VITAGRI ORG LTD | WHITE PAPER | 2026

GROWING HEALTH

From Soil to Human Health

A review of evidence and the case for rewarding farming for higher nutritional density

Seven Point Action Plan

1. Measure What Matters
2. Reward What Works
3. Build the Evidence Base
4. Connect Farm to Fork
5. Democratise Access
6. Create Trusted Standards
7. Scale Through Collaboration

MEASURE | VALIDATE | REWARD

Frank Parkinson AGRICULTURAL TRUST
Kindly supported by a generous donation from the Frank Parkinson Agricultural Trust

Vitagri
Growing Health Together

Contents

How to Use This Document

This white paper is an industry report for farmers, food industry buyers, healthcare leaders, and policymakers. It outlines Vitagri's proposition: if we measure what matters in food production and reward what works, we can reconnect farming, nutrition, and human health.

What this report is:

- A shared systems lens for the 'soil-to-health' challenge.
- A practical framework for piloting verification of nutrient outcomes and building trusted markets.
- A transparent view of evidence strength and uncertainty, so decisions are grounded rather than ideological.

What this report is not:

- A critique of farmers, food brands, retailers or any one production method of food.
- A promise of universal health outcomes from any single practice.
- A definitive conclusion — this is a living approach designed to learn and improve.

A note on citations: Numbered citations appear as bracketed references in the text [like this]. Each number corresponds to a full reference in Appendix A (References).

How this report works, there four chapters:

1. **Reality** → start with lived pressure and practical constraints.
2. **System** → make incentives and feedback loops visible.
3. **Evidence** → treat knowledge as a landscape — what is strong, what is emerging, what is uncertain.
4. **Invitation** → move from analysis to action through pilots, partnerships, and shared standards.

Evidence Base and Methodology

Using a PRISMA-informed systematic review approach, more than 3,000 research papers were screened and critically assessed. This rigorous process led to the development of a structured evidence library and a powerful curated database of more than 1,000 relevant peer-reviewed studies, of which 125 are directly cited in the body text, and a further 27 are listed as highly relevant further reading. The literature review spans 1977–2026 and draws primarily on meta-analyses, systematic reviews, and large-scale trials sourced from PubMed, Web of Science, and CAB Abstracts.

The literature review and study database development are a commitment to safeguarding independence and scientific integrity, thereby providing a rigorous and credible foundation for this White Paper.

This work directly aligns with our beliefs about best practice, informed by strategic, science-led research, thereby strengthening the connection between agricultural systems, environmental stewardship, and public health outcomes.

We created a living version of this research in a free-to-use AI agent, where anyone can access this information: Vitagri – Pulse.

Welcome to Vitagri Org

Chairman's Foreword

This White Paper is not simply another contribution to an already crowded debate. It offers an honest, transparent assessment of the evidence to date on the links between farming and human nutrition, with a core purpose of calling for practical, collective action.

By bringing together, we believe, the largest catalogue of global research with deep, real-world farming experience, we clarify what we know, where uncertainty remains, and what steps must follow.

It does not claim to offer final answers. Instead, it sets out a framework for collaboration, trials, measurement, and leadership.

At the heart of this work are farmers, whose decisions shape not only productivity but also the nutritional quality of the food on every table.

Vitagri is a growing team of experts from across the farming, food, and healthcare industries. Volunteers are joining together on a five-year mission to ensure that sustainable farming is measured and rewarded for its nutritional outcomes. It's an open framework, and we welcome new people to join us in our mission.

For me, this work is about legacy. Agriculture's responsibility is not only to produce food but also to nourish future generations. If we align farming decisions more closely with measurable health outcomes, we strengthen both our land and our communities.

This is an open invitation to everyone. Let's question, participate, and together change the future of the farming and food industry for good.

Growing health together is not an aspiration. It is our responsibility — and our opportunity — to shape the health of future generations.

Acknowledgements

Our sincere thanks go to the Frank Parkinson Agricultural Trust for its belief in this work's vision and potential.

We are deeply grateful to Caroline Drummond, Hannah Fraser, and Tom Pearson for inspiring and shaping that vision in its early stages.

Special thanks to James Thompson for the many hours spent gathering, reviewing, and structuring a vast body of research into a clear and coherent framework.

We also acknowledge the ongoing encouragement and support of the Nuffield Farming Scholarships Trust, whose community continues to foster leadership across agriculture and beyond.

To the wider Vitagri team, thank you for your time, challenge, cross-checking, and commitment to ensuring this paper is robust, balanced, and practical.

We are equally indebted to the many researchers and authors whose work underpins this report. Their dedication to advancing knowledge has made this synthesis possible. Thank you, Louise Manning, Hannah Fraser, Alina Warren-Walker, Bill Young, Tom Pearson, Doug Wanstall, Henny Lowth, Barbara Bray, David Miller and Sarah Calcutt.

Finally, my personal thanks go to Rob Ward, whose clarity, energy, and determination have helped shape this paper into more than a summary of evidence — into a call to action. His commitment to turning insight into impact continues to drive us forward as we grow food for health.

David Rose
Co-Founder, Investor & Chairman,Vitagri.org Ltd.

Join us at Vitagri.org — We are Growing Health Together!

Executive Summary

What This Report Is All About

This white paper is built on four interlocking layers — **Reality, System, Evidence,** and **Invitation** — because the food system is complex, uncertain, and human. The following summarises each.

The Pressure

Living system layer: Reality

A livestock farmer who has invested years in building soil health has no credible way to prove that their milk is more nutritious than the commodity alternative. A school meals buyer who wants to source better has no standard to specify at the point of purchase. A healthcare professional treating a patient with iron-deficiency anaemia sees the human consequences of a food system every day, yet has no food production lever to pull. A parent trying to feed a family well on a tight budget discovers that price, not quality, is the only signal the system provides.

These are not policy concepts. They are the daily reality of a food system that has learned to measure everything except what matters most, namely, food nutrition. The UK's mandatory back-of-pack nutrition declaration requires only seven macro-level nutrients to be declared — precisely the nutrients least sensitive to how food is produced. The micronutrients, essential fatty acids, and phytonutrients most affected by farming systems are invisible to the regulatory infrastructure (see Section 3.10).

Decades of yield and cost optimisation have produced abundant calories but have also led to declining micronutrient quality. Documented reductions in the vitamin, mineral, and phytonutrient content of staple crops over the past half-century coincide with a population-wide nutrition crisis: the UK National Diet and Nutrition Survey (2019–2023) found that 96% of the population fails to meet recommended fibre intake, with significant shortfalls in vitamin D, iron, folate, and vitamin B^{12} [72]. Meanwhile, farmers are trapped in a cost-driven cycle that rewards volume over quality, absorbing rising input costs while receiving prices that do not reflect the nutritional value of their products. Food businesses face growing consumer demand for quality but lack a credible framework to differentiate or verify it.

> ***"No credible framework exists in the UK to measure, verify, and reward nutrient-dense food production."***

The consequences are not abstract either. In the UK, direct NHS (government) spending on diet-related ill health is estimated at £7–10 billion annually [140], but the total economic burden — including social care, productivity losses, and wider societal costs — has been estimated at £268 billion per year [103], almost equivalent to the entire annual UK healthcare spend of £292 billion. Even when narrowed to obesity and excess weight alone, the costs reach £126 billion annually [104]. The pressure falls hardest on the least affluent communities, where diet-related disease prevalence is highest, and access to quality food is most constrained. Any credible response must reach the whole population — not just those who can afford a premium.

The Broken Loop

Living system layer: System

The food system currently operates in an open loop. Farmers produce. Processors process. Retailers sell. Consumers eat. But no meaningful signal about nutritional density flows back to the farm gate. The loop is broken at a specific point: because nobody systematically measures nutrient outcomes at the production level, quality remains invisible — and what is invisible cannot be rewarded.

This creates a self-reinforcing cycle. Farmers have no economic incentive to invest in practices that improve nutritional quality. Buyers have no basis to pay for it. Consumers have no way to identify it. Health professionals treat the human consequences, while the causes of food production go unaddressed. Policy targets the symptoms of poor nutrition — reformulation, fortification, labelling — while the quality of food production itself remains unmeasured and unrewarded. This measurement gap is not merely conceptual — it is embedded in the regulatory infrastructure itself. Under the Food Information Regulations 2014, the mandatory back-of-pack nutrition declaration requires food businesses to declare only seven macro-level nutrients: energy, fat, saturates, carbohydrates, sugars, protein, and salt. These are the nutrients least sensitive to farming-system differences. The micronutrients, essential fatty acid profiles, and phytonutrients that the evidence reviewed in Part 3 shows are most affected by how food is produced are either voluntary to declare, absent from the UK's official food composition dataset (CoFID), or reported only as undifferentiated generic averages that cannot distinguish between producers or farming systems. Even the UK's comprehensive Composition of Foods Integrated Dataset — which underpins both food labelling and the National Diet and Nutrition Survey — does not include phytonutrients or bioactive compounds,

and provides a single generic nutrient profile for each food regardless of how it was grown. The system that is supposed to tell consumers what is in their food is structurally incapable of measuring what farming practices put there (see Section 3.10).

Vitagri proposes to close this loop. The model is built on three connected actions: **measure** nutrient outcomes at the farm level using standardised, affordable protocols; **verify** them through a credible, tiered certification framework; and **reward** them through procurement specifications and market mechanisms that enable farmers to earn premiums for verified nutrient density and enable food businesses to procure with confidence.

A central innovation is Vitagri's predictive modelling system, developed in partnership with the Bionutrient Institute in the United States. It links farming practices, soil metrics, and environmental variables to measured nutrient outcomes — enabling farmers to predict and optimise nutritional quality, and enabling buyers to assess nutrition forecasts for food without laboratory testing every product. The aim is to turn nutrition from an invisible output into a manageable, valuable one.

Closing the loop also changes the economics of decarbonisation. When a buyer pays a premium for verified nutrient density, the soil-health practices that deliver it — cover cropping, reduced tillage, organic amendments, and managed grazing — simultaneously sequester carbon and reduce input costs. Decarbonisation becomes a co-benefit of improved farm economics, not a separate obligation to be absorbed.

What the Evidence Shows

Living system layer: Evidence

This white paper synthesises over 3,000 peer-reviewed studies, cites 158 references (131 directly, 27 as further reading), and draws on industry reports and international policy documents to map the relationship between farming practices, soil health, and the nutritional quality of food. This endeavour is now supported by growing international scientific consensus: the second EAT–Lancet Commission

(2025) explicitly frames healthy, sustainable, and just food systems as interdependent goals, reinforcing the need for approaches that link agricultural practices to nutritional outcomes [143].

The evidence is not unanimous — and this report makes that clear. Disputed findings are addressed transparently in Section 3.7, and evidence gaps and limitations are set out honestly in Section 3.8. The structural limitations of the UK's own nutritional measurement infrastructure — and why it cannot capture the farming-system effects documented here — are examined in Section 3.10. Vitagri's position is that the evidence is sufficient to justify investigation and structured evaluation, but not sufficient to make definitive health claims.

Where the evidence is strong: Practices that promote soil health are associated with measurably higher concentrations of vitamins, minerals, and protective phytonutrients in the food they produce. For dairy, a meta-analysis of over 170 studies found that organic milk contains 56% more total omega-3 fatty acids than conventional milk. For fruits and vegetables, organic produce typically contains 20–70% higher levels of polyphenolic compounds and 5–25% more vitamin C. For meat, organic production is associated with 23% higher total polyunsaturated fatty acids and 47% higher omega-3 fatty acids. Evidence for cereals and grains is more mixed, with variety selection often mattering as much as or more than the farming system. None of these differences are captured by the UK's mandatory nutrition declaration system.

Where the evidence is emerging. Rapid advances in soil metagenomics and spectral crop analysis are opening new pathways to measure, in real time, the link between soil microbial communities and plant nutrient uptake. Predictive modelling — correlating practice, soil function, and nutrient outcome — is in its early stages but shows promise for reducing reliance on costly laboratory analysis. The role of phytonutrients beyond simple antioxidant capacity — including their interactions with the human gut microbiome — is an active and rapidly developing research frontier.

Beyond the organic–conventional binary. Critically, the evidence extends beyond the question of whether food is labelled organic or conventional. What matters most is ***how farmers manage their soil.*** Practices that build soil biology — cover cropping, reduced tillage, diverse rotations, organic amendments, and managed grazing — are associated with higher nutrient concentrations, regardless of certification status. This is the report's most important finding: it is farming-system agnostic, not a case for any single label or method. The mechanisms linking soil biology to crop nutrition — including mycorrhizal networks, microbial nutrient cycling, the dilution effect, and mineral bioavailability — are examined in detail in Part 3.

Where significant uncertainty remains. Causal pathways from specific soil conditions to crop nutrient profiles and, ultimately, to measurable human health outcomes are not yet fully established. Most existing evidence is associational rather than interventional. Long-term, controlled trials linking farming-system changes to population health outcomes are scarce and expensive. The evidence base is strongest for individual nutrients and weakest for whole-diet, whole-system effects, which ultimately matter most.

> *"The evidence is sufficient to justify a structured investigation — but not sufficient to make definitive health claims."*

What Vitagri Proposes

This white paper outlines a pathway to reconnect the broken loop between farming, nutrition, and health. The **Manifesto for Change** that follows sets out seven concrete commitments — from publishing measurement protocols and launching pilot farms to embedding nutrient outcomes in public procurement and national policy. Each commitment includes specific targets, timelines, and accountable parties.

The accompanying **Roadmap** outlines delivery from 2026 to 2030 across four stages: build the foundations, prove the model, scale across regions, and embed the framework within national standards. **Part 4** provides detailed descriptions of five integrated workstreams: generating on-farm trial data across diverse UK farming systems; developing a credible Nutrient-Dense verification standard; piloting value-based procurement with anchor buyers; linking food quality to measurable community health outcomes through Food is Medicine pathways; and building public understanding through communications and storytelling.

Crucially, at least 50% of procurement pilots will serve communities with above-average indices of deprivation. Vitagri takes the two-tier risk seriously: this is a public health intervention that must reach the entire population to succeed, not a niche quality initiative for those who can already afford to choose.

An Invitation to Build It Together *Living system layer: Invitation*

This is not a finished answer. It is a starting framework — honest about what we know, transparent about what we don't, and practical about what we intend to do next.

The techniques for measuring nutritional outcomes, the standards for verifying them, and the market mechanisms to reward them do not yet exist in a mature form. They will not be built by any single organisation. They will be built by a community of practitioners — farmers trialling measurement protocols on their land, food businesses piloting procurement specifications, researchers contributing to an evolving evidence base, health professionals linking upstream food quality to downstream patient outcomes, and policymakers creating the regulatory conditions for this work to scale.

Vitagri exists to convene and support that community. It is a platform, not a project — a shared space for learning, co-development, and collective progress. The standards will evolve. The evidence will deepen. The models will be refined. What holds it together is a shared commitment to measuring what matters and rewarding what works, developed transparently, rigorously, and together.

Every reader of this report — whether farmer, agronomist, food buyer, chef, healthcare professional, nutritionist, policymaker, or researcher — has a role in reconnecting the loop between how food is grown and the health of the people who eat it. Section 1.3 outlines what this work means for each audience. The Manifesto translates this into seven concrete commitments. To help you identify your practical starting point, Vitagri created **Vitagri – Pulse**, a free AI-powered tool that personalises your action plan, whatever your role.

If you are looking for certainty, this report will disappoint you.
If you are willing to build it with us, please join us at ***Vitagri.Org***.

"We are Growing Health Together"

Growing Health, Soil to Human Health — A Seven-Point Action Plan

Manifesto for Change

Call for Action

This is a call to arms for the entire farming, food and health industry. The food system will not fix itself. It needs farmers willing to measure, food businesses and retailers willing to invest in nutrient quality, health professionals willing to connect prevention to production, and policymakers willing to align incentives with outcomes. We do not have all the answers. We are committed to building them — transparently, rigorously, and together.

1

Measure What Matters

We will establish standardised, affordable measurement protocols for soil health and food nutrient density across UK farming systems. Every pilot farm will have access to baseline soil testing, crop nutrient profiling, and residue screening — creating a shared evidence base that replaces opinion with hard data.

Targets and objectives:

- Publish a core measurement protocol for soil health and nutrient density by Q3 2026.
- Equip 100% of pilot farms with baseline soil and crop testing within 6 months of enrolment.
- Establish laboratory partnerships to reduce per-sample testing costs by 30% by 2028.
- Develop and validate a predictive modelling tool for nutrient screening by 2028.

Who is responsible: Farmers, researchers, laboratories, Vitagri scientific advisory board.

2

Reward What Works

We will collaborate to define or support a credible, tiered verification framework that connects farming practices to measured nutrient outcomes. This will enable food businesses to procure with confidence and farmers to earn premiums for verified quality — breaking the cycle of cost-only competition.

Targets and objectives:

- Launch a draft 'Nutrient Dense' verification framework by the end of 2026. Pilot tiered certification ('Verified', 'Improving', 'Exemplar') on at least 20 farm products by 2027.
- Achieve accreditation partnership with at least one established assurance scheme by 2028.
- Demonstrate a quantifiable price premium for verified nutrient-dense products by 2029.

Who is responsible: Farmers, food businesses, certification bodies, Vitagri verification team.

(Contd.)

3

Build the Evidence Base

We will generate rigorous, practice-specific evidence through on-farm trials and demonstration. We will publish all results — positive, negative, and mixed — and will actively fill the evidence gaps identified in this white paper, with particular emphasis on UK-specific data and human health outcomes.

Targets and objectives:

- Recruit and support a minimum of 10 pilot farms across diverse UK farming systems in 2026.
- Publish the first set of demonstration case studies by Q4 2027.
- Expand to 50+ farms across regional hubs by 2028.
- Commission at least two UK-specific randomised trials testing the link between farming practices and food nutrient outcomes by 2029
- Run a weekly global search for new peer-reviewed studies that are relevant and add appropriate and verified studies to the citation catalogue.

Who is responsible: Farmers, universities, research institutions, Vitagri research members

4

Connect Farm to Fork to Health

We will build practical procurement pathways that route nutrient-dense food into schools, hospitals, workplaces, and communities where diet-related ill health is highest. We will demonstrate that outcome-based procurement is economically viable and replicable.

