soil scientist based in Nairobi at the International Institute of Tropical Agriculture.

Many agricultural researchers are now looking to a set of practices known as sustainable intensification. The specifics vary depending on the setting, but a growing number of examples from around the world highlight the possibility of a second green revolution – one that might better live up to its name.

Many roads to sustainability

The concept of sustainable intensification was popularized[2] in 1997 by Jules Pretty, an environmental scientist at the University of Essex in Colchester, UK. His goal was to challenge the idea that increasing yield is inherently incompatible with environmental health, with an agricultural philosophy that encompasses parameters such as biodiversity and water quality as well as the social and economic welfare of farmers. Researchers have defined the scope of sustainable intensification in different ways, but the big picture, says Pretty, entails recognizing that agriculture is inexorably connected with the environment and designing cultivation strategies accordingly. "Components of sustainable systems tend to be multifunctional," he says. "You want a diverse system that provides support to pollinators, fixes nitrogen and provides a break against insects." Advocates of sustainable intensification recognize that global agriculture can't be reinvented in one fell swoop and that progress will come from incremental steps that improve efficiency, as well as more-dramatic measures that redesign the farming landscape.

Lucas Garibaldi, an agroecologist at the National University of Río Negro in Bariloche, Argentina, has focused on pollinators as a crucial component of what he calls ecological intensification. "Crop yield depends not only on the count of pollinators, but also on the biodiversity of pollinators," says Garibaldi. "Millions of honeybees alone will not replace the function of diverse species of wild bees and butterflies and birds." He notes that different bees pollinate different crops, but also allow more efficient pollination for some plant species. To create a haven for these airborne assistants, Garibaldi advocates minimizing pesticide use and including non-agricultural zones in farmland. These could be wild-plant borders that surround fields or just hedgerow-like strips of flowers that are appealing to the bees that traverse them.

Growing a mix of crops can have many benefits, including attracting pollinators. Conventional monoculture leaves soil exposed for much of the year, Garibaldi says. This creates opportunities for weeds to grow – necessitating herbicides – or leaves soil susceptible to erosion. With multiple crops or rotation throughout the year, more durable root

systems that densely and extensively permeate the ground can be established, reinforcing the soil and preventing the nutrient depletion associated with long-term monoculture.

Diversity can also eliminate the need for pesticides. Pretty says around 180,000 farmers in Kenya, Uganda and Tanzania now use push–pull cropping practices when growing maize. They plant grasses around the edges of maize plots that produce chemicals that 'pull' a common pest, the maize stalk borer (*Busseola fusca*), away from crops, while the maize itself attracts parasitic wasps that prey on the stalk borer. The farmers also intersperse legumes of the genus *Desmodium* with the maize that enrich the soil with nitrogen, and produce compounds that 'push' away pests and kill off a genus of invasive weed known as *Striga*.

Sustainable soil management is a thorny issue, particularly in resource-limited settings. Vanlauwe notes that nutrient depletion is one of the greatest threats to yield for African farmers, making a hard-line approach to sustainability unrealistic. "People who say you can trigger agricultural development in Africa without fertilizer do not have on the ground experience," he says. But there are environmentally friendly ways to feed the soil. Jo Smith, a soil scientist at the University of Aberdeen, UK, has been equipping farmers in Africa and Asia with anaerobic digesters — simple systems that use microbes to convert animal manure into biogas for fuel and leave a nutrient-rich bioslurry. "It's like giving them a little fertilizer factory — it gives you available ammonium that the crop can take up quickly," she says. The biogas is also less harmful than conventional fuels, reducing household air pollution and improving quality of life, Smith adds.

Much of the world's farming takes place on smallholder plots. One study[3] estimated that one-third of the global food supply is produced on farms of less than two hectares. This fragmentation can make it challenging to introduce sustainable intensification practices. "Smallholder production systems are absolutely risk-averse," says Vanlauwe. "Falling from earning US$100 to $50 a month can be the difference between being not-hungry and being hungry."

Close collaboration with individual farmers is needed, but this is difficult to achieve at scale. Fortunately, smallholders are increasingly participating in collectives that can accelerate information sharing and reduce the risk associated with adopting new cultivation strategies. In August[4], Pretty and his colleagues reported that, worldwide, around 8 million such groups have formed over the past two decades. "That's about 240 million people working in collective-action efforts around areas like irrigation, forest management, pest management and water," says Pretty. By partnering with these groups, researchers can design programmes that are more likely to be compatible with social, cultural and environmental conditions, and establish local networks of collaborators to facilitate the dissemination of information.

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Crops rely on pollinators such as bees.

Some governments are also taking a more active role. Ethiopia, for example, has focused on aspects of ecological repair by establishing 'exclosure' areas for depleted soils. "Areas are fenced off, and after about ten years the land starts to recover," Smith says.

In China, Fusuo Zhang, a plant-nutrition specialist at the China Agricultural University in Beijing, and his colleagues are working with government officials to mobilize an effort to help smallholder farmers across the nation transition to more evidence-based, sustainable cultivation. This includes selecting seed varieties that are suited to a given plot, using modelling techniques to guide planting based on levels of sunlight, water and nutrients, and optimizing the timing and density of seed planting. "We sent faculty members and groups of students to live among the farmers in the villages, and work with them to try to change their management," says Zhengxia Dou, an agricultural scientist at the University of Pennsylvania in Philadelphia, who collaborated with Zhang's team. By 2015, the effort had grown to include nearly 21 million farmers across China, who, on average, achieved a more than 10% boost in yield while using around 15% less fertilizer and reducing their greenhouse-gas output[5].

Many farmers in India are embracing a national programme known as zero-budget natural farming (ZBNF). This cultivation strategy involves using soil microbes and mulch rather than synthetic fertilizers to enrich lands. Farmers in several Indian states are pursuing the approach, including around half a million farmers in Andhra Pradesh. But some scientists are concerned that the approach is untested and unproven. Last year, Panjab Singh, president of the National Academy of Agricultural Sciences in Delhi, told the newspaper *The Hindu*, "We are worried about the impact on farmers' income, as well as food security."

Smith concurs. "It was a political move, not a scientific move," she says, adding that the natural farming approach has "not been properly trialled". To assess the technique, she and her colleagues modelled the long-term impact of ZBNF on soil health. They found that the approach could meaningfully and sustainably improve nitrogen levels for low-yield lands, but that it would offer little benefit to farms already achieving high yields[6]. They concluded that a more targeted implementation of ZBNF is needed to protect overall national food security. Smith remains largely positive about ZBNF, which has been gaining momentum among farmers. "There's a lot of good things about it, but it needs more science," she says.

Outside national initiatives, smallholder sustainable intensive farming requires targeted investment and efforts to support social and economic stability. Vanlauwe contends that, in many parts of sub-Saharan Africa, environmental and political conditions mean that many farmers will continue to struggle at the margins for the foreseeable future. Still, he sees a path towards economic mobility. "Give them access to credit they pay back over time, and invest in integration and value-chains so they can get rid of or sell excess produce," he says. "It's about creating incentives and access systems."

But durable change also requires building local expertise in crop and soil research, and in ecosystems. Many specialists in these areas are also involved with international education and training. For example, as director of the Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification, Prasad has helped to coordinate undergraduate- and graduate-level agriculture programmes in places such as Senegal, Cambodia and Bangladesh. Normally, these programmes take on a few dozen students at a time, but the shift to online training as a result of the coronavirus pandemic could prove to be a long-term gain for capacity building. "We are now talking to about 500 or even 1,000 students," he says.

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