Regenerative Agriculture

How to improve natural ecosystems and increase yields

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- Louise Manning, Professor of Sustainable Agri-food Systems, Lincoln University
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- Claudia Veiga Jardim, Corporate Sustainability Manager, Syngenta
- Kevin Ashford, Global Technical Development Lead - Plant and Soil Health, UPL Corp
- James Hunt, Global Strategy Director – Agriculture, Croda

Introduction

In the 1970s, Punjab was the centrepiece of an agricultural revolution, adopting high-yield crop varieties, intensive irrigation, and heavy use of synthetic fertilisers and pesticides to boost wheat and rice production. It turned the region into India's agricultural powerhouse, dramatically increasing food output.

But over time, problems emerged. Continuous monocropping of rice and wheat stripped the soil of nutrients. Overuse of chemicals and tillage degraded microbial life and soil structure, leading to loss of soil biodiversity. As yields declined, farmers used ever more fertilisers and pesticides to maintain productivity.

By the 2000s, many parts of Punjab faced chronic soil fatigue, declining yields, and increased costs of inputs, making farming economically and ecologically unsustainable. The strain turned once fertile land into wasteland, robbing many of their livelihoods and food supplies.

It doesn't have to be this way. As we will show in this paper, Regenerative Agriculture – in various forms – is showing that decline can be stopped and degraded land can be rehabilitated.

Part 1:
An introduction to RegenAg

What is RegenAg?

RegenAg is a system of farming that aims to restore and enhance the health of ecosystems, particularly soil. It goes beyond simply being 'sustainable', instead seeking to improve natural systems to create agricultural systems that are resilient and productive over the long term.

There is no universally agreed definition, but most agree that regenerative agriculture should aim to improve soil health, increase biodiversity, minimise chemical use, improve soil water retention, and remove carbon from the atmosphere to store it in soil.

The tools for doing this – as we will come to – range from farming methods to technological innovations. They include no till farming, crop rotation and livestock integration, more resilient seeds, soil and plant treatments, precision farming, and use of greener alternatives to fertilisers and pesticides.

Unlike some sustainable farming approaches, definitions of RegenAg emphasise the need to support the growth of farming as a means to feed the world, and recognise that sustainable farming includes enabling farms to be profitable at scale.

The World Business Council for Sustainable Development (WBCSD) defines regenerative agriculture as an outcome-based food production system that aims to nurture and restore soil health, protect the climate, water resources and biodiversity, and enhance farms' productivity and profitability. Bayer's definition of RegenAg includes yield increases alongside the aforementioned goals.

This outcome-focused approach – which does not prescribe any particular products or practices – enables farmers and AgTech to explore different ways to improve the environment. That creates a lot of opportunity for innovation in both farming practices and technologies.

Why does RegenAg matter?

Agriculture has a major global impact on the environment. It generates around 25% of greenhouse gas (GHG) emissions and uses 70% of the world's freshwater. Intensive farming practices, such as over-tilling and the heavy use of fossil-fuel-based fertilisers and pesticides, and heavy equipment, degrade soil structure, which leads to erosion, and chemical runoff, which pollutes nearby waterways.

Better ways to farm, which reduce chemical use, minimise water use, and absorb GHGs, would all reduce farming's impact on the world.

But unsustainable farming practices are also harmful to farmers. Intensive farming practices will eventually degrade soil to a point where land no longer produces the same quantity or quality of food.

Monoculture crops bred for high yield in limited crop rotations often come at the expense of resilience. That means more nitrogen and pesticides are needed to protect them from disease, hastening soil degradation. Even then, a single unexpected pest or disease could wipe out an entire monoculture crop.

A major focus of RegenAg is therefore ending damaging practices and returning degraded soil to health – creating healthy, resilient ecosystems in which crops can be grown forever. If we do this right, it will improve yield and reduce risk in a changing climate, boosting farmers' profits and food security. And it will reduce farming's enormous environmental impact.

RegenAg vs organic farming: What's the difference?

Organic farming

Organic farming is an approach to farming with clear definitions around avoiding synthetic fertilisers, pesticides, genetically modified organisms, and emphasising natural processes to grow food sustainably. This has the advantage of being easy to understand for consumers, and easy to validate and label, but it increases the cost of production and has a natural ceiling of people willing to pay for it.

