AngloAmerican

The Future of Fertiliser

Expert perspectives on a changing landscape

Table of Contents

Foreword

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Responsibly produced, balanced and sustainable crop nutrition is crucial to feeding ever more people.

How can we resolve the need to feed ever more people in the world with better quality food from decreasing areas of available and productive farmland, while at the same time reducing the environmental impact of the fertilisers that have played such an important role in increasing food production over the past 75 years? This is a conundrum that we all need to figure out with urgency before our planet's soils are beyond repair.

Addressing these issues is no mean feat. The solution must ensure that food productivity meets both profitability criteria and the desire for improving living standards from a growing global population. The challenge, therefore, is not merely about implementing responsible farming practices in isolation, but also about integrating them into a holistic and resilient food system that aligns with both ecological limits and economic imperatives.

As we head towards 2050, the agricultural sector and its systems have a responsibility to adapt to navigate this increasingly complex challenge. Part of the solution lies in the fertilisers we use and how we use them, given their essential role in global food production, and how we can increase yields and strengthen food supply chains while reducing their high levels of waste.

Fertilisers are indeed essential to feeding the growing global population. 50% of people today rely on food grown with fertilisers[1] yet their continued use must evolve to support long-term soil health, water conservation, and lower agricultural emissions. Farmers will need to produce more food, better food, more efficiently and with fewer unwanted outcomes. Now is the time to embrace change before it is too late.

As a future producer of a wholly natural and abundant organic fertiliser, Anglo American calls on the agricultural industry to grab the opportunity for innovation, smarter application, and cross-sector collaboration. This report envisions a future in which sustainable crop nutrition solutions are the backbone of a resilient global food system. The path forward requires multi-stakeholder engagement, from policymakers to farmers, working together to create scalable, impactful solutions.

We invite you to explore this report not only as an analysis of the current situation, prevalent trends, and emerging initiatives, but also as an inspiration for transformation. The future of fertilisers must be one where sustainable solutions nourish people and sustain the planet, building on the incredible successes of food production since the mid-20th century. Greater use of sustainable fertilisers has a vital role in increasing crop yield and resilience in parallel with protecting nature and improving soil health.

A prime example of such a fertiliser is polyhalite – a low-carbon, multi-nutrient mineral that can help restore damaged soils and lift yields, thereby increasing returns for farmers and making their land more productive for generations to come. Anglo American will supply polyhalite from the innovative Woodsmith mine that we're developing in the UK. Woodsmith is our next generation of FutureSmart mine – a benchmark in responsible mining with close to zero waste and that is barely noticeable at the surface.

We're determined to play our part, but we also want to be at the heart of the debate that will lead to the best of solutions for the future. We're committed to working across the agricultural value chain, from researchers and policymakers to farmers and consumers, to shape a future where responsible food production can nourish our people and our planet.

We hope this report will help you see into the future, to imagine our agricultural system in 2050, and consider how we can get there.

Together, we can contribute to a future where everyone has access to the food they need, produced in a way that respects and protects our planet, for generations to come.

We invite you to join our conversation. A future with an abundant, sustainable food system will not happen by accident; we must build it together.

Duncan Wanblad
Chief Executive, Anglo American

Executive Summary

Executive Summary

This 'Future of Fertiliser' report represents the opinions of a diverse group of 74 agricultural experts from around the world who we asked to look 25 years into the future and tell us how agriculture will have changed by 2050 and what needs to happen in the fertiliser industry to keep it successfully and sustainably feeding the world.

Our experts included industry leaders, farmers, fertiliser producers, food companies, academics, policy influencers, analysts, investors, and other stakeholders representing different parts of the food value chain.

Interviewees were given five key trends in the global agri-food system (sustainability and regulation; incentives; agricultural practices; innovation; and collaboration), and asked what degree of change they expected to see in each.

They were then asked to share recommendations on the success factors required to deliver these changes, including the role the fertiliser industry will play to deliver a thriving food system.

Our experts provided a cautiously optimistic vision of the future; one in which new regulation and financial incentives will drive change towards adoption of more sustainable practices, such as regenerative and precision agriculture techniques, supported by advances in technology.

A clear priority was identified: to enable a successful transition while maintaining food security, we must invest in the production and application of sustainable fertilisers, at scale.

This, they said, is because unbalanced crop nutrition and poor chemical fertiliser practices have caused damage to nature, soil and the environment, and governments and the food value chain will increasingly act together to address it.

Fertilisers will remain crucial for improving yields because they are the main supplier of the underlying crop nutrients on which our food system depends, but scaleable improvements in their efficiency, application, delivery and management are urgently needed.

This requires the fertiliser industry to adapt to think beyond yield, to recognise the value of sustainability, balanced nutrition, and soil health, and to collaborate across the value chain to deliver change.

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The world in 2050

Our interviewees told us that by 2050:

Regulation will have driven a transition in sustainable agricultural practices, though the pace and scale of the transition would depend on frameworks to internalise the environmental costs of modern agriculture.

Financial incentives will have evolved to encourage more sustainable agricultural practices – a marked change, as agricultural subsidies have historically incentivised unsustainable practices.

Agricultural practices will prioritise the importance of soil health to drive long-term yield and improve crop quality. This will result in the growth of regenerative agriculture.

Adoption of innovative agri-tech solutions will have accelerated with AI and robotics driving change particularly in high-value crops. Adoption of sustainable fertilisers will play a crucial role, but only if they are affordable, scalable, and easily adopted by farmers.

Collaboration across the agricultural value chain will have increased – especially among farmers, policymakers and food manufacturers. However, concerns about deglobalisation and economic protectionism could hinder broader industry-wide collaboration.

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The experts concluded that there would be variations in these trends across geographies, with developed economies more likely to increase sustainability regulation and evolve agricultural practices. Specifically:

- Europe is expected to lead in sustainable agricultural practices, due to higher consumer willingness to pay, stronger regulations, and environmental performance incentives under the Common Agricultural Policy and related initiatives.
- The United States may lag in adoption, due to the affordability of chemical fertilisers, large-scale commodity crop production, and limited government intervention.
- China is most likely to increase its investment in international agribusiness, but also to address the degradation of soil and farming land at home, through limiting artificial fertiliser and promoting more balanced practices.
- Brazil will continue to implement policies fostering agribusiness investment and infrastructure development, building on its position as a major global soybean, beef and poultry player, and significantly boosting the nation's economic growth.
- Developing economies will focus on closing the yield gap, potentially leapfrogging to sustainable alternatives if adequate financing and training programmes are implemented.

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Recommendations for change

To build the thriving food system that our experts foresee, our panel highlighted the need for the fertiliser industry to adapt – its thinking, structures, and rules. Fertilisers and the nutrients they provide will continue to underpin agricultural success (and we cannot feed the world without them), but how we think about their application must evolve, to preserve our resources for the long term. Specifically, our panel said the industry needs to:

1. Redefine the metrics for business success – **move away from a sole focus on yield**, and create frameworks to measure and value soil health, emissions, food nutrient content and the impact on nature;
2. **Prioritise scalable crop nutrition** solutions with proven agronomic effectiveness across a broad range of crops, to maximise return on investment;
3. **Tailor solutions and incentives** to the real needs of farmers;
4. Focus more on **soil health;**
5. **Internalise the environmental costs of chemical fertilisers** to define the real value of sustainable alternatives and incentivise their use; and
6. **Work with farmers** to build trust.

By embracing these shifts and seizing the opportunities they present, the sector can ensure that future fertiliser practices not only meet the growing demand for food, but also contribute positively to the planet and future generations.

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Above all else, our interviewees emphasised the need for a greater spirit of collaboration, openness, and humility on the road to 2050. Real progress, they said, hinges on fostering new and genuine partnerships between previously siloed stakeholder groups, to move towards a more resilient and sustainable future.

How the research was conducted

Anglo American commissioned Deloitte to carry out interviews with 74 independent stakeholders from across the food value chain, and to contribute to drafting the contents of this report.

Interviews were designed to test 12 key hypotheses describing the food value chain in 2050. Responses captured in this report reflect the independent views of the interviewees and not those of Anglo American.

CHAPTER 1

Introduction: Resolving the challenges facing the agriculture industry

This report explores the views of key industry players on how the agri-food sector and fertiliser industry should evolve between now and 2050.

To ensure a balanced set of perspectives, we consulted 74 experts from across the agriculture value chain, including scientists, policymakers, industry leaders, and farmers. We sought their views on how the future of agriculture and the fertiliser industry would pan out. Their views highlighted the trade-offs the industry must make, as well as the collaboration needed to address competing demands. Interviews were designed to capture their vision for the future:

- What will the agricultural sector look like in 2050?
- What forces will create this future?
- What role will fertiliser play?

Setting the horizon in 2050 gave our experts the opportunity to step back from the challenges of today and imagine a different food system; to be bold and optimistic about how we can grow food that supports our people and our planet.

At the heart of this discussion is soil health, which is the foundation of sustainable agriculture. Fertilisers must not only deliver the right nutrients to support higher yields, but also contribute to long-term soil regeneration and resilience.

We consulted **74 experts** from across the agriculture value chain, including scientists, policymakers, industry leaders, and farmers

This introduction is followed by an overview of the 'farm-to-fork' value chain, the key stakeholders we engaged to understand this evolving ecosystem, and the competing demands upon it.

We then present three further chapters to capture the views of those we have consulted in the context of the past, present and future for the world of fertilisers.

Chapter 2.
Delivering modern agriculture's interlinked objectives: The role of fertiliser

A look back at how fertiliser helped feed the world, the consequences of applying unbalanced fertiliser, and an overview of the innovative solutions that could transform our food system.

Chapter 3.
Envisioning the world in 2050

A step into the future, through the eyes of independent agriculture experts.

Chapter 4.
The future of fertiliser: Recommendations for change

Five key steps the fertiliser and broader food ecosystem can take to help ensure we can sustainably feed the world by 2050.

Introducing the fertiliser value chain

The fertiliser value chain is a complex and interconnected system shaped by global, regional and local geopolitical, socio-economic and environmental factors. As such, the producers, traders, farmers, retailers, Consumer Packaged Goods (CPG) companies, policymakers, advocates and others who make up the chain hold differing perspectives on the key opportunities and challenges on the road to 2050. For example, farmers prioritise their immediate economic viability. Governments take a longer-term view and try to champion policy and regulation for system change.

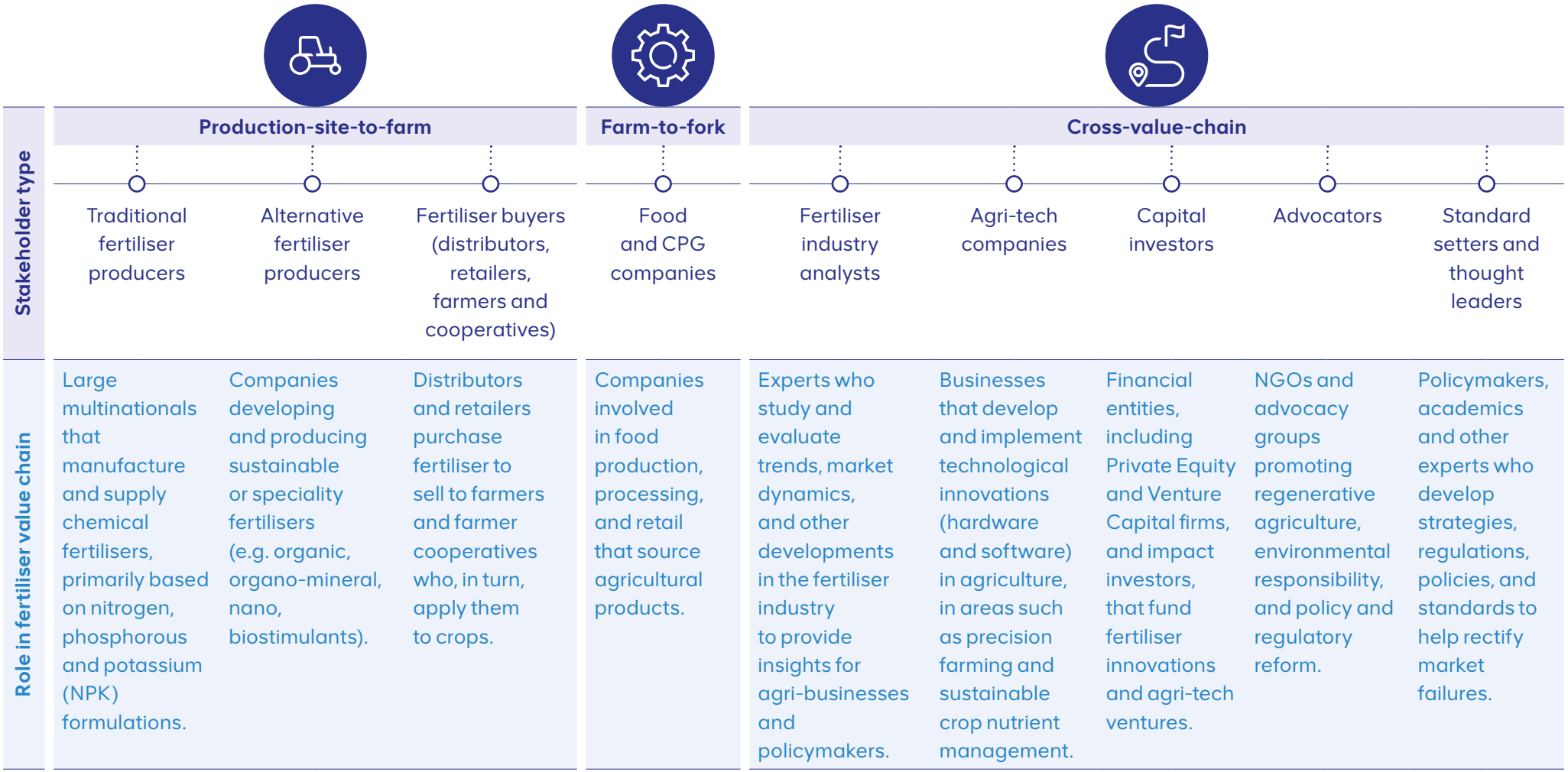
Traditional fertiliser manufacturers believe that research and development can enhance the efficiency of today's fertilisers and eliminate the environmental impacts associated with their production, to meet food demand sustainably while maintaining profitability.

To ensure a well-rounded vision in this report, our panel of 74 experts included a wide range of senior stakeholders from across the fertiliser value chain.

We categorised them into nine groups; Figure 1 provides an overview of who these stakeholders are, and their role in the fertiliser ecosystem.

> "We're moving from commodity to specialty … fertiliser will not only be for nutrition, but also to deal with the stress tolerance and recovery. We'll move towards more environmentally friendly fertilisers with lower carbon footprint. It will come down to nutrient use efficiency and water use efficiency."
>
> **Royie Mashiah, Speciality Fertilizers Marketing & Portfolio Director, ICL**

Figure 1: The fertiliser value chain



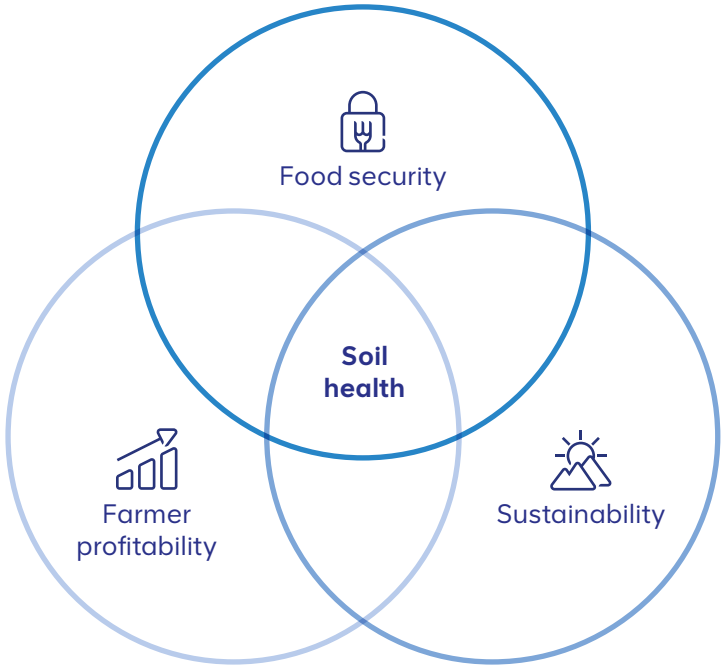
Goals of the fertiliser value chain in 2050

The experts we consulted all expressed related but conflicting goals that the 2050 fertiliser value chain must achieve. Getting nutrients to the farm and into food for the consumer is complicated, and typically involves many interdependent stakeholders with differing demands. Farmers often lack the financial capital and incentive to make systematic changes quickly and, in many parts of the world, need to remain focused on immediate returns. Large food businesses recognise that consumers have easy brand-switching options should their products not meet environmental standards, in addition to the expected balance between quality and price. Investors need to source opportunities for yield profiles and certainties that fit with portfolio expectations.

Despite these apparently conflicting priorities, three fundamental and interlinked objectives emerged during the research that all parties agreed must be met for the industry to deliver a more sustainable fertiliser system:

- **Food security** – Deliver nutrients of the right type, in the right quantities, at the right time and at a fair price to grow enough food for a growing population.
- **Sustainability** – Deliver food and profit without destroying the environment, especially soil and ecosystem health, nor harming long-term food security and profitability goals.
- **Farmer profitability** – Ensure a fair profit for farmers and other businesses in the agri-food system.

Figure 2: Modern agriculture's interlinked objectives



> "Everything starts and ends with soil. It's the start point, the end point and everything in between of profitability, food security, environmental security."
>
> **Ben Taylor-Davies**, Regenerative Farmer

These objectives cannot all be achieved at once. For example, to achieve food security, we may need to grow crops rapidly using fertilisers that impact the environment. To achieve sustainability, there may be an impact on farmer profitability.

But regardless of the trade-off, at the heart of these objectives is the crucial resource that sustains the world's food system: healthy and productive soil.

Food security: Meeting growing demand for food

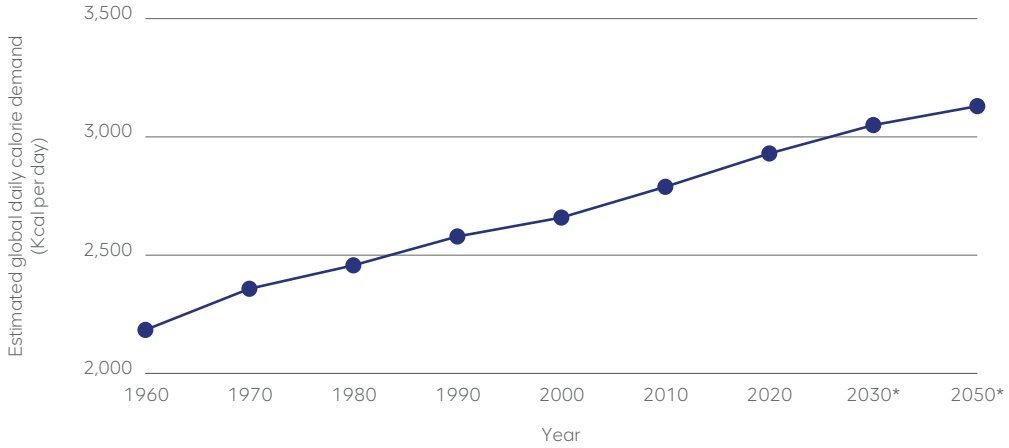
Latest UN estimates suggest 2.4 billion people currently face food insecurity, while global demand for food is still growing. By 2050, the global population is projected to reach nearly 9.7 billion[2] with much of that growth focused in developing countries. Our experts agreed that this will be *the* key driver of change and growth in the fertiliser value chain. Compounding the challenge of population growth is the rise in daily per capita calorie consumption.

People are consuming measurably more calories today than in previous generations, and this is expected to continue to 2050 as incomes rise. In 1960, the average daily intake was approximately 2,200 calories; this has risen roughly 30% over the past half century.[3] As incomes rise globally, diets will continue to shift towards more meat and animal products, as well as higher-value vegetable crops – all of which require more land for agriculture.

Based on expected population growth, changing diets and rising average calorie consumption, global daily calorie demand is expected to increase almost 50% from 1960 levels to 2050.