Targets and objectives:

- Secure 1–3 anchor procurement pilots (school meals, workplace catering, or community food programmes) by the end of 2026.
- Co-design procurement specifications with at least two local authorities or NHS trusts by 2027.
- Publish a replicable 'farm-to-institution toolkit' for councils and caterers by 2028.
- Engage national procurement frameworks to embed nutrient outcomes within public procurement standards by 2029.

Develop an NPM-aware procurement specification addendum: a simple method for buyers to (a) remain compliant with "less healthy" classifications under NPM 2018 where relevant, and (b) specify measured positive nutrient outcomes (e.g., nutrient density markers, residue-risk reduction, and evidence-tiered attributes) for eligible categories [138, 139].

Who is responsible: Local authorities, NHS trusts, caterers, food businesses, Vitagri procurement team.

5

Democratise Access to Nutrient-Dense Food*

We will prioritise affordability and equity in everything we do. Nutrient-dense food must not become another premium product accessible only to the wealthy. Our verification and procurement systems will ensure that improved food quality reaches communities with the greatest health needs first.

Targets and objectives:

- Ensure that at least 50% of procurement pilots serve communities with universal (non-discriminatory) offerings such as school meals and patient hospital food
- Develop pricing models demonstrating that nutrient-dense food can be cost-competitive with conventional alternatives.
- Launch at least one 'Food is Medicine' community health programme linked to farming outcomes by 2027.
- Measure and publish dietary quality improvement in pilot communities by 2029.

Who is responsible: Community health organisations, local authorities, British Society of Lifestyle Medicine, food banks, and any relevant specialist health and rehab services. Vitagri equity lead.

(Contd.)

6

Create Trusted Standards

We will support or establish governance structures, scientific oversight, and communication principles that protect the integrity of every claim. An independent Scientific Advisory Board, a Farmer Advisory Panel, published methods, and regular independent audits will ensure Vitagri's standards earn and maintain public trust.

Targets and objectives:

- Convene the Scientific Advisory Board and Farmer Advisory Panel by Q2 2026.
- Publish all methods, trial designs, and governance protocols on the Vitagri website by Q3 2026.
- Develop and enforce claim and communications guidance to prevent overstatement by the end of 2026.
- Commission the first independent audit of Vitagri's verification processes by 2028.

Who is responsible: Scientists, farmers, independent auditors, communications professionals, Vitagri governance team.

7

Connect Farm to Fork to Health

We will grow Vitagri as a national alliance — farmers, food businesses, health professionals, scientists, and citizens working toward the same goal. We will share tools, data, and learning openly. We will embed nutrient outcomes into policy frameworks, so the work outlasts any single organisation or funding cycle.

Targets and objectives:

- Build a Vitagri active community of 1,000+ supporters by the end of 2026.
- Establish regional demonstration farm hubs in at least three UK regions by 2028.
- Engage with ELM schemes, the National Food Strategy, and devolved agricultural policies to integrate nutrient outcomes by 2029.
- Achieve a self-sustaining financial model through certification fees, memberships, and data services by 2030.

Who is responsible: Everyone. Farmers, food businesses, healthcare leaders, policymakers, researchers, and citizens.

*** Guardrail: compatibility with NPM 2018 and HFSS classifications**

Vitagri's nutrient-outcome recognition will not be used to bypass or undermine public health protections. Where a product is classified as "less healthy" under NPM 2018 thresholds, Vitagri recognition must be expressed in a way that is specific, evidence-based, and non-misleading—focusing on measured nutrient attributes and verified production outcomes rather than implying blanket "healthiness" [139]. Vitagri will publish approved claim templates and prohibited phrases, and require partners to pre-clear public-facing nutrient density statements against these templates.

Part 1 – Farming For Health Story

1.1 Why it's time to change

It is a cliché, but sadly true — for far too many people, the food system is broken.

Farmers are under intense pressure to produce more for less, while absorbing rising costs, coping with climate volatility, and facing uncertainty about the future. Food businesses are locked into cost-driven models that leave little room for creativity or long-term thinking. Shoppers want to eat well but are overwhelmed by conflicting labels, mixed messages, and rising prices.

Many feel the system isn't working. And yet, are stuck inside it.

***This is why we created Vitagri**, which stands for 'Vitality from Agriculture' — to **reconnect** what has been pulled apart: **farming**, **nutrition**, and **human health**.*

Vitagri is an organisation representing the entire industry, from farmers to food manufacturers and retailers, to improve the connection between human nutrition and food production. We do not claim to have all the answers. We are committed to walking this path together — farmers, scientists, food businesses, retailers and healthcare professionals — guided by evidence, openness and trust.

Building a new farming reward mechanism that works for the entire food system.

Farmers should be rewarded for growing food that nourishes people and ecosystems, not just for volume. Food businesses should be empowered to produce delicious, nutritious food with confidence and credibility. Shoppers should feel informed, not confused—and enjoy eating as part of their well-being. Nutrition should be measured, not marketed. Progress should be collaborative, not competitive.

Vitagri is Growing Health Together.

1.2 How our journey began

Despite considerable effort and good intentions, the system all too often delivers poor outcomes: rising chronic disease, environmental degradation, and farmer burnout. What is missing is not intent — it is a shared framework across the entire farming and food industry to align on a clear, focused commitment to a healthier future.

Vitagri began with a simple but uncomfortable observation: **everyone in the food system is under enormous pressure yet feels stuck in a vicious circle.**

1.2.1 What on earth is Nutrient Density?

We have separated farming from health and nutrition from production. We talk about sustainability but rarely about nutritional value in a meaningful, measurable way. Selling 'Nutrient Density' without a meaningful measure of nutritional density means a true comparison cannot be made about whether a food product is more nutrient-dense. The greatest danger is that the present wave of enthusiasm for nutrient-dense food could wither away as a meaningless passing fad.

Vitagri exists to change that dynamic, not by offering a silver bullet but by creating a shared framework in which farmers, scientists, food businesses, and communities can move forward together. Our belief is simple: if we measure what matters, reward what works, and reconnect people with food, better outcomes will follow.

> *"If we measure nutrition, reward what works, and reconnect people with food from farms, better health outcomes will follow."*

Vitagri represents a promise to fight for:

"That farmers can be recognised and rewarded for growing food that genuinely nourishes people, that food businesses can develop innovative solutions centred on nutrition, all with confidence and credibility, and that eating healthy food can once again feel enjoyable, meaningful, and valued."

1.3 What this means for you

This section translates the Vitagri story into practical relevance for different audiences. Each group is part of the same system, so the invitations are complementary rather than competing.

For **farmers**, Vitagri offers a pathway to have soil-health investments recognised and rewarded through verified nutrient outcomes.

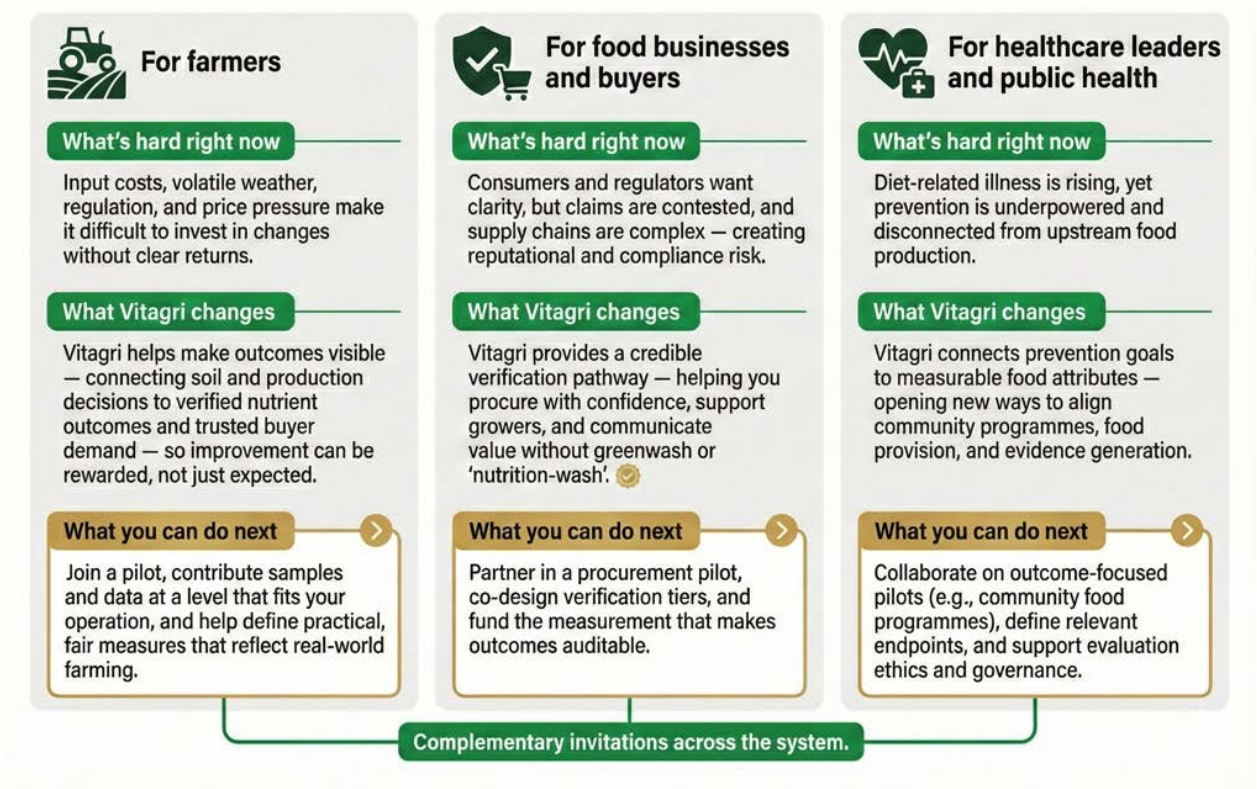
For **food businesses**, it provides defensible, data-backed differentiation in a market moving towards nutrient density claims.

For **healthcare professionals**, it bridges the gap between dietary advice and food production systems.

For **researchers**, it offers a collaborative platform and access to on-farm trial data.

For **policymakers**, Vitagri demonstrates how outcome-based measurement can align agricultural support with public health objectives—and complements downstream health policy tools, such as the UK Nutrient Profiling Model 2018, by providing the missing upstream verification and incentive mechanisms that link farm practice → nutrient outcomes → trusted procurement [138, 139].

Vitagri Pulse can help each of these audiences explore the evidence base in this report, filtered to their specific context.



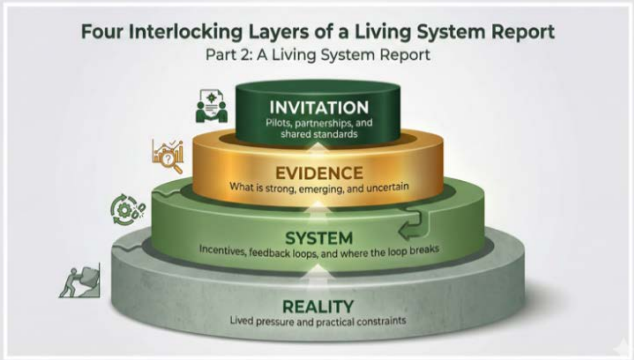
Part 2 – A Living System Report

Part 1 explained why Vitagri exists. This part explains how we approach the problem — and why that matters for the solutions we propose.

2.1 The Living System Approach

The Vitagri White Paper is intentionally designed as a Living System Report. Rather than explaining the food system from the outside, the report mirrors how systems behave: complex, uncertain, and human. It is built on four interlocking layers.

- **Reality**: start with lived pressures and practical constraints (on-farm, in supply chains, in the healthcare system, and in communities).
- **System**: make incentives and feedback loops visible — what is rewarded, what is hidden, and where the loop breaks.
- **Evidence**: treat knowledge as a landscape — what is strong, what is emerging, and what is uncertain — so learning is farming-agnostic and honest.
- **Invitation**: move from analysis to action through pilots, partnerships, and shared standards that can scale.



2.2 The World as It Is — A System Under Pressure

Living system layer: ***Reality***

The way forward begins with understanding. Farmers face economic and emotional risk. Buyers are constrained by price-led systems. Shoppers are confused and fatigued. No single actor is failing — the system is misaligned. UK farm income has become increasingly volatile, with Total Income from Farming fluctuating between £3.2bn and £7.9bn over the period 2015–2022 [113], while farm-gate prices for many commodities failed to keep pace with input cost inflation.

> ***"No single food sector is failing—the system is dysfunctional."***

2.3 The Broken Loop

Living system layer: ***System***

Efficiency and cost metrics are driving a decline in nutritional quality, while siloed systems erode trust. Even where intent exists, economic pressure from farming through to the consumer makes system change risky and improvements fragmented. The true economic cost of this broken system is far greater than is commonly acknowledged.

Direct NHS spending on diet-related ill health is estimated at around £7–10 billion annually [140], but this captures only a fraction of the total burden. The most comprehensive analysis to date — a 2024 report commissioned by the Food, Farming and Countryside Commission — estimates the total cost of diet-related chronic disease in the UK at £268 billion per year, comprising healthcare (£67.5bn), lost productivity (£116.4bn), the human cost of chronic disease and reduced quality of life (£60bn), social care (£14.3bn), and welfare spending (£10.1bn) [103].

> ***"The total cost of diet-related chronic disease in the UK is estimated at £268 billion per year — almost equivalent to the entire annual healthcare spend of £292 billion."***

This is almost equivalent to the UK's entire annual healthcare spend of £292 billion [103]. Even when narrowed to obesity and excess weight alone, Nesta and Frontier Economics estimate costs of £126 billion annually, including £31 billion in lost productivity and £12.6 billion in direct NHS treatment [104]. Yet virtually none of this expenditure is directed at incentivising the production of nutrient-dense foods — the system treats the symptoms of poor nutrition downstream while ignoring the quality of food upstream.

Policy signal: the UK's updated Nutrient Profiling Model (NPM 2018)

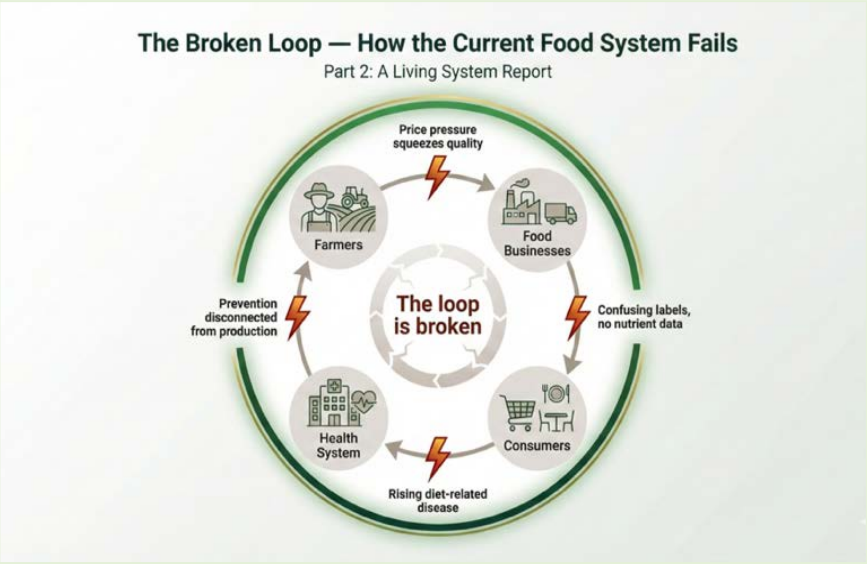
In January 2026, the Department of Health and Social Care published the outcome of the 2018 review of the UK Nutrient Profiling Model and confirmed the updated model (NPM 2018) [138]. NPM 2018 defines how foods and non-alcoholic drinks are classified as "less healthy", including the thresholds used across policy and compliance contexts (foods ≥4; drinks ≥1) [139].

Why this matters for Vitagri: it reinforces that nutrition is becoming measurable and enforceable in the food environment—yet the system still struggles to measure and reward nutrient outcomes at the farm level. Vitagri complements NPM 2018 by building upstream verification and procurement pathways that make nutrient outcomes visible, investable, and fair to farmers.

International policy momentum

The UK's NPM 2018 sits within a broader international convergence around food-system reform. In December 2025, the USDA launched a dedicated Regenerative Pilot Program — framed explicitly as health policy under the 'Make America Healthy Again' agenda — to support farmers transitioning to regenerative practices [146]. At the multilateral level, the UNFCCC Climate Action portal now includes a plan to accelerate regenerative agriculture for 'healthy soil and healthy diets' [147], and the second EAT–Lancet Commission has placed the integration of healthy, sustainable, and just food systems at the centre of global scientific and policy discourse [143]. Vitagri's measurement-first approach, therefore, aligns with an accelerating global trajectory that treats farming practices, nutrition, and health as a single interconnected system.

> ***"The system addresses the symptoms of poor consumer nutrition while ignoring the nutritional value of food."***



2.4 What We Believe — an What We Do Not Claim

Living system layer: ***System*** *(with guardrails)*

This section explicitly sets out Vitagri's beliefs and their limits. We believe in measurement, collaboration, and trust. We do not claim to guarantee outcomes, offer universal models, or present finished science.

2.5 The Evidence Landscape

Living system layer: ***Evidence***

We recognise the current evidence landscape, which includes contradictory results: some studies report significant nutritional differences, while others find no statistical difference. For example, the Barański et al. meta-analysis of 343 studies reported significantly higher antioxidant levels in organic crops [4], compared with conventional crops, whereas Dangour et al.'s earlier systematic review of 55 high-quality studies found no evidence of differences in nutrient quality between the two practices [9]. Part 3 explains how and why these conclusions differ.

2.6 Vitagri's Role — a Platform, not a Project

Living system layer: ***Invitation***

Vitagri acts as a convener, translator, unifier, and verifier — enabling others to act with confidence through shared frameworks and pilots. Part 4 outlines the delivery model.