RegenAg

RegenAg has recommendations on farming techniques but focuses on outcomes – especially improvements to ecosystems and the environment. That leaves the door open to a wide range of farming approaches that can marry environmental improvement with increasing yield and reducing cost. However, that flexibility makes it challenging to measure success and certify farms as regenerative.

Part 2: How to deliver RegenAg

The science that drives RegenAg practices

Probably the most fundamental part of RegenAg is soil. Healthy soil improves yields, retains water, and absorbs carbon dioxide. Before we discuss how to regenerate soil, we'll need to define what 'healthy soil' means.

Healthy soil is a thriving, complex ecosystem full of **microorganisms, organic matter, enzymes, and nutrients** that interact to support plant growth, nutrient cycling, and resilience.

Microorganisms can create nutrients, removing the need for these to be added artificially. **Bacteria** play a crucial role in turning organic plant matter into nutrients such as nitrogen, phosphorus, potassium, and calcium, whilst **fungi** form relationships with plant roots to improve nutrient uptake. **Actinomycetes** break down organic compounds to produce antibiotics that suppress soil-borne pathogens. Larger organisms such as **arthropods and earthworms** contribute to soil structure and organic matter breakdown.

Organic matter, including plant residues and microbial biomass, provides a food source for microorganisms, improves soil structure, increases water retention, and stores carbon. Soils with 3–6% organic matter are generally considered healthy, but many farmed lands fall below 2%.

Enzymes play a key role in carbon and sulphur cycling; breaking down plant matter to release nutrients, mobilising phosphorus for plant use, turning urea into usable nitrogen.

Soil also improves **carbon sequestration**. Plants capture carbon dioxide, CO_2, from the atmosphere through photosynthesis, and turn it into organic compounds. Some of these are secreted into the soil through roots, and pass into the soil through dead roots or other plant matter. Soil microbes turn this into microbial biomass and humus, a stable, long-lasting form of organic carbon that can remain in soil for decades or centuries. Good soil structure shields this organic matter from the microbes and oxygen that cause it to decompose and release its carbon back into the air.

Conventional farming practices can degrade soil biology. Tillage disrupts soil structure, breaks up microbial habitats, and exposes organic matter to oxygen and rapid decomposition. Monocultures limit plant diversity, which narrows the range of microbial life supported by roots. Overuse of agrochemicals kills beneficial organisms and enzymes. Over time, these practices can diminish microbial diversity, deplete organic matter, reduce enzymatic activity, and impair the soil's ability to retain water and nutrients, ultimately leading to poorer plant health and lower resilience to stress.

Louise Manning of Lincoln University sums it up: "Soil is a living environment. Regenerative methods aim to rebuild its vitality".

Delivering RegenAg: The core farming principles

The first and most important thing we can do to deliver regenerative agriculture is to improve farming practices to enable ecosystems to recover. Whilst new technologies and treatments will also play a role in boosting these ecosystems further – see next section – they will not deliver these outcomes unless we first change how we farm.

Groundswell, **a popular Regenerative Agriculture festival of ideas, places these practices into five categories.**

Don't disturb the soil, for example by ploughing or using heavy doses of fertiliser. Instead, plant crops directly into the residue of previous crops using specialised equipment.

1

Keep the soil surface covered throughout the year to protect it from the elements, e.g. by growing cover crops between harvests.

2

Keep living roots in the soil. These are vital for maintaining the soil's living ecosystem.

3

Grow a diverse range of crops through companion cropping (two crops grown at once and separated after harvest) or cover cropping (growing a crop which is not taken to harvest but helps protect and feed the soil) to support soil diversity and protection.

4

Bring grazing animals back to the land. These contribute to soil diversity and allow land time to rest and regenerate.

5

Kevin Ashford from UPL Corp summarises these principles, saying, "The first thing we need to do is stop harming the soil - if you're constantly churning it up and applying degenerative techniques, it will degrade very quickly. If we just remove the harmful practices, healthy soil will gradually regenerate on its own, though that can take years, and farming needs fast improvements. That's why we need to proactively deploy these sets of regenerative tools and techniques if we are to give soil a chance of rapid recovery."