Estimates suggest that, at the agricultural productivity levels we see today, feeding the world in 2050 would require roughly 593 million hectares of additional land – an area twice the size of India.[4]

Figure 3: Estimated global daily calorie demand, 1960-2050 (*represents projected figures)[5, 6]



Of course, quantity is not the only measure of a successful food system. Quality nutrients and healthy diets are also essential, and in the past 60 years these have been in sharp decline. It's estimated that more than 2 billion people are suffering from micronutrient deficiency, and about 3.1 billion people are unable to afford a healthy diet that both meets energy requirements and provides all essential micronutrients.[7, 8]

In other words, people are overfed but undernourished due to consuming nutrient-poor diets. Studies estimate that this double burden of malnutrition costs public healthcare systems around $3 trillion a year.[9, 10]

Amongst the causes of this decline are the mis- and over-application of some fertilisers, which have contributed to damaged soil health, and compromised its ability to hold and make nutrients available to crops. The decline in the nutritional quality of foods has also been fuelled by the economic draw on farmers to prioritise yield uplift, encouraging the production of less-nutritious, yet higher-yielding, commodity crops such as potato, maize and wheat in place of nutrient-dense crops such as millets, conventional fruits and vegetables. Further, farmers are also having to introduce higher-yielding yet less-nutrient-dense *varieties* of crops such as millets, conventional fruits and vegetables. For example, fruits such as apples, oranges, mangos, guavas and bananas, and vegetables such as tomatoes and potatoes, have lost 25-50% of their nutritional density over the past 50 to 70 years.[11]

The answer lies in a more tailored and balanced approach to crop nutrition, alongside a far more efficient use soil, fertilisers, water, energy and labour.

How fertilisers are developed and supplied will evolve over the next 25 years, and the monitoring of their use relative to soil health outcomes will expand significantly. With the appropriately sourced fertilisers applied in the right way, at the right time and in the right place, fertiliser use will substantially improve. As Randy Jagt, Senior Partner and Future of Food Lead at Deloitte, puts it.[12]

> "Without significant changes to how food is produced, feeding a growing population will likely require additional natural resources that are already under pressure – especially water and land. Fertiliser, when applied correctly, can help us to be much more efficient with the resources we have."
>
> **Randy Jagt**, Senior Partner and Future of Food Lead, Deloitte

The availability of those natural resources and crop nutrients to cope with growing and complex demands is already complicated by geopolitical turmoil, and the pressures created by border and resource supply conflicts lead to ever-increasing threats to national and international security, including the supply and distribution of food. Unless the barriers to crop nutrient supply are overcome, other measures to achieve sustainable agricultural systems will be largely ineffective.

As we cover later, having a blend of smarter, data-driven nutrient management, prioritising soil health restoration, achieving affordable access to technology, plus stronger research, education and governance, are all vital components towards addressing these challenges.

> "There will always be a need for fertiliser because there will always be a need for nutrients."
>
> **Shay Mey-Tal**, VP Marketing & Agronomy, ICL

Spotlight: Food security is national security

"In 2050, if climate change, access to water and soil degradation persist, tension over access to food will likely increase. Governments have built food contingency plans across Europe. The demand for additional food out of fast-growing economies has in the past years massively impacted world food supply chains."

Robert Erhard, Group Dairy Lead, Corporate Sustainable Agriculture, Nestlé

Our research findings predict that rising geopolitical tensions will compel governments to adopt new strategies to ensure food security, such as 'food onshoring' and 'farming out'.

Food onshoring. Increasing the national production of food – and the fertiliser to grow it – and shoring up larger strategic reserves, to reduce exposure to food supply shocks. This affects both production and planning for supply chain interruption.

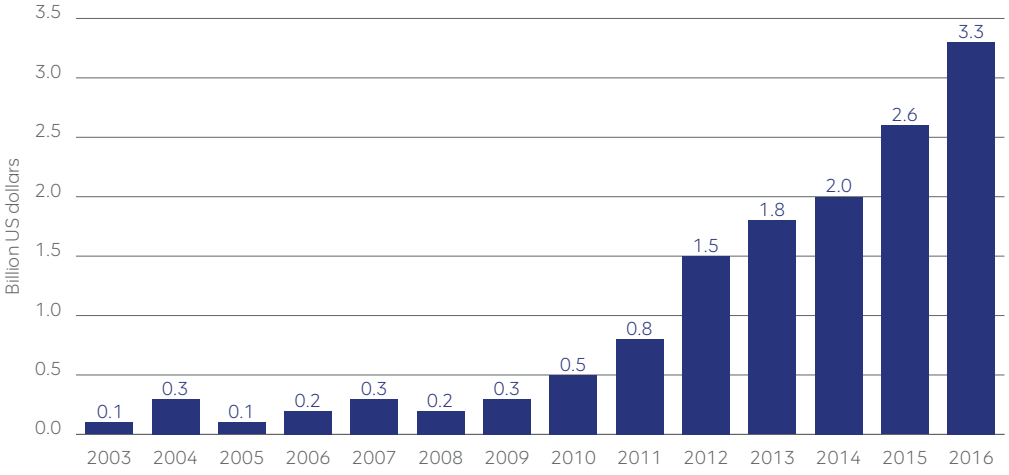
"We must shift to local food production and focus on restoring soils; otherwise, the system will collapse."

Pius Floris, Strategic advisor, PUM

Farming out. Investing in agricultural land and businesses abroad, to bolster food supplies while increasing soft power and international influence.

The Chinese government is one of the best-known examples of this practice. Rapid economic development and industrialisation in China has led to population growth and urbanisation – both of which are projected to continue.

Figure 4: China's direct overseas investment in agriculture, forestry, and fishing



Source: USDA, Economic Research Service analysis of data from China National Bureau of Statistics.

At the same time, agricultural land has been degraded. Estimates suggest one-third of the 3.3 million hectares of agricultural land in China is degraded or polluted.[13] As a result, since the early 2000s, the Chinese government has consistently increased investment in agriculture abroad, as shown by Figure 4.[14]

From 2004 to 2012, such investments focused mainly on crop production, fishing ventures, and acquiring raw materials for the Chinese market, targeting neighbouring south-east Asian countries and eastern Russia. More recently, a strategic shift has seen Chinese companies and officials acquiring agribusinesses in Europe, North America and Oceania – for example, ChemChina's $43-billion purchase of Syngenta; Shuanghui International's purchase of US-based Smithfield Foods; and China National Cereals, Oil and Foodstuffs Corporation's (COFCO) purchase of Noble Agri and Nidera, both major agricultural traders.[15]

Brazil is another good example of governments acting strategically to bolster their revenues from agriculture. From 2000 to 2020, the nation's agricultural output doubled. Recognising agriculture's economic potential, the Brazilian government implemented policies fostering agribusiness investment and infrastructure development. This approach catapulted Brazil into becoming a major global soybean, beef and poultry production and exports player, significantly boosting the nation's economic growth. The value of Brazil's agricultural exports surged by an average of 9.4% annually from 2000 to 2021, accounting for 37% of the country's total exports.[16, 17]

These examples demonstrate how the centres of global food production can change in response to geopolitical events and the strategic priorities of national economic policy. The landscape will likely shift again on the road to 2050 – and there's a need to ensure that, in those locations to which production shifts, there's a reassessment of how to best drive sustainable productivity in a way that matches the regional and local contexts.

Sustainability: Limiting agriculture's impact on nature and the environment

In contrast to the 1950s when the modern fertiliser industry was created, the impact of agricultural practices on the environment is now well understood. There was consensus amongst our interviewees that future production must take account of the effects on soil, water, and biodiversity.

What has been termed 'intensive farming' – increased agricultural production per hectare – has historically been used to deliver food security, but has caused significant environmental damage.[18]

> "We are no longer in the arena of just producing food. It's not simply about yields any more. It's very much about the impact on the environment."
>
> **Yvonne Pinto, Director General, International Rice Research Institute**

The modern agricultural system must therefore:

- **Reduce greenhouse gas emissions**. Around 2-7% the world's greenhouse gas (GHG) emissions come from the production and use of nitrogen fertilisers – more than global aviation and shipping combined.[19] Agriculture also drives a disproportionately large share of methane, global nitrous oxide (N_2O) and ammonia (NH_3) emissions (80% and 70% respectively)[20], which originate predominantly from the application of livestock manure and synthetic nitrogen fertiliser.
- **Limit nutrient leaching to water bodies** caused by the unbalanced use and/or over-application of fertiliser, and excessive nutrient run-off.
- **Prevent groundwater depletion** caused by over-extraction, to support local agriculture.
- **Protect biodiversity** and reduce the impact of farming on pollinator species and soil organisms, to maintain soil health.

Spotlight: Beyond carbon, a broader view on sustainability

The pressure to change the system is coming primarily from governments recognising, directly and on behalf of their consumers and citizens, that the future system needs to work in a drastically different way than the current system. This in turn has resulted in leading actors in the value chain, such as international food companies, adopting ambitious goals and strategies to drive change.

> *"From what I've seen and from all the customers that we've talked to, global companies like Nestlé, Griffith and Pepsi are moving towards sustainable agriculture and wanting to do regenerative agricultural practices."*
>
> **Hataikan Kamolsirisakul**, Head of Strategy, Sustainability & Innovation, Thai Wah

So far, much of the focus of environmental action and regulation has been on emissions; specifically, carbon. We know the financial impact of a kilogram of carbon – for example, the cost of property loss to rising sea levels, or the damage to crops of changing weather patterns.

Through carbon pricing, the value chain can capture this cost and pass it on to the emitter, making it possible to establish standardised carbon accounting and target-setting frameworks. However, attention is also beginning to turn to other GHGs, such as methane and nitrous oxide, which will increasingly be the subject of broader emissions regulations.

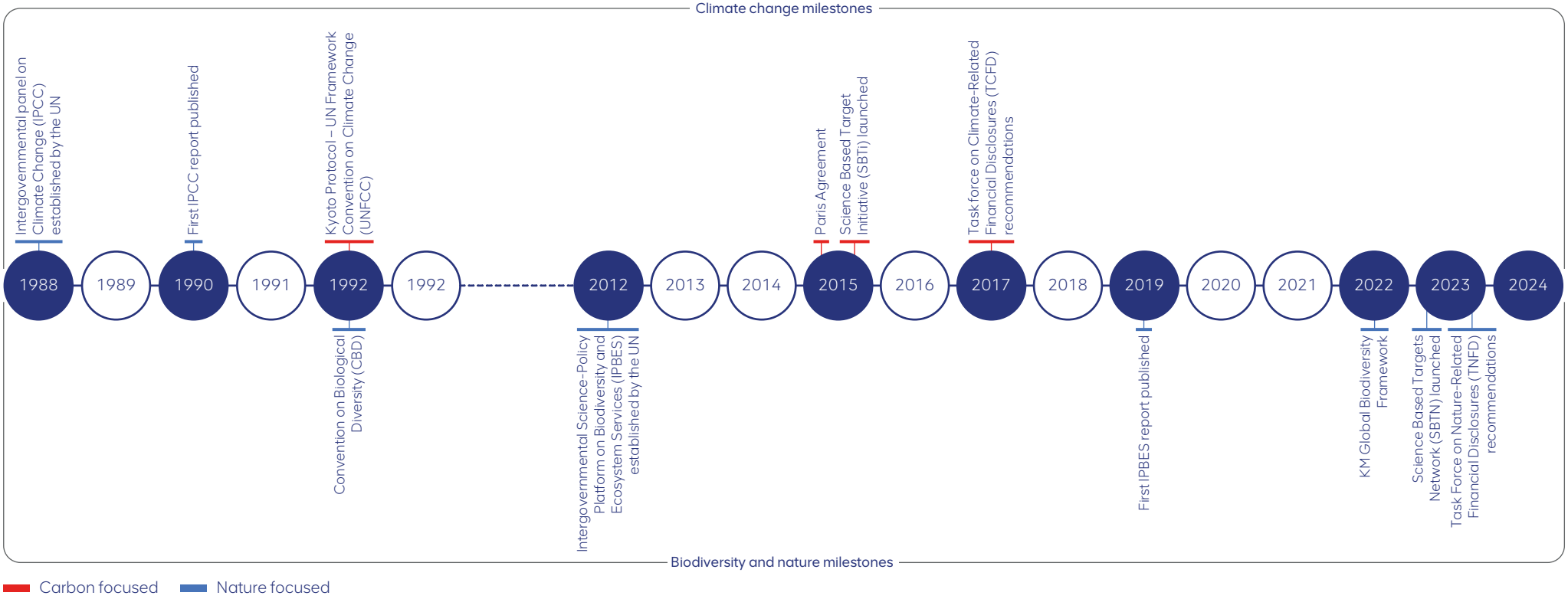
This will impact the use of nitrogen fertiliser, which, even if its production is successfully decarbonised, still results in emissions in field use through volatilisation, denitrification and leaching. This means it is likely to invite continued scrutiny from regulators and value chain stakeholders focused on environmental impact.

> *"[Sustainability] regulations will actually be pulling in different directions … some are going to enhance one aspect of sustainability and some are going to enhance a different aspect of sustainability that will make other things harder and less sustainable."*
>
> **Professor Jack Bobo**, Executive Director Rothman Family Institute for Studies, UCLA

In line with changing consumer preferences, regulatory attention will also extend to other nature-focused issues, such as biodiversity. This is illustrated on the timeline on the next page. Many food businesses are already pioneering in this space voluntarily, but it is likely that pressure to make compliance mandatory will increase in the coming decades.

The graph below illustrates the shift towards broader regulatory measures that include biodiversity and nature.[21] This all adds up to a very different production landscape in 2050 than the current picture.

Figure 5: The changing focus of regulation from carbon alone, to nature more broadly.



Farm profitability: Securing livelihoods and enabling investment

All our experts agreed that, from the perspectives of both producers and investors, sustainable and profitable returns are vital to ensure economic viability and growth. Change is risky for farmers – trialling a new product affects an entire growing season, when margins are already thin; however, even a small increase in yield can have a significant impact on profitability. For farmers to adopt new practices, the cost and performance of the product must balance the environmental impact and, crucially, there must be clear evidence of performance.

> "Farmers are looking for things that will make us more profitable. Yield is still the primary focus for most."
>
> **Joe Stanley, Head of Sustainable Farming at the Allerton Project, Game and Wildlife Conservation Trust**

Over 500 million of the 570 million farms globally are small farms that provide livelihoods for 2.5 billion people.[22] These businesses operate on low margins and are thinly capitalised, with little recourse to additional finance.

Investment in sustainable agriculture is a key lever for reducing poverty and raising incomes for some of the world's most vulnerable,[23] yet many of its intended beneficiaries will struggle to afford the necessary investment in the technology and practices required to protect yields and build a more sustainable food system.

Both capital and disruption to cash flow in the transition period are potential barriers making the evolution of the sector slow, and passing all the risk onto the farmer.

Some farmers simply aren't in a position to invest, and require external support to transition to more sustainable alternatives.

> "Farmers are seeing that returns are falling … their response is to derisk, underinvest, and focus on survival."
>
> **Dr Charlotte Kirk, Investment Principal, Clean Energy Ventures**

According to Deloitte's research, the transition to more sustainable agriculture, such as regenerative farming, requires a farmer to spend from $1,600 to $4,300 per hectare upfront, and wait for at least five years before they see a return on that investment.[24]

Small and medium-sized farms are the most financially vulnerable, due to a lack of economies of scale, whereas larger farms are better able to invest because their size can give them more favourable ROIs. This emphasises the need for governments to provide a variety of financial incentives to farmers, to encourage the transition to more sustainable approaches such as regenerative agriculture.

> "We need to stop focusing on short-term profits, and prioritise giving farmers transitional supports to unlock long-term sustainability. Farmers can't make the shift alone."
>
> **Professor Tim Benton, University of Leeds School of Biology**

The heart of the modern agricultural challenge: Soil health

Our experts argued that soil sits at the heart of the three conflicting objectives (food security, sustainability, farmer profitability).

"Healthy soil is the basis for crop growth."

Zhang Yijun, Head of Agrochemical Center, Heilongjiang Beifeng Agricultural Production Materials Group Co., Ltd

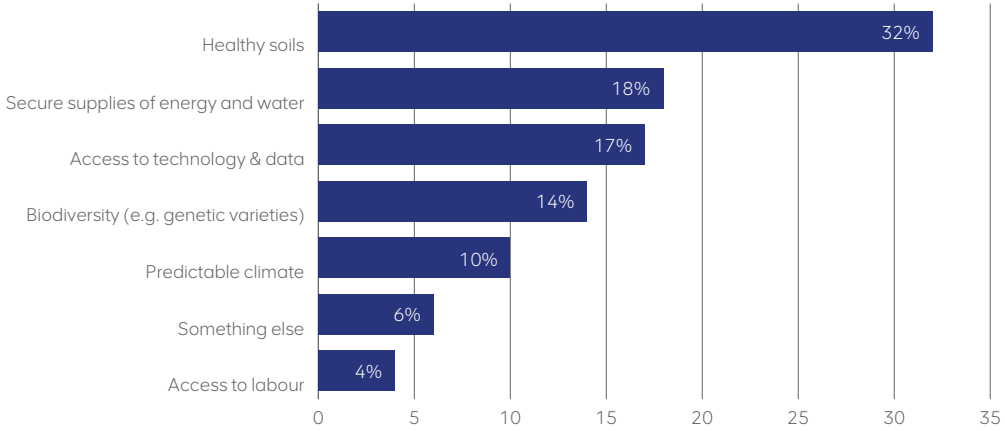
"Good food needs good soil."

Zaman Mohammad, Head of Soil and Water Management and Crop Nutrition Section at International Atomic Energy Agency

"Soil health is connected to human health. It's essential to ensure long-term productivity and ecosystem services."

Alberto Acedo, Co-Founder, Biome Makers

Figure 6: Interview question – To build a food system that delivers food security, protects nature and achieves net zero by 2050, which areas should we prioritise today? % ranked in top three.



The #1 solution

to achieving modern agriculture's interlinked objectives – food security, sustainability, farmer profitability – is **healthy soil**, said our agriculture experts

The #1 pillar

of a food system that delivers food security, protects nature and achieves net zero by 2050 is **healthy soil**, said our agriculture experts.

The Intergovernmental Technical Panel on Soils (ITPS) defines soil health as "the ability of the soil to sustain the productivity, diversity, and environmental services of terrestrial ecosystems".[25]

The implication is that soil health is multifactorial, and no single measure will capture the complexity of the system.

That said, soil health can be maintained, promoted or recovered through the implementation of sustainable soil management practices that address:

- **physical health**: temperature, texture, structure and bulk density;
- **chemical health**: water-holding potential, pH, ion exchange capacities and nutrient load; and
- **biological health**: root zone, organic matter, predators, pathogens and microorganisms.

Currently, 33% of world soils are moderately to highly degraded.[26] If degradation continues at the current rate, scientists warn that 90% of the Earth's soil could become degraded by 2050.[27]

The type and amount of fertiliser applied has a significant impact on the soil health of farmland. The specifics of this will be unpacked further in Chapter 2.

"One-third of arable land has been destroyed in the past 50 years. We need to learn how to recover degraded land, and apply those lessons globally."

Alberto Acedo, Co-Founder, Biome Makers

Why is soil health important?

- **Food security**: Healthy soils are more fertile and, in turn, support improved crop yields. At a global scale, this can increase agricultural productivity to combat food insecurity.
- **Crop quality**: Healthy soils promote better crop growth and nutritional density.
- **Water quality**: Healthy soil acts as a filter to clean water, as it percolates through and improves water quality. It can also reduce runoff and erosion, protecting water sources by having improved structure and compaction resistance.
- **Drought resistance**: Healthy soils are rich in organic matter, which acts like a sponge to better absorb and store moisture. This moisture is then available to crops over longer periods, enabling harvests to withstand extended periods of dry weather.
- **Climate change mitigation**: Soil stores vast amounts of carbon. Healthy soil practices can help sequester carbon from the atmosphere, mitigating climate change.
- **Biodiversity**: A diverse range of organisms in the soil contributes to a healthy ecosystem, supporting plant growth and resilience.
- **Farm economics**: Healthy soil leads to higher crop yields, reduced input costs, increased farm profitability, and higher land valuations.

Spotlight: The impact of soil health on human health

> *"If we don't change, not only will we have exacerbated climate change to unprecedented levels, but we will also have thrown money away on our healthcare bills."*
>
> **Colin Campbell**, CEO, James Hutton Institute

Lady Balfour, the founder of the Soil Association, stated that "the health of our soils, plants, animals and people are one and indivisible".[28]

Healthy soils are foundational to achieving nutrient adequacy and nutrient balance – the key pillars of a healthy diet. Soils supply nutrients that are stored in plant tissues and, ultimately, get transferred to humans through consumption.

Of the 29 vitamins and minerals essential for human life, 18 are obtained from the soil.[29, 30] When soil health declines due to erosion, salinisation, nutrient depletion and so on, it causes a series of negative impacts for human health.