2.7 The Path Forward — Learning Together

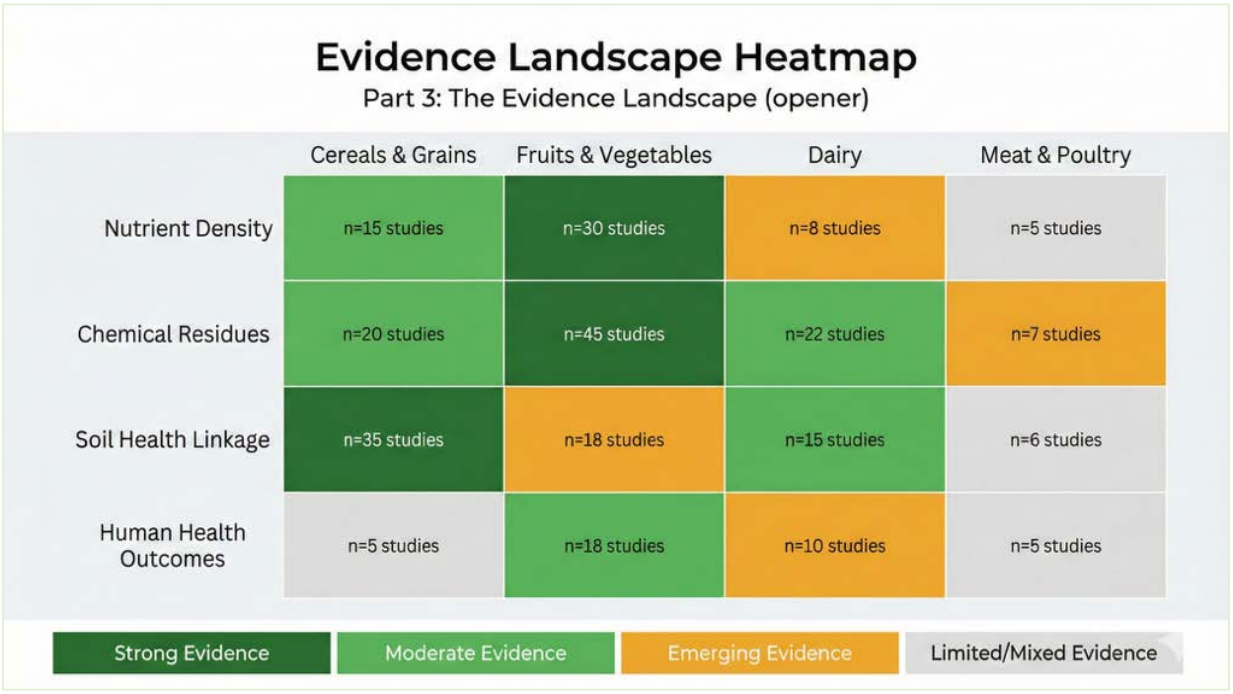
Living system layer: ***Invitation***

The path forward is framed as a learning pathway rather than a lock-in. Action is guided by three principles: **build the evidence, operate as a single system, and restore trust and confidence.**

Part 3 – The Evidence Landscape

3.0 Methodology and Evidence Approach

This section outlines the approach used to identify, evaluate, and present the scientific evidence in this white paper. Transparency about the methodology is essential for readers to assess the strength of the claims that follow.



Scope and search strategy. The evidence reviewed spans the period 1977–2026 and draws primarily on peer-reviewed meta-analyses, systematic reviews, and large-scale trials. Key databases included PubMed, Web of Science, and CAB Abstracts. We prioritised meta-analyses and systematic reviews as the highest level of available evidence, supplemented by well-designed randomised and observational studies where systematic reviews were unavailable. Search terms combined 'soil health', 'nutrient density', 'organic', 'regenerative', and 'farming systems' with specific food categories and nutrient classes.

Evidence grading. We classify the evidence supporting each claim using four tiers:

Tier	Definition	Typical source
Tier 1: **Strong**	Consistent findings across multiple meta-analyses or large-scale randomised trials with low heterogeneity.	Barański et al. 2014 (343 studies); Średnicka-Tober et al. 2016 (170+ studies)
Tier 2: **Moderate**	Supported by at least one meta-analysis or multiple well-designed studies, but with notable heterogeneity or confounders.	Montgomery et al. 2022; Davis et al. 2004; Smith-Spangler et al. 2012
Tier 3: **Emerging**	Preliminary evidence from individual trials, cohort studies, or mechanistic plausibility not yet confirmed by replication.	Pilot on-farm comparisons; animal feeding studies; single-site trials
Tier 4: **Limited / Mixed evidence**	Too few studies, contradictory results, or methodological limitations that prevent confident conclusions.	Specific crop–health outcome links; long-term UK-specific data

Limitations of this review. This white paper is not a systematic review. It is a narrative synthesis of evidence intended to inform policy and practice. Although the selection of studies is comprehensive, it may not capture all relevant publications. We encourage readers to consult the primary sources cited in Appendix A and to engage with the ongoing work of Vitagri's Scientific Advisory Board.

UK Dietary Context: Why This Matters

The UK National Diet and Nutrition Survey (NDNS, 2019–2023) reveals persistent micronutrient shortfalls across the population: [72]

Folate

83% of women of childbearing age have levels below the threshold for neural tube defect risk.

Vitamin D

deficiency affects **21–38%** of the population during winter months.

Iodine

insufficient in girls aged 11–18 and women aged 16–49, with a **29% decline** in urinary iodine over the past decade.

Vitamin A

intakes **declining 13–29%** across all age groups over the past decade

Selenium

over half of adult women and a quarter of men have intakes below the LRNI [141] — a shortfall compounded by the naturally low selenium content of UK and European soils.

Fibre

Those in the most deprived areas have consistently poorer diets and lower fruit and vegetable intake. For children aged 11–18 and for adults, 96% did not meet fibre recommendations.

These shortfalls establish the population-level relevance of Vitagri's work. However, farming-system improvements are one lever among several — including fortification, supplementation, dietary education, and food access — that must work in concert (see Section 3.9). The scale of remaining evidence gaps is reflected in the EU-funded Zero Hidden Hunger project (2024–2028), a Horizon Europe initiative involving 19 partners across 12 countries — including UK institutions co-funded by UKRI — which aims to quantify the true prevalence of micronutrient deficiencies across European populations and develop food-focused strategies to address them [142].

3.1 Defining Nutrient Density

Nutrient density is the concentration of beneficial nutrients in a food relative to its energy content [149]. The World Health Organisation defines the broader discipline of nutrient profiling as "the science of classifying or ranking foods according to their nutritional composition for reasons related to preventing disease and promoting health" [150]. The term is used in public health to identify foods that deliver higher levels of vitamins and minerals while meeting energy requirements [12, 69]. However, to assess nutritional quality, we need to know what we are comparing it against.

Di Noia's "powerhouse" classification ranks fruits and vegetables by their provision of seventeen nutrients of public health importance, defining powerhouse foods as those that provide ≥10% of the daily value for these nutrients per 100 kcal [12].

In this paper, nutrient density encompasses three components:

Macronutrients: protein, fats and carbohydrates (including fibre). Although the macronutrient composition is relatively insensitive to farming systems, some studies report slightly higher grain protein in long-term organic systems and higher levels of beneficial fatty acids in pasture-fed animal products [5, 8, 43]. Fibre warrants particular attention: 96% of older children and adults in the UK do not meet fibre recommendations [72], and fibre intake is strongly influenced by crop diversity, variety selection and the degree of processing — all of which are shaped by farming-system decisions.

Micronutrients: essential vitamins (A, C, D, B-complex) and minerals (iron, zinc, calcium, magnesium, selenium). Documented declines in crop micronutrient levels over recent decades underpin much of this review [10, 11].

Phytonutrients (phytochemicals): plant-derived compounds such as polyphenols, flavonoids, carotenoids, and glucosinolates. Meta-analyses show that organic crops contain 18–69% higher concentrations of individual antioxidant compounds than comparable conventional crops, and the authors estimate that switching to organic consumption would increase overall antioxidant intake by 20–40% [4]. The clinical significance of these compounds is well documented. A randomised controlled trial at Queen's University Belfast demonstrated that a polyphenol-rich diet—incorporating six portions of fruit and vegetables (including berries) and dark chocolate—significantly improved endothelium-dependent vasodilation in hypertensive participants, an established marker of cardiovascular risk [122]. These compounds have broader health significance. Williamson (2017) reviews evidence linking flavanols to improved blood pressure, cholesterol levels, and endothelial function, and associates regular tea and coffee consumption with a reduced risk of type 2 diabetes [123]. A recent systematic review and meta-analysis of 9 case-control studies found that higher dietary phytochemical intake was associated with a 60% lower risk of cancer (OR: 0.40; 95% CI: 0.29–0.54) [124]. A 2025 review further consolidates this evidence by mapping the interconnections among regenerative organic agriculture, soil quality, antioxidant content in food, and human health outcomes [144].

Although an adequate intake of macronutrients is important for health, the modern diet generally provides sufficient carbohydrates, protein and fat. In contrast, micronutrients and phytochemicals are frequently lacking, with significant consequences for health. Although recommended daily intakes exist for many micronutrients, a substantial proportion of the UK population fails to meet these levels [72].

> *"Higher dietary intake of phytochemicals was associated with a 60% lower risk of cancer."*

There are **no formal recommended intake levels for phytochemicals**, but the evidence reviewed above — linking polyphenol-rich diets to improved cardiovascular markers [122], flavanol intake to better blood pressure and cholesterol profiles [123], and higher dietary phytochemical intake to lower cancer risk in observational studies [124] — suggests that increasing phytochemical density in foods could meaningfully contribute to long-term health outcomes.

A practical public health anchor is the "powerhouse" classification: foods that provide ≥10% of the daily value for ≥17 nutrients per 100 kcal [12].

3.2 Soil Health

Soil health is the capacity of soil to function as a living ecosystem that sustains plants, animals, and people [13]. Soil health indicators are interdependent: physical structure governs water and oxygen availability; biology drives nutrient cycling; and chemistry regulates nutrient availability and toxicity [70].

> *Soil health is the capacity of soil to function as a living ecosystem that sustains plants, animals, and people*

Key indicators span three interdependent domains:

- **Physical:** soil structure (aggregation, porosity), water infiltration and retention, and absence of compaction or severe erosion.
- **Chemical:** adequate levels of organic matter and essential nutrients (N, P, K, micronutrients), favourable pH, low salinity, and absence of toxic contaminants.
- **Biological:** rich and diverse microbial communities (bacteria, fungi), active soil organic carbon cycling, and the presence of beneficial soil fauna (earthworms, arthropods).

These indicators are highly interdependent and interact through reinforcing feedback [70]. Increased soil organic matter enhances microbial abundance and activity, promoting soil aggregation through microbial by-products and fungal hyphae. Improved aggregation enhances soil structure, porosity, and water-holding capacity, thereby creating conditions that further support biological activity and nutrient cycling.

No single test directly measures 'soil health'; instead, many composite indices can be used. In one preliminary paired-farm comparison, regenerative fields consistently scored higher on the Haney soil health test than their conventional neighbours, though the magnitude of the difference varied markedly between sites [30].

Several indices exist to indicate the health of soil [22, 27], some of which include:

Physical indicators

- Soil bulk density
- Aggregation
- Water infiltration rate

Chemical indicators

- Soil organic matter (SOM) or soil organic carbon (SOC)
- pH
- Cation exchange capacity (CEC)
- Macro and micronutrient availability (N, P, K, S, Mg, Ca, Zn, Cu, Fe, Mn, etc.)

Biological indicators

- Microbial biomass carbon (MBC) and nitrogen (MBN)
- Soil respiration assays, such as CO_2 burst, basal respiration, dehydrogenase activity, metabolic quotient
- Enzyme activity, including urease and protease
- Microbial community assessments, including bacteria:fungi ratio, PLFA analysis, DNA sequencing

Part of this project's work will be to determine which test combination best distinguishes healthy soil and which indices correlate with higher nutrient density in food products.

3.3 Farming Practices and Soil Biology

The relationship between farming practices and nutrient density operates through interconnected soil processes — biological, chemical, and physical [145]. Practices that build soil organic matter and microbial diversity create conditions for enhanced nutrient cycling and plant uptake.

> *"The relationship between farming practices and nutrient density operates through interconnected soil processes."*

3.3.1 Cover and Catch Crops

Cover and catch crops play distinct but complementary roles. A catch crop is a fast-growing, short-term crop (typically 6–8 weeks) established between harvest and autumn cash-crop drilling to capture residual soil nitrogen before it is lost. By contrast, a cover crop occupies the ground over winter in readiness for a spring-drilled cash crop, adding biomass and organic matter, fixing atmospheric nitrogen where legumes are included, and feeding soil microbes. Both scavenge nitrogen and reduce leaching, while supporting soil biology. A meta-analysis confirms that cover cropping increases soil microbial biomass and diversity [23], and diverse cover crop root architectures promote aggregation, macroporosity, and water-holding capacity.

An experiment with organic kale found that cover crop choice influenced the kale's nutrient profile, with a legume cover crop (faba bean) particularly affecting protein content and mineral concentrations [46]. A 19-year study in California showed that integrating compost with cover crops led to measurable gains in soil carbon across the soil profile [45].

The evidence for the effectiveness of catch crops is substantial. A meta-analysis of 35 Nordic studies found that non-legume catch crops, primarily ryegrass species undersown in spring cereals, reduced nitrogen leaching by 50% while causing only a 3% reduction in grain yield [107]. A subsequent global meta-analysis reported a comparable 56% reduction in nitrate leaching under non-legume cover crops, with earlier planting dates and greater shoot biomass further enhancing effectiveness [108]. UK field trials conducted by ADAS for Affinity Water and Portsmouth Water found that catch crop mixes of phacelia, oil radish, and oats reduced nitrate leaching by up to 90% compared with weedy stubble controls, while increasing soil nitrogen supply to the following spring cereal by up to 35 kg N/ha [110]. Deep-rooted brassica species such as fodder radish are particularly effective nitrogen scavengers, with roots reaching one metre depth within 43 days, enabling capture of nitrate that has migrated below the reach of most cash crop root systems [109]. These findings are directly relevant to UK water quality policy, where agriculture affects over 60% of rivers that currently fail to meet good ecological status, and catch cropping is increasingly recognised by Defra and water companies as a practical intervention to meet Nitrate Vulnerable Zone obligations.

3.3.2 Reduced or no tillage

Conservation tillage aims to protect soil structure and living roots. A global meta-analysis confirms that increasing soil organic matter is positively associated with crop yields [32], and combining reduced tillage with cover crops is a practical way to build organic matter. No-till systems significantly increase the abundance of arbuscular mycorrhizal fungi and phosphorus uptake [55].

On-farm trials found that regenerative no-till fields had much higher soil carbon and health ratings than adjacent tilled fields, correlating with higher crop micronutrient densities [30]. Long-term trials indicate that reduced tillage, when paired with appropriate fertilisation, can maintain crop yields while improving soil aggregation and nutrient uptake [56]. However, a recognised trade-off is that reduced-tillage systems can increase reliance on herbicides — particularly glyphosate — for weed control [77]. This raises broader concerns about chemical residues, herbicide-resistant weeds, and environmental impacts, all of which are under ongoing regulatory review. Integrated weed management strategies combining cover crops, diverse rotations, and targeted mechanical control can help mitigate this dependency [77]. With several jurisdictions considering restrictions on glyphosate use, publicly funded research into effective non-chemical weed management for reduced-tillage systems is essential as a risk-management strategy [77].

3.3.3 Crop rotations and diversity

Monocropping depletes specific nutrients and increases pest prevalence. Diverse rotations break pest and disease cycles and alternate nutrient demands on the soil. Rotating grains with legumes naturally replenishes nitrogen, and long-term rotation trials show measurable effects on soil carbon and nitrogen pools [19]. Crop diversity is also expected to support a more diverse soil microbiome, though direct evidence linking rotation complexity to microbial community composition remains an active area of research. A 2025 review confirms that diverse crop rotations significantly increase soil organic matter, reduce pest pressures, and support long-term sustainable yields [57].

> ***"Diverse crop rotations significantly increase soil organic matter, reduce pest pressures, and support long-term sustainable yields"***

3.3.4 Organic amendments (compost and manure)

Adding compost, manure, or other organic waste increases soil organic matter and nutrient content. A review of food quality in organic versus conventional systems suggests that compost-treated soils can yield crops with higher levels of certain micronutrients and beneficial phytochemicals [18]. In long-term trials (e.g., the Rodale Farming Systems Trial), manured organic plots have developed significantly more soil organic matter than comparable conventional plots [36].

3.3.5 Synthetic fertilisers and pesticides

Historical analyses of USDA food composition data indicate that the nutrient concentrations of many crops have declined over the past half-century [10, 11]. Several factors may contribute, including the ***'dilution effect'*** — where higher-yielding cultivars and intensive fertilisation increase biomass but reduce micronutrient concentrations — and changes in crop varieties bred for yield rather than nutritional quality. Arbuscular mycorrhizal fungi and other soil symbionts play a key role in crop uptake of zinc, copper, and phosphorus [26], and farming practices that disrupt these organisms may therefore compromise nutrient cycling. A 2017 review noted that excessive reliance on chemical fertilisers and pesticides often depletes soil organic matter and biological diversity over time [58].

Crops grown with organic manure rather than synthetic fertilisers tend to contain higher concentrations of phenolic compounds and other phytochemicals [4]. One explanation is that the lower, less readily available nitrogen supply from organic manures places mild nutritional stress on plants, stimulating the production of phenolic compounds involved in defence against pests and diseases [105]. These same compounds, particularly phenolic acids and flavonoids, act as potent antioxidants and have well-documented health benefits in humans.

3.3.6 Animal feed practices

Grass-fed or pasture-based diets produce dairy and meat with higher omega-3 fatty acids and conjugated linoleic acid (CLA), and lower omega-6:omega-3 ratios, compared with grain-feeding regimes [42, 43]. It is important to note that the omega-3 advantage in organic dairy and meat is primarily attributable to the forage-based diets required by organic standards, rather than to organic status itself. Conventional pasture-based systems can achieve fatty acid profiles comparable to those of organic systems [5, 8]. A 2025 comparison of commercial North American grass- and grain-finishing systems confirmed significant differences in fatty acid composition and broader nutrient profiles, with variability linked to finishing regime, forage quality, and management practices [121]. In the Dutch KOALA birth cohort study, children whose dairy intake was predominantly organic (≥90%) had a lower incidence of eczema than those consuming mainly conventional dairy, with an odds ratio of 0.64 (indicating about a 36% lower risk) [24]. Given the observational nature of the study, this finding may reflect other dietary or lifestyle factors associated with organic consumption.

