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CIRCULAR ECONOMY IN AGRIGULTURE
STORIES FROM ITALY

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REVISION
July 2025

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Consulate General of Italy London

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EXECUTIVE SUMMARY

Agriculture today stands at a pivotal inflection point. On one hand, it is a major contributor to environmental degradation—responsible for biodiversity loss, soil exhaustion, and a large part of global greenhouse gas emissions. On the other, it must continue to feed a growing, increasingly urbanised global population amid climate instability, geopolitical tensions, and resource scarcity. Traditional, linear models of farming—based on extraction, external inputs, and waste—are no longer fit for purpose.

The circular economy offers a fundamentally different paradigm: one rooted in regeneration, resilience, and closed-loop thinking. At its core, circularity is not just a technical or economic framework, it is a rediscovery of what nature has always done best: operate as a self-sustaining, regenerative system where nothing is wasted, and every element plays a role in supporting the whole. Applying this logic to agriculture means designing food systems that work with, rather than against, natural processes.

This white paper examines how circular principles are being applied and advanced within the agricultural landscape, through three case studies: Quintosapore, JustOnEarth, and Zero Farms. Each presents a distinctive yet complementary pathway—from soil-level regeneration and ecological complexity to real-time data infrastructure and predictive systems, to high-tech, decentralised food and biomanufacturing platforms. Together, these examples demonstrate that circular agriculture is not a niche or idealistic goal—it is a practical, replicable, scalable, and increasingly necessary foundation for future food systems. They show that circular agriculture requires a shift from fragmented, retrofitted sustainability efforts to holistic systems designed with circularity as a foundational principle. This means integrating resource flows, governance, and infrastructure from the outset to avoid the inefficiencies of extractive models. By fostering modular, locally adapted solutions and supporting knowledge exchange across sectors, stakeholders can accelerate the transition to regenerative and resilient food systems that are both scalable and context-specific. Ultimately, embracing circularity in agriculture is essential for building food systems that are not only productive and sustainable, but also adaptable and future-proof.

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1. THE NEED FOR CIRCULARITY IN AGRICULTURE

1.1 THE ROLE OF THE CIRCULAR ECONOMY AMIDST ENVIRONMENTAL CHALLENGES

It is no secret that modern agriculture significantly impacts the environment. The sector is responsible for around 11% of global greenhouse gas emissions and is a leading driver of biodiversity loss, primarily through activities such as intensive livestock production, deforestation, monoculture cropping, and soil degradation. These pressures pose a serious threat to long-term food security and to our ability to produce enough for a growing population, underlining the need to adopt more regenerative approaches. This entails closing resource loops, such as returning nutrients to the soil through composting, capturing and reusing water, and utilising waste as a productive input, rather than allowing them to escape as pollution.

Circular agriculture aims not only to reduce harmful externalities but also to create regenerative systems that actively restore ecosystems, build resilience to climate change, and support local economies. Even more so, it has the potential to promote decentralised, localised food systems, thereby shortening supply chains and reducing emissions from transport, as well as reconnecting producers with consumers.

At its core, the concept of circularity refers to a system in which resources are used efficiently, kept in circulation for as long as possible, and regenerated at the end of their life cycles. Unlike linear models of production and consumption, which follow a 'take, make, dispose' trajectory, circular systems aim to minimise waste by treating it as a resource. In the natural world, circularity is intrinsic: nothing is wasted, and the by-products of one process invariably serve as the inputs for another. This cyclical logic offers a profound model for how human systems, including agriculture, could operate more sustainably and efficiently. As such, it is not just about mitigating risks; it is also about redesigning food systems to be regenerative by default. It is an invitation to return to nature's original blueprint: a system where nothing is wasted, and everything has value in one way or another.

From the outset, it is important to distinguish between the terms "agriculture" and "farming" when discussing this transition. Farming refers to the day-to-day practice of growing crops and raising animals, typically at the level of individual operations. In contrast, agriculture is a broader term that encompasses not only farming itself, but also the associated systems of land management, food processing, distribution, and policy. Agriculture includes everything from planting and harvesting to the design of supply chains and the development of farming technologies, and it is within this holistic view of agriculture that we explore the relevance and potential of the circular economy.

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1.2 ALIGNMENT WITH SUSTAINABILITY GOALS

The transition to circularity within agriculture is not only a practical response to environmental and economic challenges—it is also a strategic alignment with key global sustainability objectives, including major European policy directives as well as the United Nations' Sustainable Development Goals (SDGs). Together, these frameworks offer tangible pathways for transforming the agri-food sector into one that is more resilient and environmentally conscious.

At the European level, initiatives such as the European Green Deal and the Farm to Fork Strategy explicitly call for a fundamental shift in how food is produced, distributed, and consumed. These policies aim to reduce environmental impacts, restore biodiversity, and build fairer, more transparent systems. Circularity directly supports these ambitions by promoting practices that regenerate natural ecosystems, reduce dependence on finite resources, and shorten supply chains.

On the global stage, circular agriculture also aligns with the aims of several Sustainable Development Goals (SDGs). It can support SDG 2: Zero Hunger by enhancing food security through practices that improve soil fertility, reduce vulnerability to climate extremes, and increase the long-term productivity of farmland. By reducing reliance on costly external inputs and restoring degraded land, circular methods help farmers maintain consistent, sustainable yields—especially in areas most at risk of food insecurity. It also supports SDG 12: Responsible Consumption and Production by embedding resource efficiency into the core of farming systems. By reusing organic waste as compost, recycling water, and closing nutrient loops, circular agriculture reduces emissions, pollution, and unnecessary input use, all while improving the overall resilience and sustainability of food systems. Finally, it supports SDG 13: Climate Action by promoting farming practices that reduce greenhouse gas emissions and sequester carbon in soils and biomass. Agroecological methods, such as cover cropping, reduced tillage, and agroforestry, contribute to climate mitigation while also strengthening adaptive capacity in the face of increasing climatic variability.