1. Impact on nutrition

When soil health declines, the nutrient content of crops diminishes, leading to deficiencies in essential micronutrients such as boron, zinc and iron.[31]

2. Impact on water quality

Healthy soils act as natural filters, trapping undesirables such as heavy metals, pesticides and pathogens from reaching waterbodies. This filtration function ensures cleaner water supplies, and reduces the spread of waterborne diseases.

3. Impact on gut health and chronic diseases

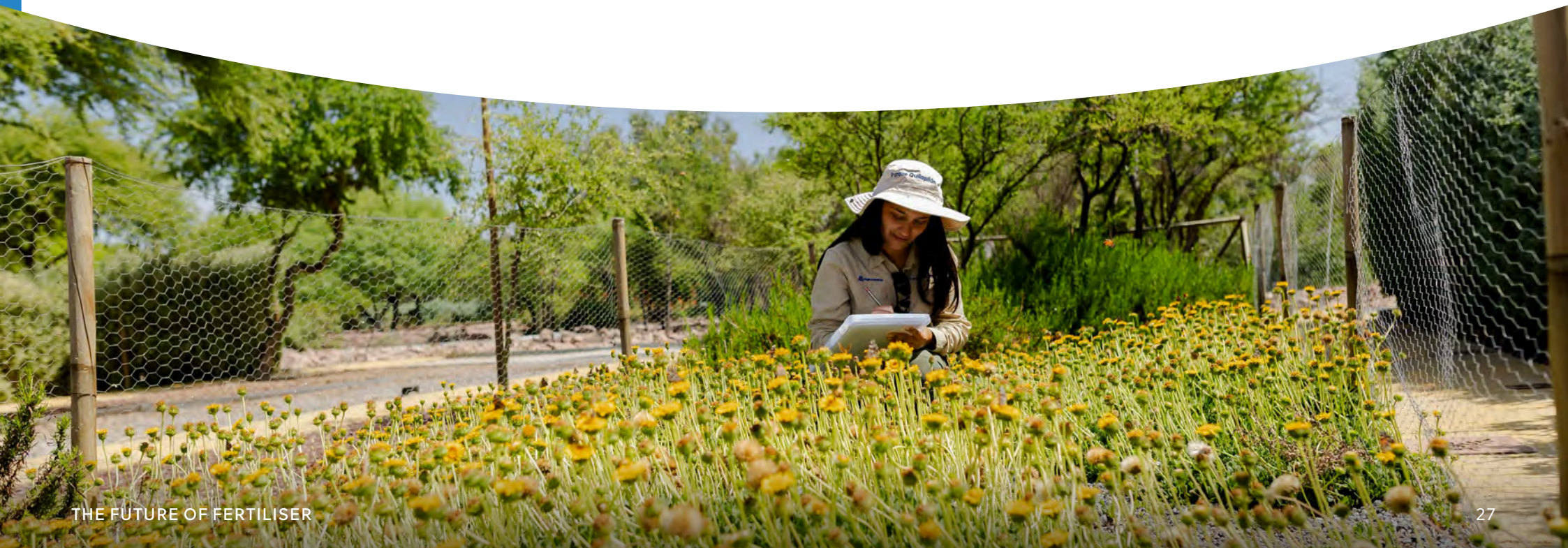
The microorganisms in healthy soil are crucial for maintaining a balanced gut microbiome, which regulates digestion, immune response and overall health. Reduced exposure to soil microbes – partly due to modern industrialised farming techniques – has been linked to a decline in gut microbiome diversity, and correlated to an increase in chronic diseases.[32]

Chapter 1 takeaways

The fertiliser value chain is a complex global system that encompasses many stakeholders with, at times, competing priorities.

This can deliver conflicting demands on the system but with common needs: the delivery of food and nutrient security, sustainability and farm profitability.

At the heart of these conflicting demands is soil health: the foundation of our agri-food system.



CHAPTER 2

Delivering more food more sustainably: The vital role of fertiliser

Back to basics botany: What plants need to grow

Plants require sunlight, water, carbon dioxide and 14 essential nutrients for growth.[33]

While many factors and inputs can influence plant health and nutritional value, this fundamental scientific fact remains and will not change: growing healthy, strong, productive, profitable, sustainable crops requires a consistent supply of 14 essential nutrients. These nutrients are taken up by the plant, then removed from the field at harvest and consumed by humans. To grow next season's crop, these nutrients must be replenished.

For agricultural plants, macronutrients are needed in large amounts, to drive crop yield and quality, while micronutrients, although needed in small amounts, are just as crucial for plant health and development. Plants should be able to access macro and micronutrients from the soil as needed to thrive. Different crops have different nutrient requirements, depending on variety, soil and climate conditions, and intended end-use of the crop.

Take the example of a potato plant.
It needs six key macronutrients (and a range of micronutrients in small doses) to grow, typically provided in kg/ha:

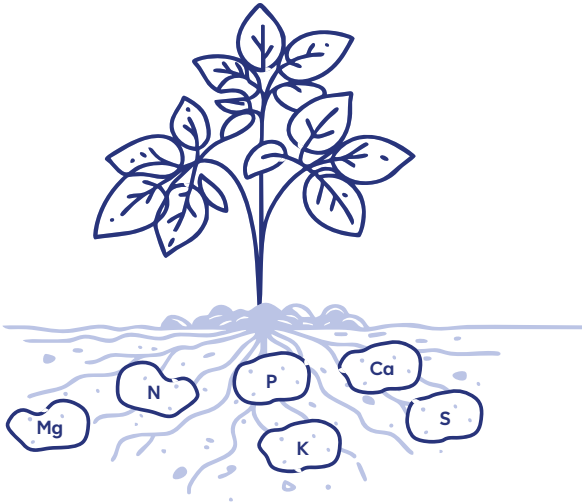
- **Nitrogen (N)** for leaf growth and tuber bulking.
- **Phosphorus (P)** for root growth, tuber development and dry matter.
- **Potassium (K)** for overall plant health, tuber growth, disease resistance, and water regulation.
- **Calcium (Ca)** for skin finish, cell wall development and strength.
- **Magnesium (Mg)** for chlorophyll and canopy development.
- **Sulphur (S)** for overall health, energy for starch production, protein synthesis and enzyme activity.

Sulphur, specifically, is regarded as an enabling nutrient given its role in facilitating critical metabolic activity.

Figure 7: Calcium-deficient potato plant

> "Without nutrients, plants don't grow."
>
> **Alzbeta Klein, CEO, International Fertilizer Association**

Nutrient deficiency caused by poor crop nutrition and farming practices can have profound effects on crop quality and yield. The image in Figure 7 illustrates what happens when potato crops don't have access to the right nutrition: calcium deficiency has caused internal browning and hollow tubers.[34]



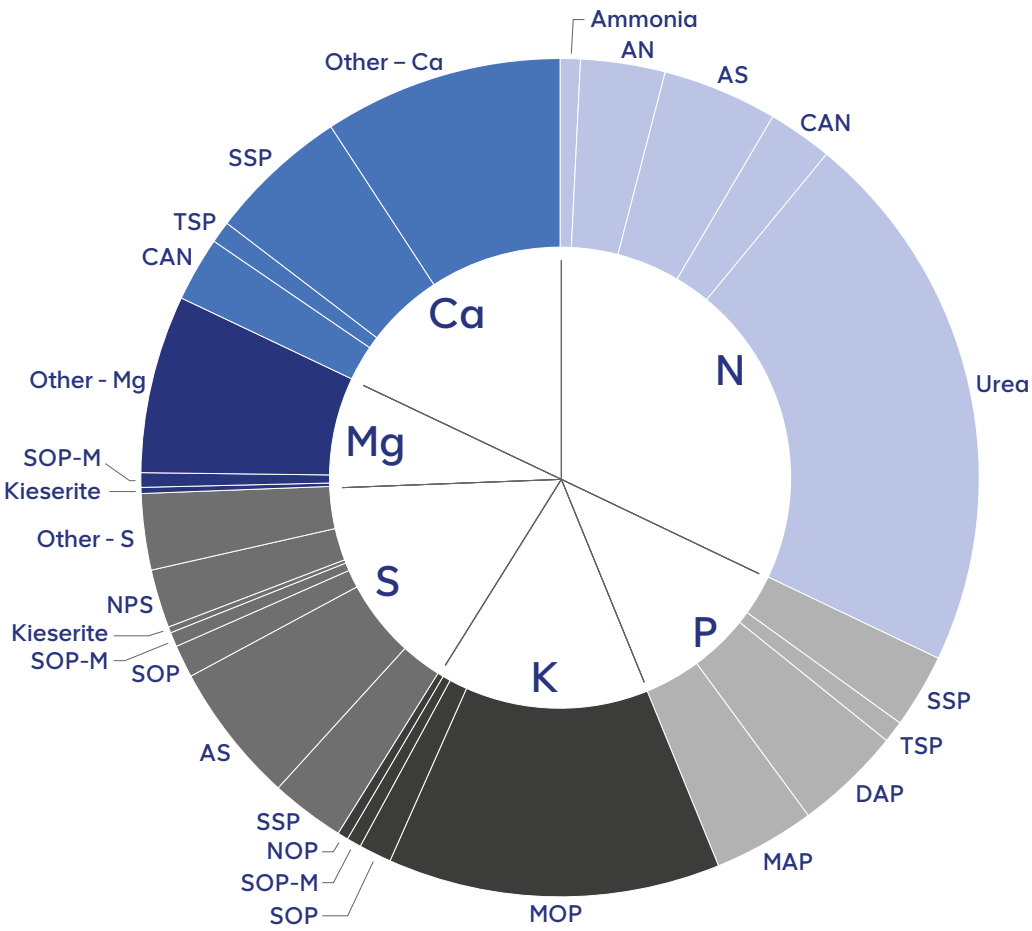
When crops are harvested, the vital nutrients used for their growth are extracted with the crop. If the soil is not replenished, the next crop will struggle to grow.

This is where fertiliser comes in, as it increases the availability of these essential nutrients in the soil. There are many types of fertiliser, with different formulations within the following broad categories:

- **Natural or organic fertilisers.** Products that are suitable for use in organic farming derived from animal or vegetable waste (e.g. manure, compost), or from naturally occurring minerals with little physical or chemical processing (e.g. polyhalite, struvite, langbenite, kieserite). They break down slowly over time, to release nutrients into the soil.
- **Inorganic, or chemical fertilisers.** Products are manufactured using chemical processes; primary focus is NPK, which is delivered in more concentrated and precise ratios.
- **Organo-mineral fertilisers.** Products are derived from the reaction or mixture of inorganic chemical fertiliser with organic fertiliser, to create a single product.

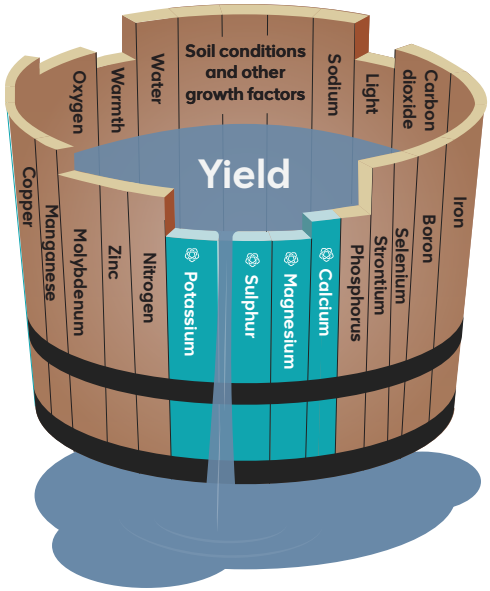
Farmers use different products from these three broad categories of fertilisers in varying proportions to try to satisfy the breadth of their crops' nutrient needs. Figure 8 provides a useful overview of the range of products currently in use and the corresponding nutrients that they deliver (it does not contain data about manure, since this is difficult to accurately capture).

Figure 8: Wheel of major fertiliser products



The farmers' task is to apply nutrients from this range of fertiliser products in the correct balance required by the plant and soil to maximise yield. However, if an insufficient amount of one nutrient is available, growth will be restricted. This 'Law of the Minimum', which states that the maximum achievable crop yield is determined by the most-limiting nutrient, was first postulated by German scientist Justus von Liebig in the 19th century. However, farmers are constrained by a relatively narrow range of existing fertiliser products available, and often struggle to access enough products to supply the balanced nutrition that Liebig's model demands.

Figure 9: Liebig's Law of The Minimum – growth is determined by the scarcest resource



Macro nutrients contained in POLY4 (See appendices for more information about POLY4)

Further innovation into new and different sources of nutrients will be needed to improve this access and to improve the crops' ability to utilise them. This can be augmented by AI, biologicals and other advanced fertiliser application technologies, but can't be replaced by it.

Fundamentally, we will always need the same six macronutrients to grow the world's food, but improvements in access to them and the efficient use of them is urgently required.

"The inputs won't fundamentally change, we will get more efficient in how we use them."

Kwadjo Ahodo, Sr. Research Analyst, IHS Markit

Spotlight: The impact of rising sulphur prices on chemical fertilisers

After NPK, sulphur is the fourth major crop nutrient, and is crucial to the production of proteins and chlorophyll, enabling enzyme activation and efficient use of nitrogen.

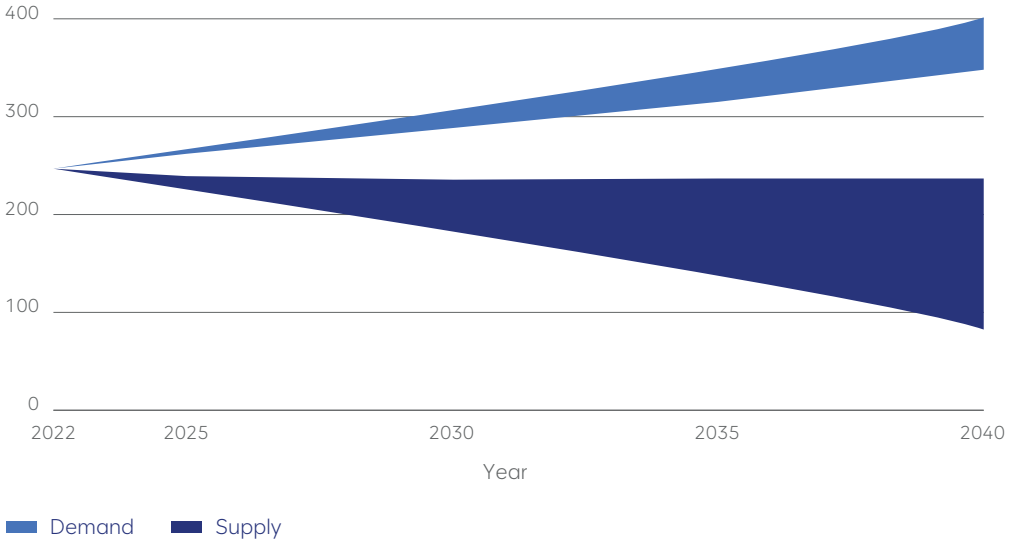
It's effectively a multipurpose nutrient that drives a multitude of key processes within the crop. A recent study showed the addition of sulphur significantly increased crop yields and reduced nitrate leaching by 46% compared to nitrogen alone.[35] 65% of global sulphur demand comes from chemical fertilisers. There is a recognised decline in the availability of sulphur through atmospheric deposition as clear air regulations have lowered SO_2 emissions.

Sulphur obtained from fossil fuel processes is also waning due to clean energy decarbonisation[36] policies and practices.

These supply challenges will need to be addressed through alternative sources, and more precise application of sulphur supplements to minimise leaching.

To avoid sulphur price rises and shortages, novel methods of sulphur production are required to secure its use in agriculture. These include extraction from waste streams (e.g. biogas desulphurisation), biological sources (compost, manure), or mining (e.g. polyhalite). However, the first two streams suffer from a lack of scalability and difficulties in on-field application.

Figure 10: Total sulphuric acid outlook (million tonnes)[37]



Past: The fertiliser origin story

The history of fertilisers dates back thousands of years, with early civilizations relying on natural substances to enhance soil fertility and improve crop yields. Research suggests that Neolithic farmers employed livestock manure, compost, and wood ash to enrich their fields and sustain crop production.

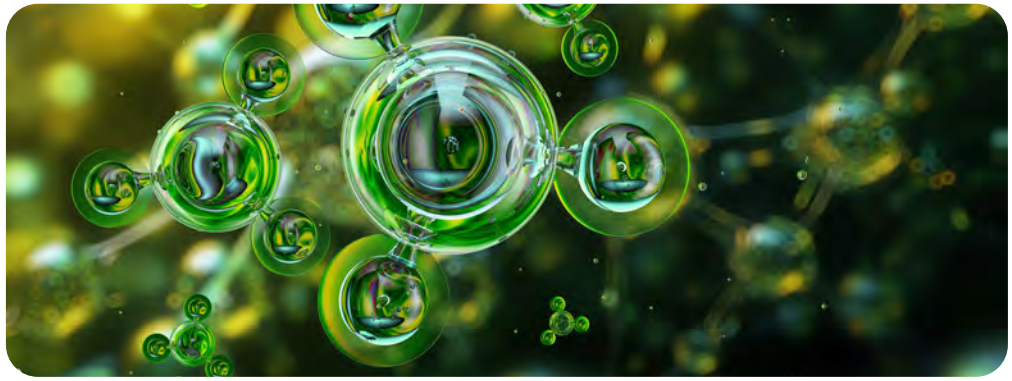
The first large-scale, industrial use of fertilisers began in the 19th century with the global trade in Guano – a nutrient-rich seabird excrement. Guano was highly valued for its high nitrogen, phosphorus and potassium content, and became a sought-after commodity – especially in Europe and the United States.

Similarly, natural mineral deposits of sodium nitrate (known as salitre) were mined and exported as a key nitrogen source for agriculture. This period marked the beginning of fertilisers being commodified and traded globally, foreshadowing the development of synthetic fertilisers that would eventually transform agricultural productivity worldwide.

By the early 20th century, naturally occurring organic fertilisers had reached their biophysical limits. Farmers faced mounting pressure to feed a growing population, but early forms of fertiliser proved insufficient for sustaining large-scale agriculture. To nourish a growing global population, agricultural productivity needed a revolutionary breakthrough.

In 1913, Nobel-Prize-winning chemists Fritz Haber and Carl Bosch developed the Haber-Bosch process. This chemical reaction enabled the large-scale production of ammonia, by fixing atmospheric nitrogen with natural gas under high pressure and temperature.

Unlike organic fertilisers, which were constrained by the availability of manure, chemical fertilisers provided a consistent, abundant and cost-effective nutrient source.



"Since the invention of the Haber-Bosch process, there hasn't been any innovation that has changed the fertiliser industry."

Tshepo Maeko, Senior Global Product Development and Agronomic Expert, Maaden

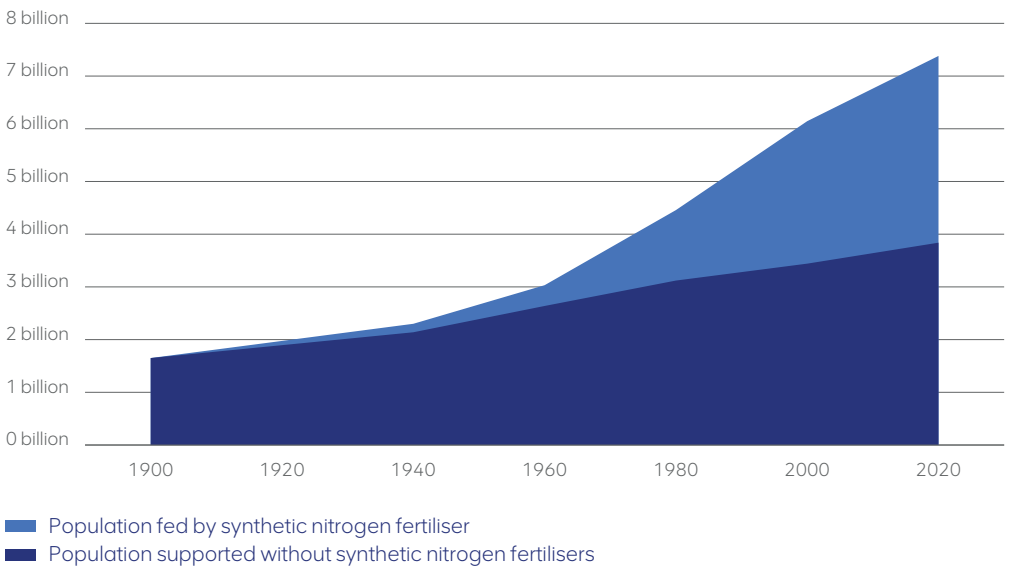
Present: Artificial fertilisers helped feed the world, but their overuse has environmental and social impacts

Fertilisers support around 50% of global food production; only half the world's population could be sustained if such fertilisers were not in use.[38]

The low cost of artificial fertilisers, driven by abundant raw materials supply (natural gas for nitrogen and mined minerals for phosphorus and potassium), has been a key driver of demand over the past century and has supported rapid growth for NPK products.