3.3.7 Farming trade-offs and unintended consequences

Every farming practice involves trade-offs — understanding them is as important as understanding the benefits. The practices described throughout Part 3 deliver measurable benefits for soil health, nutrient density, and residue profiles, but each carries associated risks and limitations that must be managed within the specific context of UK farming systems.

> *"Every farming practice involves trade-offs — understanding them is as important as understanding the benefits."*

The Tillage Paradox

While reduced tillage preserves soil structure and mycorrhizal networks, a common concern is that no-till systems increase reliance on herbicides for weed control. This claim requires careful examination, as the evidence largely stems from North American farming contexts — particularly the large-scale monocultures of the US Midwest, where no-till adoption has been closely linked to the use of glyphosate-tolerant genetically modified crops. In those systems, herbicide dependence is well documented: USDA/NASS survey data indicate that 93% of no-till corn and soybean acres rely on synthetic herbicides (as reported in [137], an advocacy review drawing on USDA/NASS data).

In the UK, where GM crops are not grown commercially, the picture is more nuanced. No-till and minimum-tillage systems typically use glyphosate for pre-drilling weed control and cover crop termination [77]. However, Metcalfe et al. [77] found that the trade-offs of reducing or eliminating glyphosate in UK arable systems are manageable when well-designed integrated strategies are employed — including diverse rotations, cover crops, delayed drilling, and competitive crop varieties.

Weed management in reduced-tillage systems requires a different approach rather than necessarily presenting a greater challenge. Blackgrass (Alopecurus myosuroides) is frequently cited as a barrier to no-till adoption, but it is equally problematic in plough-based systems: seeds can persist for several years underground, and repeated cultivation redistributes the seedbank through the soil profile rather than depleting it. As a marsh-adapted species, blackgrass thrives in waterlogged, high-nitrogen conditions — both of which tend to diminish under regenerative management as soil structure and drainage improve and synthetic nitrogen inputs are reduced. The grass weed most specifically associated with no-till systems is sterile brome (Bromus sterilis), whose short-lived seeds accumulate on undisturbed soil surfaces. Integrated management through delayed drilling, spring cropping, competitive crop varieties, and stale seedbeds is effective [112]. More broadly, the framing should be 'how to manage weeds in reduced-tillage systems' rather than 'no-till requires more chemicals' [77, 112].

Green bridge and pest pressure

Cover crops and reduced tillage can maintain a 'green bridge' that harbours slugs, aphids, and fungal pathogens between cropping seasons. In high-rainfall UK conditions, slug pressure in no-till systems is a well-documented challenge that can offset yield benefits [151]. Effective management requires attention to cover crop termination timing, residue management, and targeted molluscicide application where necessary — decisions that must be made in the context of local soil type, climate, and rotation.

Nutrient mineralisation timing

Organic amendments release nutrients in response to microbial activity and temperature, not to crop demand. In cold, wet UK springs, nitrogen mineralisation from compost and manure may lag crop requirements, creating a temporary nutrient deficit that must be managed through careful application timing, complementary fertiliser strategies, or the inclusion of leguminous cover crops to front-load nitrogen supply [152].

Biosolids and contaminant risk

While sewage-derived biosolids are widely used as organic amendments, they may contain persistent organic pollutants, microplastics, and heavy metals. The Soil Association prohibits their use in organic systems for this reason, and there is ongoing consultation on the future use of sewage-derived biosolids on agricultural land. This is a live policy area where precautionary approaches and robust monitoring will be essential.

The cocktail effect

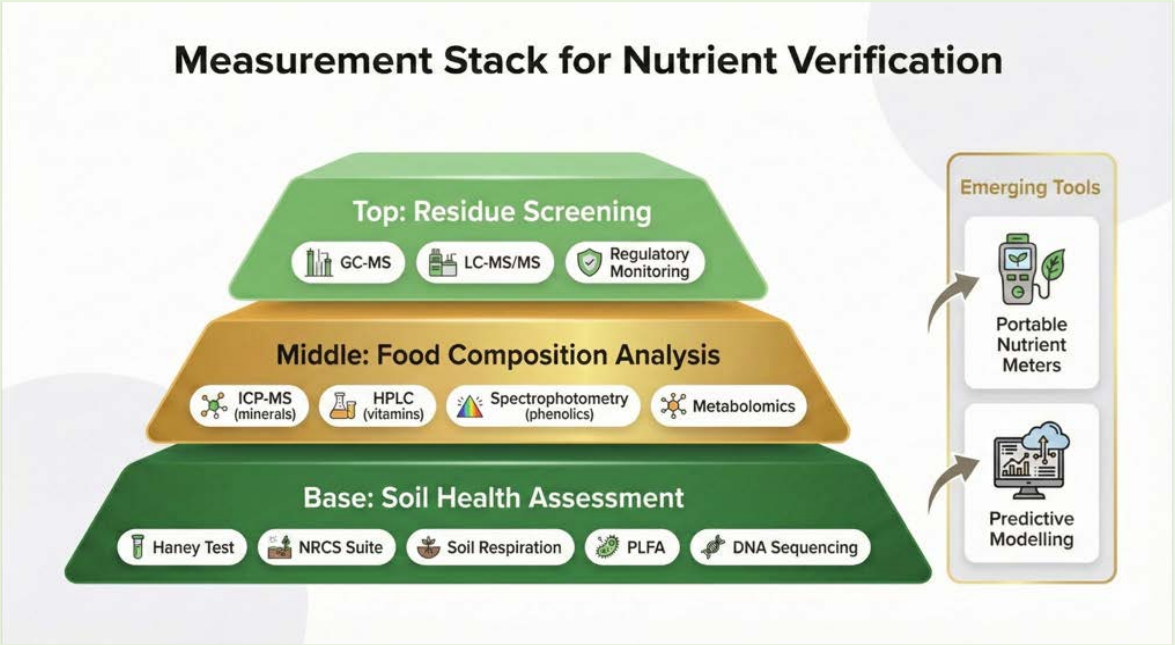
Pesticide risk assessment is conducted on individual active substances, but real-world dietary exposure involves mixtures of multiple low-level residues [14]. Research into the cumulative effects of these mixtures — the so-called 'cocktail effect' — remains limited, and regulatory frameworks have been slow to address this gap. This does not imply that conventional foods are 'unsafe'; regulatory systems exist to manage acute exposure risk [14]. However, current assessment methodologies may not fully capture chronic exposure to multiple residues at low concentrations. Reducing unnecessary exposure — for example, through farming practices that lower overall residue levels [4] — therefore aligns with precautionary public health principles.

3.5.8 Systems-level thinking

Table 1. Farming Practices — Soil Health, Nutrient Density and Residue Effects

Practice / Factor	Soil Health Impact	Nutrient Density Effects	Residue / Exposure Effects
Cover & Catch Crops	↑ Organic matter; ↑ microbial biomass and diversity [23]. Catch crops deplete residual soil mineral N by 40–72% [132]	↑ Plant-available N (legumes); ↑ micronutrients in crops (e.g. kale Ca, Mg, Fe) [46]	May reduce need for synthetic N; non-legume catch crops reduce nitrate leaching by 50–56%; UK trials showed up to 90% reduction vs. weedy stubble [107, 108, 110]
Reduced Tillage	↓ Soil disturbance; ↑ soil structure and carbon; ↑ mycorrhizal networks [55]	↑ Long-term soil C may boost nutrient supply; a preliminary comparison found higher micronutrient density in regenerative systems [30]	↓ Soil erosion and sediment loss; weed management approach shifts (e.g. pre-drilling glyphosate) but total herbicide load does not necessarily increase; integrated strategies (delayed drilling, diverse rotations, cover crops) can reduce chemical dependency [77]
Diverse Rotations	↑ Soil biodiversity; break pest/disease cycles [57]	More balanced soil nutrients; measurable effects on soil carbon and nitrogen pools [19]	Usually ↓ disease and pesticide use; essential component of integrated weed management in reduced-tillage systems [57]
Compost / Manure / Digestate	A review of organic systems suggests ↑ soil organic C, nutrient pools, and microbial activity [18]	↑ Certain micronutrients and phytochemicals in organic systems [18]	Organic inputs avoid synthetic residues; biosolids carry contaminant risk (persistent organic pollutants, microplastics, heavy metals)
Synthetic Fertilisers & Pesticides	↓ Microbial diversity with intensive use [41]; ↓ arbuscular mycorrhizal fungi [26, 55]	↑ Yield but ↓ micronutrient concentration (dilution effect) [10, 11]	↑ Frequency of detectable pesticide and nitrate residues in food [4]; individual residues typically within MRLs [14], but cumulative multi-residue effects remain under-researched
Animal Feed (Pasture vs Grain)	Rotational grazing can improve pasture soil health	↑ Omega-3, CLA, vitamin E in pasture-fed meat/dairy [5, 8, 42, 43]	Organic systems restrict antibiotics to therapeutic use only, ↓ residues and resistant bacteria [39]; pasture-based systems typically use fewer veterinary inputs but are not bound by the same rules unless certified organic

Arrows indicate direction of effect relative to conventional baseline (↑ = increase, ↓ = decrease). References in square brackets correspond to the white paper reference list.



3.4 Chemical Residues and Food Safety

The nutritional quality of food cannot be considered in isolation from its chemical safety profile. Farming systems differ substantially in their use of synthetic pesticides, herbicides, nitrate fertilisers, antibiotics, and growth-promoting agents, and these differences are reflected in the residue profiles of harvested products.

However, the health implications of nitrates in vegetables are complex and require careful interpretation. Nitrate from plant sources is metabolised differently from the nitrates and nitrites used as preservatives in processed meats. In vegetables, co-present polyphenols, vitamin C, and other antioxidants inhibit the endogenous formation of potentially harmful N-nitroso compounds (nitrosamines), whereas in processed meats, the combination of nitrite with amines, amides, and heme iron actively promotes nitrosamine formation. A systematic review and meta-analysis of 13 studies involving nearly 900,000 participants found that neither high nor moderate intake of plant-derived nitrate or nitrite was associated with an increased risk of digestive cancer; indeed, meta-regression analysis showed that gastric cancer risk decreased with increasing plant-derived nitrate intake [125]. The concern about nitrate in leafy vegetables, therefore, relates primarily to high-nitrate cultivation practices — particularly excessive nitrogen fertilisation — rather than to the inherent presence of nitrate in well-grown crops [71], and should be weighed against the cardiovascular and metabolic benefits now being attributed to dietary nitrate from vegetable sources.

Residue Risk Landscape by Food Category

Table 2 / Figure supporting Section 3.4 - **White Paper: Part 3, Section 3.4 — Chemical Residues and Food Safety** (February 2026)

	Pesticides	Herbicides	Fungicides	Insecticides	Growth Regulators
Fruits					
Vegetables					
Cereals					
Animal Products					

Organic/Regenerative Advantage — Clear evidence of lower residue risk

Mixed or Context-Dependent Evidence — No clear advantage either way

Not Applicable or **Insufficient Data** for this food category

> *"Conventionally grown crops were approximately four times as likely to contain detectable pesticide residues as organic crops."*
> — Barański et al. [4]

Cadmium concentrations in conventional crops were, on average, substantially higher — roughly double those in organic crops in pooled analyses [4], likely reflecting differences in phosphate fertiliser sources. Mycotoxin levels showed no consistent difference between organic and conventional cereals in temperate climates, though organic cereal cultivation requires careful management to minimise contamination risk [59].

In animal products, UK and EU regulations now prohibit the routine prophylactic use of antimicrobials across all livestock systems. Organic and many regenerative systems go further, imposing stricter limits on permitted treatments, longer withdrawal periods, and a preference for non-pharmaceutical interventions. A systematic review found that conventional chicken and pork had a higher risk of contamination with antibiotic-resistant bacteria than organic equivalents [39] — a finding relevant to the UK's national strategy on antimicrobial resistance (AMR).

However, current risk assessment evaluates individual active substances in isolation, whereas real-world exposure involves combinations of low-level residues — the so-called 'cocktail effect' — whose cumulative impacts remain insufficiently understood [4, 14]. Reducing unnecessary exposure, therefore, aligns with precautionary public health principles. The strength of this evidence varies substantially by food category: residue and nutrient comparisons are most robust for fruits, vegetables, and dairy, where large meta-analyses exist [4, 43], but are considerably thinner for meat, poultry, and eggs, where fewer studies have been conducted and results should be interpreted with corresponding caution (see Table 2, Evidence Strength column).

> *"These residue differences do not imply that conventional foods are 'unsafe' — regulatory systems exist to manage acute exposure risk."*

Systems-level thinking is essential when evaluating these trade-offs. For example, reducing fungicide use — while lowering chemical residues — could increase the risk of mycotoxin contamination, including aflatoxins, potent carcinogens produced by Aspergillus fungi and a major food safety concern in cereals and nuts [59]. Conversely, the crop protection sector is increasingly shifting from broad-spectrum products towards more target-specific chemistries with narrower modes of action, and precision application technologies — including variable-rate spraying, sensor-guided systems, and drone-based targeting — now enable significant reductions in the volume of product applied while maintaining effective control [78]. These advances mean that the policy question is not simply 'more or fewer chemicals' but how to deploy the right intervention, at the right dose, in the right place — a principle that aligns directly with Vitagri's outcome-based verification approach.

3.5 Evidence by Food Category

Below, we summarise key findings linking farm management to differences in nutrient density and residue levels, organised by food category.

3.5.1 Cereals and grains

Regenerative practices can boost grain mineral content, though interpreting the evidence requires distinguishing between system and cultivar effects. In paired trials that deliberately used the same wheat variety on adjacent fields — one managed regeneratively with cover crops and compost, the other conventionally with synthetic fertiliser — spring wheat from the regenerative system had substantially higher concentrations of boron, magnesium, calcium, and zinc [30]. Because genotype, climate, and soil type were controlled, the mineral density differences are most plausibly attributable to the farming system rather than to variety choice. The authors point to enhanced soil biological activity — particularly mycorrhizal networks — as the likely mechanism [30].

The Rodale Farming Systems Trial, which compared organic and conventional grain systems on the same site over four decades, reported higher protein levels in organic wheat and corn [36]. However, the organic and conventional systems use different crop rotations and potentially different cultivars, making it harder to isolate system effects from varietal or rotational confounds. These findings should therefore be interpreted as indicative rather than definitive.

An additional complication is the well-documented 'dilution effect': decades of breeding for higher grain yields have independently reduced mineral concentrations in modern cultivars [79], a genotypic trend that runs alongside — and can mask — any phenotypic gains from improved soil management. Reduced tillage with moderate nitrogen application improved grain zinc and iron levels, whereas excessive nitrogen diluted mineral concentrations further [65], suggesting that nutrient management intensity interacts with both breeding history and soil biology.

According to monitoring data [3, 39], organic grains rarely contain detectable residues of glyphosate or other synthetic pesticides, a residue advantage that is independent of the nutrient density question and applies regardless of cultivar.

3.5.2 Fruits and vegetables

The evidence base for fruits and vegetables is among the strongest in the field. Organic fruits and vegetables contain 18–69% higher concentrations of individual antioxidant compounds and roughly 5–25% more vitamin C than their conventional counterparts [4]. The Barański meta-analysis reported that organic produce was approximately 4 times less likely to contain detectable pesticide residues and had nitrate and nitrite levels 30–80% lower, depending on crop and context [4]. A kale cover-cropping study showed that cover crop choice significantly affected mineral content, with legume cover crops increasing kale mineral and protein concentrations [46].

> ***"Across multiple studies, organic fruits and vegetables have consistently shown higher concentrations of individual antioxidant compounds, by 18–69%, and of vitamin C, typically 5–25% higher than in conventional equivalents [4]."***

Specific phytonutrients of clinical interest — including flavonoids, phenolic acids, and carotenoids — are consistently reported at higher levels in organically managed systems, driven by the mild biotic stress responses described in Section 3.6.1. The fruit and vegetable category is therefore the strongest candidate for Vitagri's initial verification trials, given both the depth of existing evidence and the direct relevance to UK public health targets for increased fruit and vegetable consumption.

3. 5.3 Dairy

A meta-analysis of over 170 studies found that organic milk contains 56% more total omega-3 fatty acids than conventional milk. This increase was driven by higher levels of three key omega-3 fatty acids: α-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA). Organic milk also contained higher levels of vitamin E and iron, but lower levels of iodine and selenium [43].

3.5.4 Meat

A meta-analysis of 67 studies found that organic meat contained 23% more total polyunsaturated fatty acids (PUFA), including 47% more omega-3 fatty acids, than conventional meat [42]. UK organic lamb contained significantly higher omega-3 levels and a more favourable omega-6:omega-3 ratio [67]. As with dairy, the fatty acid advantage is driven primarily by diet rather than organic status per se. Grass-finished beef typically has an omega-6:omega-3 ratio of approximately 2:1, compared with 7:1 or higher in grain-finished systems [8, 121].Grass-fed beef also contains higher levels of precursors to vitamins A and E and of conjugated linoleic acid (CLA) [8, 37].

Beyond fatty acids, emerging evidence suggests that pasture-based diets transfer plant-derived phytochemicals — including terpenes, phenolic acids, and carotenoid derivatives — into meat and milk, compounds largely absent in grain-fed products. [135] These findings align with the Bionutrient Institute's comprehensive beef study, which found significant variability in nutrient profiles across hundreds of compounds linked to grazing systems, forage quality, and finishing practices. [121] However, whether these compositional differences translate into measurable human health benefits remains under investigation; preliminary human trials measuring inflammatory markers after consumption of grass-finished versus grain-finished beef are in progress but not yet published. The evidence base for meat is therefore classified as Tier 2 (Moderate), with the expectation that ongoing metabolomic and clinical research will strengthen or qualify these findings.

Conventional meat is more likely to contain trace drug residues or antibiotic-resistant bacteria [39].