In this way, the principles of circularity are not merely complementary to European and global sustainability goals—they are essential to achieving them. By reimagining agriculture as a regenerative, integrated system, circular models provide a framework for sustainable transformation across the entire food value chain.

2. KEY STRATEGIES FOR SUSTAINABLE AGRICULTURE

Transitioning toward circularity in agriculture necessitates a fundamental realignment of how agricultural systems are conceived and managed. This transformation is not limited to individual practices or innovations, but instead involves a comprehensive reconfiguration of the relationships between production, resource use, land stewardship, and socio-economic development. As such, the development and successful implementation of circular agricultural systems hinge on the intersection of multiple disciplines—drawing from environmental science, technological innovation, economic planning, and institutional governance. This convergence is essential for creating systems that are ecologically regenerative and economically resilient. Crucially, it also requires acknowledging agriculture as part of a broader set of interdependent infrastructures—spanning ecological networks, market systems, and policy frameworks. In this sense, collaboration across sectors: between researchers, farmers, businesses, policymakers, and communities, is vital if we ought to build systems that are robust, scalable, and contextually relevant.

This whitepaper identifies five core strategic pillars that serve as foundations to the circular transformation of agriculture: closed-loop systems, regenerative agriculture, biodiversity and natural pest control, short supply chains and local production models, and technological innovation. Each of these elements contributes to building agricultural systems that are capable of regenerating soils, cycling nutrients and water efficiently, reducing dependency on external inputs, and mitigating the risks posed by climate disruptions. Notably, these strategies are not universal in their application; rather, they must be tailored to the specific ecological, cultural, and economic conditions of the regions in which they are implemented. Indeed, what constitutes a viable closed-loop system in a water-scarce environment may differ substantially from one suited to a temperate, high-rainfall region. Similarly, the adoption of technological innovation will vary based on infrastructure, investment capacity, and digital literacy. But this contextual sensitivity is not necessarily a limitation, as it also ensures that circular practices are rooted in the realities of local systems, increasing their relevance and long-term success. Along these lines, the underlying principles of circular strategies are inherently transferable. When supported by appropriate governance structures and robust knowledge exchange platforms, these approaches can be scaled and adapted across diverse landscapes and contexts. This interplay between local specificity and global adaptability is key to the viability of circular agriculture.

2.1 CLOSED-LOOP SYSTEMS

Closed-loop systems lie at the heart of the circular economy paradigm, offering a direct and practical means of aligning agricultural operations with the principles of resource efficiency, ecological regeneration, and waste minimisation. In essence, a closed-loop approach transforms the farm into a self-regulating system, where outputs are not discarded as waste but instead redirected as inputs to sustain the cycle of production. This systemic design emulates natural ecosystems in which nothing is wasted.

In conventional linear models of agriculture, resources flow through the system in a uni-directional path: extracted, applied, and ultimately disposed of. This not only leads to inefficiencies and pollution but it also locks farms into perpetual dependency on external inputs. In contrast, closed-loop systems directly challenge this logic by retaining and reusing valuable materials within the farm boundary, hence reducing both environmental impact and operational cost.

Water and nutrient cycles are the backbone of closed-loop systems. By retaining water on-site and returning organic matter to the soil, these systems minimise input dependency and prevent the loss of valuable resources. This internal circulation helps to preserve materials as well as strengthen the farm's ability to function under environmental and economic pressures. Beyond material reuse, closed-loop systems contribute to circularity on a broader scale through integrated energy flows. Farms that generate biogas, compost food waste, or power operations with renewables create multi-layered efficiencies that support both financial resilience and climate goals. In this way, closed-loop thinking moves beyond inputs and outputs to include energy, labour, and knowledge—embedding the farm within a wider network of regenerative systems.

In the context of circular agriculture, closed-loop systems provide the operational structure through which natural capital is retained and replenished. By moving past linear consumption, such systems actively build the resilience, efficiency, and autonomy that sustainable agriculture demands.

2.2 REGENERATIVE AGRICULTURE

Regenerative agriculture is more than a set of conservation practices; it represents a fundamental reorientation of agricultural priorities—from short-term output optimisation to long-term ecosystem renewal. Unlike conventional systems that treat soil as an inert substrate for crop production, regenerative agriculture starts from the premise that soil is a living, dynamic system whose biological integrity underpins the productivity, resilience, and sustainability of the entire farm. In this context, restoring soil health is not just an agronomic objective but a necessary foundation for building circular, self-reinforcing agricultural systems.

Central to regenerative agriculture is the restoration of the soil's biological and structural complexity. Techniques such as cover cropping, intercropping, crop rotation, reduced tillage, and the incorporation of organic matter aim to enhance soil organic carbon, improve porosity, increase water-holding capacity, and support microbial diversity. These processes, in turn, reduce dependency on synthetic fertilisers and pesticides by allowing the system to rely increasingly on internal processes for nutrient cycling, pest suppression, and resilience to climatic stress. This is a critical link to circularity: regenerative farms seek to build fertility from within, using biologically driven feedback loops instead of continuous external inputs.

Of course, regenerative agriculture does not operate in isolation from broader environmental systems. Its benefits extend well beyond the farm gate, influencing watershed health, biodiversity corridors, and even regional climate moderation. For instance, regeneratively managed soils act as significant carbon sinks, contributing to climate mitigation efforts by sequestering atmospheric carbon dioxide (CO_2). And when implemented at scale, these practices support ecosystem services that benefit entire landscapes, including improved water filtration, reduced erosion, and greater pollinator abundance.