But the misuse of current-generation fertilisers and lack of balanced nutrient formulations comes at a cost in terms of soil quality and other environmental impacts. Addressing these impacts is a long-term issue requiring continual innovation, changes to agricultural practices, and investment to fuel technological developments and enable behavioural change.

Figure 11: The proportion of the global food production reliant on synthetic nitrogen fertilisers[39]



"Nitrogen fertiliser has been really crucial in helping us feed our growing population, and that's created a surplus of poor-quality food. Most of us don't treat food like it's a valuable, scarce resource, and that mindset needs to shift."

Helen Browning, CEO, Soil Association

Although artificial fertilisers boost (short-term) productivity, our experts highlighted that a heavy reliance on them has had a variety of negative impacts on the environment, economy and wellbeing, such as declining soil health; GHG emissions; intensive energy use; run off; and increased prevalence of certain chronic health conditions.

Industry evolution and change in practice towards a more careful and considered approach are required to reduce these unintended consequences without creating additional complications.

Studies suggest that, if current productivity rates persist, 2050's crop yield will remain stagnant at 75% of yield potential.[40]

To meet growing demand for calories globally, best practice in crop nutrition must be followed, moving from a broad-brush application of NPK fertilisers to a more sustainable, tailored and balanced approach involving sources of all macro and micronutrients. This, tied with more-efficient use of resources, including soil, water, energy, and labour, together with a wholesale reduction in waste, is vital for the future.

The International Fertilizer Association (IFA) summarises the first step on this journey as the 4Rs of nutrient management[41]:

Right source. Matches fertiliser type to crop needs.

Right time. Makes nutrients available when crops need them.

Right rate. Matches amount of fertiliser to crop needs.

Right place. Keeps nutrients where crops can use them.

> "Nutrient use efficiency should be the focus. For every hectare that you grow, how could you make sure that the plant takes as much of the nutrients as possible, so that the nutrient is not wasted to the environment? It's a very simple concept."
>
> **Alzbeta Klein, CEO, International Fertilizer Association**

Future: Can innovative crop nutrition help resolve the modern agricultural challenge?

Our findings and survey feedback all point to the need for evolution – both in the type of fertilisers that get applied to the soil, and in the way that we apply them, to ensure that the right nutrients get applied at the right time, rate and place.

The solution is to find scalable novel products, methods and approaches that lower risk and present viable commercial alternatives to the way the system runs today.

"Successful innovation will be about improving the bottom line, derisking the business, increasing resilience to extremes of weather."

Colin Campbell, CEO, James Hutton Institute

"Best practice is shifting away from chemical fertilisers."

Uwe Schroder, Commercial Director, Cefetra Group

Spotlight: By 2050, we'll provide plant nutrition in a more balanced way

What will be on the International Fertilizer Association's agenda in 2050?

IFA Annual Conference 2050: A showcase of the innovations and practices revolutionising agriculture.

Each year, the IFA – a global coalition of over 500 crop nutrition providers – brings the industry together to connect and learn. Once focused on traditional fertiliser technologies, this event has become a nexus of cutting-edge innovation, environmental stewardship, and global food security strategies.

In 2050, agriculture will be a precision-driven industry, with plant nutrition provided as a service. Imagine farmers routinely talking to AI co-pilots and displays showcasing real-time nutrient content on each acre of arable land. And further imagine the impact of every kilogram of plant nutrient on yields, multiplied on a planetary scale.

IFA's focus will still be firmly on helping to feed the world sustainably. The 2050 conference will cover things such as closed-loop nutrient systems that minimise waste and maximise efficiency, perhaps using synthetic biology to create plant nutrient solutions that enhance soil health.

The attendees themselves will also reflect a changed agricultural landscape. Alongside fertiliser producers, farmers and agronomists, we might see climate engineers and quantum biologists.

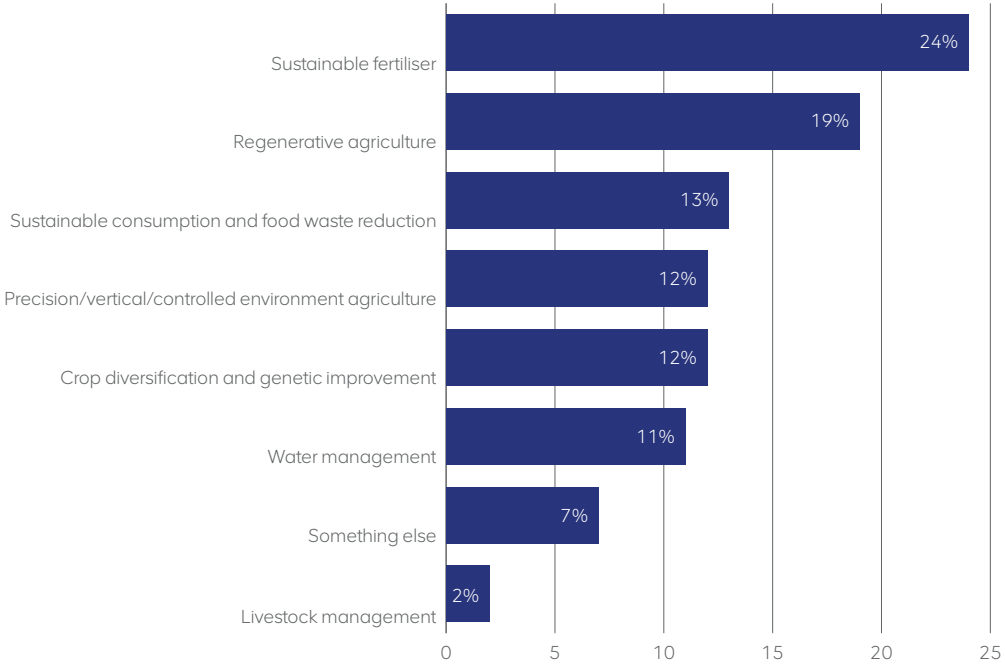
As we look ahead to this future with all its exciting possibilities, it's clear that the Annual Conference 2050 will be more than just a meeting about fertilisers. It will be a global summit on the future of humanity's relationship with food, nature and technology.

Written by **Alzbeta Klein**, CEO, IFA

Much of the innovation required for the needs of 2050 can be envisaged today because it involves using both technologies and improved practices to incrementally introduce efficiencies and waste reductions. It is more a journey of evolution than revolution in an agreed direction. We may not yet have all the scalable technologies to hand, but there's a high degree of consensus on the direction of travel.

We asked our agriculture experts about the solutions they expect will transform our food system (Figure 12). They agreed that the development and use of sustainable fertilisers, together with regenerative and precision agriculture practices, were key.

Figure 12: To build a sustainable agri-food system by 2050, which innovative solutions should we invest in today? % selected

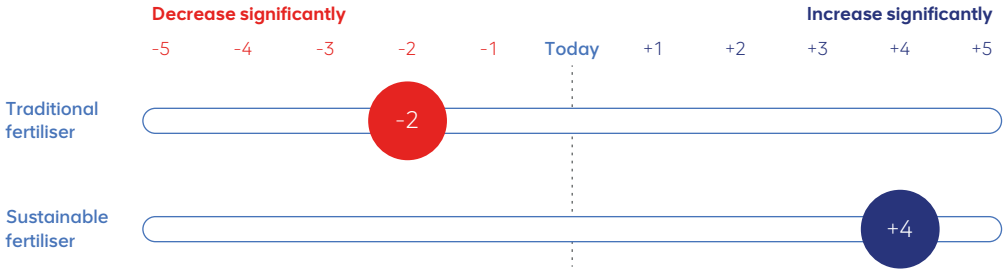


(a) Using more sustainable crop nutrient solutions: What kinds of solutions will shape the future?

The #1 priority to achieve modern agriculture's interlinked objectives is to invest in **sustainable fertiliser**, said our agriculture experts

By 2050, our agriculture experts expect traditional fertiliser use to decrease moderately, and demand for sustainable fertiliser to increase significantly.

Figure 13: How will demand for different types of fertiliser change by 2050?



Our interviewees highlighted how the lack of a widely recognised or standardised definition of 'sustainable fertiliser' was one of the barriers hindering their adoption. To assist, our experts offered some definitions, as shown below.

"Green fertilisers are not made using fossil fuels."

Kai Wirtz, VP, Sustainability Strategy & Partnerships, Bayer

"It will be fertilisers [made] from waste products, and it will be low carbon emission fertilisers."

Simon Pearson, Founding Director, Lincoln Institute of Agri Food Technology

"In black and white terms – without CO_2 impact. The more nuanced answer is 'ingredients that support the soil and give us food that's richer in nutrients'."

Robert Smulders, VP Innovation, Stamicarbon

"Sustainable fertiliser is a fertiliser that ensures efficiency of the nutrition of the plant, promotes or conserves biodiversity, and does not produce waste or residues on the land."

Alberto Acedo, Co-Founder, Biome Makers

Our experts anticipate that, by 2050, demand for a range of sustainable fertiliser solutions will have increased, driving improved yields and environmentally responsible agriculture, while also making farming more attractive for investment.

These novel solutions are unlikely to replace current products, but they will be part of a broader suite of crop nutrition solutions that help drive greater efficiency, productivity and sustainability. A snapshot of some of this solutions is presented on the next page.

Key characteristics of different fertiliser types

Fertiliser type	Fertiliser solution	What it is	Impact on food security	Impact on farmer profitability	Impact on environment	Impact on soil health	Upfront cost	Scalability
Natural or organic fertilisers	**Fertiliser derived from animal or plant matter**	Fertilisers produced from decomposed plant or animal matter. They release nutrients slowly as they break down (e.g. compost, manure, anaerobic digestate)	**Medium**	**Medium**	**Medium**	**Positive**	**Low**	**Medium**
Natural or organic fertilisers	**Natural minerals**	Fertilisers that are naturally occurring minerals, mined from the earth and used in their natural form as nutrient sources (e.g. polyhalite, langbenite, kieserite)	**Positive**	**Positive**	**Positive**	**Positive**	**Medium**	**Positive**
Inorganic, or chemical fertilisers	**Chemically processed mineral-based fertiliser**	Fertilisers derived from processed naturally occurring minerals (e.g. Muriate of Potash (MOP); Sulphate of Potash (SOP)); phosphates	**Positive**	**Medium**	**Medium**	**Medium**	**Medium**	**High**
Inorganic, or chemical fertilisers	**Chemically processed artificial fertiliser**	Artificial fertilisers derived from chemical processes (e.g. nitrogen from the Haber-Bosch process, sulphur from petrochemicals)	**Positive**	**High**	**Negative**	**Negative**	**High**	**High**

(b) Applying crop nutrients solutions more sustainably: What kinds of approaches will shape the future?

The #2 priority to deliver modern agriculture's interlinked objectives is to invest in **regenerative agriculture**, said our agriculture experts

The #4 priority to deliver modern agriculture's interlinked objectives is to invest in **precision agriculture**, said our agriculture experts

Our experts highlighted that the solutions for developing *more sustainable* fertiliser products and applying those products with *greater precision* sit side by side.

It's the combination of using fertilisers that have been produced in socially and environmentally responsible ways, together with the application of the right fertiliser at the right time, rate and place, that's key to achieving modern agriculture's trio of objectives in a cost-effective, less wasteful and more efficient manner.

More balanced and efficient fertilisation practices have rippling benefits for agriculture and the fertiliser industry beyond the farm alone. For example, they enable more efficient logistics and fewer product losses in transit; a reduced risk of supply bottlenecks; and more-stable fertiliser prices at the macro level.

"We'll see lower carbon footprint fertilisers … but you still need to combine that with precision agriculture."

Benoit Boisseuil, Principal, Astanor

"We have to be very efficient with the land that we currently use, and apply nutrients so that we get the most output per unit of input, with the minimum amount of emissions."

Alzbeta Klein, CEO, IFA

Studies support our experts' view on the importance of precision agriculture, suggesting it can improve soil health by up to 30%,[42, 43] improve yields by up to 25%,[44, 45] and optimise nutrient use-efficiency by up to 20%.[46, 47] In particular, it can improve nitrogen use-efficiency. Today, less than half of the nitrogen applied to fields ultimately provides nutrition for crops.[48] Even an increase in global nitrogen use-efficiency from 50% to c.67% (roughly the level achieved in the US and Canada today) would mean total fertiliser emissions fall 48% by 2050.[49]

> "Nitrogen is 50% of my carbon footprint on the farm. Anything that I can do to reduce nitrogen inputs on the farm will reduce my carbon footprint, and that's crucial given we're seeing more legislation designed to limit what farmers apply to crops."
>
> **Colin Chappell, Regenerative Farmer**

In 2023, 39% of farmers globally had adopted at least one new digital technology to improve operations, or were planning to in the next year.[50] Adoption rates are already high and growing in Europe (62%) compared to Asia (9%). Our experts noted some exciting innovations in the field of precision agriculture, outlined below.

> "We're facing a perfect storm, and we believe that technology is now providing us with a suite of opportunities that can enable transition."
>
> **Alastair Cooper, Head of Venture Investments, Cibus Capital**
>
> "By 2050, agricultural production methods will undergo tremendous changes. Intelligent and automated equipment, precision agriculture, vertical agriculture, biotechnology and the Internet of Things will become mainstream."
>
> **Xie Ruojun, Shikefeng Chemical Industry**

Many of the innovations that will support sustainable fertiliser use go beyond the source of the nutrients, and consider the delivery mechanisms of fertilisers. On the next page we demonstrate some of the most impactful innovations to our fertiliser delivery system.

Innovations in fertiliser usage and delivery

Solution	Overview	Stage of development	Impact on food security	Impact on farmer profitability	Impact on environment	Impact on soil health	Upfront cost	Scalability
Digital platforms *"I really want to be able to have 20 different crops in the same field, and to manage them all separately ... that's super difficult; I hope technology will make it possible."* **Thomas Gent**, Regenerative Farmer	Farm management tools will enable farmers to more precisely guide fertiliser application and avoid over-application. They will help inform farmers to use specialty crop nutrition solutions – instead of multi-purpose NPK fertilisers – to raise yields.	Late-stage	Positive	Positive	Positive	Positive	Medium	High
Satellite and GPS technology *"An organisation like ours, unsurprisingly, is looking at a wide range of technologies in terms of satellite imagery ... to build better predictive models."* **Allan Pickett**, Head of Fertilizer Analysis, S&P Global Commodity Insights	Innovations in mapping, real-time analysis, variable rate technology (VRT) and sensor-driven insights will help deliver site-specific nutrient application. This technology is now widely used, and farmers are seeing ROI; however, there can be connectivity issues and training requirements as this scales.	Late-stage	Positive	Positive	Positive	Positive	Medium	High
Soil testing *"The way we do traditional soil lab testing is a process that's 60-plus years old ... It's a highly chemical process, and it strips all of the biology from the soil ... But in looking at just the chemical side, we were missing other processes. We're realising that approach has been depleting our soils' life."* **Yasmin Cathell**, Senior Portfolio Manager, Livelihoods Venture	New approaches in soil nutrient testing include rapid soil biological assessments, DNA sequencing for microbiome analysis, and the use of near-infrared spectroscopy (NIRS) and portable digital soil analysis devices, offering faster and more comprehensive insights into soil health and nutrient availability.[51]	Mid-stage	Positive	Positive	Positive	Positive	Medium	High

Solution	Overview	Stage of development	Impact on food security	Impact on farmer profitability	Impact on environment	Impact on soil health	Upfront cost	Scalability
Robotics *"AI and robotics will transform agriculture, but soil, water, and fertiliser will remain fundamental."* **Simon Pearson**, Founding Director, Lincoln Institute of Agri Food Technology	Advanced robotic systems help improve soil structure by minimising soil compaction and ensuring nutrients are applied only where needed. This technology will require a high level of capital investment, together with ongoing maintenance costs. There are also ethical considerations concerning job losses in economies that rely on agriculture.	Early-stage	Moderate	Low	Moderate	Moderate	High	Low
AI agents *"We believe in a world where we can overlay different types of information and build agents that are like an expert for agronomy. We're giving tools to agronomists, to growers where they can ask questions to those agents."* **Claudia Roessler**, Agriculture – Strategic Partnerships, Business & Industry Copilot, Microsoft	Using machine learning and predictive modelling to assess soil health, detect nutrient deficiencies, and recommend precise interventions.	Mid-stage	Positive	Positive	Positive	Positive	Medium	Medium
Biofertilisers/microbials *"Right now, for me what's most exciting is all of our discoveries and understanding on the biology side of soil science."* **Yasmin Cathell**, Senior Portfolio Manager, Livelihoods Venture	Living microorganisms like bacteria or fungi that colonise the area around plant roots and promote plant growth by increasing nutrient availability (e.g. nitrogen-fixing bacteria, mycorrhizal fungi, seaweed extracts, compost teas).	Early	Moderate	Moderate	Moderate	Moderate	Medium	High

Solution	Overview	Stage of development	Impact on food security	Impact on farmer profitability	Impact on environment	Impact on soil health	Upfront cost	Scalability
Biostimulants	Substances or microorganisms, other than fertilisers, that enhance nutrient uptake, abiotic stress tolerance, and/or crop quality traits. They act as catalysts that boost a plant's natural processes rather than directly supplying nutrients[52] (e.g. seaweed extracts; humic substances; protein hydrolysates).	Mid-stage	Moderate	Moderate	Moderate	Moderate	Low	High
Nano-fertilisers	Nano-fertilisers are fertilisers where at least one of the nutrients is present as nanoparticles sized 1 to 100 nanometers. There are three ways they are made: from developing new compounds based on nanotechnology, encasing nutrients within nanomaterial, or coating conventional fertiliser particles with layers of nanotechnology.	Mid-stage	Moderate	Moderate	Moderate	Moderate	Medium	High

Spotlight: Innovation pipeline – a view from a venture capital investor

THE FIRST THIRTY
INVESTING IN NATURE

From soil to gut: The next fertiliser revolution

Beyond 2050, agriculture could no longer depend on a standardised, chemistry-based fertiliser model. Instead, it will be driven by biology – optimising nutrient flows from soil to plants to human health. With poor nutrition projected to cost the global economy $10 trillion annually by mid-century,[53] the need for a new approach is clear. The fertiliser industry is undergoing a fundamental transformation: moving from yield maximisation to an integrated system that enhances both soil biology and human health.

Advancements in technology – including metagenomics, metabolomics, and AI-powered nutrient mapping – are already unlocking unprecedented insights. Companies such as *Edacious* are enabling the change, measuring nutrient density in crops and linking it to soil health and farming practices. In the near future, we will monitor essential nutrients and metabolites from soil throughout the entire food system, shaping a fundamentally different agricultural landscape.

Beyond NPK: The rise of metabolite-driven agriculture

The NPK model is outdated. Science now confirms that plant health and nutritional value are influenced by dozens of additional elements – including silicon, cobalt, and selenium – alongside thousands of metabolite compounds generated by the soil microbiome, which play critical roles in nutrient uptake and crop quality. These findings are reinforced by evidence linking micronutrients to microbiome function and microbial contributions to plant nutrition. These metabolites drive nutrient density in crops, affecting everything from immune function to chronic disease risk in humans. *Biome Makers* is advancing this frontier with its BeCrop technology, using AI to map soil microbial activity and tailor nutrient strategies that go far beyond NPK.

Managing this complexity requires intelligence systems capable of integrating data from soil sensors, plant genomics, and environmental conditions, to provide precise, real-time nutrient optimisation. As computing advances, these AI-driven systems will make autonomous, biologically informed decisions far beyond human intuition.

The new agricultural infrastructure: Nature's chemical networks

Mycorrhizal fungi already facilitate nutrient exchange and boost crop resilience. With multi-omics insights and real-time soil sensing, these networks will evolve into active partners in regenerative agriculture. *Groundwork BioAg* is harnessing mycorrhizal fungi to enhance nutrient uptake and sequester carbon, laying the groundwork for this future. AI-powered analytics will optimise fungal interactions, enabling more efficient nutrient flows, higher carbon sequestration, and healthier crops – all while reducing synthetic inputs.

Over time, fungal and microbial networks will become a key part of agricultural infrastructure. Investors who recognise this shift early will shape the next wave of agricultural innovation.

The digital and biological infrastructure powering this transformation will unlock multi-trillion-dollar opportunities across agriculture, health, and energy. Investors who act now will be at the forefront of the next major shift in human and planetary health.