3.5.5 Eggs

Eggs are among the most nutrient-dense foods commonly consumed in the UK and represent a significant opportunity for quality differentiation through farming systems. Pasture-raised hens produce eggs with approximately two to three times more omega-3 fatty acids, twice as much vitamin E, and substantially higher carotenoid levels (including lutein and zeaxanthin) than eggs from caged systems [73, 74]. The omega-6:omega-3 ratio in pasture-raised eggs is typically 5:1 or lower, compared with 11–19:1 in conventional eggs [73].

However, these advantages are not universal. Studies comparing basic macronutrient composition — total protein, fat, and cholesterol — have generally found no significant differences between housing systems [73]. The gains are concentrated in specific micronutrients and fatty acid profiles, not in overall nutritional value. Furthermore, the magnitude of the difference depends heavily on actual foraging behaviour: hens labelled 'free-range' that spend limited time outdoors or have access only to bare yards may produce eggs with nutritional profiles similar to those from indoor systems. The critical variable is diet composition — particularly access to insects, grasses, and herbs — rather than the housing label or organic certification per se.

The evidence base for eggs remains weaker than that for dairy or fruits and vegetables, with fewer large-scale studies and no comprehensive meta-analysis comparable to those available for other food categories. Results should therefore be interpreted as indicative rather than definitive, and eggs are a priority category for further UK-specific research within Vitagri's pilot programme.

Organic and pasture-based egg systems use fewer routine veterinary inputs, reducing the likelihood of antimicrobial residues, though egg residue data are less extensively documented than for meat or dairy [39].

Table 2. Evidence Summary by Food Category

Category	Key Nutrient Differences	Residue Differences	Evidence Tier
Cereals & Grains	Often higher Fe, Zn and protein in healthy soils [30, 36, 65, 66]	Conventional: detectable herbicide/fungicide residues. Organic: very low detection frequency [3, 39]	Tier 2: Moderate
Fruits & Vegetables	~20–70% higher polyphenols; ~5–25% higher vitamin C; higher carotenoids [4].	~4× higher pesticide likelihood in conventional [4]. Around 30–80% lower nitrate in organic, depending on crop [4]	Tier 1: Strong [4]
Dairy	~56% higher ω-3; much lower ω-6:ω-3 ratio [43]. ↑ vitamin E and iron [43]	Organic: virtually no antibiotic or hormone residues	Tier 1: Strong (~170 studies [43])
Meat & Poultry	~23% more Total PUFA, ~47% more ω-3 in organic [42]; UK lamb confirms [67]; grass-finished beef ω-6:ω-3 ~2:1 vs ~7:1 grain-finished [8, 121]; pasture-derived phytochemicals detected in grass-fed meat [135]	Conventional: higher antibiotic residue and resistance risk [39]	Tier 2: Moderate [42]
Eggs	2–3× more ω-3, 2× vitamin E, ↑ carotenoids in pasture-raised [73, 74]	Organic/pasture: no routine medication residues	Tier 2: Moderate

Evidence Tier Key

Tier 1: Strong — Consistent findings across multiple meta-analyses or large-scale randomised trials with low heterogeneity.

Tier 2: Moderate — Supported by at least one meta-analysis or multiple well-designed studies, but with notable heterogeneity or confounders.

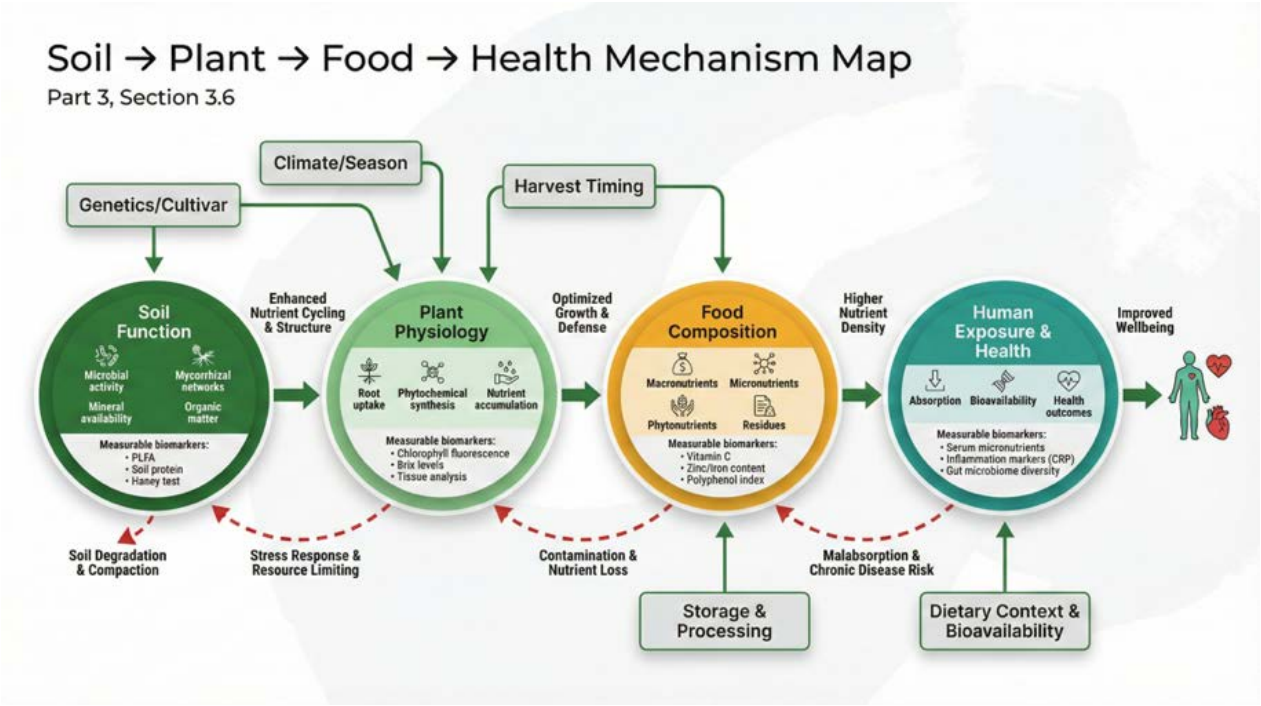
Tier 3: Emerging — Preliminary evidence from individual trials or cohort studies, not yet confirmed by replication.

Tier 4: Limited/Mixed — Too few studies, contradictory results, or methodological limitations that prevent confident conclusions.

3.6 Key Mechanisms Linking Soil to Nutrient Density

Understanding how farming practices affect food composition requires examining the biological and chemical mechanisms linking soil function to nutrient uptake and food quality.

A healthier, more diverse soil microbiome — typically an outcome of regenerative farming [23, 30, 32, 55] — enhances nutrient cycling [48] and, through mycorrhizal networks, makes phosphorus and certain micronutrients, such as zinc and copper, more accessible to plants for uptake [26, 38]. Recent reviews confirm this integrative framework, mapping pathways from soil management through food quality to human nutritional security [145, 148].



3.6.1 Soil microbial activity and mycorrhizal networks

Soil microbes drive nutrient cycling. Bacteria decompose organic matter, releasing nitrogen, phosphorus, and trace minerals in plant-available forms. Arbuscular mycorrhizal fungi (AMF) form symbiotic relationships with most crop plants, dramatically increasing uptake of phosphorus, zinc, copper, and nitrogen [26, 38]. Nitrogen-fixing bacteria and mycorrhizal fungi supply a large fraction of plant N and P each year [48]. Microbial by-products (e.g. glomalin from AMF, bacterial polysaccharides) help bind soil particles into aggregates, improving aeration, water retention, and root penetration [35].

Soil moisture is a fundamental regulator of these microbial communities and their nutrient-cycling functions. Microbial activity, enzyme production, and nutrient mineralisation are strongly correlated with soil water content, and both extremes — drought and waterlogging — can disrupt the biological processes that underpin crop nutrition [81, 82].

Under well-drained aerobic conditions, oxygen-dependent processes predominate. Nitrifying bacteria convert ammonium to plant-available nitrate. AMF networks extend through air-filled pore spaces to access phosphorus and micronutrients. Decomposer communities mineralise organic matter efficiently. Optimal microbial activity typically occurs at around 50–60% of the soil water-holding capacity, where moisture supports the diffusion of nutrients and metabolites without restricting oxygen supply [82].

When soils become waterlogged, oxygen is rapidly depleted, shifting conditions from aerobic to anaerobic (anoxic). This triggers a well-characterised sequence of redox changes with direct consequences for crop nutrition [83]. First, denitrifying bacteria convert plant-available nitrate to nitrous oxide and atmospheric nitrogen, causing substantial nitrogen losses — a process that also generates a potent greenhouse gas [83]. As oxygen depletion deepens, iron and manganese oxides are chemically reduced from their insoluble forms (Fe^{3+}, Mn^{4+}) to soluble forms (Fe^{2+}, Mn^{2+}), which can rise to levels toxic to plant roots [83]. Phosphorus availability may temporarily increase as iron oxides release bound phosphate, but prolonged waterlogging restricts root growth and nutrient uptake, ultimately reducing crop phosphorus status [83]. AMF are obligate aerobes and are particularly sensitive to flooding: colonisation rates and species diversity decline sharply in saturated soils, with flooded conditions producing the lowest AMF diversity and suppressing the symbiotic phosphorus uptake pathway that is critical for crop mineral nutrition [85, 84].

Conversely, drought stress also suppresses microbial activity and enzyme production, reducing nutrient mineralisation and availability [81]. This is achieved through extensive hyphal networks that access soil micropores beyond the reach of root hairs, improving both water and nutrient uptake [85]. AMF also enhance soil aggregate stability through glomalin production, improving water retention and the microbial habitat during dry periods [35, 85]. However, AMF networks can partially buffer crops against drought: a meta-analysis found that AMF-inoculated plants showed 86% higher phosphorus uptake, 35% higher nitrogen uptake, and 49% greater overall growth under drought stress compared with non-mycorrhizal plants [86].

AMF achieve these moisture dynamics, which are particularly relevant to UK farming. Heavy clay soils in regions such as the Midlands, East Anglia, and parts of Wales are prone to seasonal waterlogging, while lighter soils in eastern England face an increasing risk of summer drought. Management practices that improve soil structure — including cover cropping, reduced tillage, and organic matter additions — enhance both drainage and water-holding capacity, creating aerobic, well-aggregated conditions in which beneficial soil biology thrives. The relationship between soil moisture, microbial function, and crop nutrition underscores why soil structure management is not merely an agronomic consideration but a direct determinant of food quality.

3.6.2 Soil mineral content and chemistry

Plants obtain mineral nutrients via root uptake. Regional soil geology sets the baseline: wheat grain selenium levels varied by 10–100× across Australian fields, directly reflecting soil selenium concentrations [28]. Soil pH strongly affects micronutrient availability; high pH and excess calcium carbonate are major causes of zinc deficiency in crops [2].

3.6.3 The dilution effect

Modern high-yield cultivars and intensive fertilisation produce more biomass without a proportional increase in mineral or phytochemical content. Davis et al. documented declines of 6–38% in protein, calcium, vitamin C, and other nutrients in 43 U.S. garden crops over 50 years as yields increased [10, 6, 11].

> ***"Modern high-yield cultivars and intensive fertilisation produce more biomass without a proportional increase in mineral or phytochemical content."***

3.6.4 Environmental and genetic factors

The nutrient composition of any harvested crop is determined by two interacting influences: genotype (the genetic makeup of the variety) and phenotype (the observable characteristics that result from the interaction of that genotype with its growing environment and management). Distinguishing between the two is essential for interpreting the evidence presented in this paper and for designing effective measurement and verification systems.

Crop genotype sets the baseline range of nutrient potential. Differences among varieties can equal or exceed the effects of farming system or environment for certain nutrients [62]. In organic wheat trials, variety was the primary factor governing grain antioxidant levels, with environmental and management effects secondary [63]. Similarly, mineral composition can vary substantially between cultivars of the same crop grown under identical conditions [64]. This means that variety selection is itself a powerful lever for nutrient density — one that operates independently of soil health or farming system.

However, genotype defines potential, not outcome. The phenotypic expression of that potential — how much of a nutrient accumulates in the grain, leaf, or fruit — is shaped by environmental and management factors, including soil biology, moisture, temperature, light, and nutrient supply. Sunlight, especially UV-B radiation, stimulates plants to synthesise protective phytochemicals such as flavonoids and phenolic acids. Mild water stress can increase antioxidant concentrations as part of the plant's defence response, though severe drought reduces overall growth and yield. Rising atmospheric CO_2 concentrations can dilute protein and mineral concentrations in grain and leaf tissue, even when total biomass increases — a form of the dilution effect driven by the environment rather than breeding [61].

"A crop's genetics set the potential — but it's the soil that delivers the outcome. Even the most nutrient-rich variety cannot outperform good soil biology."

The practical implication is that genotype and phenotype are not competing explanations; rather, they interact. A high-nutrient variety grown in degraded soil may underperform a lower-potential variety grown in biologically active soil with strong mycorrhizal networks. Conversely, the best soil management cannot overcome the genetic ceiling of a variety bred solely for yield. This genotype × environment × management interaction — sometimes abbreviated as G×E×M — is one of the least-studied but most important determinants of nutrient density and represents a priority research gap for UK farming systems (see Section 3.7)

In Vitagri's verification framework, this distinction has direct operational significance: measuring nutrient outcomes without recording both variety and management practices would make it impossible to accurately attribute results or to guide farmers towards the most effective combination of genetics and husbandry.

3.6.5 Ripeness, harvest timing, and animal diet

Many vitamins and phytonutrients are synthesised late in crop development, so premature harvest reduces final nutrient density [25]. An animal's diet is also important. Grass-fed beef contains significantly more omega-3s and CLA, and higher precursors of vitamins A and E [8, 37]. Recent research has also identified pasture-derived phytochemicals — terpenes, phenolic acids, and carotenoids — in grass-fed meat and milk, compounds that are virtually absent in grain-fed products [135]. A comprehensive comparison of commercial grass- and grain-finishing systems confirmed that these nutrient differences are significant and linked to management practices and forage diversity [121].

3.6.6 Bioavailability

Bioavailability is the proportion of a nutrient in food that is absorbed, transported, and made available for use or storage by the body [88]. It is arguably the most important — and most overlooked — concept in the nutrient density debate. A food may contain high levels of a given mineral or vitamin, but if that nutrient cannot be released during digestion and absorbed through the gut wall, its presence in a laboratory analysis is of limited practical value. Bioavailability, therefore, bridges the gap between what is measured in a crop and what contributes to human nutrition.

Several factors determine bioavailability, and they operate at every stage from the field to the gut. These can be grouped into three broad categories: the food matrix, the presence of dietary enhancers or inhibitors, and the individual consumer's physiology.

The food matrix and nutrient form. The physical and chemical structure of a food influences how readily nutrients are released during digestion. Minerals bound within plant cell walls or complexed with organic molecules may be less accessible than those in animal-source foods, where nutrient forms are often closer to the molecular structures used by the human body [88]. Cooking, fermentation, and mechanical processing can disrupt cell structures and release nutrients, but they can also destroy heat-sensitive vitamins. Dietary fat enhances the absorption of fat-soluble nutrients (vitamins A, D, E, and K, plus carotenoids); as little as 3–5 g of fat consumed alongside vegetables can significantly improve β-carotene absorption [34]. Vitamin C consumed in the same meal substantially increases non-haem iron uptake from plant foods.

Anti-nutrients: a distinct but related issue:

> *"Anti-nutritional factors are not contaminants or defects — they are part of the plant's evolved defence system."*

Anti-nutritional factors are naturally occurring compounds in plant foods that interfere with the absorption of specific nutrients. They are not contaminants or defects — they are part of the plant's evolved defence chemistry — but their presence means that the total nutrient content of a food can be a poor predictor of the nutrients delivered to the body. The principal anti-nutrients relevant to crop nutrition are:

- **Phytic acid (phytates):** the primary storage form of phosphorus in seeds, grains, and legumes. Phytates chelate divalent cations — particularly iron, zinc, and calcium — in the gut, forming insoluble complexes that pass through the digestive tract unabsorbed. A phytate-to-iron molar ratio exceeding 1:1 significantly impairs iron bioavailability, and phytate-to-zinc ratios above 15:1 compromise zinc absorption [89, 17].
- **Oxalic acid (oxalates):** found at high levels in spinach, rhubarb, beetroot, and some legumes. Oxalates bind calcium with high affinity, rendering it unavailable for absorption, and excess oxalate can contribute to kidney stone formation [17].
- **Tannins**: polyphenolic compounds concentrated in seed coats, particularly in coloured beans, lentils, and sorghum. Tannins inhibit protein digestion and reduce iron absorption by binding both nutrients in the gut [90]. Legume varieties with darker seed coats typically contain higher tannin levels than pale-seeded varieties.
- **Protease inhibitors and lectins** are found mainly in raw legumes. Trypsin inhibitors reduce protein digestibility, while lectins can impair nutrient absorption and, at high doses, cause gastrointestinal distress. Both are largely inactivated by [89].

Legumes: a case study in bioavailability. Legumes deserve particular attention because they are among the most nutrient-dense plant foods — rich in protein, iron, zinc, folate, and B vitamins — yet also among the highest in anti-nutritional factors [89]. Raw kidney beans, chickpeas, and lentils contain substantial levels of phytates, tannins, protease inhibitors, and lectins, all of which reduce the bioavailability of their considerable nutrient content. This is why traditional food cultures worldwide developed preparation methods to address these compounds: soaking, sprouting, fermenting, and prolonged cooking. The science confirms the wisdom of these practices. Soaking kidney beans for 12–24 hours reduces phytate content by 12–16% and tannins by 23–30%; cooking for one hour can reduce phytates by up to 80%; pressure cooking achieves the largest combined reductions; and fermentation of legume flours can reduce phytates by over 85% while also degrading trypsin inhibitors and increasing mineral bio-accessibility [89, 91, 90]. The implication for Vitagri is clear: measuring nutrient levels in legumes without reference to preparation method — and therefore bioavailability — gives an incomplete and potentially misleading picture.