Socially and economically, regenerative approaches also offer a compelling counter-narrative to the extractive logic of industrial agriculture. By reducing reliance on imported inputs, regeneratively managed farms can become more financially autonomous and less vulnerable to global supply shocks. Moreover, such systems tend to favour diversified cropping mixed farming, and smaller-scale operations—models that create more stable employment opportunities and support rural livelihoods, thereby reinforcing local economies and strengthening community-based food systems.

In the context of circular agriculture, regenerative farming serves as the ecological engine that drives system renewal. Its emphasis on rebuilding natural capital, particularly soil fertility, provides the baseline upon which other circular strategies can operate effectively. Without biologically active, structurally sound soils, efforts in nutrient cycling, water reuse, or biodiversity conservation are unlikely to succeed in the long term.

2.3 BIODIVERSITY AND NATURAL PEST CONTROL

Biodiversity has become one of the most widely cited yet often misunderstood terms in the sustainability landscape. As global awareness grows around the fragility of ecosystems, biodiversity is increasingly recognised as a critical indicator of environmental health and a cornerstone of resilience. At its core, biodiversity refers to the variety and variability of life forms within a given ecosystem, including not only the number of species, but also the diversity of genes, functions, and interactions that sustain ecological balance. In agriculture, this diversity is essential.

As agricultural systems have become increasingly industrialised and specialised- nowadays often centred around monocultures which are to some extent the epitome of biodiversity loss- they have favoured uniformity and standardisation. This simplification has contributed significantly to the ecological crises we face today, from soil degradation and pollinator decline to pest resistance and the loss of habitat. In this context, biodiversity is in fact a precondition for the long-term sustainability of farming systems. Diverse agroecosystems are more resilient to disruptions, more capable of self-regulation, and less dependent on external chemical and mechanical inputs. In circular agriculture, biodiversity plays a functional role in maintaining ecological processes that are often replaced or suppressed in linear systems. Diverse plantings can improve soil health, support beneficial insect populations, and create microclimates that reduce water stress and disease pressure. These dynamics are not side benefits—they are the mechanisms by which circularity is sustained.

A central tool in biodiversity-driven farming is Integrated Pest Management (IPM). Rather than eliminating pests through broad-spectrum chemical controls, IPM applies a suite of complementary techniques such as biological controls, habitat management, mechanical barriers, and strategic crop selection to keep pest populations below damaging levels. This reduces chemical dependency and the risk of resistance while preserving beneficial species that contribute to natural pest suppression. Other practices such as intercropping, rotational grazing, and the integration of perennial species further build resilience. These elements, when woven into the fabric of a farm, transform it from a production unit into a functioning ecosystem with many layers of productivity and self-renewal.

Biodiversity also provides insurance against the unknown. In an era of increasing climatic volatility and ecological instability, we know that diversified systems are better equipped to adapt and recover. From a circular economy perspective, this enables the regeneration of natural capital and the long-term stability of yields, making it an integral component of sustainable agriculture. Ultimately, embedding biodiversity into the design and management of agricultural systems ensures that the essential functions of farming are supported by the very systems they depend on, reducing reliance on external inputs and reinforcing the principles of regeneration and circularity.

2.4 SHORT SUPPLY CHAINS AND LOCAL PRODUCTION MODELS

Reducing the spatial and relational distance between food producers and consumers is another key part of circular agriculture. Short supply chains not only address the inefficiencies and emissions associated with conventional food logistics but also help reconfigure the value and meaning of food within society. In contrast to often long, opaque supply chains, localised systems promote transparency, adaptability, and deeper social engagement. Within this same ethos of “soil-to-fork” or “farm-to-table,” these models bring consumers closer to producers, fostering a clearer understanding of how and where food is grown.

At the environmental level, short supply chains significantly reduce the carbon footprint of food systems. Minimising the need for long-distance transport decreases fossil fuel consumption, while eliminating multiple layers of packaging and refrigeration reduces material waste and energy use. At the economic level, shorter supply chains facilitate the retention of value within the region of production. By enabling direct transactions between producers and consumers, through farmers’ markets, community-supported agriculture (CSA) schemes, or cooperative distribution networks, local systems reduce intermediaries and increase the share of profits that remain with the grower. This not only enhances farm viability, especially for small and medium-scale producers, but also supports the wider rural economy through multiplier effects.

Additionally, short supply chains foster a more participatory and place-based approach to food. They encourage consumers to understand where their food comes from, who grows it, and how it is produced. This relationship strengthens trust, encourages dietary shifts towards seasonal and sustainable options, and allows for greater accountability in terms of farming practices and labour conditions. In this way, food becomes more than a product—it becomes part of a social and ecological system that values connection and shared responsibility rather than a detached commodity with an unclear past.

In the framework of circular agriculture, short supply chains serve as essential conduits for closing loops in materials as well as in knowledge, value, and even decision-making. They provide the structural basis for local feedback loops that can quickly respond to changing environmental conditions, market dynamics, and consumer needs, thereby making farms more flexible and adaptable. Ultimately, these models challenge the notion of food as a distant, anonymous commodity. Instead, they ground food in place, in community, and in the rhythms of local ecosystems, enabling consumers to be more conscious of what they consume.

2.5 TECHNOLOGICAL INNOVATION

While circular agriculture draws heavily from ecological principles and traditional land-based knowledge, its widespread adoption and scalability may increasingly depend on technological innovation too. Emerging tools and systems offer new ways to enhance efficiency, reduce waste, and operate within ecological limits—particularly in contexts where land, water, or labour are constrained.