Whilst farming practices are critical, they have been well covered elsewhere by organisations like Groundswell. We will therefore focus the bulk of this section on the scientific and technological innovations that could drive RegenAg forward in the coming years.

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Kevin Ashford

Delivering RegenAg: The innovations and technologies

Some small farms may be able to go completely regenerative. But completely regenerative farming practices are unlikely to be viable at a global scale. So the second thing we can do is harness agricultural innovations. A wide range of technologies exist, or are emerging, that could help reduce harm, improve soil, and ensure crops thrive in these new ecosystems.

1. Reducing chemicals that degrade soil and harm water systems

A range of innovations could reduce the world's dependence on harmful chemicals.

A good start is to do less of what's bad for the ecosystem. Improved fertilisers and pest treatments can deliver the same outcomes with less harm.

"Chemical pesticides are not going away any time soon. They are an essential tool in a farmer's toolbox", says Daniel Glas of Bayer. "But they can be more sustainable, for example by creating products that act in more targeted ways, and which break down quickly, helping to prevent unintended and off-target effects on the surrounding environment."

"Adding chemical pesticides and inputs directly to seeds is another way to reduce pesticide use", says James Hunt of Croda. "This allows for precise delivery of active ingredients at the point of germination, reducing the need for broad spraying."

"Furthermore", Hunt adds, "adjuvants – additives that help chemical formations stick, mix, or penetrate – can be integrated into pesticides or herbicides to optimise delivery, reducing the levels of toxic ingredients needed. Likewise, adjuvants in fertilisers can help soil absorb water or plants absorb nutrients, reducing the amount of water or nitrogen that you need to apply." Combining these improved products with precision farming – driven by digital monitoring tools, artificial intelligence (AI), and GPS-guided robotics that can apply treatments at the right time, place, and rate – could significantly cut the harm that agricultural practices do to the soil.

Minimising such practices gives the soil a chance to maintain balance, and even partially regenerate. But use of chemical treatments will always mean fighting against the natural ecosystems that RegenAg aims to nurture. And, as Louise Manning from Lincoln University points out, "RegenAg comes with recognising the trade-offs. Ploughing is used to control weeds, so if we don't plough, we need other means of weed control, and that can't just be a reliance on chemical solutions or the whole exercise is pointless".

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>
> ***Daniel Glas***

Biocontrol solutions are the obvious tool to reach for, providing natural methods for managing pests, diseases, or weeds. These use living organisms, or their by-products, such as beneficial bacteria, fungi, or viruses that target pests or pathogens; as well as beneficial bugs that kill pests, such as certain types of nematodes and mites. These can be formulated as liquids, powders, or granules and applied as seed treatments, foliar sprays, or directly to soil.

2. Improving soil diversity - Biological solutions and biostimulants

Reducing damaging practices is the critical first step for allowing a degraded system to regenerate. Next, we need to give that regeneration the boost it needs. “A lot of farmed soil eroded", says Sjoerd van der Ent of Koppert. “So AgTech companies are looking at microbial solutions that can restore the balance of biological life.”

One solution is **biofertilisers,** natural fertilisers that contain living microorganisms which, when applied to seeds, plants, or soil, promote growth by increasing the availability of nutrients.

A notable 50-year German study, running from 1972 to 2022, found that natural fertilisers enhance soil nutrients over time, including carbon levels, magnesium, and essential plant nutrients, whilst supporting stable crop yields.

Furthermore, adding the right nutrients in the right proportion can do a lot of good. “Using appropriate nutrients, and adding calcium lime and gypsum, where calcium is short, is a really simple way to improve soil health", says UPL Corp's Kevin Ashford.

“And healthy soil takes care of itself, reducing the need for chemicals”, Ashford adds, “Some farm soils are bubbling with worms, creating hundreds of kilograms of nitrogen that plants need. Others are adding hundreds of kilograms of fertilisers from a bag. Systems designed to control pests also control beneficial microbes. It can be a downward spiral.” Then there are **biostimulants**, a growing area of research, which apply chemicals or microorganisms to seeds, plants, or soils to enhance growth and soil health - not by directly supplying nutrients (like biofertilisers), but by stimulating natural processes in plants and the soil.