Plant stress and anti-nutrient production. Anti-nutrients are not produced at fixed levels. They are part of the plant's secondary metabolite defence system, and their concentration responds to growing conditions. When crops experience abiotic stress — drought, salinity, waterlogging, nutrient deficiency, UV exposure, or pest and pathogen pressure — they upregulate the production of defensive secondary metabolites, including tannins, phenolic compounds, and phytic acid [93, 94]. For example, tannin biosynthesis is regulated by defence-related phytohormones such as salicylic acid, jasmonic acid, and abscisic acid, all of which increase under stress [93]. Phytic acid accumulation in seeds can increase under phosphorus-deficient or drought-stressed conditions, as the plant diverts resources into storage and defence compounds.

This has direct consequences for crop nutrition. Management practices that reduce plant stress — adequate soil moisture, healthy soil biology, balanced nutrient supply, and appropriate variety selection — may produce crops with lower anti-nutrient levels and therefore higher effective bioavailability, even if gross nutrient content appears similar. Conversely, crops grown under chronic stress may accumulate higher concentrations of defensive compounds, reducing the nutritional value of the harvest for humans. This mechanism is underexplored in the UK context and represents a significant research opportunity for Vitagri's pilot programme: measuring not only nutrient levels in harvested crops but also key anti-nutrient ratios (particularly phytate:iron and phytate:zinc) would provide a far more meaningful picture of nutritional quality.

Individual variation. Finally, bioavailability is not solely a property of the food. Age, gut health, existing nutrient status, genetic variation, and the overall meal composition all influence how efficiently any given nutrient is absorbed [88]. Iron-deficient individuals absorb a higher proportion of dietary iron than iron-replete individuals. These factors are beyond the scope of agricultural management but are an important context for interpreting any nutrient density claims.

3.6.7 Post-harvest, processing, and transport effects

The journey from field to fork is not nutritionally neutral. Storage, transport, and processing can preserve, diminish, or, in some cases, enhance the nutrient content and bioavailability of harvested crops. Critically, processing can also alter the physical structure of food, affecting how the body responds to it — sometimes with adverse health consequences that nutrient analysis alone would not predict.

Nutrient losses during storage and transport. Refrigerated vegetables may lose anywhere from 15% to more than 75% of their vitamin C within seven days of harvest — depending on the crop — with losses accelerating in leafy greens stored at higher temperatures or under light exposure [15, 33]. By contrast, rapid freezing effectively retains nutrients: vegetables frozen within hours of harvest retain more vitamin C and carotenoids than "fresh" produce that has spent several days in the supply chain. This has practical relevance for Vitagri: the time between harvest and consumption — and the conditions during that interval — may influence nutritional outcomes as much as the farming system itself.

Processing can enhance the nutrient value of foods. Not all processing is detrimental. Heat treatment can increase the bioavailability of certain compounds: for example, cooking tomatoes breaks down cell walls and significantly increases the bioaccessibility of lycopene, a carotenoid with antioxidant properties [16]. Fermentation can synthesise new nutrients: fermenting a cauliflower-bean mixture increased riboflavin by 76–113% and folate by 32–60% [47]. As discussed in Section 3.6.6, fermentation and sprouting also reduce anti-nutritional factors, such as phytates and tannins, thereby improving the bioavailability of the minerals already present in the food. These are examples of processing that adds genuine nutritional value.

Processing that removes fibre and disrupts food structure. However, processing can also remove or disrupt components that are essential not for their nutrient content per se, but for their role in regulating how the body absorbs nutrients from food. Fibre is the most important example. The physical structure of intact plant foods — cell walls, fibrous matrices, and the structural architecture of whole grains, fruits, and legumes — acts as a natural brake on digestion, slowing the release of sugars into the bloodstream and promoting satiety.

When processing removes or disrupts this structure, previously bound nutrients are suddenly made available, overwhelming the body's regulatory mechanisms. The classic illustration is the difference between a whole orange and orange juice. A whole orange contains approximately 3 g of fibre, which slows sugar absorption, stimulates satiety signalling, and produces a moderate glycaemic and insulin response. Orange juice, from which the fibre has been largely removed, delivers the same sugars in liquid form, causing a faster, larger spike in blood glucose and insulin [96, 97]. Whole oranges are associated with a reduced risk of type 2 diabetes in cohort studies; orange juice consumption is associated with an increased risk [96]. The nutrients are nominally the same — the food structure is not.

This principle extends beyond fruit. Despite its age, the landmark study by Haber ***et al.*** (1977) remains highly relevant and demonstrated a clear hierarchy: intact apples elicited the lowest insulin response, apple purée (with fibre physically disrupted) elicited a higher response, and fibre-free apple juice elicited the highest [97]. More recent work has confirmed that physically disrupting dietary fibre — even in blended smoothies where fibre is retained but structurally broken — can alter glycaemic and insulin responses compared with whole fruit [98].

Grain refining follows the same logic on a much larger scale in the diet. Milling wheat into white flour removes the bran and germ. According to USDA nutrient data, whole-grain wheat flour contains ~10.7 g fibre per 100 g, whereas enriched white all-purpose flour contains ~2.7 g per 100 g—around a 75% reduction [130, 131]. Removing the bran and germ also strips out most of several B vitamins and substantial proportions of minerals, including iron, zinc, and magnesium. The remaining starchy endosperm is rapidly digestible, producing higher glycaemic and insulin responses than equivalent wholegrain products. The high insulin concentrations associated with chronic consumption of refined grains may, over the long term, promote weight gain by shifting metabolic fuels from oxidation to storage [126]. Epidemiological evidence consistently associates wholegrain consumption with a reduced risk of type 2 diabetes, cardiovascular disease, and colorectal cancer — benefits that are not replicated by refined grain products, even when they are fortified to match the micronutrient profile of the original grain [101].

The food matrix effect. These examples illustrate a broader concept now recognised in nutritional science as the "food matrix effect": the observation that foods with equivalent chemical composition can yield different nutritional outcomes and health effects depending on their physical structure [101]. The food matrix determines how quickly nutrients are released during digestion, how they interact with other food components, and how they are sensed by the gut's hormonal signalling systems. Processing that destroys the matrix — juicing, refining, extruding, or puffing — can fundamentally alter a food's health impact, even when its nutrient profile appears unchanged or is artificially restored through fortification.

Implications for Vitagri. This has direct and important implications for Vitagri's work. Measuring nutrient density at harvest is necessary but not sufficient. A nutritionally superior crop that is then refined, juiced, or ultra-processed may deliver fewer health benefits than a less nutrient-dense crop consumed in its whole, minimally processed form. Vitagri's verification framework should therefore consider not only what is grown and how, but also how crops are processed and consumed — recognising that the food matrix is itself a nutritional component that deserves protection.

> *"Measuring nutrient density at harvest is necessary but insufficient. A nutritionally superior crop, if refined, juiced, or ultra-processed, may yield no better health outcomes."*

3.7 Disputed and Mixed Findings

Intellectual honesty requires that this paper address findings that challenge or contradict the narrative of farming-system-linked nutrient density. Two major systematic reviews have reached more cautious conclusions than those cited above:

Dangour et al. (2009) conducted a systematic review of 162 studies (55 of which were of satisfactory quality) for the UK Food Standards Agency. Their conclusion was unequivocal: "on the basis of a systematic review of studies of satisfactory quality, there is no evidence of a difference in nutrient quality between organically and conventionally produced foodstuffs." [9] They found that organically produced crops had significantly higher phosphorus and titratable acidity, whereas conventionally produced crops had higher nitrogen levels. No differences were detected in the remaining 8 of 11 nutrient categories analysed. A follow-up review of health outcomes (Dangour et al. 2010) also found the evidence lacking [75].

Smith-Spangler et al. (2012) reviewed 17 human studies and 223 studies of nutrient and contaminant levels at Stanford University. Their conclusion: **"the published literature lacks strong evidence that organic foods are significantly more nutritious than conventional foods."** [39] However, they found that consuming organic produce reduced pesticide exposure by 30% and that organic chicken and pork had lower levels of antibiotic-resistant bacteria.

3.7.1 How do we reconcile these findings?

Scope and timing: The Dangour review covered studies up to 2008. The Barański meta-analysis (2014) included 343 studies — more than double the dataset — and used different analytical methods that may have captured differences the earlier review missed [4].

Analytical methods: Dangour et al. excluded studies below their quality threshold and aggregated broadly. Barański et al. used weighted meta-regression and reported significantly higher antioxidant levels with lower heterogeneity for specific compound classes. Both approaches have strengths and limitations.

The 'organic vs. conventional' binary: All three reviews aggregated diverse farming systems into binary labels. A farm transitioning to organic may differ markedly from a well-established organic system with mature soil biology. This confound weakens all meta-analyses in the field [9].

Heterogeneity: Smith-Spangler et al. noted that "all estimates of differences in nutrient and contaminant levels in foods were highly heterogeneous." [39] This suggests that both positive and null findings should be interpreted cautiously

.Vitagri's position is that the evidence is sufficient to justify investigation and evaluation, but insufficient to substantiate definitive health claims. This is why we propose a verification framework based on measurement rather than assumption.

Update (2025): Since Dangour (2009) and Smith-Spangler (2012), the evidence base has continued to develop. A 2025 narrative review by Rosier et al. maps pathways from soil management to food quality to nutrition security, concluding that regenerative practices can measurably improve the micronutrient and phytochemical content of food [145]. Feliziani et al. (2025) similarly confirm the interconnections between regenerative organic agriculture, soil quality, antioxidant content, and human health outcomes [144]. The second EAT–Lancet Commission (2025) now explicitly frames healthy, sustainable, and just food systems as interdependent goals [143]. These reviews do not eliminate the heterogeneity or methodological challenges identified above, but they shift the weight of evidence further towards practice-specific mechanisms — moving beyond the binary organic-versus-conventional framing that limited earlier meta-analyses.

What we do not yet know:

(1) Which specific farming practices drive the largest nutritional gains in UK conditions.

(2) Whether compositional differences in each food translate to measurable health outcomes in controlled human trials.

(3) The minimum duration of soil-health improvement needed before measurable improvements in nutrient density changes appear in crops, or animals that eat the crops.

(4) How genotype × environment × management interactions determine nutrient outcomes across UK regions.

3.8 Evidence Gaps and Limitations

Despite suggestive findings, the evidence linking farming systems to food nutrition has important limitations that must be acknowledged transparently.

Heterogeneity and study design: Many comparative studies are observational. Meta-analyses reported substantial heterogeneity [4, 9].

Organic vs conventional confound: Many reports present results without distinguishing which specific practices drive the differences [9].

Measurement inconsistencies: 'Nutrient density' as a term is not uniformly defined across studies [9].

Short-term and small-scale: Long-term trials are scarce. The Montgomery et al. study had only 2–3 replicate farms per comparison [30].

Geographic and crop gaps: Most studies focus on fruits and vegetables; fewer on grains, legumes, and eggs. Evidence is skewed towards Europe and North America.

Health outcome uncertainty: Few studies link compositional changes directly to health outcomes in people. A 2024 review reported associations but emphasised that observational links are not yet conclusive [68].

These gaps warrant caution when interpreting findings from the existing evidence base. More targeted research is needed, including randomised farm experiments and human feeding trials.

> *"More targeted research is needed, including randomised farm experiments and human feeding studies."*

3.9 Alternative routes to, and impacts on, nutrient-dense food

Farming-system improvement is one pathway to better food quality, but it is not the only one. A balanced evidence synthesis must recognise complementary and competing approaches.

Industrial fortification and nutrient restoration: Adding nutrients to processed foods (e.g. folic acid to flour, iodine to salt, vitamin D to margarine) has a strong evidence base for reducing nutrient deficiency at the population level. However, an important distinction exists between ***fortification*** — adding nutrients not originally present, or present only at low levels, to address a population-wide deficiency — and ***restoration*** (sometimes termed restitution), in which nutrients stripped out during processing are added back to approximate the original nutritional profile. Under the Bread and Flour Regulations 1998, non-wholemeal wheat flour milled in the UK must have iron, thiamin (B1), and niacin (B3) added to restore what is lost when bran and germ are removed during milling; calcium carbonate is added separately for enrichment. Wholemeal flour is exempt because these nutrients remain naturally present in the whole grain. By contrast, the UK's mandatory addition of folic acid to non-wholemeal wheat flour from December 2026 is true fortification: a public-health intervention to reduce neural tube defects, adding a nutrient at levels not naturally found in white flour. [127] This distinction highlights a fundamental question: whether public-health strategy should focus on processing food in ways that retain nutrients in the first place, or on industrially replacing what processing removes — and whether the synthetic forms used in restoration are equally bioavailable. Evidence on the bioavailability of the reduced elemental iron currently used in UK flour restoration, for example, remains contested — with some studies reporting absorption as low as 36% relative to ferrous sulphate, while others have argued that bioavailability from UK flour is adequate. [128, 129]

Biofortification through plant genetics: Conventional breeding and agronomic techniques can increase the intrinsic nutrient content of crops. By 2024, nearly 450 biofortified varieties of 12 crops had been released in 41 countries [49, 76]. The HarvestPlus programme has demonstrated measurable improvements in iron and zinc status through biofortified beans, pearl millet, and wheat. Biofortification offers a systemic advantage over industrial fortification: the nutrient is incorporated into the plant's own tissue and food matrix, potentially improving bioavailability (see Section 3.6.6). However, biofortification typically targets a single nutrient, whereas the farming-system approach investigated by Vitagri may simultaneously influence multiple nutrients through soil biology and plant stress responses. The two strategies are not mutually exclusive, and combining high-nutrient varieties with optimised soil management — the G×E×M interaction described in Section 3.6.4 — may yield the greatest gains.

Supplementation: Targeted supplementation with dietary supplements (e.g. vitamin D in winter, folic acid in pregnancy) remains essential for specific deficiency states and high-risk groups. Supplements can be precisely dosed and targeted, making them effective for clinical deficiency. However, supplementation operates at the individual level rather than the population level and depends on compliance. There is also growing evidence that nutrients consumed within a whole-food matrix may behave differently from isolated supplements — a concept sometimes described as 'food synergy' — reinforcing the importance of improving food quality at source rather than relying solely on supplementation to compensate.

Dietary diversity and food access: The single most effective intervention for nutrient adequacy is a varied diet rich in fruits, vegetables, wholegrains, and animal products. For many UK households, the primary barrier to nutrient adequacy is not food quality but food access, affordability, and dietary knowledge. However, if the baseline nutrient density of staple crops continues to decline (see Section 3.6.3, the dilution effect), even a diverse and affordable diet may fall short of historical nutritional expectations. Improving nutrient density at the point of production makes dietary diversity more effective as a public-health strategy, because each portion delivers more nutritional value.

International trade and supply chain: The UK imports approximately 46% of its food. [136] Global supply chains can deliver nutrient-dense foods year-round, but importing food also raises questions about food miles, seasonality, and post-harvest nutrient loss. As discussed in Section 3.6.7, the physical disruption and nutrient degradation associated with extended storage, long-distance transport, and industrial processing can significantly reduce the nutritional value of food between farm gate and plate — regardless of how nutrient-dense it was at harvest.

Vitagri's approach complements these strategies, not replaces them. Our focus on farm-system-linked nutrient density addresses a specific gap: the absence of measurement and reward mechanisms that link soil health to food quality within UK production systems. This gap cannot be filled by fortification, restoration, or supplementation alone — each of which compensates for nutrient loss after the fact rather than addressing the root cause at the point of production.

3.10 The Measurement Gap: UK Nutritional Assessment and Its Limitations

What the UK system requires: Food Information Regulations 2014, Big 7 mandatory declaration, three value-determination methods [151, 152].

The national food composition dataset: CoFID history, scope (2,887 foods, 275 nutrient components), role underpinning NDNS. Notes that CoFID gaps propagate to population-level intake surveys cited in the white paper [72, 152, 153].

What the system does not capture: Four structural limitations: (1) no phytonutrients/bioactives (held in eBASIS, not integrated) [4, 156]; (2) acknowledged gaps in omega-3, omega-6, folate, amino acids, vitamin D (Nutritics GB23 project) [5, 155]; (3) no farming-system differentiation (single generic value per food, averaging approach smooths variation) [154]; (4) sporadic narrow updates (62 items in 2019, pork cuts only in 2021) [152, 153].

The Nutrient Profiling Model and the reformulation bias: NPM 2018 scores A-nutrients minus C-nutrients; none are farming-system-sensitive. Rewards reformulation not production quality [138, 139]. 3.10.5 What this means for Vitagri's case — Constructive framing: system not failing at its purpose, but designed for a different era. Science has moved on. Farmer improving antioxidants by 40% has no declaration pathway. Vitagri fills gap without replacing existing infrastructure.

> *"The system that is supposed to tell consumers what is in their food, but it is not measuring what farming practices put there."*

Part 4 – What Are We Doing: Vitagri's Role

4.1 What Guides Us

Vision

A world where farming and nutrition are integrated: food quality is measured and valued, healthy soils support nutrient-dense foods, and farmers are recognised as essential contributors to public wellbeing.

Mission

To empower and connect farmers, researchers, nutrition and health professionals, and supply chain actors to improve nutrient density, strengthen soil and ecosystem health, and route better food into everyday diets, particularly where health inequalities are greatest

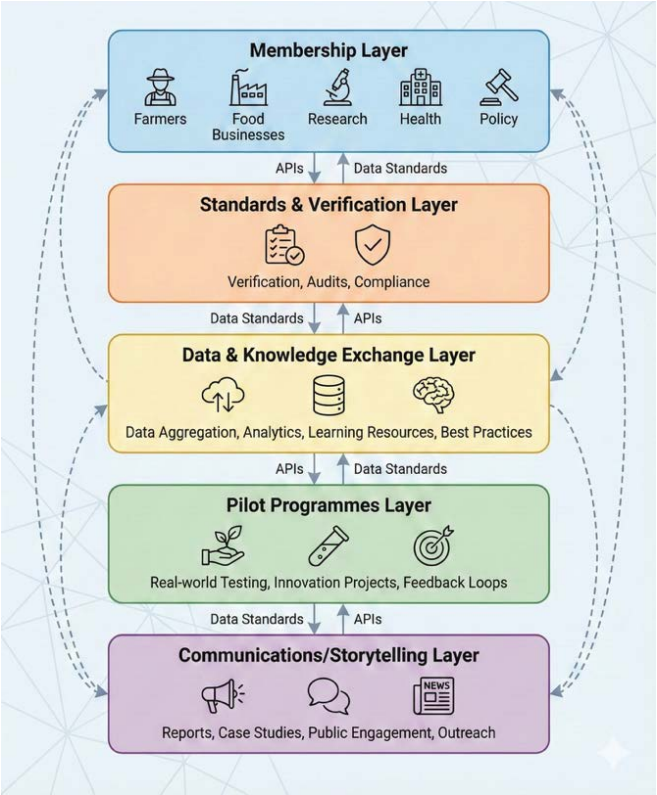
CORE PRINCIPLES

- **Non-partisan**: to work across multiple farming systems and focus on impact
- **Evidence-led:** to test, measure, engage and improve.
- **Farmer-led:** to champion practice and let lived experience shape solutions.
- **Health-driven:** to ensure quantifiable public health impacts are the unifying goal.
- **Transparency:** to share methods and results with stakeholders, including what works and does not work.
- **Equality:** to prioritise affordability and access to nutrient-dense foods, avoiding niche 'well-ness'.
- **Pragmatism**: to design approaches underpinned by real farm economics and real consumer constraints.