Within the philosophy of ‘measure to manage’, technologies such as precision agriculture, which leverage data analytics, remote sensing, and automation, enable farmers to monitor and respond to field conditions with unprecedented accuracy. This allows for site-specific application of resources that significantly reduces input use while improving yields. Likewise, controlled environment systems, such as hydroponics and vertical farming, open new possibilities for food production in urban areas or degraded landscapes. These methods operate with minimal land and water, offering a compact, resource-efficient alternative to conventional models which also take up a lot of space.

This said, the role of innovation in circular agriculture is not simply to optimise, but also to integrate. The effectiveness of these technologies lies in their ability to complement, not substitute, the ecological processes that underpin circularity. When used appropriately, they can support closed-loop nutrient cycles, extend the productivity of regenerative systems, and make sustainable models viable at larger scales. In this light, technology becomes not an end in itself, but a set of enabling tools that are critical for advancing circular agriculture where natural cycles alone may be insufficient.

3. CASE STUDIES

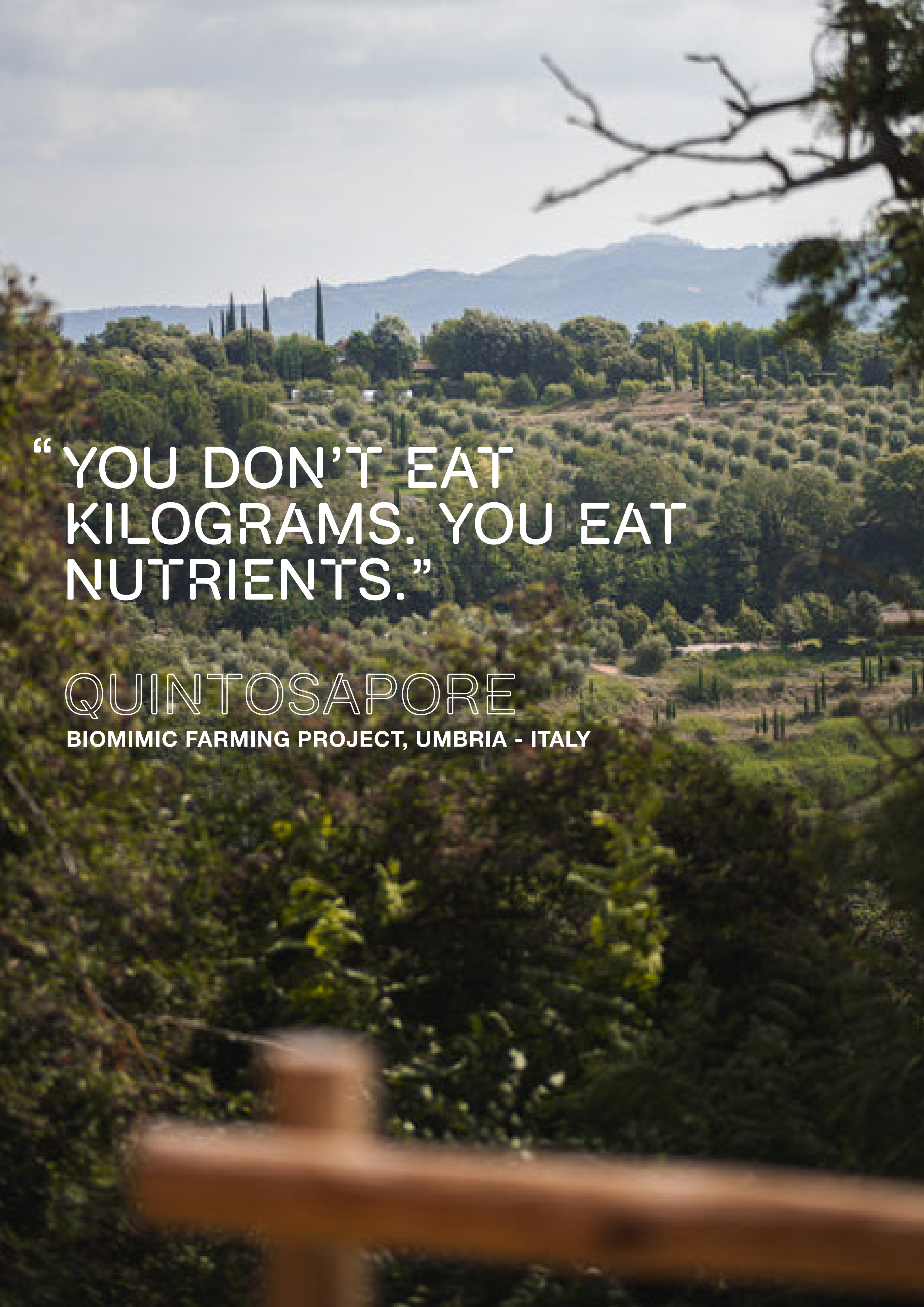
3.1 QUINTOSAPORE

Quintosapore is a forward-thinking agricultural initiative located in the hills of Umbria, Italy, built on the principle that agriculture must evolve in tandem with the ecological realities of our time. Operating on a model known as biomimic farming, the farm exemplifies the systemic application of circular economy principles—rooted in ecological complexity, regenerative processes, and closed-loop resource flows.

Unlike wide-spread operations focused on monocultures, Quintosapore cultivates more than 2,000 varieties of vegetables, alongside olive oil and wine, deliberately rejecting the standardisation and uniformity that define industrial agriculture. Conceived as a response to the widening disconnect between food production and ecosystem integrity, the project seeks not to return to past methods, but to synthesise traditional knowledge with contemporary innovations to address today's ecological and social pressures.

