

The Critical Need for Smart and Sustainable Agriculture

Context

Global agriculture faces an unprecedented convergence of challenges that traditional farming practices can no longer address. The global agrifood system currently accounts for approximately one-third of all greenhouse gas emissions, with these emissions projected to rise as food demand increases to feed a global population expected to reach 9.7 billion by 2050. Simultaneously, agriculture must contend with intensifying climate volatility, depleting freshwater resources, degraded soils, and declining biodiversity - all while maintaining or increasing food production to ensure nutrition security for the world's poorest populations, 75 percent of whom depend directly on agriculture for their livelihoods.

This interconnected crisis demands fundamental transformation of how food is produced. **Smart and sustainable agriculture** that integrates advanced digital technologies with environmentally regenerative farming practices has emerged as **the necessary response to this triple imperative**: increasing productivity, enhancing climate resilience, and drastically reducing environmental footprints.^{[2][1]}

Imperative	Productivity	Resilience	Environment
Problem	Food demand is expanding ➡ Higher production using the same land ➡ Need to keep regenerating the land	Intensive conventional farming ➡ Depletion of soil organic matter ➡ Higher vulnerability to drought	Intensive conventional farming ➡ High use of inputs ➡ High environmental footprint
Smart and Sustainable Agriculture Solutions	<ul style="list-style-type: none">Optimization of seed placement depth, spacing, and density based on soil mapping and historical field dataFertilizers/pesticides precise application based on needsAI data processing from sensors, drones, and satellites, enabling targeted interventions that prevent yield losses	<ul style="list-style-type: none">Real-time soil monitoring systems, enabling farmers to implement regenerative practices tailored to specific field conditionsPrecise irrigation based on needsForecast weather patterns	<ul style="list-style-type: none">Reduce emissions, enhance resilience, improve profitability through reduced input costs and premium market access, and contribute to global food security.

Regenerative Agriculture: Restoring Soil While Feeding the World

Regenerative agriculture represents a fundamental departure from input-intensive conventional farming. Rather than simply sustaining current productivity levels, regenerative approaches actively restore soil health, enhance biodiversity, sequester atmospheric carbon, and increase agricultural resilience - all while maintaining or improving food production.^{[16][17]}

Core regenerative practices work synergistically to transform agricultural systems. **No-till and minimum-till farming** minimize soil disturbance, reduce erosion and carbon dioxide emissions while preserving soil structure and microbial communities. **Cover crops** provide year-round vegetation protection, preventing soil exposure to erosion while their root systems improve infiltration and water retention. As cover crop biomass decomposes, soil microbes convert organic matter into stable compounds, sequestering carbon while building soil fertility.^{[16][14]} **Intercropping and crop rotation** introduce plant diversity that disrupts pest and disease cycles, reducing chemical pesticide requirements while replenishing soil nutrients. For example, pairing nitrogen-fixing legumes with grains creates balanced systems where soil nitrogen is continually renewed through natural biological processes. **Mulching** protects exposed soil from degradation while decomposing organic material feeds soil microbes and increases carbon sequestration.^[18]

The productivity and profitability outcomes of **regenerative agriculture challenge the conventional wisdom that ecological farming sacrifices yields**. A comprehensive study comparing regenerative and conventional corn production systems found that despite producing 29% less grain, regenerative farms achieved nearly **twice the profitability** of conventional operations. This profitability advantage stemmed from dramatically lower input costs—regenerative farms spent only 12% of gross income on seeds and fertilizers compared to 32% on conventional farms—coupled with higher revenues from diversified products including livestock and organic premiums.^[19] Regenerative practices also enhance drought resilience through improved water retention in soil with higher organic matter content, a critical advantage as climate volatility increases. Research in Kenya demonstrated that regenerative practices applied to maize, sorghum, and beans **increased yields by up to 200%**, while studies across the United States found yields increased proportionally with rising soil organic matter concentrations.^{[17][20]}

The global food system faces unprecedented pressures from climate change, resource scarcity, and the need to feed a growing population without further degrading the planet's ecosystems. In response, innovative agricultural technologies and regenerative farming practices are emerging as transformative solutions that can increase food production while restoring soil health, conserving water, and preserving biodiversity. Among the

most promising approaches are bioponics and aquaponics that challenge the conventional separation of agriculture from nature and demonstrate that farming can actively improve environmental conditions.

Innovations in Sustainable Food Production

Bioponics: Organic Hydroponics for a Circular Economy

Bioponics represents a significant advancement in sustainable agriculture by combining the resource efficiency of hydroponics with organic nutrient sources derived from waste materials. Rather than relying on synthetic mineral fertilizers, bioponic systems utilize locally or regionally available organic waste streams, including agricultural byproducts and aquaculture effluents (aquaponics).^{[21][22]}

The environmental and productivity advantages of bioponics are substantial. Research conducted by the NEIKER technology center demonstrated that lettuces grown in bioponic systems were 20% larger than those cultivated in conventional hydroponic systems, while chard production increased by 13%. This productivity advantage occurs despite bioponics' slower nutrient release compared to inorganic solutions, as nutrients become available gradually through microbial conversion of organic matter. By replacing mineral fertilizers with organic sources, bioponics reduces carbon dioxide emissions into the atmosphere and minimizes environmental impact while closing nutrient cycles locally.^[23]