4.2 How to make an impact

If farmers are enabled to implement and test practical approaches that improve soil function and nutrient outcomes, and if those outcomes are verified and rewarded through markets and procurement, then nutrient-dense foods can become more widely available, affordable, and normalised, leading over time to improved diet quality, reduced diet-related disease risk, and better health outcomes.

Population dietary change requires coordinated action across multiple layers of the food system. Vitagri's workstreams align with these levers for change as follows.



4.2.2 From Verification To Prediction: Bridging The Nutrient Density Gap

The consumer market is moving faster than science: retailers are selling "nutrient-dense" food without a clear definition of the term. Vitagri's predictive modelling system, developed in collaboration with the Bionutrient Institute, aims to address this gap.

Vitagri predictive model for nutritional profiling

Vitagri's predictive modelling system is designed to bridge the gap between consumer sentiment for nutrient-dense food and what qualifies as nutrient-dense at the farm gate. The system correlates measurable farming inputs—soil biological activity, management practices, input regimes, crop varieties, grazing systems, and environmental conditions—with measured nutritional outputs in the harvested crop or in meat or dairy products. As the dataset grows across farms, soil types, and seasons, the model builds statistical confidence in which combinations of practices and contexts reliably produce higher nutrient density. Over time, this shifts the system from one that requires every batch of food to be laboratory-tested to one that can forecast a product's likely nutritional profile based on verified metadata about its production.

> *"The practical implications for the farming industry are transformative"*

The practical implications for the farming industry are transformative. Rather than treating nutritional quality as an unknowable variable, the predictive model provides farmers with evidence-based guidance on which management decisions are most likely to enhance the nutrient density of their output. A beef farmer can see how grazing rotation, forage diversity and soil biology correlate with fatty acid profiles and mineral content in the finished animal. An arable farmer can understand how reduced tillage, organic matter strategies and variety choice relate to mineral balance, protein quality and phytonutrient concentration in harvested grain. A potato grower can assess how soil management and input regimes affect dry matter, antioxidant levels and mineral uptake. In each case, the model converts what was previously opinion or assumption into a quantified, evidence-based relationship between practice and outcome.

A market that needs evidence

Consumer demand for nutrient-dense foods is accelerating ahead of the evidence base that should underpin it. On 29 December 2025, Marks & Spencer launched a dedicated 'Nutrient Dense' range of twenty meals, snacks and drinks, developed with the British Nutrition Foundation to address widespread micronutrient deficiencies [133].

The UK Government's National Diet and Nutrition Survey (2019 to 2023) found that 96% of the population fails to meet the recommended daily fibre intake, with significant shortfalls in vitamin D, iron, folate, and vitamin B12 [72]. Waitrose's Food & Drink Report 2025–26 found that 57% of consumers now replace meals with nutrient-dense snack formats. Tesco has filed trademarks for gut-health product lines [115], and Sainsbury's aims to achieve 85% of healthy and better-for-you sales tonnage (as a proportion of total sales tonnage) by 2025/26 [134].

The use of GLP-1 weight-loss medications is rising, with 2.9% of the UK adult population now taking a GLP-1 or GLP-1/GIP medicine specifically to support weight loss in the past year (survey fieldwork Jan–Mar 2025). In the United States (adults), 12.4% reported taking a GLP-1 medicine specifically for weight loss (Fall 2025; Gallup National Health and Well-being Index figure, as cited in a policy brief) [117], further intensifying demand for food that delivers maximum nutritional value with every calorie.

"57% of consumers now replace meals with nutrient-dense snack formats."

Beneath this commercial momentum lies a fundamental problem: there is no agreed baseline for what "nutrient-dense" means at the point of production. Retailers select ingredients and formulate products to maximise fibre or specific micronutrients, yet without a system that traces nutrient density back to the farming practices, soil conditions, and biological processes that produce it.

The result is a consumer market making nutrient-density claims that are disconnected from the agricultural systems that produce the food. This gap represents both a credibility risk for the market and a missed opportunity for farmers, who could be rewarded for practices that demonstrably improve the nutritional quality of their products.

> ***"Nearly a decade invested in establishing the scientific foundations linking farming practices to measurable nutrient density outcomes."***

Built on proven science: the Bionutrient Institute collaboration

Vitagri's predictive modelling approach is not developed in isolation. It is built on and validated by the extensive research of the Bionutrient Institute (BI), a US-based organisation founded in 2016 that has spent nearly a decade establishing the scientific foundations linking farming practices to measurable nutrient-density outcomes. Through a growing network of research partners, laboratories and farmers across the United States and Europe, the BI has assembled a dataset spanning more than twenty crops and over 10,000 samples, linking soil health indicators, management practice metadata, and environmental conditions to laboratory-measured nutrient profiles. This body of work, including a peer-reviewed publication in Scientific Reports, has conclusively demonstrated that significant, measurable variation in nutrient and mineral content exists within crop types, and that this variation correlates with soil health parameters and management practices.

The BI's work is directly relevant to Vitagri's predictive model because it establishes both the methodology and the proof of concept. In the crop domain, the BI has developed predictive models using spectral data and machine learning to estimate relative nutrient rankings, supporting calibration of its first-generation Bionutrient Meter. In the beef domain, the BI is leading the first comprehensive study to define nutrient density in beef, integrating advanced metabolomics and targeted nutrient analyses across hundreds of compounds—fatty acids (omega-3 to omega-6 ratios, conjugated linoleic acid), minerals (iron, zinc, selenium, magnesium), and phytochemicals—to characterise how management practices, soil health, forage quality, genetics and microbiome dynamics influence nutritional outcomes. The first peer-reviewed paper from this beef study was published in December 2025, confirming significant variability in nutrient profiles linked to grazing systems and finishing practices. Human health trials led by Dr Stephan van Vliet are measuring inflammatory markers after consuming grain-finished versus grass-finished beef, providing a critical link between food nutrient content and measurable health outcomes in people.

The underlying mechanism is straightforward: when management practices support soil biology, nutrients become more available for plant uptake; as plants take up more nutrients, they become more abundant in the crop product, increasing the opportunity for human consumption. This principle—that management practices, rather than certifications, drive nutritional outcomes—is central to both the BI's research and Vitagri's predictive model. The BI's tiered sampling approach (baseline samples for broad coverage, enhanced samples with detailed management and soil metadata, and research-intensive samples for deeper analysis) provides the methodological template that Vitagri will adapt for UK farming systems.

Vitagri
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THE BIONUTRIENT INSTITUTE

> *"Management practices, rather than certifications, determine nutritional outcomes."*

What nutrients, where, and how: the model in practice

The Vitagri–BI predictive model links specific nutrient panels to defined farming system variables across three initial UK commodity groups.

For beef, the model tracks fatty acid profiles (including omega-3:omega-6 ratios and conjugated linoleic acid), mineral content (iron, zinc, selenium, magnesium, phosphorus), and phytochemical markers, and correlates these with management metadata, including grazing system, forage diversity, finishing regime, breed, and soil biological indicators.

For wheat, the model examines mineral balance (zinc, iron, selenium, and manganese), protein quality and composition, antioxidant concentration, and Brix levels, and correlates these with tillage regime, rotation design, organic matter strategy, variety choice, fertiliser inputs, and soil microbial activity.

For potatoes, the model assesses dry matter content, mineral uptake (potassium, magnesium, iron), antioxidant levels, and disease incidence, and correlates these with soil management, input regimes, variety, storage conditions, and soil biological health.

In each case, the methodology follows the BI's recommendation to sample across a wide range of real-world farming systems to establish a meaningful baseline of nutrient variation, rather than relying primarily on replicated trials on a small number of farms. The broader the sample base and the metadata captured, the greater the chance of recognising patterns and identifying a representative range of nutritional content. Establishing the natural range of variation within UK supply chains comes first; targeted agronomic recommendations or management changes can then be tested on selected farms in a second phase.

An international platform: How the UK and BI collaborate

The Vitagri–BI collaboration is structured as a two-way partnership in data and methodology, laying the foundation for an international platform that accelerates the link between farming systems and nutritional outcomes. BI contributes its existing dataset of nearly 4,000 crop samples, comprehensive beef study results, validated spectral analysis and machine-learning methodologies, a laboratory network, and experience with tiered sampling design across diverse farming systems. Vitagri provides UK-specific farming system data across beef, wheat, and potato supply chains, access to UK laboratory and university partners, and a commercial verification framework that links predictive insights to market value.

Critically, the UK datasets generated by Vitagri's pilot farm trials feed back into the BI's global model, while the BI's US and European data strengthen the statistical power of UK-specific predictions. This reciprocal architecture means the model improves faster than either party could on its own. Where the BI has already proven correlations between soil biological activity and crop nutrient uptake in North American farming systems, Vitagri will test whether those relationships hold across UK soil types, climatic conditions, and management contexts—and where they differ, the model adapts. The BI also proposes to expand its detailed nutrient-density research to 20 crops worldwide in 2026, creating a shared global evidence base that Vitagri's UK work will both contribute to and draw upon.

> *"The UK datasets feed into the Bionutrient Institute's global model, while the Bionutrient Institute's US and European data strengthen UK-specific predictions."*

How the farming industry will materially benefit

The predictive model has the potential to transform the economics of nutrient-dense food production for UK farmers in four concrete ways.

1. Dramatically reduce the future cost of nutritional testing. As the evidence base grows, the model generates high-certainty predictions of the likely nutritional profile of food produced under defined conditions, progressively replacing expensive per-batch laboratory analysis with metadata-based screening. This shifts the cost curve: early participants bear the costs of building the model, but subsequent participants benefit from validated predictions at a fraction of the cost.
2. Provides farmers with an evidence-based pathway to enhance their value proposition. A farmer whose management data and soil metrics align with the model's high-nutrient-density profile gains a defensible, science-backed claim that can command premium pricing or preferred procurement.
3. For the first time, it enables farming decisions to be influenced by nutritional outcomes. Rather than optimising solely for yield and cost, farmers can see the predicted nutritional impact of specific management changes—such as switching grazing rotations, adjusting input regimes, and altering tillage practices—and weigh the creation of nutritional value alongside conventional metrics.
4. Supports value creation across the entire supply chain. Retailers, food service operators, and public-sector buyers gain a credible basis for nutrient density claims that links marketing language to measured, farm-level reality—closing the gap between what the M&S Nutrient Dense range promises and what the agricultural system behind it can verify.

At higher levels of model confidence, these correlations support responsible claims and enable nutritional performance to be recognised as a supply-chain attribute, thereby creating the conditions for farmers to be rewarded not only for what they produce but also for the nutritional quality of their output.

4.2.3 From Evidence to Incentives: Decarbonisation and Value Creation

Decarbonisation has become a central requirement across the UK and global food systems. Farmers, processors, retailers, and food service operators are increasingly expected to measure, reduce, and report greenhouse gas emissions to meet regulatory requirements, investor expectations, and voluntary commitments.

Despite this shared ambition, the costs and risks of decarbonisation are most often borne at the farm level, while financial and reputational benefits accrue further up the supply chain. This imbalance constrains adoption and weakens farm resilience.

The OFC 2026 Report [102], written by Louise Manning, directly addresses this structural issue, noting that many current decarbonisation pathways rely on producers internalising costs rather than on value creation across the supply chain.

Why carbon-only approaches struggle to deliver value

Carbon metrics are essential for environmental accountability, yet they rarely translate into meaningful commercial differentiation. For most consumers and buyers, carbon intensity remains abstract and disconnected from food quality or health outcomes.

As a result, decarbonisation is often seen as a cost to be absorbed rather than a value to be rewarded, creating a misalignment between climate ambition and economic reality.

> *"Decarbonisation is often seen as a cost to be absorbed rather than a value to be rewarded."*

A nutrition-led pathway to shared value

Vitagri proposes a complementary pathway in which decarbonisation is embedded within a value proposition centred on nutritional outcomes. Many practices associated with lower emissions intensity—such as improved soil organic matter, reduced synthetic inputs, diverse rotations, and pasture-based livestock systems—are also linked to changes in the nutrient density and biological markers of food.

Unlike carbon metrics, nutritional outcomes are directly measurable within the product. Nutrients, fatty-acid profiles, phytonutrients, and residue reductions can be quantified and verified.

From verification to prediction

Vitagri's verification framework links farming practices to measured nutritional outcomes through field trials, biological marker analysis, and transparent grading of evidence. As datasets expand, predictive models are developed to forecast the nutritional outcomes of defined farming systems with greater certainty.

As the evidence base matures, the predictive modelling framework described in Section 4.2.1 enables nutritional performance to be recognised as a supply-chain attribute, thereby creating conditions in which decarbonisation becomes a co-benefit of economically valued farming systems rather than an unfunded obligation.

When decarbonisation becomes mutually beneficial

Where farming systems deliver both improved nutritional outcomes and lower emissions intensity, decarbonisation becomes a co-benefit of economically valued systems rather than an unfunded obligation.

> ***"Where farming systems deliver both improved nutritional outcomes and lower emissions intensity, decarbonisation becomes a co-benefit rather than an unfunded obligation."***

The OFC 2026 Report emphasises the importance of outcome-stacked value creation, in which environmental, health, and economic benefits reinforce one another rather than compete.

Implications for who pays

Under a nutrition-led model, value flows through the supply chain. Farmers are rewarded through improved margins or procurement preferences; brands gain defensible differentiation; and public buyers can link food spend to long-term health outcomes.

Vitagri's role

Vitagri's role is to provide measurement, verification, and predictive capabilities that enable this shift. In partnership with the Bionutrient Institute, Vitagri is building an international evidence platform that makes nutritional outcomes measurable and valuable, helping to realign incentives so that climate action, health outcomes, and farm viability advance in tandem.

4.3 How Vitagri will make a difference

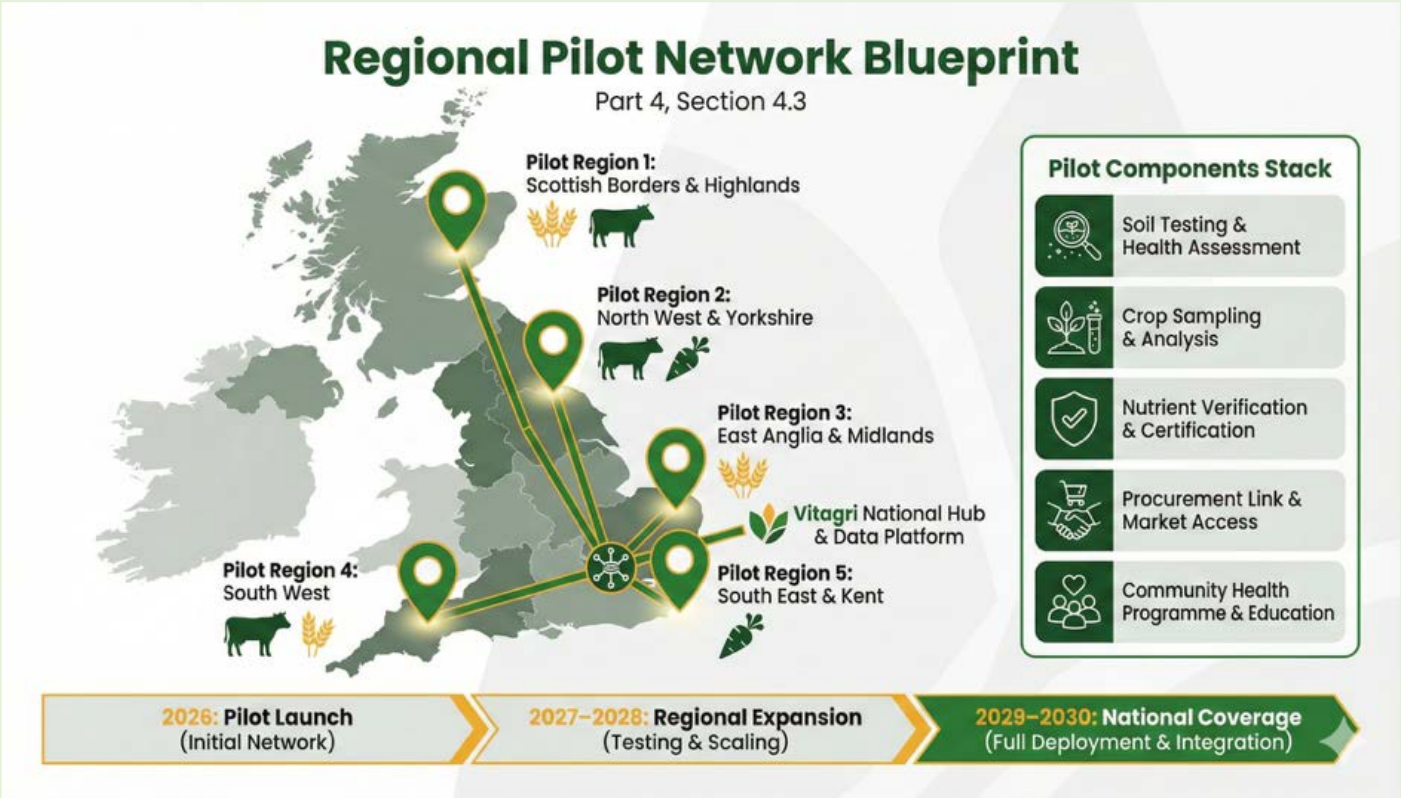
Vitagri's delivery model comprises five integrated workstreams.