Soil and microbial health as a regenerative engine

A central pillar of circularity at Quintosapore lies in its innovative approach to soil and water management. The farm applies EM (Effective Microorganism) technology, injecting beneficial fungi and bacteria into the soil to build a thriving microbial ecosystem that supports nutrient cycling and plant resilience. This is complemented by the use of biochar—produced from on-site organic waste such as olive pruning residues—which enhances soil structure and water retention by up to 75%, hence reducing dependence on chemical fertilisers and intensive irrigation. Circularity at Quintosapore extends above ground as well. The farm is experimenting with frequency-based technologies derived from quantum physics to stimulate plant growth and improve responses to environmental stress. By focusing on regenerative practices that enhance soil health, this approach aims to create a self-sustaining, closed-loop system that promotes regeneration, reduced dependencies, and long-term land productivity.


"YOU DON'T EAT KILOGRAMS. YOU EAT NUTRIENTS."
QUINTOSAPORE
BIOMIMIC FARMING PROJECT, UMBRIA - ITALY

Balancing competition and diversity

Broadly speaking, the entire ecosystem is intentionally designed to embrace ecological competition rather than suppress it. Quintosapore recognises that eliminating one species or problem creates a "biological hole"—a void in the system that nature is likely to fill with something potentially more disruptive. Just as organisms in wild ecosystems compete for space, nutrients, and light, the interactions at Quintosapore are allowed to self-regulate. Weeds, pests, beneficial insects, microbes, and companion plants interact dynamically to keep one another in check. This doesn't produce a flawless or pest-free environment, but it does create a system that is resilient, adaptive, and far less dependent on external chemical intervention.

The same principle of complexity extends to nutrient flows, crop design, and disease management. Through intercropping, agroforestry, microbial inoculation, and high species diversity, Quintosapore replicates the stabilising feedback loops of natural ecosystems. In doing so, it transforms competition into a tool of circular agriculture—creating a self-organising farm system where balance is achieved through diversity, not domination. In a similar fashion, for their waste management, organic matter, from vegetable scraps to tree trimmings, is reincorporated into the soil through composting, cover cropping, and mulching. In this way, the farm reinforces circularity at every level, creating a regenerative flow of energy, nutrients, and productivity.

Quintosapore also re-establishes what it means for food to be "local." In ecological terms, few crops are truly native to the regions where they are now commonly grown. And seeds, like the food systems they support, are global by nature. As climate change accelerates, an insistence on strictly local sourcing may in fact undermine food resilience. With unpredictable weather patterns, extreme temperatures, and increasing crop stress, limiting production to 'traditional' varieties is not necessarily sustainable and Quintosapore embraces genetic diversity to future-proof its operations. This flexible and adaptive philosophy is central to biomimic farming. It shows that working with complexity—not against it—can lower resource use and increase productivity. With minimal machinery, no synthetic fertilisers, and a reliance on natural processes, the farm achieves both ecological richness and economic viability.

Scaling challenges

Despite the promise of this model, scaling remains a major challenge. Quintosapore identifies two core barriers: inadequate financing and an unsupportive market structure. European agricultural subsidies continue to treat regenerative and extractive models as equal, failing to reward practices that restore long-term ecosystem function. Meanwhile, market systems still prioritise cheap, uniform, and transportable food over nutrition, seasonality, and sustainability—placing regenerative producers at a disadvantage. Quintosapore navigates these challenges through a diversified distribution model. It sells directly to local customers, supplies regional restaurants and hotels, and ships to selected cities. In doing so, the farm also reframes how value itself is understood. "You don't eat kilograms," they say. "You eat nutrients." This perspective challenges standard pricing mechanisms, urging a broader view of food that includes its environmental footprint, health impact, and production ethics.

In recognising these broader dynamics, Quintosapore positions itself not just as a farm, but as a platform for advocacy and systemic change—convening international gatherings and contributing to efforts like a global soil manifesto. More than a demonstration site, it is a working model of circular agriculture: replicable and technically scalable given the right support. By mimicking nature, closing loops, and integrating appropriate technologies, Quintosapore offers a blueprint for a more resilient, inclusive, and sustainable future.

3.2 JUSTONEARTH

In the discourse on circularity within agriculture, digital infrastructure is often underrepresented, yet it is essential. Data, while intangible, plays a material role in how agricultural systems are designed, operated, and evaluated. JustOnEarth, a research-oriented environmental intelligence company based in Italy, exemplifies how geospatial analysis, artificial intelligence (AI), and open-source data can be mobilised to make agricultural systems more circular, adaptive, and ecologically responsive. The core value of JustOnEarth's approach is not in the novelty of its tools, but in what they enable: a shift from reactive farming toward predictive, data-informed, and feedback-driven practices. At a time when agriculture must transition away from linear input-output logics, JustOnEarth's methodology supports a deeper, systemic transformation in which information replaces excess and overcompensation.

Data as a circular resource

JustOnEarth's work centres on using satellite observation and machine learning to monitor the real-time condition of agricultural landscapes, especially in relation to water use, soil health, and plant stress. Rather than collecting data as an end in itself, JustOnEarth process it to generate insights that can be applied directly to improve system design. For example, monitoring vegetative health across an entire field allows for the redistribution of irrigation or inputs only where they are needed, thereby reducing waste, mitigating runoff, and increasing input-use efficiency. This logic, central to circularity, reflects a move away from uniform application toward site-specific intervention and systemic optimisation.

From a circular economy perspective, this shift is foundational. Agriculture, particularly in industrialised contexts, has long operated, and still largely operates under conditions of oversupply—of water, fertilisers, and energy. These excesses create not only environmental degradation but also impact agricultural systems more generally: systems that are input-dependent are also vulnerable to price shocks, supply chain disruptions, and environmental thresholds. By enabling real-time monitoring and learning across the entire cultivation cycle, JustOnEarth supports a model in which resilience is built through resource literacy and systems awareness, not merely through technological substitution.