Most biostimulant research focuses on plant growth (more on that in the next section) but some biostimulants also activate beneficial soil microbes which are essential for nutrient cycling and soil structure, ultimately supporting long-term soil health and more resilient crops.

3. Making crops more resilient

Soil health is critical to RegenAg, but we must also acknowledge that a perfect soil ecosystem will not always be achievable. So innovations that improve crop yield and resilience – without piling on ever more chemicals – must also be seen as a key element of RegenAg.

Here is where our biostimulant friends really come into their own. Biostimulants are molecules that send signals to plants to trigger specific biological processes, often by activating or suppressing gene expression or metabolic activity. They can be delivered into plants via seed treatments, soil treatments, or foliar sprays.

For example, they can stimulate root development to improve efficient nutrient uptake in subpar soil systems; boost antioxidant production which enables plants to mop up harmful chemicals that are often overproduced by plants under environmental stress; or help plant cells maintain their water content in water-deprived environments.

These 'abiotic stress' solutions increase yield and enable plants to grow in less hospitable environments. On the other hand, within hospitable environments, they allow plants to thrive whilst needing less water or nitrogen.

The other approach to resilience is breeding seeds to be more resilient. "Plants are much more resilient in nature than on farms", says Sjoerd van der Ent, of Koppert. "But typically breeding has focused on factors like yield or flavour at the expense of resilience. So we have relatively vulnerable plants that rely in part on chemicals to protect them. Seed breeding companies have recognised this, and there is now a movement to look at breeding more defensive plants."

The challenges of delivering RegenAg

So if the benefits are so clear, why isn't every farm using resilient seeds, supported by precisely applied biofertilisers, biocontrol solutions and biostimulants? Good though all this sounds, creating these products is hard and comes with costs, and using them can require significant changes to farming practices.

Innovation challenges for AgTech

Creating biologicals and biostimulants is not as easy as established lines of chemical treatments. Many involve living organisms that have a limited shelf life and need to be stored under certain conditions (often below certain temperatures) to ensure they stay dormant until they are in the soil. That creates a barrier for farmers, reducing the market incentive to develop them.

Formulating these living biological solutions into seed coatings and foliar sprays is also tricky. "The product needs to function", says UPL Corp's Kevin Ashford. "It needs to stick on the leaf, penetrate the leaf, move through the phloem and xylem, and send signals to roots or flowers, taking into account that plant biology changes over the growing season".

But innovations abound that help with formulation stability and control, and plant and seed adherence, that can make things easier for farmers. "New stabilisers are keeping biological formulations stable for longer and across a wider range of storage environments", says James Hunt of Croda. "Adjuvants are enabling precise delivery of biologically active ingredients into plants via leaves and roots, and surfactants are helping biological treatments stay where they are meant to be."

A RegenAg strategy will also benefit from availability of more targeted products, which work with the differences in soil, plants and microbes in different environments. That would mean product R&D needs to consider different compositions for different environments, all of which must undergo an arduous product registration process. That makes developing targeted solutions – which could support regenerative practices – harder to develop.

RegenAg also requires different thinking about field trial testing. To date, products are mainly tested for safety and efficacy to generate data for approval.

That might not be enough to position products as enablers within a RegenAg system.

"We need to start thinking about how products can contribute as building blocks within a multi-crop, multi-season system", says Bayer's Daniel Glas. "That's a big mindset shift for input companies, which are inherently product-centric."

Mindset challenges for farmers

Making this shift to RegenAg also requires a wholesale change of thinking for farmers.

In many cases, adding biological solutions without making broader changes to farming practices will have little impact. Biological solutions such as microbes and beneficial nematodes are living organisms. They won't be able to thrive – and may not even survive – on farms with monoculture, excessive herbicide and nitrogen use, or constantly churned up soil.

Sjoerd van der Ent says: "If you overfeed plants with nitrogen, it can damage their health – just like giving a human too much of something they crave – and make them more susceptible to pests and disease. And not only does that harm plants, but it also harms the soil ecosystem, meaning microbial and other beneficial biological solutions don't stand a chance. So we need to reduce artificial nutrients to support both plants and biologicals."