Workstream 1: On-farm trials and demonstration

Purpose: *generate practical, credible evidence on how farming practices, crop varieties, and soil biology relate to nutrient outcomes in food.*

- Select and support a cohort of pilot farms across diverse systems (arable, horticulture, livestock, mixed).
- Agree on a core measurement protocol that includes baseline soil metrics, crop/product nutrient profiles, and management records.
- Run focused trials (e.g. variety choice; soil biology interventions; rotations; reduced disturbance; organic matter strategies).
- Design the pilot data-capture and sampling protocol to support predictive modelling (minimum viable metadata, biomarker panels, and QA).

Exemplar farm selection criteria: Pilot farms will be selected to represent diverse UK farming systems across a range of soil types, climatic zones, and enterprise scales. Selection criteria include willingness to share data openly, commitment to a minimum 2-year trial period, existing farm records supporting the baseline assessment, and geographic distribution across at least 3 UK regions. A fast-track knowledge-exchange process will facilitate peer-to-peer learning among pilot farms.



Workstream 2: Nutritional verification and a Nutrient-Dense standard

Purpose: *create a credible framework that rewards nutrient outcomes and avoids vague marketing claims.*

As Section 3.10 demonstrates, the UK's existing nutritional measurement infrastructure — including the mandatory back-of-pack declaration and the national food composition dataset (CoFID) — cannot capture the farming-system-driven nutritional variation documented in Part 3. This structural gap defines the need for Vitagri's farm verification layer.

Design principles:

- **Outcome-oriented**: focus on measured nutrient density and relevant proxies where appropriate.
- **Evidence-tiered**: clearly separate established, emerging, and uncertain research claims.
- **Feasible**: verification activities (e.g. independent testing and auditing) must be affordable and practicable for farmers.
- **Compatible**: an approach designed to complement existing assurance schemes rather than duplicate elements within them.

Vitagri – Pulse already provides personalised access to the evidence framework underpinning this standard. As the verification methodology evolves, Vitagri – Pulse will be updated to reflect the latest protocols.

Workstream 3: Value-based procurement and supply chain pilots

Purpose: *translate farm-level improvements into healthier diets by creating reliable demand channels for nutrient-dense foods.*

- Identify 1–3 anchor procurement pilots (school meals, workplace catering, community food programmes).
- Co-design procurement specifications that prioritise diet quality, transparency, and local resilience.
- Build relationships with national frameworks and procurement bodies to embed nutrient outcomes within standards.

Workstream 4: Community health programmes (Food is Medicine pathways)

Purpose: *link farming and food quality to measurable health-related programmes, prioritising communities with the highest diet-related burdens.*

Health professionals are increasingly recognising the interconnectedness of human and environmental health. The World Health Organisation's ***One Health*** framework reflects this, explicitly linking environmental, animal and human health. However, those working in healthcare are often far removed from food production and may have limited understanding of the wide variation in farming systems and how these differences can influence the nutritional quality of food. Vitagri is uniquely positioned to bridge this gap by collaborating with health professionals to explore how farming practices affect nutrient density and translate this knowledge into practical strategies to improve diet quality and population health.

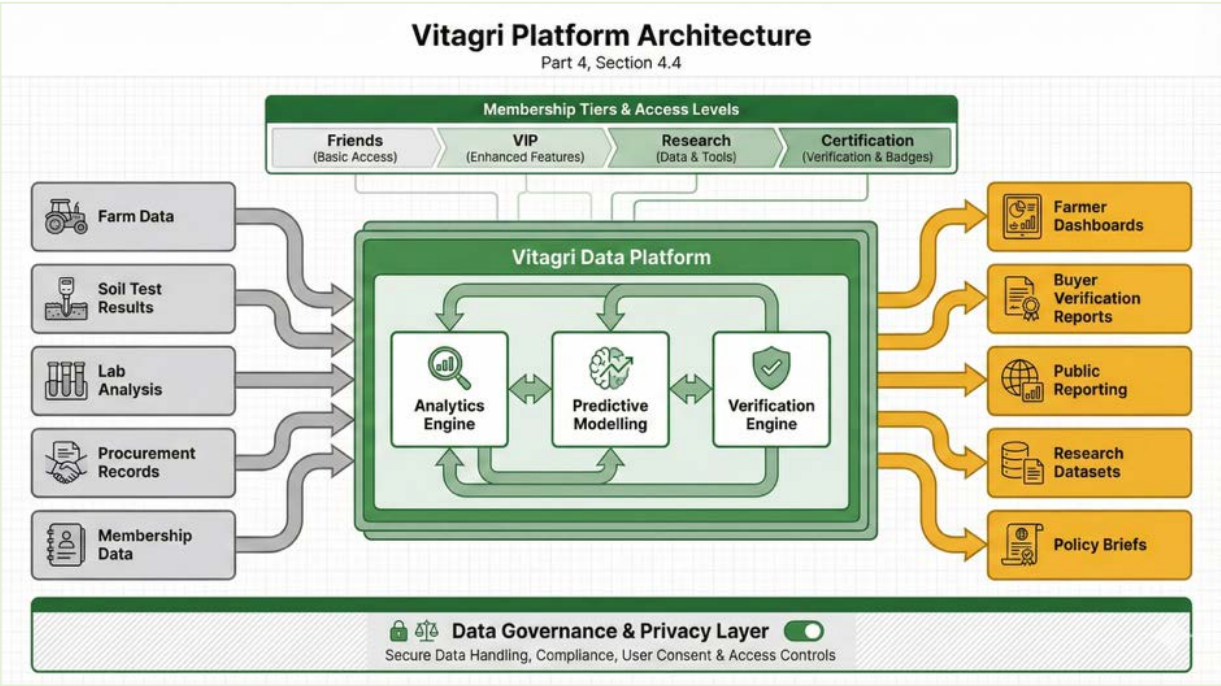
This workstream will develop practical partnerships among Vitagri pilot farms, community health organisations, and local health services. Initial activities include co-designing a 'Food is Medicine' pilot with at least one NHS Integrated Care System (ICS), establishing referral pathways from primary care to community food programmes that source verified nutrient-dense produce, and developing an evaluation framework that captures dietary quality and health-related quality of life measures. Social prescribing, in which healthcare professionals, including GPs, refer patients to community-based activities such as food programmes, already has an established infrastructure under the Health and Care Act 2022.

Workstream 5: Storytelling and communications

We will build trust through five principles: farmer-first and practical language; evidence-based claims; outcomes over ideology; no ***greenwash*** or ***healthwash***; and whole-system collaboration — with farmers, scientists, clinicians, buyers and assurance voices at the table.

4.4 Alliance and our community

Vitagri is designed to scale as an alliance of many thousands of people across farming, food, health, and science. Participation is deliberately tiered: open access for supporters, paid tiers for deeper capabilities, and enterprise-grade offerings for supply-chain actors.



Predictive modelling for Nutrient Density — the Vitagri–Bionutrient Institute partnership:

Certification partners will be offered an optional predictive modelling analytics layer to support scalable supplier assessment, contributing to the development of a medium-term predictive modelling system to accelerate farming for nutritional outcomes. This layer is powered by the collaborative research framework between Vitagri and the Bionutrient Institute (BI), which draws on nearly a decade of validated research across more than 20 crops and nearly 4,000 samples, advanced metabolomics for beef nutrient density characterisation, and machine-learning models calibrated against spectral and laboratory data. Through this partnership, Vitagri's UK-generated datasets from pilot farms and funded trials feed into the BI's global model, while the BI's US and European evidence base strengthens UK-specific predictions—creating an international platform that accelerates the science faster than either organisation could achieve alone. As model confidence grows, the cost of nutritional verification decreases: metadata-based predictions progressively replace per-batch laboratory testing, making the system more affordable and scalable for every farmer in the network.

Data governance and farmer incentives

Farmers who contribute data to Vitagri's verification and research programmes retain ownership of their individual farm data. Aggregated, anonymised datasets may be used for research and predictive modelling with prior consent. Data access agreements will be published, and a Farmer Advisory Panel will oversee the implementation of data governance principles. Participating farmers will benefit from reduced testing costs, priority access to predictive modelling tools, and visibility within Vitagri's procurement network.

> *"Farmers who contribute data retain ownership of their individual farm data."*

4.5 What's next — Roadmap 2026–2030

The roadmap is designed around a phased delivery model: build, prove, scale, embed.

UK Policy Context

Vitagri's work aligns with several live UK policy frameworks. The Environmental Land Management (ELM) schemes reward farmers for environmental outcomes; Vitagri's verification approach could extend this reward structure to include nutritional outcomes. The National Food Strategy recommended measuring food quality at the system level. Public procurement reform is creating space for outcome-based specifications in school meals and NHS catering.

Specifically, the Government Buying Standards for Food and Catering Services (GBSF) set nutritional and sustainability requirements for public-sector procurement. NHS Integrated Care Systems (ICS), established under the Health and Care Act 2022, provide a governance framework for coordinating food and health strategies at the regional level. Social prescribing pathways — in which GPs and other health professionals refer patients to community-based activities, including food programmes — offer a practical way to link farming outcomes to health interventions. Vitagri's procurement pilots will be designed to align with GBSF specifications and to engage at least one ICS as a formal partner by 2027.

Governance and Accountability

An independent Scientific Advisory Board will review evidence claims, trial design, and nutritional verification thresholds. A Farmer Advisory Panel will ground-truth the protocols. All methods, results, and conflicts of interest will be published. Vitagri will commission periodic independent reviews.

Vitagri's origins lie with a group within the Nuffield Farming Scholarship Trust. Today, the growing team at Vitagri includes many farmers, industry experts, scientists, and nutritionists from outside the Nuffield Farming Scholarship Trust. The Nuffield Farming community will provide an essential international network to support Vitagri's growth.

Table 3. Phased Roadmap 2026–2030

Phase	Timeline	Key Activities	Success Metrics
Build	2026	Launch pilot farm cohort; agree core measurement protocol; define draft Nutrient Dense framework; secure 1–3 procurement pilots; establish governance and verification protocols.	10+ pilot farms active; draft framework published; Scientific Advisory Board convened
Prove	2027–2028	Publish demonstration case studies; pilot verification on initial products; expand to regional hubs; begin predictive modelling development	50+ farms; verified products in procurement; predictive model v1 operational
Scale	2029	Replicable toolkits published; accreditation partnerships agreed; national procurement engagement; predictive modelling for screening live	200+ farms; multiple procurement regions; independent audit completed
Embed	2030	Nutrient outcomes embedded in policy incentives; self-sustaining market demand; continuous improvement loop operational	Verification recognised in policy frameworks; dietary quality improvement demonstrated in at least two pilot communities, assessed using a validated dietary assessment tool (e.g., NDNS-aligned food frequency questionnaire), with pre-registered targets and a minimum detectable improvement of 10% in at least one key indicator (fruit and vegetable variety score, fibre intake, or micronutrient adequacy ratio) compared to baseline

4.6 The Economic Case

The economic rationale for Vitagri's approach spans multiple levels — farm, business, and system — and the scale of the opportunity is far greater than commonly recognised.

For farmers, practices that build soil health can reduce input costs — particularly expenditure on synthetic fertilisers and crop protection — while commanding premium prices through verified quality claims. Regenerative and soil-focused systems have shown lower variable costs per hectare than high-input conventional approaches, though the transition period may involve short-term yield trade-offs (see Section 3.7). Vitagri's verification framework enables farmers to capture the nutritional value their management practices create — value that is currently unmeasured and unrewarded.

For food businesses, verified nutrient claims provide a defensible market position as consumer demand for transparency and provenance grows. Unlike subjective quality labels, data-backed nutrient verification provides an objective basis for differentiation that can withstand regulatory scrutiny. This is particularly relevant as the UK's food labelling and health claims framework evolves.

At the system level, the economic burden of diet-related ill health far exceeds the commonly cited £7–10 billion in direct NHS costs [140]. As detailed in Part 2, the total cost of diet-related chronic disease in the UK is estimated at £268 billion annually [103], and even when narrowed to obesity alone, costs reach £126 billion per year [104]. The current system treats the symptoms of poor nutrition downstream while investing virtually nothing in food quality upstream. Even modest improvements in population dietary quality — achieved through higher nutrient density at the point of production — could yield significant savings across multiple cost categories, not just healthcare.

Affordability and fairness are central to this economic case. Vitagri does not advocate a two-tier food system in which nutrient-dense foods are available only to those who can afford a premium. The farming-system improvements that drive nutrient density — healthier soils, better crop rotations, and reduced reliance on synthetic inputs — are not inherently more expensive to implement at scale. The verification model shows that nutritional quality and affordability are not in conflict and that the greatest gains may come from improving the baseline quality of staple foods rather than creating a niche premium market.

> ***"The greatest gains will come from improving the baseline quality of staple foods rather than from creating a niche premium market."***

The verification model is designed to be economically self-sustaining: certification fees, membership subscriptions, and data services fund ongoing measurement, while predictive modelling reduces per-farm testing costs as the dataset grows. As the evidence base expands, Vitagri aims to quantify the relationship between investment in farming systems and downstream health savings — building the economic case for redirecting even a small fraction of the current £268 billion burden to incentivise nutrient-dense food production.

4.7 Affordability, Equity, and the Two-Tier Risk

A credible objection to nutrient-dense food initiatives is that they risk creating a two-tier food system in which quality becomes a luxury. Vitagri takes this risk seriously.

Our mitigation strategy has four elements.

1

First, at least 50% of procurement pilots will serve communities with above-average indices of deprivation.

2

Second, we will develop and publish pricing models showing that nutrient-dense food can be cost-competitive with conventional alternatives when valued on a nutrient-per-penny basis rather than a calories-per-penny basis.

3

Third, verification will operate across farming systems — not only in organic or premium systems — so that improvements in conventional agriculture are recognised and rewarded.

4

Fourth, we will actively engage with food access organisations, community food networks, and social prescribing programmes to ensure that the benefits of verified food quality reach those who need them most, rather than those who can pay the most.

> ***"This is not a niche wellness project. It is a public health intervention that must reach the entire population to succeed."***

An Invitation

Vitagri invites farmers, food businesses, healthcare leaders, researchers, and policymakers to join our practical learning network to verify, scale, and reward food and nutritional outcomes — starting with measurable soil function and nutrient markers and progressing towards a healthier food system for all.

> ***If you are looking for certainty, this report will disappoint you. If you are willing to build it, you are welcome to join us. We are Growing Health Together.***

4.8 Vitagri – Pulse: Quick Reference

For a full introduction to Vitagri – Pulse — including personalised example prompts for farmers, agronomists, food buyers, chefs, healthcare professionals, nutritionists, policymakers, and researchers — see the "Your Toolkit: Vitagri Pulse" section earlier in this report.

VITAGRI – PULSE

Your Personalised AI Toolkit to discover how you can connect farming systems to human nutrition

This white paper outlines the evidence, the framework, and the commitments. However, evidence alone does not change systems — people do. That is why Vitagri has developed Vitagri – Pulse, an AI-powered agent designed to help every actor in the food system identify their practical starting point for change.

Vitagri – Pulse is a conversational AI tool that translates the science, evidence, and frameworks in this white paper into personalised, actionable guidance. Whether you are a farmer exploring how cover crops might improve your soil biology, a procurement officer designing nutrient-outcome specifications for school meals, a nutritionist linking dietary advice to food production systems, or a healthcare leader building a case for food-based prevention programmes, Vitagri – Pulse meets you where you are and helps you take the next step.

Pulse is not a substitute for professional advice, scientific peer review, or the relationships that enable genuine collaboration. It is a bridge — making the knowledge in this white paper accessible, conversational, and specific to your context.

What Pulse can do for you

- Explore the evidence linking farming practices to nutrient density — filtered to your crop, soil type, or supply chain.
- Build a personalised action plan: which practices, which measurements, which first steps.
- Navigate policy and procurement frameworks relevant to your region.
- Connect with Vitagri's pilot network, events, and resources.

(If the links are blocked - Here's the website for Vitagri – Pulse:
https://chatgpt.com/g/g-693301d5e3cc8191a57a128dc50f27ec)

Try NOW

Start a conversation and discover your toolkit for change:

Vitagri Pulse

Free to use. A free ChatGPT account may be required.

Beyond the Report: Engage with the Living System

This white paper is just the baseline. Join the Vitagri community as we pilot, measure, and scale healthier food systems.

The Living Report & Insights

Don't wait for the next annual report. Get bi-weekly updates on pilot data, emerging evidence, and deep-dive analysis delivered to your inbox.

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The Vitagri Platform Hub

Explore the full scope of our methodology, view the pilot network map, and access the technical architecture underpinning our verification system.

Visit Vitagri.org

www.Vitagri.org

Professional Network & Partnerships

Connect with the team, follow real-time announcements of new partners, and join the debate on the future of soil-to-health incentives.

Follow on LinkedIn

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Appendix A: References

For the complete list of References citations:

Visit: https://vitagri.org

Thank You

Vitagri
Growing Health Together

Rob Ward
CEO, Vitagri.Org Ltd

The Vitagri Team are extremely excited about the prospects for a new era in the farming sector.

The evidence is compelling and increasing that farming systems influence the nutritional content of food.

By measuring and rewarding both nutrition and yield, the farming and food industry will have achieved a paradigm shift, ensuring that food production prioritises human health and remains affordable.

Our Vision is clear:

"We want to live in a world where farming and nutrition are integrated: food quality is measured and valued, healthy soils support nutrient-dense foods, and farmers are recognised as essential contributors to public wellbeing."

How will we get there?

Our Mission is to empower and connect farmers, researchers, nutrition and health professionals, and supply chain actors to improve nutrient density, strengthen soil and ecosystem health, and route better food into everyday diets, particularly where health inequalities are greatest.

Invest in Vitagri.Org Ltd

Vitagri is actively seeking new investors to join our existing investors. If you believe in 'Growing Health' by farming for nutrition, join us and be part of the revolution that is about to happen in the farming and food industry.

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Growing Health — From Soil to Human Nutrition.
We are Growing Health Together – join us.
Visit: Vitagri.Org