Contextual Intelligence

What makes such practical applications instructive is not the particular crops they address, but the structural challenge they confront: the need for tools that can function effectively across diverse geographies and support real-time decision-making without increasing the material burden on farms. By drawing on remote sensing and open data, JustOnEarth shows that circularity can be pursued not only through the development of new agricultural techniques, but through more intelligent coordination and use of existing information systems. Critically, this intelligence is not deployed in isolation but rather integrated within local regulatory and agronomic contexts, co-designing workflows with farmers and agronomists, and adjusting system parameters based on region-specific requirements and practices. This localisation reflects a deeper truth about circularity: that it cannot be imported uniformly, but must be configured in place, based on environmental feedback and local input. In this sense, technology is not antithetical to ecological agriculture, rather it is increasingly necessary for it.

From a circular economy perspective, this shift is foundational. Agriculture, particularly in industrialised contexts, has long operated, and still largely operates under conditions of oversupply—of water, fertilisers, and energy. These excesses create not only environmental degradation but also impact agricultural systems more generally: systems that are input-dependent are also vulnerable to price shocks, supply chain disruptions, and environmental thresholds. By enabling real-time monitoring and learning across the entire cultivation cycle, JustOnEarth supports a model in which resilience is built through resource literacy and systems awareness, not merely through technological substitution.

Local integration

The scalability of JustOnEarth's platform further underscores its relevance. Because the system is non-invasive and requires no physical infrastructure, it can be redeployed across geographies without replicating the costs of hardware installation or on-site customisation. In contrast to centralised, high-capital solutions, this approach suggests that the transition to circularity need not be prohibitively expensive and can be adaptive. This is particularly the case when coupled with open data ecosystems and decision-making processes that actively involve farmers. By removing barriers to entry—such as technical expertise, capital expenditure, or rigid infrastructure—JustOnEarth's model creates a pathway for inclusive innovation, where even small-scale or remote farms can participate in the benefits of precision and predictive agriculture. In this context, farmers are equipped with contextualised knowledge to adapt practices in response to dynamic environmental feedback and can move beyond fixed prescriptions or uniform standards. In this sense, the technology facilitates circularity not by imposing a template, but by enhancing the system's ability to learn, respond, and self-correct over time.

JustOnEarth challenges the notion that high-tech solutions must be resource-intensive or inaccessible, instead offering a model that is transferable and aligned with the principles of circularity. Through real-time observation, predictive insight, and systems-based thinking, their technology offers a path forward in which agriculture becomes more responsive, and ultimately more circular by design. Central to this is the concept of pre-emptive decision-making—reducing inputs ahead of time rather than reacting after the fact. In this way, the role of data is not simply to describe the agricultural system, but to continuously inform and improve its function.

Zero Farms represents a shift in how agriculture can be conceptualised, engineered, and scaled in an era of climate disruption, urbanisation, and ecological limits. Operating out of northern Italy, the company builds upon the framework of Controlled Environment Agriculture (CEA) to offer a new kind of agricultural infrastructure- one that rethinks not just how food is grown, but how production systems themselves are designed, distributed, and sustained

Redesigning agricultural infrastructure

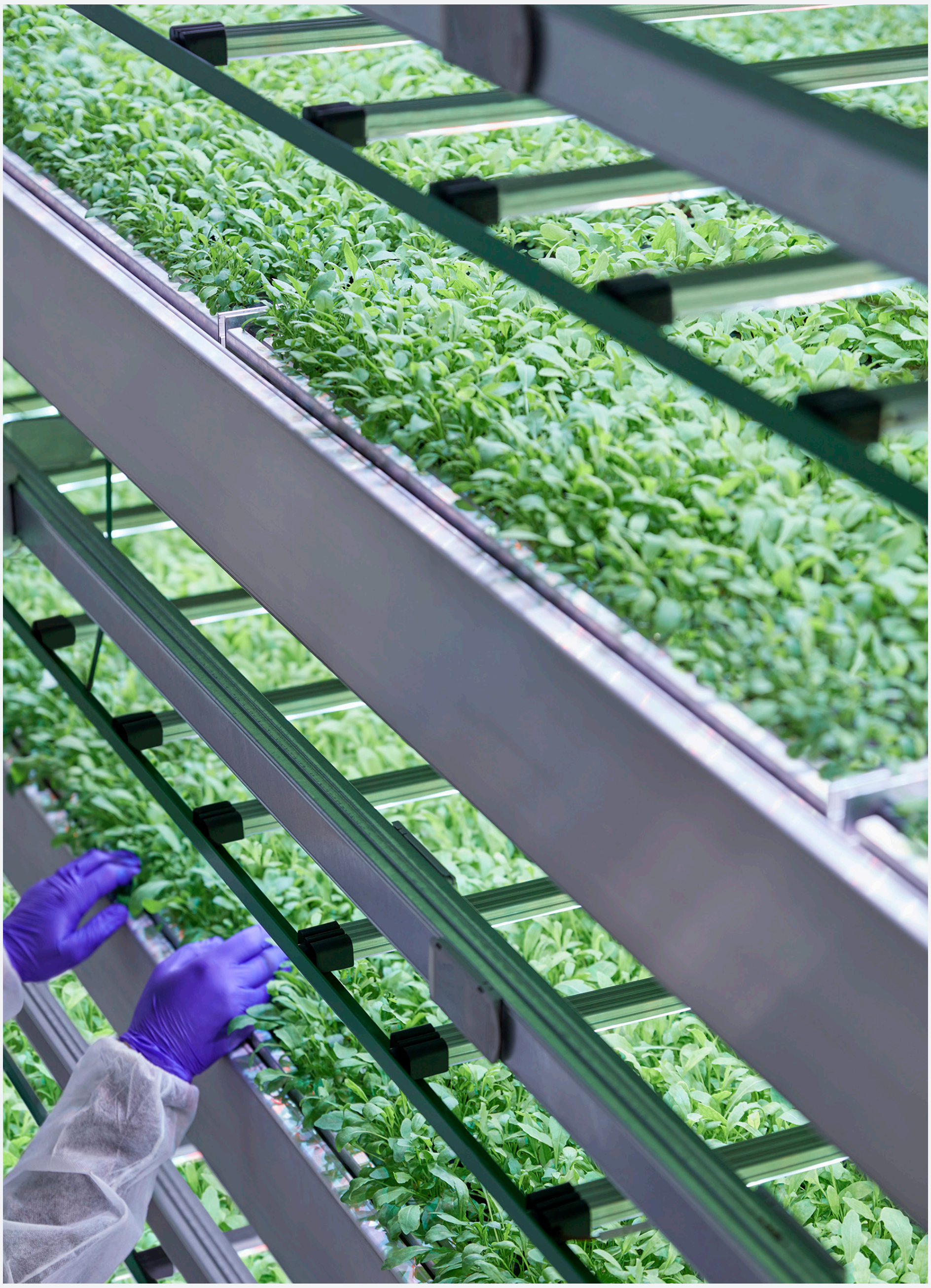
At its core, Zero Farms positions itself not simply as a food producer, but as a deep-tech enterprise offering a blueprint for scalable, circular, and future-facing agricultural infrastructure by rethinking ways to use natural resources, structure supply chains, and build resilience into food systems. While vertical farming has often been heralded as a response to land scarcity and climate variability, most ventures in the space have struggled to overcome critical economic and technological barriers, particularly those related to energy intensity, capital costs, and limited profitability. Zero Farms directly addresses these challenges by rebuilding the economic logic of CEA from the ground up. Its model centres on technological independence, with proprietary control over both hardware and software systems, enabling real-time feedback between design, operation, and performance. This level of integration reduces complexity, lowers risk, and enhances the adaptability needed for circular production systems.