Empowered plants: The next decision-makers

Breakthroughs in CRISPR gene editing will allow plants to self-optimise their nutrient acquisition through multiple pathways, including enhanced root architecture, engineered symbiotic relationships with beneficial microbes, and advanced transport systems that improve nutrient uptake.

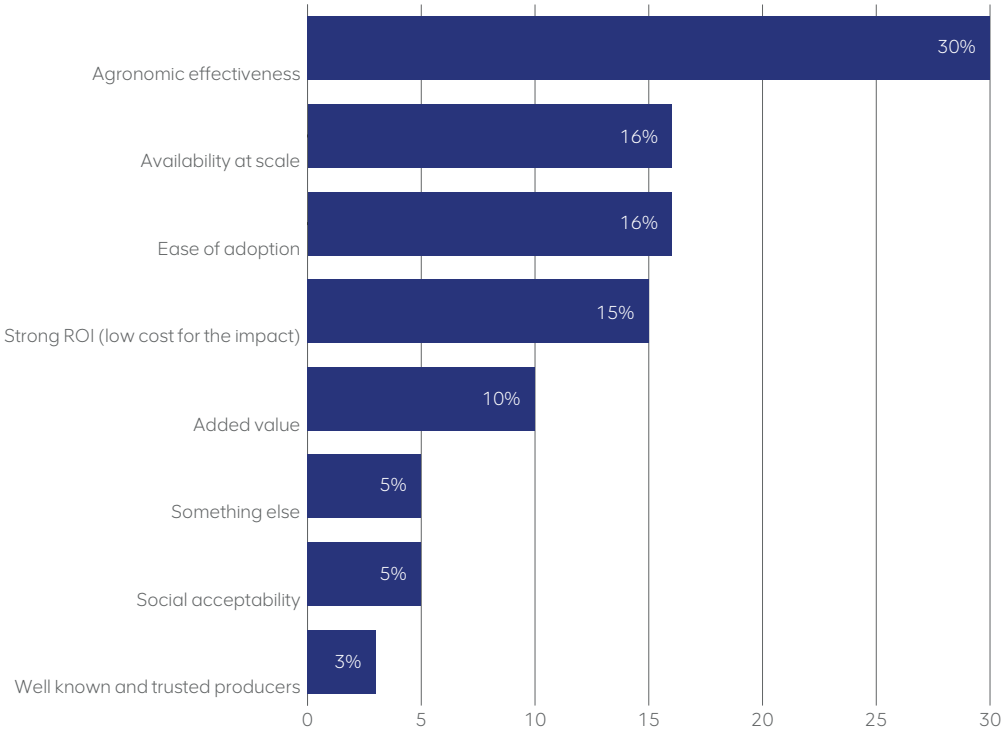
Startups such as *InnerPlant* are already enabling plants to communicate their needs – engineering crops to fluoresce when stressed, signalling nutrient gaps to farmers via sensors. Plants naturally communicate with fungal networks, and soon, these biological signals will integrate with AI, enabling real-time responses to soil conditions.

Written by **Anthony Yousefian**, Partner, The First Thirty

What will characterise successful product adoption?

We asked our experts to rank the factors that would evidence that innovation in green fertiliser development was on track.

Figure 14: Aside from environmental sustainability, what do green fertiliser solutions need to have to be successful? % ranked in top three



1. Agronomic effectiveness: Yield and beyond

This is the most important success factor for novel fertiliser solutions, as yield determines whether farmers will use them. However, our experts also highlighted that many crop nutrient providers place too much emphasis on yield alone. Farmers also value enhanced crop quality, nutritional value and environmental impact, as their buyers are demanding higher-quality, sustainably produced food.

> "It's about getting information on the benefits into the hands of those people who farmers trust."
>
> **James Farrar, CEO, York & North York Moors Combined Authority**

> "To be successful, we need to stop just promoting the yield advantage. The sole focus on yields for the past 60 years has brought us to where we are today: empty calories. We need to move from increased yields to better nutritional value."
>
> **Hannes Van Eynde, Farming, Feed and Crops Manager, Danone**

2. Availability at scale

Availability at scale is the second-most-important factor for sustainable fertiliser solutions. Experts raised two key elements of scalability:

a. the ability to shift novel solutions from promising tests in a lab environment to real results in the field that farmers can rely on purchasing. This is a key issue for experimental solutions that are still in the early phases of development; and

b. the availability of solutions at a large enough scale that they are affordable for farmers, and can have real impact on achieving modern agriculture's interlinked objectives. This is a key issue for both green ammonia, which remains prohibitively expensive, and circular solutions, which are difficult to scale up to the system level. There will be a conflict here in that localised production is great for shortening supply chains, but centralised production offers greater net benefits through scalability.

"In farming, you have enormous variability in climate, soil, production systems, machinery, and farmer knowledge and technical skill. To move from a small trial to a widely adoptable crop nutrient solution, you need products that are robust, stable, easy to transport, that can be mixed in the spray tank, and so on."

Alastair Cooper, Head of Venture Investments, Cibus Capital

"You look at products like green ammonia nitrogen and other more sustainable fertilisers; the major issue is that they are far more expensive than the conventional alternatives at present. Polyhalite is a comparable price to conventional fertilisers but does offer additional benefits within a more sustainable farming system."

Joe Stanley, Head of Sustainable Farming at the Allerton Project, Game and Wildlife Conservation Trust

3. Ease of adoption

Our experts stressed that ease of use will be crucial to adopting sustainable fertiliser products. The products and methods must be easy to understand and integrate into a farmer's current approach, machinery and skillsets. Making a new sustainable fertiliser as compatible as possible with existing practices, and educating farmers in its use, can help to overcome inertia to change, and drive successful adoption across a range of different agricultural production systems and crop types.

> "This is not a revolution for the farmer; it doesn't have to change his view of the world or his responsibility to the world. It's just good practice … from what we know today, using [regenerative practices and sustainable fertiliser solutions] is the reasonable thing to do."
>
> **Uwe Schroder,** Commercial Director, Cefetra Group

4. Strong return on investment

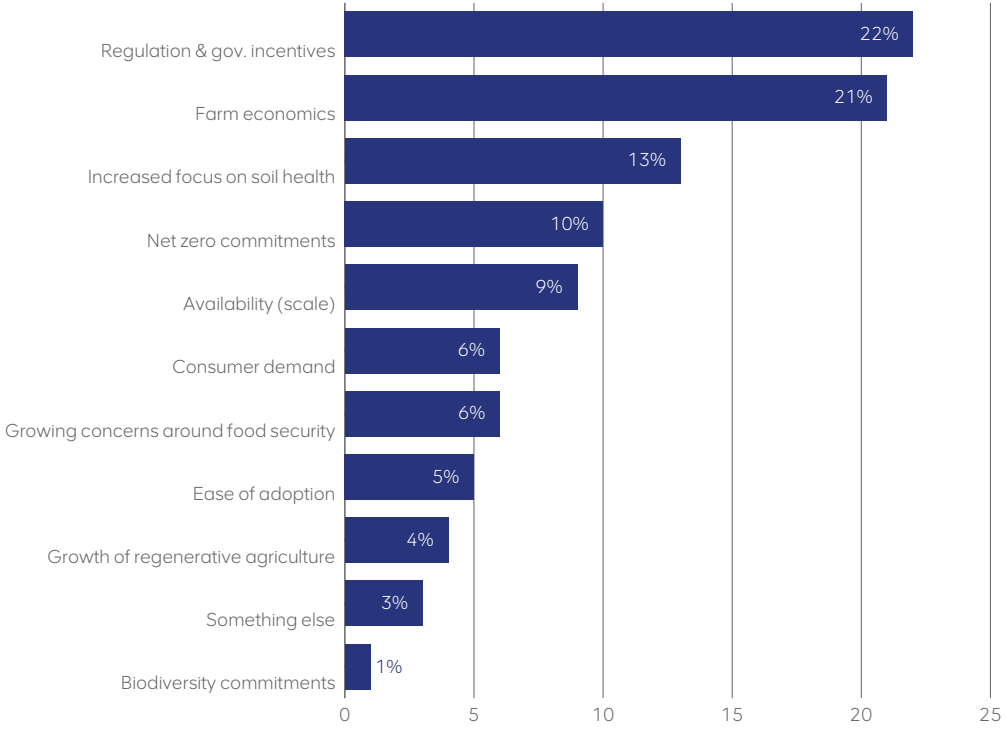
Our experts were clear that for sustainable fertilisers to gain widespread adoption, they must be economically viable for farmers. This requires a keen focus on both actual and perceived cost-effectiveness.

> "If you want adoption, you've got to prove to the farmer that you're going to give them that ROI. They need to see a positive impact on profit within a year… I wouldn't waste time going to a farmer unless you could promise an ROI of three to five times. They want that type of ROI for a new technology."
>
> **Alastair Cooper,** Head of Venture Investments, Cibus Capital

What external pressures will drive adoption?

In addition to the close-quarters pressure from within the supply chain to drive the adoption of sustainable fertiliser products, there will be pressure from outside the immediate supply chain. The increasing use of land devoted to sustainable farming methods is clear evidence of the trend towards sustainable practices – Europe's organic/regenerative/agro-ecological farming area doubled in size between 2011 and 2020.[54] Our experts expect this trend to continue, with the key drivers shown in Figure 15.

Figure 15: Which of the below factors will have the biggest impact on the adoption of sustainable fertiliser? % ranked top three



1. Regulation and government incentives

> "In Europe, we will have CBAM [the EU's Carbon Border Adjustment Mechanism], and that will give sustainable fertiliser adoption quite a push, making it more competitive."
>
> **Marc Van Doorn, President, Ammonia Europe**

Given the long timescales associated with farming, our experts highlighted that farmers need to see long-term commitment to the sustainability agenda through clearer and more progressive regulation, policy and incentives before they invest time and capital in change. The role of government in providing this stimulus is vital to offset the risk of changing a tried and tested approach if there isn't a very clear and compelling reason to do so.

There is precedent for governmental measures tipping the economics of new technologies – for example, in green power generation with the Renewables Obligation and Feed-in Tariffs, which gave suppliers confidence to invest.

2. Farm economics

There's a growing body of evidence that the use of sustainable fertilisers is good for farm economics and represents good value for money. A recent study quantified the saving to be around $105 per hectare.[55] Similar financial analysis on Kansas-based wheat farms that used biofertilisers (microorganism application) and reduced conventional artificial fertilisers improved revenues by approximately 18%.[56]

Our experts suggested that sustainable alternatives need to become the rational economic choice. This will mean internalising the true costs (e.g. GHG emissions, water pollution, etc.) of modern agriculture. Factoring in these costs can ensure that protecting soil health, climate and nature are profitable choices, not only moral ones.

This is particularly important at points on the supply chain where price elasticity, or willingness to pay, is low. Interviewees suggested price elasticity is lowest at farm (e.g. inputs such as fertilisers) and fork (e.g. produce and food products).

"Farming is a commercial business, and we need to find ways in which we are incentivising farmers to do the right thing whilst maintaining food production."

Steve McLean, Head of Agriculture and Fisheries Sourcing, Marks and Spencer

"To maximise the transition, a biohybrid route could well have greatest success; a combo of reduced synthetic fertiliser and biologicals."

Alastair Cooper, Head of Venture Investments, Cibus Capital

"From what I've seen in the United States, the farmers are all for it [sustainable agriculture]. They just want to see a lot more of the value of what they can get out of it."

Gerri Botte, Founder and Director, NSF Engineering Research Center CASFER

Our experts suggested that the middle of the value chain (e.g. food processors, CPG companies, supermarkets) will remain the centre of profit across the food system. They were hopeful this will enable organisations to invest in sustainable alternatives, not to 'do good', but to build long-term competitive advantage. For example, Walmart's (US) Project Gigaton aims to reduce GHG emissions by one billion tonnes from its global value chain by 2030.[57] For farmers, fertiliser will be a key driver of emissions reduction. Those who can demonstrate they are using sustainable alternatives will be securing access to a larger market.

"Our intention is to continue to differentiate our farmed products, improving sustainability and quality, and ensuring any additional costs are justified in the eyes of our customers."

Steve McLean, Head of Agriculture and Fisheries Sourcing, Marks and Spencer

"Big food supply chain players aren't charities, they're private businesses. They want to make money... [change] is going to have to come from a fair price for farmers. That doesn't have to come from higher consumer prices; it could just come from lower levels of profit being taken out by the rest of the food supply chain. Farmers in the UK take home around 5% of the value of the food chain; we produce 60% of the food."

Joe Stanley, Head of Sustainable Farming at the Allerton Project, Game and Wildlife Conservation Trust

3. Increased focus on soil health

As outlined in section 2, our experts see soil health at the heart of a thriving food system. They believe the shift towards valuing soil as an asset to invest in, coupled with the pricing of externalities into the cost of chemical fertilisers, will raise demand for sustainable alternatives.

"Without healthy soil, we can't grow anything."

Anouk Bosman, Marketing and Communications Lead, Kelp Blue

"There's no farmer who will say 'I don't care about my soil'. Soil health is becoming a non-negotiable."

Natalie Collard, CEO, Farmers for Climate Action

Improvements in our understanding of the science of soil will also help drive this. Traditional fertiliser practices thought of soil as an inert medium (or even 'dirt') into which plants and fertilisers were placed. However, today we understand soil to be a living ecosystem that requires nurturing and safeguarding. This has led to the emergence of burgeoning practices such as regenerative farming, which are expected to gain in popularity and uptake in the next decades.

Linked to factor 1, governments are also expected to legislate to protect and improve soil health, as well as bring in incentive measures to do so.

The EU's Soil Monitoring and Resilience Directive, proposed in 2023, is one of the first examples to reach statute books, but the topic is also generating increasing interest at a UN level, with significant lobbying and discussion of the issue at COP meetings and beyond.

Spotlight: Energy transition – a lesson in systems change

The rise of renewable energy as a real alternative to fossil fuels holds valuable lessons for agriculture. The photovoltaic effect was first observed in 1839 by Edmond Becquerel, but commercially viable solar panels only became available in the 1990s and 2000s – and widespread global adoption has only been seen over the past decade or so.

The uptake of renewable technologies was slow for three main reasons.

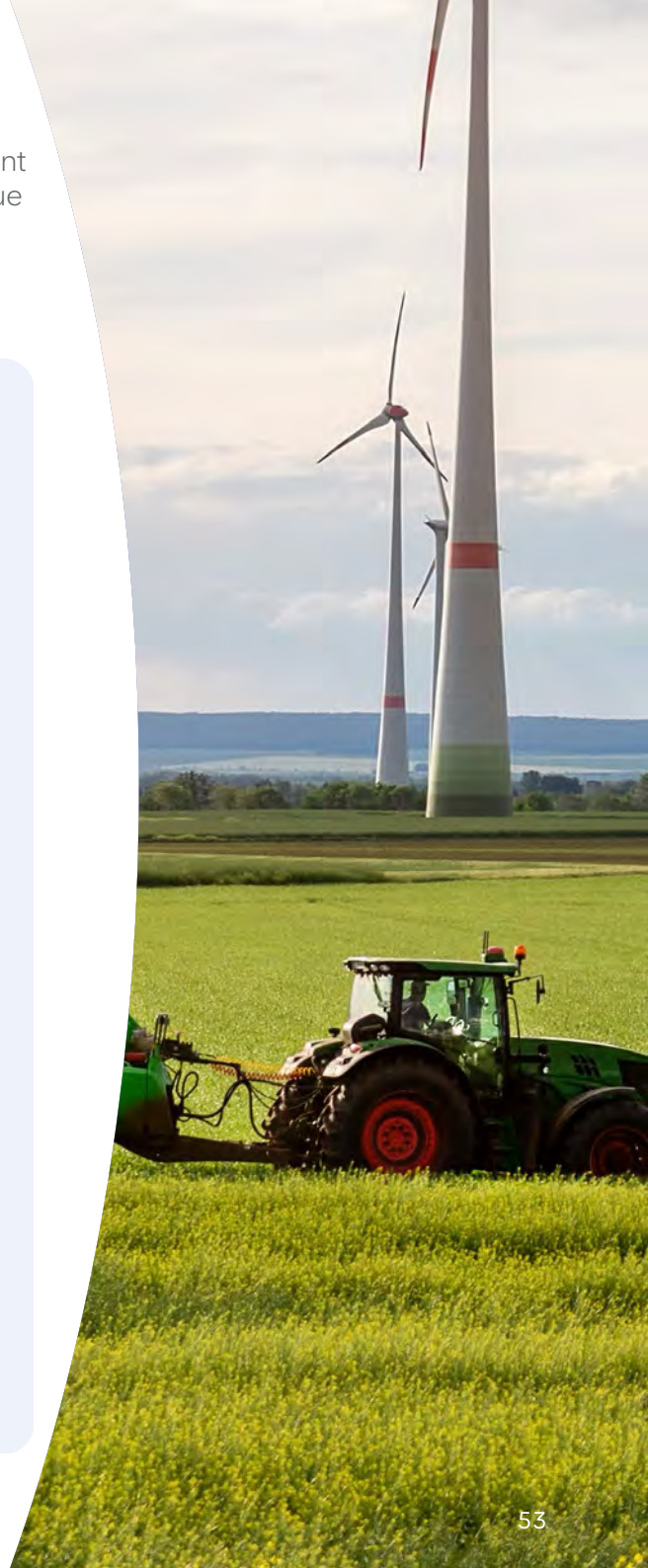
- **Value was unclear.** Historically, renewable energy technologies had higher initial costs than traditional fossil-fuel-based systems.
- **Policy uncertainty.** Changes in government policies, priorities and incentives meant investors didn't have the certainty to invest in long-term infrastructure.
- **Lack of industry and public awareness.** People didn't understand the real impact of fossil fuels, or the benefits of renewable energy.

These reasons mirror the current state of the sustainable fertiliser industry, where economics, policy uncertainty and a lack of awareness hinder widespread adoption. Although forward-thinking agricultural players are now exploring sustainable fertiliser alternatives, government support is crucial for these innovations to truly take root – just as it was for renewable energy.

Consider the parallels. Consumers and suppliers, accustomed to cheaper fossil-fuel-based electricity, were hesitant to switch to renewables. Similarly, farmers, facing tight margins, are reluctant to embrace what they see as 'costly' sustainable alternatives.

Just as governments stepped in with feed-in tariffs, renewable energy certificates, and auction schemes to incentivise the uptake of renewable energy, similar mechanisms are needed for sustainable fertilisers. These could include tax breaks for producers, subsidies for early adopters, and regulations promoting sustainable practices.

These measures would create an economic tipping point, attracting investment and driving innovation. Increased production would lead to economies of scale, ultimately making sustainable fertilisers more affordable and accessible, mirroring the trajectory of renewable energy.



Innovation and economics enable behaviour change

Our experts reflected that farming is an industry inherently based on trust. For many, it's a family business, and one they hope to pass on to future generations. Although profitability differs farm to farm, margins are often tight, making the prospect of investing in change a risky one. Having innovative solutions that make immediate economic sense to farmers will help them to make changes that raise the priority of sustainability and embed lasting habits.

"A lot of that [change] is based on developing confidence with partners across the supply chain."

Yvonne Pinto, Director General, International Rice Research Institute

"The biggest mistake people make when it comes to innovation in agriculture is they treat it the same as any other innovation... If I want to test a new app, I can test it 1,000 times a day. With farming, I can only grow a crop once a year. So, in my whole life, I'll probably only get 50 tries ever."

Thomas Gent, Regenerative Farmer

But our experts also highlighted that farming is an industry where change is a constant. Farmers take decisions every day that can have consequences for years to come. They are always responding to changing weather conditions, input prices and food prices – and ultimately make their decisions based on what's right for their land and their business. Our experts concluded that we're all actively involved in the food value chain. If not as policymakers, inputs providers, growers, food producers or distributors, then certainly as consumers – and that behaviour change needs to span the whole chain. Some suggested that, ultimately, consumers will have to pay more for food, while others argued for a 'carrot over stick' approach.

"The realities of farming are constantly responding to change."

Alastair Cooper, Head of Venture Investments, Cibus Capital

"By 2050, there'll be more connection with quality and how food is made."

Ben Taylor-Davies, Regenerative Farmer

"I'm told by all the players in the supply chain that people aren't interested in paying more money for a 'greater good' issue like biodiversity or climate change. The reality is, we can't necessarily rely on consumers to drive the positive change."

Joe Stanley, Head of Sustainable Farming at the Allerton Project, Game and Wildlife Conservation Trust

"We've got to make it easy for people to do the right thing; to lead through pleasure, and make the healthy sustainable choice the thing people want."