"RegenAg needs to be approached as an ecosystem, not product by product", says Kevin Ashford. "Farmers need to select a mix of products aligned to their desired regenerative outcomes, not just one product for each goal. Otherwise, one product will be working against another." That needs a big change in thinking.

Spotlight: the Reverte Regenerative Agriculture programme in Brazil

Launched in 2019, the Reverte program is a partnership between Syngenta, Itaú BBA bank, and The Nature Conservancy (TNC), which helps farmers adopt regenerative methods through a technical and financial support package.

Participating growers receive a 10-year loan, provided by Itaú BBA and supported by a $150 million sustainability-linked bond from development finance institutions IFC and IDB Invest, with a three-year grace period to ease the transition.

"For us, it's a process to achieve sustainable agriculture, helping growers restore soil health and productivity."

Gabriel Moura

Farmers also benefit from customised agronomic guidance, including no-till farming, cover cropping, biological inputs, and precision agriculture tools. Soil health is monitored using advanced biological and chemical markers, among them, measuring the presence of enzymes like β-glucosidase and α-sulfatase, which serve as early indicators of soil biological recovery.

"For us, it's a process to achieve sustainable agriculture, helping growers restore soil health and productivity," says Gabriel Moura, Sustainability Coordinator and Syngenta's lead on the program. "The emphasis on soil regeneration is central."

The results are striking. Over 260,000 hectares of degraded land have been enrolled across Brazil's Cerrado, Amazon, and Atlantic Forest biomes. According to TNC, the program contributes to carbon sequestration, water protection, and biodiversity restoration.

Reverte aims to scale up to 1 million hectares by 2030. "We are showing that we don't need to deforest to produce more", says Syngenta's Claudia Veiga Jardim, Corporate Sustainability Manager. "We just regenerate already-open areas with RegenAg practices. That helps everyone: growers, businesses, and the planet."

"We are showing that we don't need to deforest to produce more."

Claudia Veiga Jardim

Part 3: The economics of RegenAg

The theory is sound, and pockets of successful RegenAg already exist. "But ultimately, RegenAg needs to make money for the farmer in its own right", says Daniel Glas.

So, is any of this viable at scale?

Whilst views of our expert interviewees ranged from optimistic to sceptical, there are good reasons to believe RegenAg will find a market – and perhaps even become a mainstream way of farming.

We can consider the opportunity for financially viable RegenAg on three time horizons

Near term: A RegenAg premium?

For early adopters, there are some clear incentives. There is potential brand equity for big companies in embracing RegenAg and showing their efforts to improve the environmental impact of agricultural production. McCain has been making a big play in the space. Meanwhile, smaller RegenAg farms may be able to capture a share of high-paying conscientious consumers.

This will depend on public recognition of RegenAg, which does not yet exist at scale. It may need labelling, which will be hard in an industry that does not define itself by clear metrics.

And this approach has its limits. "The organic movement has a natural ceiling of people willing to pay for sustainable products, which is about £3 billion a year in the UK", says Louise Manning. "But on the other hand, as certain practices become more mainstream, the ability to charge a price premium diminishes as happened with free-range eggs and companies will go out of business if they can't balance income and costs."

So the premium-related strategy may provide a near-term boost and get RegenAg on the map, allowing some farms to test ideas and prove concepts. But it is probably not the route to mainstream adoption.

However, revenue may come from places other than the consumer. Regenerative farms could sell carbon or biodiversity credits to supplement their farming income. Or low-carbon farms may be able to charge a premium to large commercial buyers such as supermarkets or food brands who are looking to reduce their supply chain (Scope 3) emissions.

> "There is a potential win-win if farmers can get paid for carbon and biodiversity services that are outputs of Regen Ag."
>
> ***Louisa Manning***

Louise Manning adds, "There is a potential win-win if farmers can get paid for carbon and biodiversity services that are outputs of Regen Ag. But those markets are nascent and uncertain, and often rely on reducing emissions against a baseline, so once that value is delivered, it can be hard to keep earning more income". So again, it's a lever to add value, but not likely to be the sole answer to making RegenAg profitable.