Aquaponics: Integrating Fish and Plant Production

Aquaponics represents a paradigm shift in food production by integrating fish aquaculture with plant cultivation in a closed-loop system where fish waste provides nutrients for vegetables. In these systems, fish are raised in rearing tanks, and their metabolic waste—rich in nitrogen and other essential nutrients—is biologically converted into plant-available forms through microbial activity in biofilter tanks. The nutrient-enriched water then flows to plant growing beds, where crops remove nutrients and purify the water before it returns to the fish tank, creating a complete cycle.^[24]

The sustainability advantages of aquaponics are remarkable. Compared to conventional soil-based agriculture, aquaponic systems demonstrate water savings exceeding 90%, a critical advantage in water-scarce regions. In comparative studies, basil yields from aquaponic systems were three times greater than field-grown crops, while aquaponic okra production achieved yields 18 times higher than field-grown equivalents. Beyond yield improvements, aquaponic vegetables often display higher nutritional quality and superior antioxidant activity compared to conventionally grown produce.^{[25][24]}

Recent innovations have further enhanced aquaponics' sustainability profile. Multitrophic circular systems that integrate, for instance, microalgal photobioreactors enhance nutrient retention by utilizing plants unutilized nutrients, and enables the generation of diversified co-products, including biofertilizers and protein-rich aquafeeds. ^[26]

AmpliAqua®: a Success Story

AmpliAqua® is a pre-commercial R&D+i unit, based in Nazaré, Portugal, dedicated to the development and validation of regenerative food production systems, with a strong focus on bioponics, liquid biofertilizers, and integrated aquaculture. Operating as a TestBed infrastructure, it enables technology transfer trials up to TRL 6/7, supporting the scale-up of innovative solutions for sustainable food systems. Its decoupled Integrated Multi-Trophic Aquaculture (IMTA) model integrates fish, plants, and microalgae in independent but interconnected water circuits, ensuring high levels of control over water quality, nutrients, and microbiology. Nutrients recovered from aquaculture effluents are converted into safe, efficient bioponic nutrient solutions through an innovative, low-energy capacitive deionization process, while microalgae provide final nutrient polishing and biomass for biofertilizer production. Housed in a near-zero energy building (NZEB), AmpliAqua® exemplifies how regenerative agriculture, bioponics, and aquaponics can converge in resilient, circular, and energy-efficient food production systems. ^[27]

Farmers, industry, and academia involved or interested in promoting sustainable food production will be able to explore further during the AmpliCentro project activities - webinars, open days, workshops, fairs and gastronomic events will enable stakeholders to gather around innovative recirculating aquaculture systems. For more information, visit the Food4Sustainability social media pages.

Final Remarks

The urgency of food system transformation cannot be overstated. Global agricultural systems must simultaneously increase productivity to feed a growing population, reduce their environmental footprint, and enhance resilience to climate volatility. The convergence of regenerative farming practices, bioponics, aquaponics and microalgae production demonstrates that agriculture need not be extractive. Instead, farming can become restorative, producing abundant nutrition while actively regenerating the natural systems upon which all life depends.

References

1. <https://climateadaptationplatform.com/how-climate-smart-agriculture-supports-sustainable-farming/>
2. <https://www.worldbank.org/en/topic/climate-smart-agriculture>
3. <https://www.naos-international.com/challenges-of-digital-transformation-in-the-agricultural-sector/>
4. <https://projects.research-and-innovation.ec.europa.eu/en/horizon-magazine/magic-microalgae-sustainable-ingredients-food-feed-and-frAGRANCE>
5. <https://climatech.live/trends/climate-smart-agriculture-the-new-food-system-paradigm/>
6. <https://www.azocleantech.com/article.aspx?ArticleID=2079>
7. <https://www.allynav.com/blog/precision-agriculture-2026/>
8. <https://academic.oup.com/erae/article/50/4/1277/7208892>
9. <https://www.greenclimate.fund/story/climate-smart-farming-boosts-forests-and-food-security-madagascar>
10. <https://capiwell.ch/en/smart-farming-reaches-swiss-fields-in-2025/>
11. <https://www.horizoncodecs.eu/digital-farming-and-sustainability-promise-vs-reality/>
12. <https://gca.org/harvesting-resilience-the-fight-for-food-security-through-climate-smart-agriculture/>
13. <https://climatechange-summit.org/digital-farming-smart-solutions-for-a-sustainable-future/>
14. <https://robovision.ai/blog/top-5-agtech-trends-in-2025>
15. <https://www.sciencedirect.com/science/article/pii/S2214662824001026>
16. <https://eos.com/blog/regenerative-agriculture/>
17. <https://www.syngentagroup.com/regenerative-agriculture>
18. <https://boomitra.com/seven-regenerative-practices-restore-soils/>
19. <https://PMC5831153/>
20. <https://www.weforum.org/stories/2022/10/what-is-regenerative-agriculture/>
21. <https://poniclabs.com/bioponics/>
22. <https://www.verticalfarmdaily.com/article/9532150/bioponics-an-organic-closed-loop-soilless-cultivation-system/>
23. <https://neiker.eus/en/news/larger-and-more-environmentally-friendly-lettuces/>

24. <https://attra.ncat.org/publication/aquaponics-multitrophic-systems/>

25. <https://onlinelibrary.wiley.com/doi/full/10.1111/jwas.13049>

26. <https://www.mdpi.com/2673-9410/6/1/14>

27. <https://www.bgi.pt/ampliaqua-pt>