Helen Browning, CEO, Soil Association

Our respondents concluded that unless sustainable alternatives become the affordable option, only the most affluent consumers will choose them. Targeting these segments through consumer awareness campaigns and education will help incrementally increase demand for sustainable food, but it will remain a minor part of the global solution. Ultimately, no single actor can hold all the risk, cost or investment – it must be split across the value chain and scaled globally to have real impact.

"It's not about pinning this on individual responsibility, but saying we need to change the food environment. We've got to make it easy for people to do the right thing."

Helen Browning, CEO, Soil Association

"We can't expect that because we're investing in sustainable solutions, our products can be more expensive. If we pass costs on to consumers, then that means it's only sustainable for us but not sustainable for them ... The whole value chain needs to be better off."

Hataikan Kamolsirisakul, Head of Strategy, Sustainability & Innovation, Thai Wah

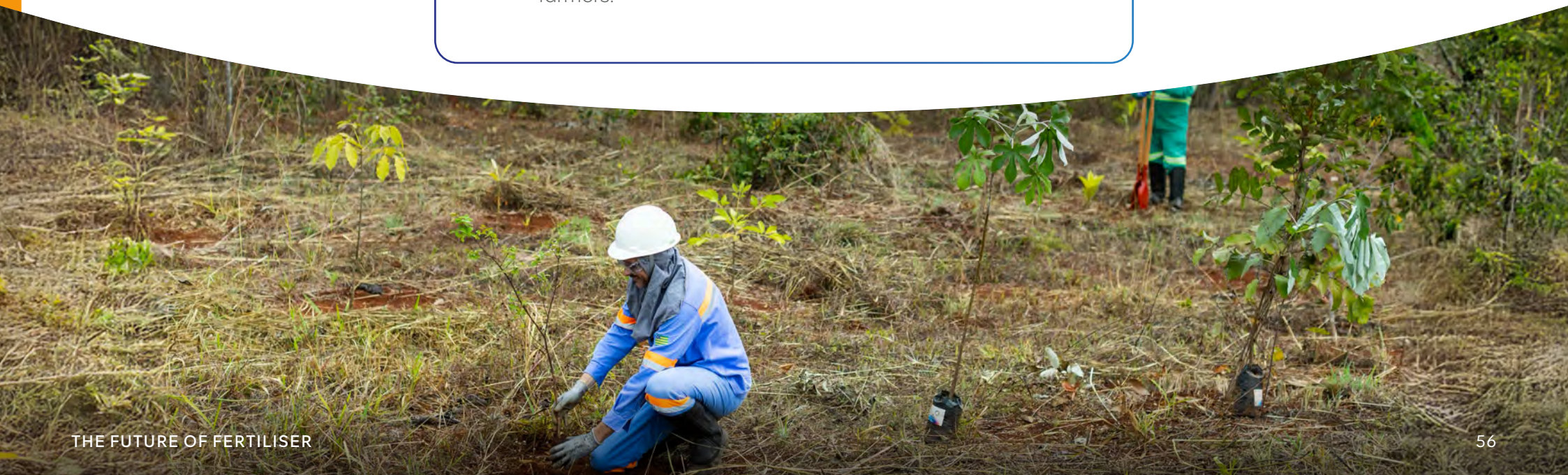
Chapter 2 takeaways

Without fertiliser, we wouldn't be able to feed the population.

Over-application of fertiliser has caused long-term damage to nature and soil, which must be addressed through innovation and system change to avoid further damage and impact on yields.

Investing in fertiliser that is more sustainable will be key to achieving modern agriculture's interlinked objectives. Although many novel solutions exist, few are available at a scale and price point to drive real change.

The risks and costs of innovation must be spread across the value chain and coupled with widespread behaviour change to have real impact. The changes in behaviour must make sense from the perspective of all stakeholders – especially farmers.



CHAPTER 3

Envisioning the world in 2050

Five key themes to shape our exploration of the future, and key findings

We asked our 74 experts to envision the global future agri-food system of 2050.

Broadening the key interlinked objectives sought by modern agriculture (food security, sustainability, farm profitability) to consider the journey to 2050, we chose five interconnected high-level themes for our interviews, to cover the breadth and depth of agri-food stakeholder interests:

Sustainability and regulation – describing the extent to which regulations aiming to drive a more sustainable agri-food system will strengthen by 2050.

Incentives – describing the extent to which public and private incentives for driving a more sustainable agricultural system will strengthen by 2050.

Agricultural practices – describing the extent to which sustainable agricultural practices will be adopted by 2050.

Innovation – describing the extent to which investments in innovations that support sustainable agriculture will accelerate by 2050.

Collaboration – describing the extent to which stakeholders from across the agri-food value chain cooperate to promote a more food secure, sustainable and equitable agricultural system by 2050.

Although these themes are interrelated within the global agricultural system, we have separated the views of those surveyed under each topic, to keep the analysis as simple as possible. More detail on our methodology is outlined in Appendix 6.2.

Overall, our interviewees painted a cautiously optimistic vision for the future of the global agri-food system and how it might evolve by 2050, focusing on the five interconnected themes. **Experts anticipate regulations to drive sustainability will increase**, with Europe leading the way due to policies such as the Common Agricultural Policy. However, global harmonisation is unlikely, due to geopolitical and economic differences.

Financial incentives will play a crucial role in encouraging more sustainable agricultural practices. Experts stress that future incentives must be different from existing subsidies, which have sometimes promoted less sustainable practices.

Farmers are expected to adopt regenerative agriculture, due to its long-term benefits for soil health and productivity, though adoption rates may vary depending on market conditions and regulatory support.

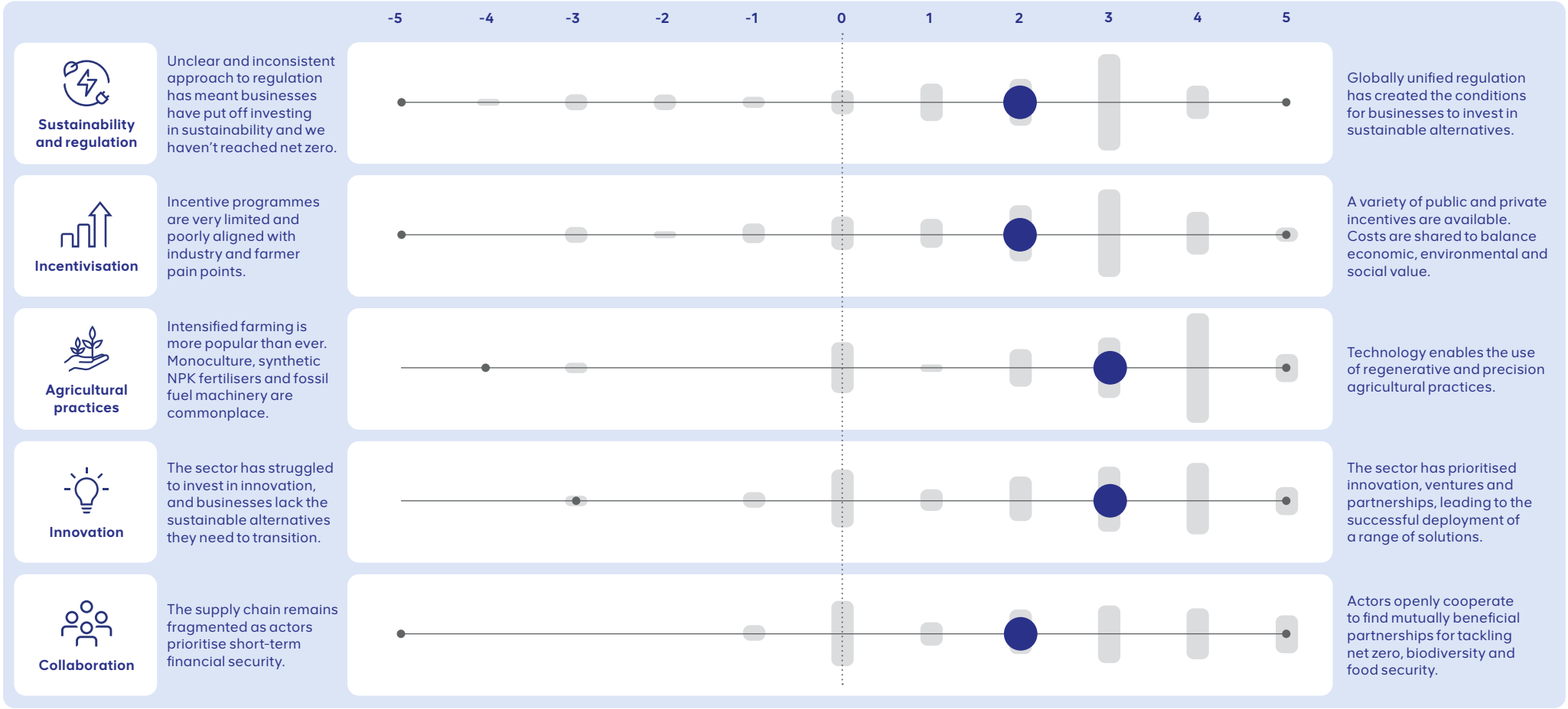
Innovation – particularly in agri-tech, AI, robotics and fertiliser efficiency – is considered key to supporting a sustainable industry. **Experts are optimistic about technological breakthroughs**, but highlight cost, scalability and awareness as challenges that must be overcome. Although investment is expected to accelerate, adoption might initially be limited to high-value crops, before spreading to broadacre farming.

Collaboration across the agricultural value chain is seen as essential but challenging. Although increasing cooperation is evident today – among farmers, policymakers and food manufacturers – concerns about deglobalisation and economic protectionism could hinder broader industry-wide collaboration.

Regionally, Europe is expected to be at the forefront of more sustainability-driven agricultural policies, while the US may lag, due to different economic priorities.

In developing regions, the focus will remain on closing the yield gap, with sustainability efforts driven primarily by financial viability. The industry's collective vision is captured in the chart below.

Figure 16: The world in 2050 – median scores across each key category



Sustainability and regulation

Most experts foresee an increase in regulation that drives sustainable agricultural practices, as shown by the median score and clustering of grey bars towards the positive end of the sustainability and regulation axis in Figure 16. They suggested that the pace and scale of transition would depend on frameworks to internalise the environmental costs of modern agriculture. Some suggested best practice emerging in Europe and the US (e.g. the Common Agricultural Policy and the Carbon Border Adjustment Mechanism) would be adopted more widely. Figure 16 highlights a minority of outliers towards the negative end of the axis who suggested we will make little progress on sustainability. Growing deglobalisation, the rise of geopolitical tensions and economic protectionism were shared as reasons for this lack of progress around sustainability and regulation. The consensus was that global regulation is highly unlikely thanks to different market structures, and socio-economic and environmental contexts. However, a greater degree of regional harmonisation will take place, given their more shared challenges on the road to 2050.

Incentivisation

Our experts were optimistic about the evolution of incentives, and were fairly consistent in this view, as illustrated by the median score and relatively clustered distribution of scores along the incentivisation axis in Figure 16. They believed that financial incentives would continue to be key in the sector, and should be used to encourage farmers to adopt sustainable inputs and practices. Again, our interviewees believed the rest of the world would follow the precedent set by the EU in this area. Interviewees raised that incentives must be markedly different to current agricultural subsidies, which have often incentivised unsustainable behaviour, and caused distrust across the value chain. To rebuild trust and credibility, governments must show political will for long-term change, and engage farmers in future subsidy design.

Agricultural practices

Our experts had a fairly consistent view on the extent to which they see sustainable agricultural practices being adopted by 2050. The consistency of this view is illustrated by how the majority of scores are distributed towards the positive end of the agricultural practices axis in Figure 16. They highlighted that farmers are increasingly recognising the benefits of protecting soil health to drive longer-term yield uplifts and improve crop quality. The majority of our experts felt this shift would be enough to drive the growth of regenerative agriculture at sufficient scale and pace. However, a small minority felt that, without additional policy and regulatory supports, this adoption would remain confined to parts of the food system where:

- margins are higher and farmers have the financial resources to change;
- consumers can afford to pay a premium for sustainably produced food; and
- regulation will encourage transformation across the supply chain.

Innovation

Most of our interviewees felt that innovation would be a key driver for achieving a sustainable agricultural system in 2050. They were hopeful about the transformative potential of more advanced agri-tech solutions, such as AI and robotics, but did emphasise the need to better put farmer needs at the heart of the innovation process. They expected adoption to start in specialised agricultural systems that produce high-value crops, before costs come down and enable adoption in lower-value systems (e.g. broadacre crops).

On innovations in fertiliser, our interviewees had a nuanced view. They emphasised the broad benefits that sustainable fertiliser can bring, and the critical importance of accelerating their adoption and efficient use. However, some interviewees (as shown by the number of scores around -1, 0 and +1 in Figure 16) felt that without addressing key barriers – primarily cost, scalability, ease of adoption and the general lack of industry awareness – adoption would remain sluggish.

Collaboration

Our interviewees had a more measured outlook on the extent to which the industry will collaborate to drive greater food security, sustainability, and a more equitable future for farmers – illustrated by the lower median score in Figure 16, and the greater range of interviewee responses between -5 and +5. Interviewees saw evidence of increasing collaboration today, driven primarily by food manufacturers, and expect to see more collaborations between farmers, policymakers and regulators in a bid to overcome systemic barriers to sustainable transformation.

A small minority of interviewees held a more negative view, citing doubts that the industry would come together – particularly in a world where deglobalisation and national economic protectionism may persist.

The world in 2050: How different stakeholders view the future

As we would expect, there's both alignment and marked differences between the views of different stakeholder categories when it comes to optimism in the future agricultural system – and the fertiliser sector in particular.

The alignment between respondents often pointed to the current success of initiatives, policy and regulations, and the resultant change to industry dynamics as a cause for optimism. There was also widespread belief that agricultural practices would continue to evolve through innovation and education towards more regenerative and precise solutions being adopted. Capital investors were generally the most optimistic of the groups represented, and clearly saw their role as enablers of the technological developments needed to seed change in the agri-food system as it makes its way to 2050, when many believe that the change achieved will be largely self-sustaining thereafter and require considerably less financial incentivisation. This is not to say that the path to 2050 is seen as an easy one. The existing sector and system is fragmented within value chains and between regions. Progress will be heavily dependent on some of that fragmentation yielding to consolidation and collaboration.

Sustainability and regulation

We surveyed the extent to which stakeholders saw regulations designed to drive a more sustainable agri-food system would strengthen between now and 2050.

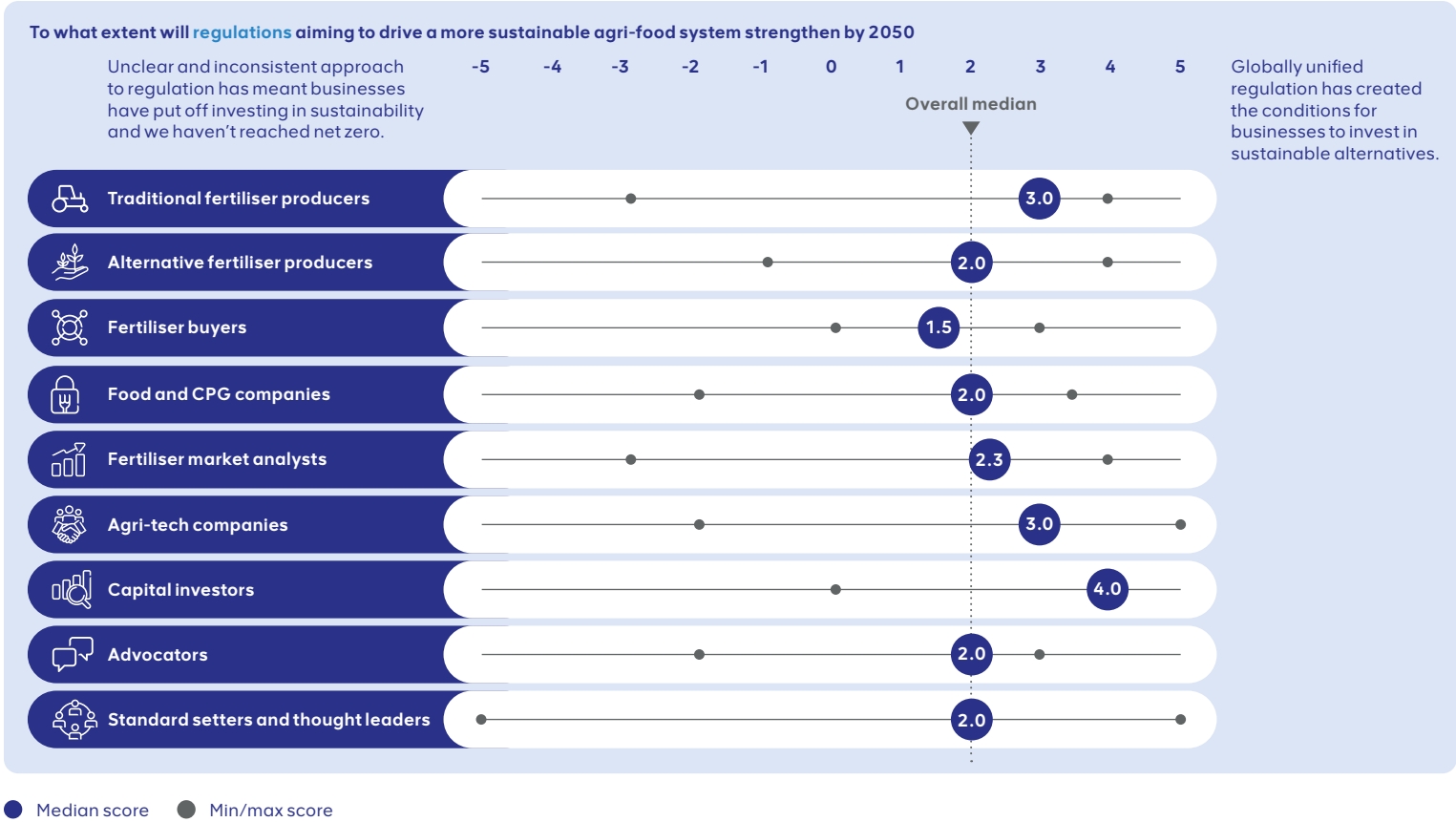
The most consistently optimistic stakeholder class is that of capital investors, who see the current trend and recent surge in investment and strategic partnerships for sustainable fertiliser adoption continuing.

Those partnerships have been sparked by welcome improvements to agri-food policy accompanied by regulatory frameworks that encourage compliance.

These movements pave the way for more of the same, and create a virtuous cycle of cooperation such as we've seen in major food retailers piloting sustainable fertilisers with farmers.

From an investment perspective, this points to a positive and buoyant sector ahead. At the other end of the optimism spectrum, we see farmers, as the immediate buyers of fertiliser, taking a different view. Their experience is that government and regulators fail to take into account the practical needs of farmers when developing policy and regulations when it comes to the adoption of sustainable fertiliser products. Political support for sustainable agriculture is uncertain and variable. The farming community, as a whole, lacks confidence that this will change any time soon.