Closed-loop systems and resource efficiency

The implications for circularity are manifold. Within each farm module, water and nutrients are recycled in closed-loop systems that reduce inputs and eliminate runoff. Artificial lighting and environmental conditions are tuned to maximise photosynthetic efficiency while minimising energy waste. The entire system is also designed for replication: pre-fabricated, stackable, and scalable, which enables decentralised deployment in spaces where traditional farming is unfeasible like urban centres and repurposed industrial zones. This not only brings production closer to consumption but in doing so reduces transportation emissions and packaging waste, advancing circularity across multiple aspects.

Beyond operations, Zero Farms introduces a systems-level innovation through its concept of “Future Farming Districts”: locally embedded hubs that co-locate energy production, food cultivation, and in some cases pharmaceutical manufacturing. These are not isolated projects but multi-use infrastructures that actively integrate into local economies and ecologies.

A particularly notable innovation lies in Zero Farms’ application of CEA beyond food. By treating plants as bio-manufacturing platforms, the company explores applications in molecular farming and bioproducts such as vaccines, enzymes, or cosmetic compounds that replace resource-intensive manufacturing processes with controlled biological ones. This positions agriculture not just as a provider of calories, but as a foundational infrastructure for a bio-based economy too. As these systems use fewer resources, generate fewer emissions, and are inherently modular, such an approach aligns with both the logic and goals of circularity.



Scaling circular agriculture through system design

JustOnEarth's approach also reflects a broader path to sustainability. Indeed, Zero Farms is not solving for yield alone, but for long-term viability across multiple axes: economic, ecological, spatial, and institutional. It reduces dependency on volatile supply chains, creates context-responsive production capacity, and supports a transition to more localised and accountable food systems. This localisation does not come at the expense of technological sophistication, rather it enables it—demonstrating that decentralised and vertical agriculture can be both high-tech and low-impact.

Moreover, Zero Farms' institutional strategy offers a model for how innovation can scale without reproducing the failures of past ag-tech ventures. Rather than pursuing direct-to-consumer brands or vertically integrated food supply chains, the company focuses on licensing its technology and co-developing infrastructure with governments, industry, and research institutions. What emerges is not simply a more efficient greenhouse, but an entirely new category of infrastructure that treats nature as a dynamic system. In this context, circular agriculture is not just a set of practices, but rather it is a design principle: a way to engineer systems that are adaptable, regenerative, and economically robust and that informs every layer of the system—from material flows and spatial layouts to institutional alignment and long-term finance. It shows that the path to agricultural transformation is not only technical, but architectural and financial.

In sum, Zero Farms exemplifies a new frontier of agricultural circularity. It shows that circularity is compatible with, and increasingly utilises, high-tech innovation. And it demands new models of ownership, investment, and governance that align with ecological limits and social priorities. As pressure on global food systems intensifies, models like Zero Farms offers a compelling roadmap, illustrating that regenerative, distributed, and technologically advanced agriculture is not a speculative vision, but a viable and increasingly essential pathway for the future of food production.

4. INSIGHTS

As the need for more sustainable and resilient agricultural systems grows, the principles of circularity provide a compelling framework for driving meaningful transformation. Circularity in agriculture is not merely about improving what exists—it is about rethinking systems from the outset.