Mid-term: A supported transition?

Many farmers are quite conservative, so for the movement to be successful, it needs to build trust that it will work and deliver over the long term.

That could be delivered in the short term by subsidies, funding, or other external schemes to help farmers transition.

Daniel Glas says, "Many studies suggest that when farmers shift to RegenAg, you see an initial rise in costs and a dip in yields and profitability for 1-3 years. But after that, they start to see a positive ROI in most cases, as soil improves and yield rises often above previous levels." Subsidies or other payment

mechanisms that get farmers over that barrier could be transformative.

This finance may not just come from government, but also from private investors and value chain partnerships. As the Reverte programme shows, there is a shared interest in regenerating land. Farmers make money, countries increase food security and economic growth, and AgTech companies have more farmers to sell their products to. Favourable loans contingent on farmers switching to regenerative practices, backed by collectives with long-term profitability in mind, and with partners who can offer products and training that support farmers to make the transition, could be an appealing business model.

Daniel Glas says, "Financial mechanisms should be focused on financing the transition. In the mid-to-long term, the RegenAg production system has to stand on its own feet and has to be profitable for the farmer on its own." But others argued that subsidies could play a longer-term role, noting that many countries, including EU countries, Brazil and even the US, have had agricultural subsidies for decades. Soil is a national asset, so repurposing farming subsidies to support RegenAg – which is good for a country's long-term prospects for feeding itself and exporting – shouldn't be ruled out as a strategy, they say.

Long term: A strategic investment?

Finally, there are good reasons for farmers to commit to RegenAg long-term regardless of financial support.

"Current land-degrading practices can't go on forever. There is a limit to how much nitrogen and phosphorus we can keep using", says Sjoerd van der Ent. Kevin Ashford adds that, "There are already major farming areas – from Spain to South Africa – where the soil can barely sustain crops and will soon be unusable. But they can be bought back with a regenerative approach".

"Regenerative practices make business sense even without premiums because they enable more efficient resource use and long-term sustainable yields" adds

Sjoerd. "And it is already starting - many are shifting from chemicals to biological crop protections, and investing in biostimulants."

It may also be key to a farm's ability to be economically resilient. "A bank isn't going to give you a 20-year loan to buy new equipment if your soil won't sustain current yields for that time", says Louise Manning.

"In the long run, regenerative agriculture really is the only way forward", says Sjoerd. "The question is how fast we can do it?"

How can we drive the transition at scale?

We do not have all the answers, but a few things arose from our interviews, which could help support Regenerative Agriculture, which we summarise here:

Industry (e.g. food and agriculture companies) and government should **come together to agree** on shared definitions, metrics and cost-effective measurement approaches for soil health and biodiversity.

Ultimately, that should lead to **standards and labelling schemes,** which interested parties should collectively explain and promote to create a RegenAg consumer market.

Agreed metrics for RegenAg would also **spur investment** from farmers and treatment companies.

Value chain partnerships should be explored that bring together farmers, long-term finance, and AgTech companies, who all stand to benefit and can spread the risk. This would also provide a valuable test bed for new RegenAg products to be researched and trialled.

Subsidies will likely be necessary, at least at the start. Governments should explore how these can be best targeted.

Guidance, forums, and training by companies developing RegenAg products should be further advanced and promoted to enable peer learning and shared best practices among farmers.

How Croda can help

Croda is keen to collaborate with industry and academia to explore and address the challenges of RegenAg raised in this paper.

As an agricultural innovator, we bring capabilities and expertise across the themes discussed in this report, from biologicals and biostimulants to product formation and testing of sprays and seed treatments with targeted delivery. We have a sophisticated portfolio across crop and seed enhancement, field crops and vegetables, and deep expertise in conventional and biological chemistry.

But we are just one player, and this is a big topic that needs lots of different organisations to come together and collaborate. We want to hear from others working in this space to explore projects where we can deploy our combined expertise to accelerate innovation and deploy RegenAg solutions.

"We want to hear from others working in this space to explore projects where we can deploy our combined expertise to accelerate innovation and deploy RegenAg solutions."

James Hunt

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