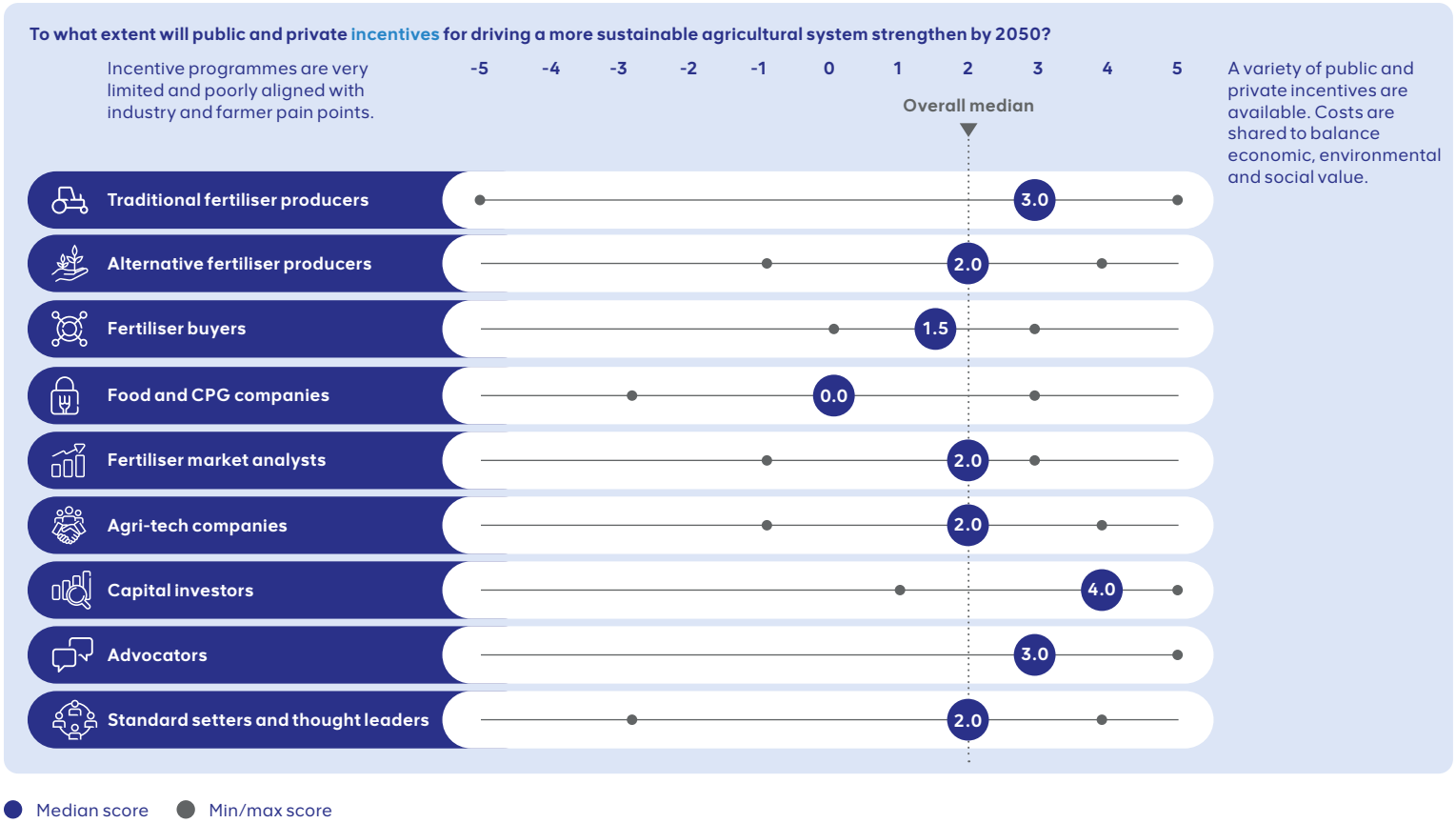
Figure 17: Perceived extent of progress on strengthening regulations, by stakeholder group



Incentivisation

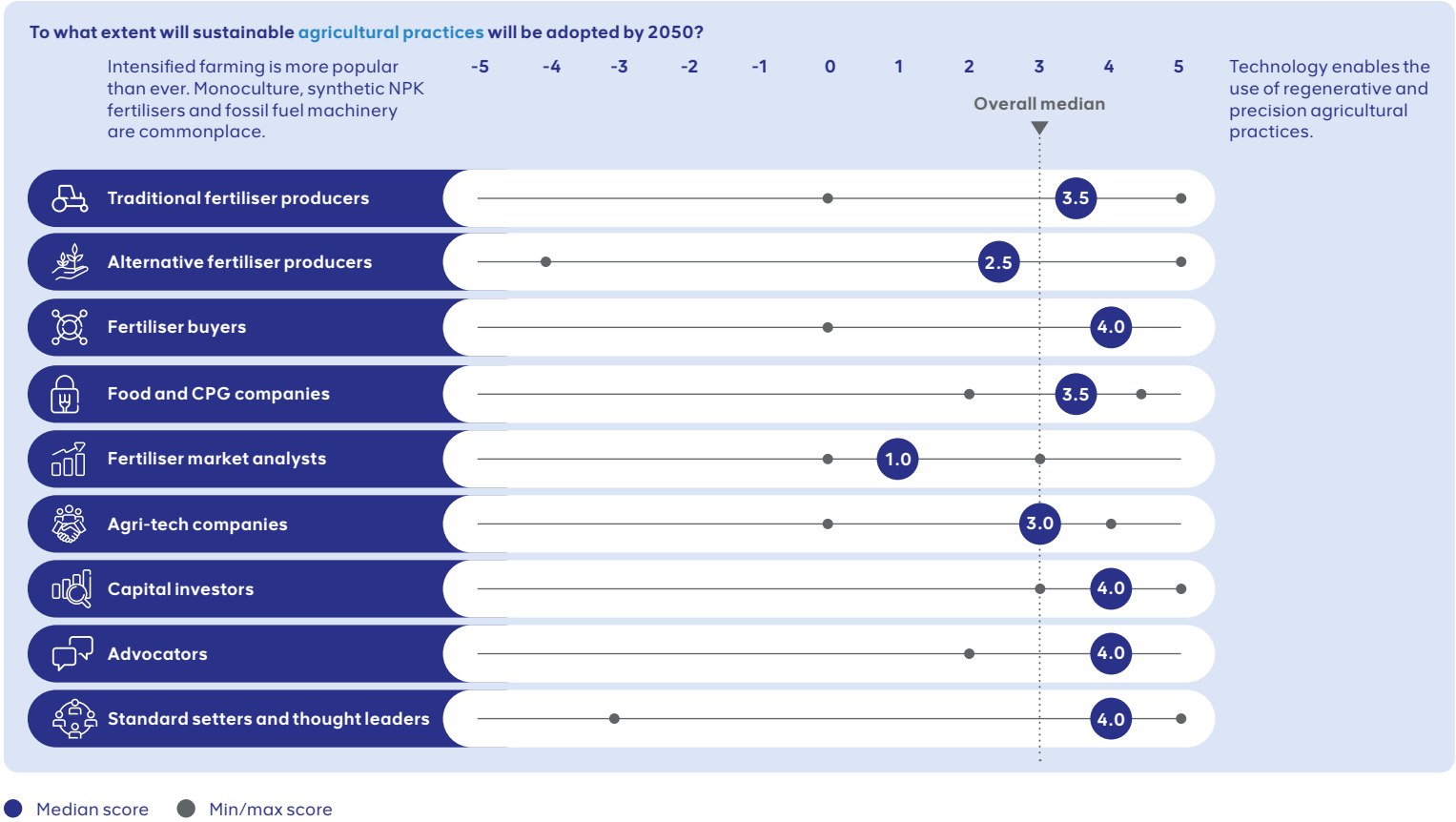
On incentivisation, we see capital investors continuing to be the most optimistic group in believing that public and private incentives for driving a more sustainable agricultural system by 2050 would be successful – particularly in the adoption of more sustainable fertilisers. Their confidence is grounded in the success of incentivisation to date continuing with fresh incentives being initiated to meet the change requirements at each step of the change journey. The least optimistic group was that of Food and CPG companies who, while recognising that the current levels of financial incentives in leading jurisdictions, such as the EU, pave the way for change, do not have faith that those incentives will develop sufficiently to support the journey towards continued adoption of more sustainable fertilisers to the levels needed – say, to achieve Scope 3 targets. In jurisdictions where incentives are currently lacking, they don't perceive any momentum to introduce or strengthen these to the level required.

Figure 18: Perceived extent of progress on strengthening incentives, by stakeholders



Agricultural practices

Figure 19: Perceived extent of progress on the adoption of sustainable agricultural practices, by stakeholder group



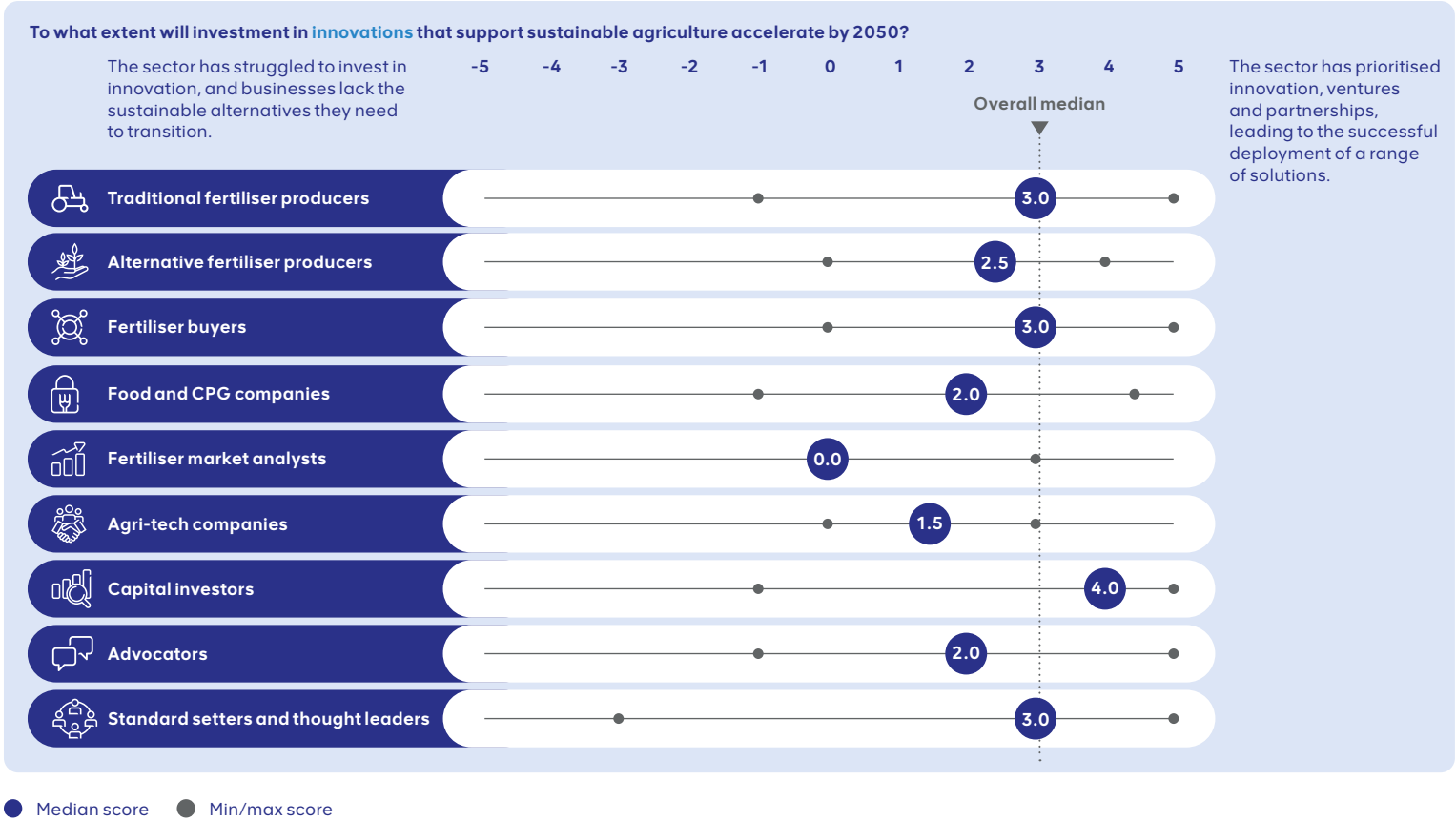
Our survey sought to establish the extent to which respondents believed sustainable agricultural practices would be adopted by 2050. On this topic, the pattern of optimism by stakeholder group changed, and we saw fertiliser buyers, advocators, and standard setters and thought leaders joining capital investors as the most optimistic cluster for marginally varying reasons. Fertiliser buyers – a group that includes farmers and farmer cooperatives – were optimistic that the shift towards regenerative agricultural practices and precision farming will be a sufficiently strong driver of the agri-food systematic change required for 2050. Their confidence was underpinned by a belief that farmers will see superior soil quality as the path to higher yield and profits, and will be enabled to achieve more precise fertilisation through practice improvements that in turn will lower overall consumption and costs. This view was generally supported by the views of capital investors. Advocators took a different stance, and were more encouraged by existing programmes of farmer-to-farmer education programmes continuing to act as a mechanism for driving the transition towards sustainable agricultural practices. Another nuanced view was taken by the cluster of standard setters and thought leaders, who placed greater emphasis on the success of projects looking at the cost-benefit outcomes (both financial and environmental) achieved by varying crop types across climate zones and soil types to achieve improved specificity. These projects act as a use-case for improvements and innovations to agricultural practices, which they see as accelerators to the broader adoption of those practices in the longer term. Of the less optimistic stakeholder groups, fertiliser market analysts stand as an outlier. Their pessimism stems from the perceived lack of financial incentives along the value chain to achieve material change. Without such incentives, they expect the adoption of sustainable agricultural solutions (both inputs and practices) to lag, which in turn will delay the take-up and transition necessary to fuel economies and benefits of scale.

Innovation

The survey focus on innovation looked at whether investment would accelerate to enable sustainable agriculture through innovation by 2050.

Again, capital investors were the most optimistic group, believing that policy and regulation would continue to develop and create opportunities for strategic partnerships and investment. The least optimistic group were fertiliser market analysts, who were confident that the pace and scale of innovation would continue to accelerate compared to today's level, but were hesitant to see that acceleration overcoming the many systemic barriers in the agri-food system that work against their successful future adoption leading to lower costs and improved production volumes. Those barriers include insufficient regulation and incentivisation to stimulate strategic partnering and consolidation within the sector. Instead, they believed the global agri-food system will remain geographically fragmented and focused on profit maximisation.

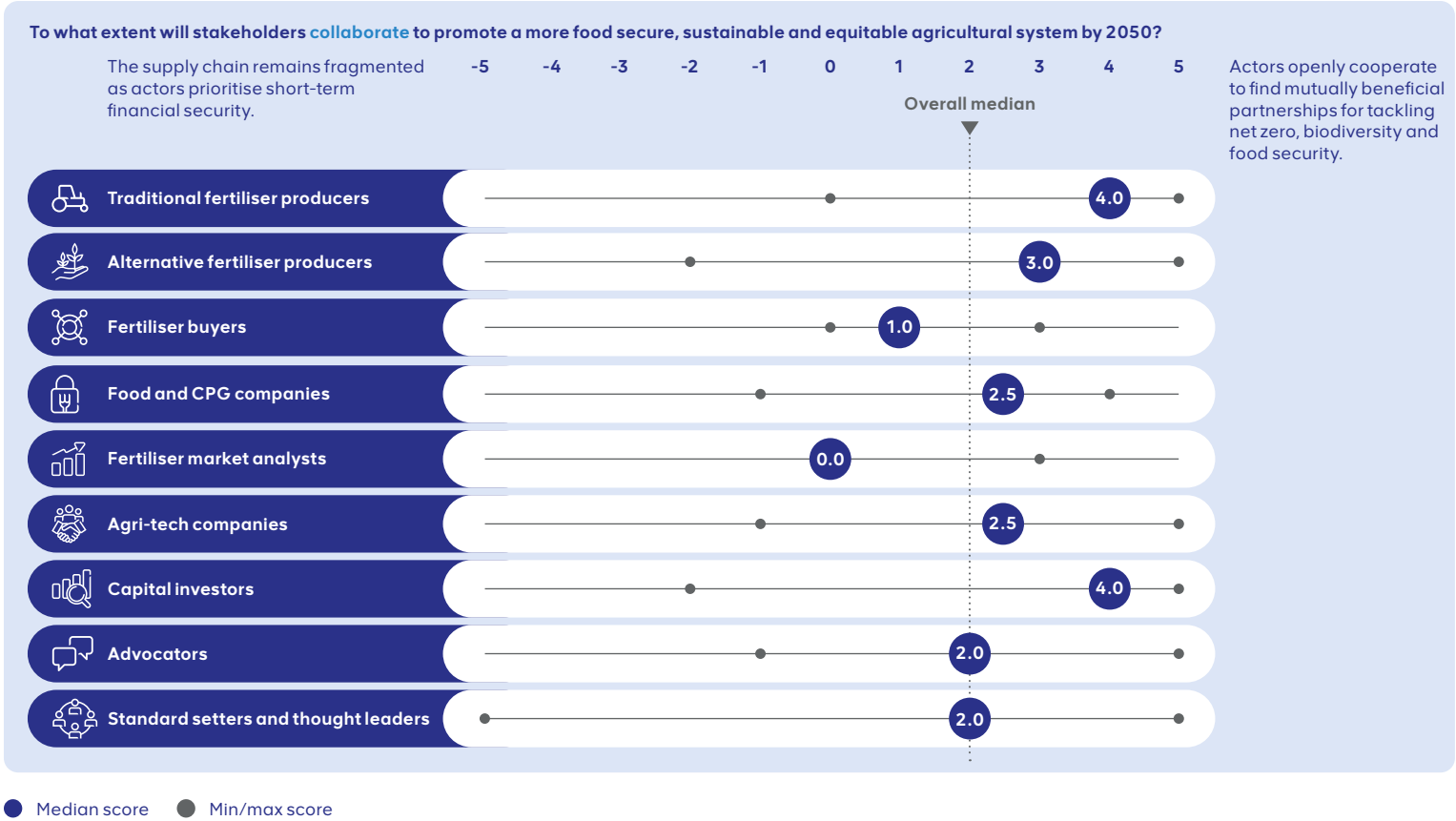
Figure 20: Perceived extent of progress on accelerating investment in innovations, by stakeholder group



Collaboration

The survey explored the extent to which respondents saw stakeholders collaborating to promote or advance a more food-secure, sustainable and equitable agricultural system by 2050. The responses followed a broadly similar pattern to that seen on the topic of innovation. In the more optimistic cluster, we saw traditional fertiliser producers and capital investors heading the field, albeit for subtly different reasons. Both groups believed that improved financial incentives along the value chain would encourage dialogue and working supply chain partnerships between farmers, food processors, food retailers and CPG companies, leading to improved adoption of more sustainable fertilisers. Traditional fertiliser producers went on to see more stringent supply-side regulation catalysing the production and therefore uptake of more environmentally friendly NPK fertilisers. At the more pessimistic end of the collaboration viewpoint spectrum were fertiliser market analysts, who foresee that policy and regulation would be insufficient to stimulate greater collaboration than that of today.

Figure 21: Perceived extent of progress on collaboration, by stakeholder group



The world in 2050: Regional differences

Our survey was largely aimed at obtaining views about the global agricultural system, but also revealed where our expert respondents saw important regional differences or nuances.

All respondents expected Europe to lead the global agenda on sustainable agriculture, highlighting the below.

- On average, higher incomes will mean consumers can afford to pay a higher price for more sustainably produced food of a higher quality.
- Stronger regulation, such as CSRD, will put pressure on downstream players in the fertiliser value chain – notably large supermarket chains and CPG companies – to set and achieve sustainability targets. This will drive more sustainable practices further up the value chain, including the choice of more sustainable inputs.
- Europe is unlikely to convert any more land for agriculture, meaning increasing yield will be essential to producing more food. Farmers, who have already maximised the yield gains that traditional fertilisers can deliver, are looking for novel ways to improve soil health and boost yields.
- Finally, developed economies, such as those in Europe, often have higher levels of technical skill and capital availability, and are more willing and able to invest in sustainable practices and inputs.

Individual respondents expressed these views with additional detail, such as **Joe Stanley** from the Allerton Project, Game and Wildlife Conservation Trust:

> ***"In the UK and across the rest of Europe, concerns about soil health will become a key driver of change, but in other markets they don't have the regulatory oversight or consumer concern to the same extent."***

Other views generally recognised that the most developed economies were more likely to increase regulation and evolve agricultural practices, but also suggested the US will be the outlier to that trend. They cited the relative affordability of conventional chemical fertiliser, the dominance of large-scale commodity crop production prioritising short-term profit over crop quality, and a low appetite for direct government intervention in agriculture as the main factors that set the US apart.

Experts based in China also expect to see positive regulatory change, but highlighted the need for checks and balances to ensure this regulation doesn't impede change. Varied incentive programmes rooted in grower needs and market dynamics were suggested as an alternative to extensive regulation.

Among the largest growers of agricultural commodity crops that feed the global population, Chinese experts highlighted that more efficient agricultural practices would be key to deliver food security while protecting the environment.

They outlined that adoption of technologies to increase precision, thereby driving efficiency, will be essential, and suggested technology could help bridge the divide between yield in high-income vs low-income countries. However, interviewees also highlighted that if technology is not available to all, it could reinforce and widen this gap.

In less-developed or lowest-income regions, such as sub-Saharan Africa and parts of India and Pakistan, our interviewees expected the focus to remain on closing the yield gap. Sustainable practices and inputs will be employed only where efficacy is clearly proven and the return for the farmer is high. If these options are available, farmers in the region are less likely to be reliant on chemical fertilisers, and can leapfrog straight to sustainable alternatives at scale.

Our experts emphasised that in regions where small holders represent the majority of growers, 'leapfrogging' would rely on the availability of capital investment, targeted financing options and relevant training.