Circularity begins at the design stage

One of the most powerful, yet often overlooked, insights from emerging models of circular agriculture is that the success of such systems begins long before seeds are planted or infrastructure is built. Circularity must be considered as a design logic—applied from the very start. This includes how land is used, how water and nutrient flows are structured, how knowledge is generated and shared, and how institutions align around resource use and regeneration.

This pre-emptive orientation is critical for resource efficiency. By integrating circular principles into early-stage planning—rather than retrofitting them later—agricultural systems can avoid the lock-in effects of extractive design and reduce the need for corrections and interventions down the line. Circular thinking at inception leads to more efficient choices in land use, infrastructure, and logistics and fosters a mindset where flexibility and resilience is a baseline assumption.

Framework flexibility

Another key insight is that circularity is not a one-size-fits-all model, but a flexible systems framework for which it is not the specific tools or practices that define whether a system is circular, but rather the relationships between them. Whether working with regenerative farming, data analytics, or closed-loop infrastructures, the defining characteristic of circular agriculture is its ability to self-regulate, to reuse and recirculate resources, and to reduce reliance on finite inputs. Crucially, these principles are transferable. They can be adapted across geographies and scales, from smallholder farms to high-tech production environments. Circular systems are, by nature, modular and context-sensitive. They shall allow for customisation without compromising on global relevance, making them especially suited to meet the diversity of conditions across regions, climates, and societies.


"CIRCULAR AGRICULTURE IS NOT A RETURN TO THE PAST, BUT A REDESIGN OF THE FUTURE - GUIDED BY ECOLOGICAL INTELLIGENCE, ENABLED BY TECHNOLOGY, AND ROOTED IN PLACE."

Integration over isolation

Moreover, circularity in agriculture cannot be reduced to the level of individual practices. It is not merely about composting, rotating crops, or reducing water use in isolation. Rather, it is about how those elements are integrated into a cohesive and self-supporting and reinforcing system. What our case studies show is that the structure of agriculture itself must evolve. Linear supply chains, siloed policy structures, and centralised decision-making are incompatible with the systemic logic that circularity demands. Circular agriculture calls for a reconfiguration of entire agricultural ecosystems—from land tenure and subsidy frameworks to supply chain dynamics and community governance. Only when institutions, markets, and technologies are aligned around regeneration can such models reach their full potential.

This, of course, also requires us to think across boundaries. Agriculture cannot be viewed as a sector in isolation, but as an interface between food, energy, water, health, and economy, of which is part of a broader web of systems whose functioning depends on cross-sector coordination. For circularity to take root, we must cultivate soil as well as systems literacy, in as much as it is to some extent our ability to understand, design, and govern complex interactions that will dictate the success of a project. That means rethinking education, financing, regulation, and infrastructure development to support multi-functional landscapes, shared value creation, and long-term ecological investment.

Scaling through networks

Finally, the greatest promise of circular agriculture lies in its potential for scalability—but only if we redefine what scale means. Scale does not need to imply uniformity or centralisation. In fact, the most successful circular systems are often distributed, modular, and adaptive: scaling by becoming more connected and replicable. Whether through local seed networks, regional energy-food loops, or globally shared digital platforms, the logic of circularity lends itself to building a network of interconnected nodes that reinforce one another through exchange, learning, and diversification. In this sense, scaling circularity is not about exporting one model, but about enabling many variations of a principle—tailored to fit the unique contexts of each place.

5. CONCLUSIONS

The transition toward circular agriculture is not an ecological or technological challenge alone—it is a systems challenge, a governance challenge, and a cultural one. It asks us to reimagine how food is produced, valued, and shared. The case studies explored in this paper are not simply endpoints; they represent initiatives that reveal a spectrum of possibilities—proofs of concept that circularity is not only feasible, but in many cases already under way and offering compelling advantages. What they demonstrate most clearly is that when agriculture is grounded in the principles of ecological design, adaptive governance, and systems integration, it becomes a tool not just for sustaining life, but for regenerating the systems that support it.

As the world faces increasing pressure on land, water, and biodiversity, and as the climate becomes more unstable, agriculture must transition from a degrading force into a renewing one. Circularity offers a map for this transformation—not through rigid prescriptions, but through a shared orientation toward balance and long-term resilience. The task now is to expand this map and support the people, projects, and policies that will turn these principles into new tangible realities. Doing so will not only reshape agriculture but also reshape our relationship with food and the world around us.

6. RECOMMENDATIONS

Design with circularity from the outset
Embed circular principles into the early stages of agricultural planning—from land use and infrastructure to resource allocation and supply chain design—rather than treating sustainability as a retrofit.

Foster systems integration, not just innovation
Align farming practices, digital tools, logistics, and governance structures into a cohesive whole, rather than pursuing fragmented, siloed interventions.

Invest in localised, modular infrastructure
Prioritise distributed systems that can be adapted to regional contexts—supporting local supply chains, reducing transport emissions, and increasing food sovereignty.

Support context-specific adaptation
Avoid one-size-fits-all solutions. Recognise that circular agriculture must be tailored to agroecological, social, and economic realities—especially in regions with limited resources.

Promote knowledge exchange and co-creation
Support platforms where farmers, technologists, researchers, and policymakers can share insights and co-develop circular models that are both scalable and locally rooted.

Develop financial models for regenerative value
Support investment frameworks that reward long-term ecosystem health and resilience, not just short-term yield.

Integrate circular metrics into certification and policy
Support reforms in certification systems and agricultural subsidies that differentiate regenerative models from extractive ones and reflect the true cost of unsustainable farming.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Tecno International, British American Tobacco (BAT), and the Italian Consulate General, London for their valuable contribution to this white paper.

With writing and research support from:

Yves Plazanet
Sustainability Analyst, Modulex Group

Organisations involved in the white paper

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