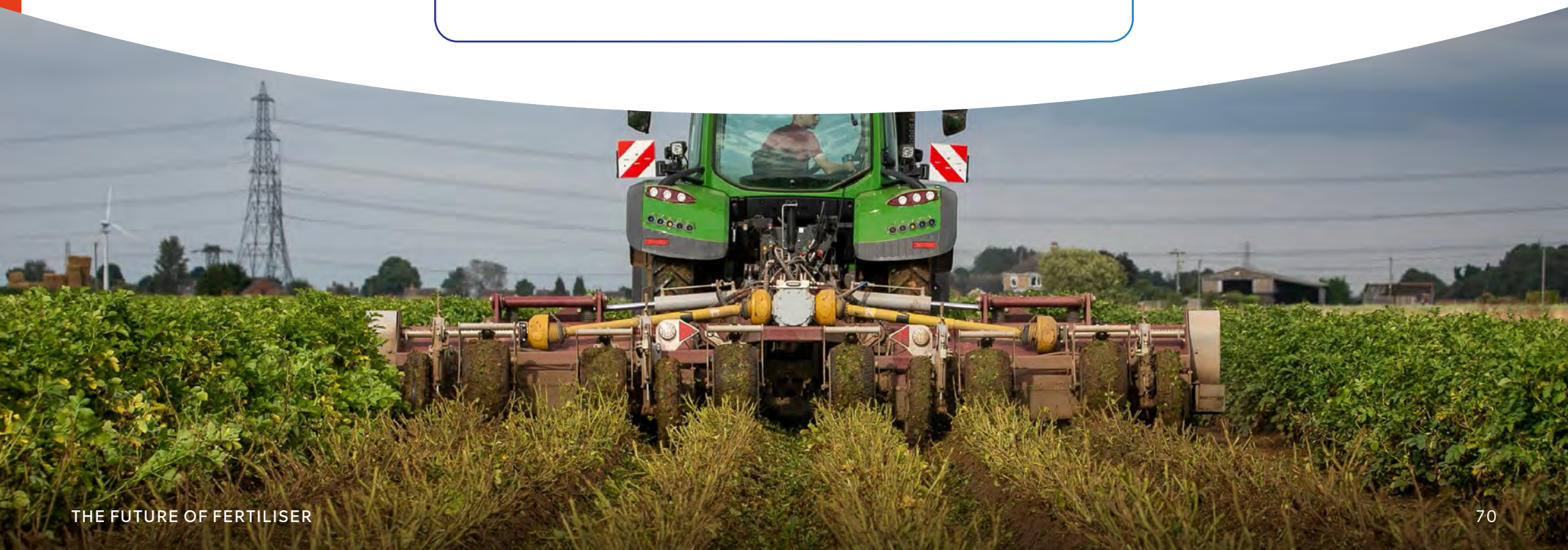
> "Africa is where the rubber hits the road in terms of these challenges. Either we solve them in Africa, which will also solve many other critical world development issues, or we will fail overall globally."
>
> **Henry Abraham, CEO, HJA Africa**

Our interviewees also highlighted important differences in the future of fertiliser between regions that produce high-value crops and lower-value agricultural commodities. They suggested regions that grow high-value crops are more likely to be early adopters of novel crop nutrient solutions and technologies because of the high return on investment from even small yield gains.

These regions include the Mediterranean basin and western Europe, where fruits, vegetables and flowers make up a significant proportion of agricultural production.

Chapter 3 takeaways

- Industry dynamics, supported by regulation, will be the primary driver of change.
- The evolution of agricultural practices towards regenerative and precision agriculture will be a defining element of the food system in 2050.
- Capital investors expect to see significant technological breakthroughs that will drive attractive business opportunities, and see themselves as a key enabler to this.
- Food and CPG companies expect that, by 2050, more sustainable agricultural practices will be self-sustaining and the incentives we see today will no longer be required.



CHAPTER 4

The future of fertiliser: Recommendations for change

Fertilisers are, and will continue to be, crucial to modern agriculture.

Chapter 2 looked at possible innovations and solutions that will help ensure fertiliser can deliver food security while protecting nature and delivering farm profitability.

Chapter 3 provided viewpoints on several themes, including confidence in innovation and the investment required to make breakthroughs in technology.

Scaling and embedding these solutions will demand change at the systems level; to the underlying structures, rules and mindsets that inhibit the achievement of modern agriculture's interlinked objectives.

> "The biggest benefits will come from whole-system thinking."
>
> **Niall Mottram, VP – Energy and CDR, Cambridge Consultants**

How do you build a thriving food system in six steps?

1. **Redefine the metrics for business success – move away from a sole focus on yield, and create frameworks to measure and value soil health, emissions, food nutrient content and the impact on nature**
2. **Prioritise scalable crop nutrition solutions with proven agronomic effectiveness across a broad range of crops, to maximise return on investment**
3. **Tailor solutions and incentives to the real needs of farmers**
4. **Focus more on soil health**
5. **Internalise the environmental costs of chemical fertilisers to define the real value of sustainable alternatives and incentivise their use**
6. **Work with farmers to build trust**

1. Redefine the metrics for business success – move away from a sole focus on yield, and create frameworks to measure and value soil health, emissions, food nutrient content and the impact on nature

For centuries, our food system has optimised for output per hectare. This is starting to evolve, with carbon emissions an increasingly important metric. Our experts expect to see a move away from yield as the sole metric of success, towards a system that optimises for soil health, emissions, food nutrient content and nature impact. Key to delivering this shift will be defining measurement frameworks and benchmarks for these emerging metrics.

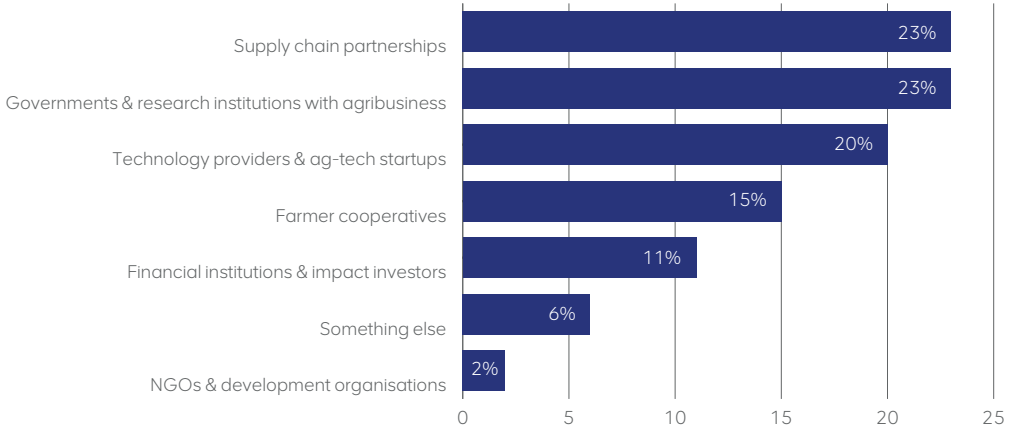
> "Right now, we have carbon tunnel vision. We're optimising for the wrong things. We've forgotten about the nutrient needs of crops that ultimately underpin healthy and nutritious food."
>
> **Yasmin Cathell**, Senior Portfolio Manager, Livelihoods Venture

2. Prioritise scalable crop nutrition solutions with proven agronomic effectiveness across a broad range of crops, to maximise return on investment

Few of the emerging sustainable fertilisers our experts discussed have the characteristics for wide adoption yet. Issues of scalability, cost-effectiveness and ease of adoption remain barriers to be overcome. Our respondents suggested that investors should look to channel capital towards scalable solutions with proven agronomic effectiveness across a broad range of crops, to maximise the impact of investment.

Our interviewees suggested policymakers must provide support to producers and farmers, to drive scale and adoption. They also highlighted the need for more partnerships between the producers of more sustainable fertilisers and other actors (Figure 22).

Figure 22: What kinds of partnerships are most important for scaling sustainable fertiliser adoption? % ranked top three



This could include partnering with larger incumbent producers to scale production, engaging farmers and food retailers to initiate field trials that raise demand-side awareness, or collaborations with technology companies, government institutions, and research facilities that can maximise the impact of novel solutions with advancements in precision agriculture.

> "Innovations [in crop nutrient solutions] are starting to enable the agri-food transition. We must raise capital to finance this transition."
>
> **Alastair Cooper, Head of Venture Investments, Cibus Capital**

> "Discrete supply chain partnerships will become blueprints for the rest of the fertiliser industry."
>
> **Sjoerd Jenneskens, Sales Director Fertilizers – Europe, OCI Global**

> "Every single part of the value chain needs to actively engage and participate, with each participant benefiting and profiting. Otherwise, it's not sustainable."
>
> **Dandan Xiang, Chief Commercial Officer, Sulvaris**

"AI holds so much power in being able to create digital twins of farms – bringing together a truly massive bulk of information about the farm's seed varieties and genomic composition, soils, weather and climate to inform the farmer about what's the best course of action for sustainably driving a profit. And major technology providers have the ability to help develop these solutions."

Claudia Roessler, Agriculture – Strategic Partnerships, Business & Industry Copilot, Microsoft

"Around 40% of the emissions from a loaf of bread are from the fertiliser used to grow the wheat. Therefore, if food retailers are going to hit their targets for upstream Scope 3 emissions, they've got to have partnerships with their fertiliser manufacturer."

Simon Inglethorpe, Editor – Fertiliser International, CRU

3. Tailor solutions and incentives to the real needs of farmers

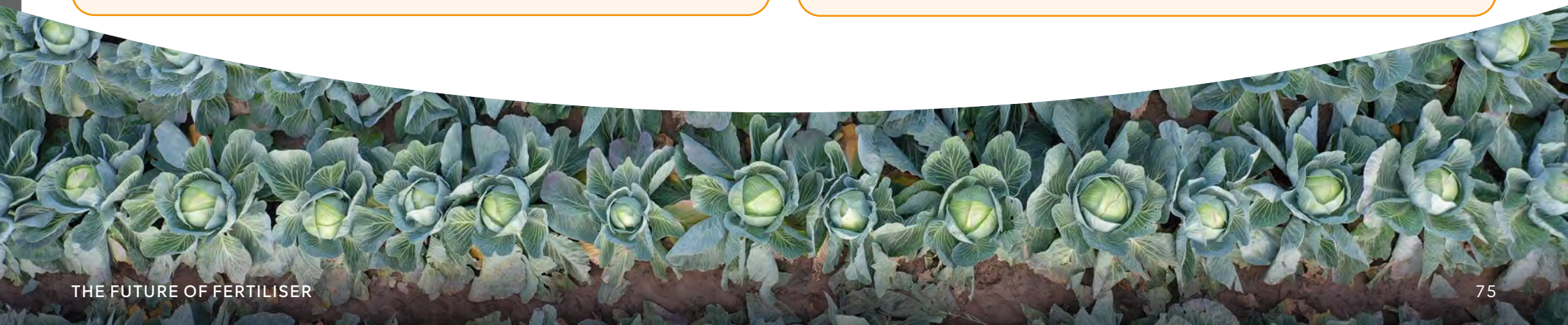
Our experts suggested that although a shift towards regenerative and precision agricultural practices will drive change, local context is key. In national or regional jurisdictions, policymakers and regulators need to be balanced, aligning regulation and incentives to the specific needs and context of their farmers. This alignment cannot come at the cost of stifling innovation. It is not about more regulation, but the right regulation for each context – and the incentives to match.

"I hope to see a world where regional policies fit together like Lego bricks."

Alzbeta Klein, CEO, IFA

"The feedback we get consistently, from probably all regions outside Europe, is that the economic conditions are not there and the carrots and the sticks are not there sufficiently for those [sustainable] products to be adopted."

Oliver Hatfield, VP Business Development, Argus Media



4. Focus more on soil health

Given the critical role of soil health in delivering the core objectives of the agricultural system outlined in the introduction to this report, interviewees suggested it must be prioritised by actors across the value chain. Interviewees highlighted that while farmers must recognise the value of healthy soils, in some regions they are already doing this.

Globally, governments must support farmers to protect and restore soil health, to ensure they can continue to grow enough food. In the US, soil health has been a topic of legislation and policy since the 'dust bowl' of the 1930s.[58] The more contemporary EU Soil Strategy for 2030 sets out a practical framework to protect and restore soils highlighting the actions key stakeholders must take to reach the goals outlined in the strategy.[59]

> "[Soil health] is already a huge priority … if you ask a farmer, it's the number one priority at this moment, at least in Western Europe … because otherwise in 25 to 50 years, the land will become so poor that they will not have any sustainable crop."
>
> **Mike Vermeer, Innovation, Cosun**

5. Internalise the environmental costs of chemical fertilisers to define the real value of sustainable alternatives and incentivise their use

Defining the true cost of chemical fertilisers, and the real value of sustainable alternatives, involves putting a true price on soil health, ecosystem services, carbon and other negative externalities. This should create a financial incentive for stakeholders to minimise environmental impact and choose more sustainable alternatives in the longer run.

The EU's Carbon Border Adjustment Mechanism is an early example of this in practice. It puts a price on the carbon emissions associated with fertiliser production. It is key that this is a managed transition to bridge between current and future practices with minimal economic disruption throughout the value chain.

> "We need to internalise the externalities of the agri-food system, so that costs are not all passed to farmers or the consumer. We need the polluter to pay."
>
> **Helen Browning, CEO, Soil Association**

6. Work with farmers to build trust

Farmers have often been marginalised voices in the food system transition, which has created resistance to change and a mistrust of the promises of corporate agri-businesses and governments. Farming is a highly localised business where the passing down of generational livelihoods and legacies carries significant emotional and cultural meaning.

Farmers have a high degree of trust for each other, their local agronomists and their local input providers. Fertiliser producers should use these channels and networks to build trust, raise awareness and educate around the financial and environmental benefits of alternative fertiliser solutions.

> "Farmers would rather get bad advice from farmers than good advice from the public sector."
>
> **James Farrar, CEO, York & North York Moors Combined Authority**

> "Farmers are asking for help to move away from unsustainable practices. It's about financial and environmental stability."
>
> **Ben Taylor-Davies, Regenerative Farmer**

Conclusion: We all have a role in building the future food system

The future of fertiliser is at a pivotal crossroads, where the balance between food security, environmental sustainability and economic viability must be redefined.

As explored throughout this report, demand for food will dictate output, and this will set the scene for how best to achieve the yields required using the optimal balance of current and emerging solutions. These emerging solutions, such as innovations in fertiliser technology, a shift towards regenerative agriculture, and systemic policy adjustments, are crucial to achieving the objectives of modern agriculture – within the context that the world still needs to be fed while systems and practices evolve.

The ambition for this report was to create an inclusive and lasting industry vision for change; one that offers a long-term pathway for the food supply chain to achieve a more secure, sustainable and equitable world in 2050. Above all else, our interviewees emphasised the need for a greater spirit of collaboration, openness, and humility on the road to 2050. Real progress, they said, hinges on fostering new and genuine partnerships between previously siloed stakeholder groups. By shining a light onto the transformative potential of alternative fertilisers for achieving modern agriculture's interlinked objectives, this report hopes to better connect their producers with the investors, advocators and business partners they need to accelerate adoption.

Key to this transformation is a whole-system approach that tailors solutions to farmers' real needs, internalises environmental costs, and redefines success metrics beyond yield alone. By prioritising soil health, investing in scalable sustainable alternatives, and fostering trust within farming communities, the fertiliser industry can move towards a more resilient and sustainable future.

Additionally, the lessons from the renewable energy transition highlight the importance of government intervention, financial incentives, and industry-wide collaboration to accelerate the adoption of new practices. As stakeholders align their efforts – from policymakers and investors, to farmers and agribusinesses – the foundation for a thriving, sustainable and profitable food system can be built.

By embracing these shifts and seizing the opportunities they present, the agricultural sector can ensure that future fertiliser practices not only meet the growing demand for food, but also contribute positively to the planet and future generations.

Appendices

About Anglo American and POLY4

Anglo American is a leading global mining company, and our products are the essential ingredients in almost every aspect of modern life.

We provide many of the essential metals and minerals that are fundamental to the transition to a low-carbon economy and enabling a cleaner, greener, more sustainable world.

Anglo American is developing the Woodsmith project in the northeast of England to access the world's largest known deposit of polyhalite – a natural mineral containing four of the six nutrients every plant needs to grow: potassium, sulphur, magnesium and calcium.

Woodsmith Mine

As a result of the highly efficient mine design and the minimal processing requirements of the polyhalite ore, our natural polyhalite fertiliser product, POLY4, will benefit from a comparatively low carbon footprint, and be suitable for organic agriculture.

With Woodsmith's full production capacity of 13 million tonnes a year, POLY4 will help farmers achieve more balanced, sustainable fertiliser practices at a scale not seen in the industry for decades. The product delivers better crop and environmental performance than the same blend of nutrients available from conventional sources today, delivering value beyond the nutrient content, and setting POLY4 apart from traditional fertilisers.
To find out more visit:
uk.angloamerican.com

A global impact

Anglo American is building a network of regional partners all around the world to prepare bringing POLY4 to market, and drive awareness of its impact through global agricultural supply chains.

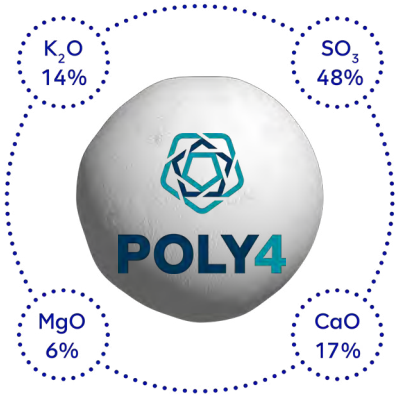
We are working with fertiliser companies, distributors, blenders, food companies, researchers, government agencies and, of course, farmers to develop innovative commercial partnerships, research programmes and products and help the industry address the challenges it faces.

Over 2,000 global trials and research projects have proven POLY4's efficacy and demonstrated its commercial applicability.

These have shown that POLY4 increases crop yields by an average of 3-5% over standard practices, supports soil health, and is predicted to have one of the lowest carbon emissions intensities of any fertiliser in the world.

Figure 23: POLY4 global trial map

Figure 24: POLY4 nutrient make-up



To find out more about partnership opportunities, please contact:

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Caleb Connor	Farmers for Climate Action
Charlie Stephen	CRU
Dr Charlotte Kirk	Clean Energy Ventures
Christine Gillespie	Gaia Global Advisors
Claudia Roessler	Microsoft
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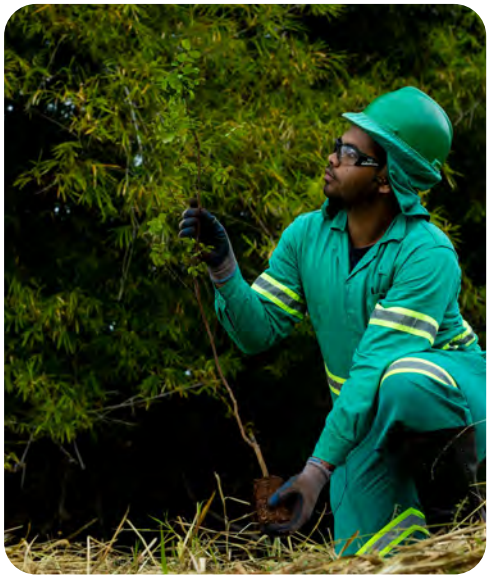
Methodology

Anglo American commissioned Deloitte to carry out research with 74 stakeholders from across the fertiliser value chain and contribute to drafting the contents of this report.

Interviews were designed to test five key hypotheses describing the food value chain in 2050. A series of interview questions were developed to test the hypotheses, and the interviews were split into three parts.



Part 1: What will the agricultural sector look like in 2050?

Interviewees were given five key themes and asked what degree of change they expected to see for in each area. Responses were a score ranging from -5 to +5 to indicate the extent of change they expected to see, where -5 indicates the least change and +5 indicates the most change, as well as qualitative insight to explain their opinion.

Part 2: The success factors.

The success factors required to sustainably transform the global agri-food system, covering a series of thematic areas:

- Soil health
- Practical, scalable solutions
- Agri-tech innovation
- Agri-practice innovation
- Market intervention
- Consumer demand
- Financing
- Social considerations

Interviewees gave qualitative responses based on their personal and professional experiences.

Part 3: Structured survey-style, multiple choice questions.

Interviews were asked seven multiple choice questions, aimed to source a selection of quantitative statistics on the future evolution of the agri-food system between 2025 and 2050. Responses to these questions have formed the charts used in this report.

Interviews were conducted, transcribed in verbatim and analysed in January and February 2025. This analysis has gleaned the interviewee perspectives, key quotes and conclusions in this report.

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