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# Ancient Roots and Modern Growth: A Critical Appraisal of Vrikshayurveda and Modern Cultivation Systems

***Dr. Deepika Singh*[1], Dr. Shalini Varshney[2]***

*[1](Designation- Post Graduate, *Dravyaguna Vigyan*, *Ayurvedic* and *Unani* Tibbia College , Delhi, India, drdeepikas965@gmail.com and 8826681263)
[2](Associate Professor, Department of *Dravyaguna Vigyan, Ayurvedic* and *Unani* Tibbia College, Delhi, India, shalinidr.v7@gmail.com and 9354925050)

**ABSTRACT :**

**Background:**
Vrikṣāyurveda, the ancient Indian science of plant life, encapsulates centuries of empirical wisdom encompassing seed treatment, soil preparation, plant protection, and sustainable cultivation. As modern agriculture increasingly grapples with challenges such as soil degradation, chemical overuse, biodiversity loss, and declining sustainability, there is renewed interest in integrating traditional agricultural knowledge like Vrikṣāyurveda with contemporary cultivation systems. This article critically appraises the principles of Vrikṣāyurveda and examines how its practices resonate with or diverge from modern farming methodologies.

**Methods:**
A comprehensive literature review was conducted, drawing on ancient Ayurvedic texts (e.g. *Surpāla's Vrikṣāyurveda*, *Upavanavinoda*) and recent research publications (including peer-reviewed journals on Vrikṣāyurveda, organic farming, biofertilizers, and ecological agriculture). Comparative analysis was performed to identify key practices from Vrikṣāyurveda (such as seed selection & treatment, organic manures like Kunapajala and Panchagavya, natural pest management, soil and land classification) and to contrast them with modern cultivation systems (synthetic fertilizers, high-yield varieties, chemical pest control, monocropping, precision agriculture). Case studies showing successful integration (e.g. organic nursery seedling production using traditional methods) were also examined.

**Results:**
The review shows substantial convergence: many Vrikṣāyurveda practices have modern analogues in organic and regenerative agriculture. Practices like seed pre-treatment, biofertilizer use, natural pest control, diversified cropping and respecting soil health are echoed in current sustainable agriculture models. Yet, divergences remain in scale, consistency, yield expectations, scientific standardization, and technological support. Modern systems often prioritize immediate yield and efficiency, sometimes at environmental cost, whereas Vrikṣāyurveda emphasises long-term ecological balance, biodiversity, and holistic plant health.

**Conclusion:**
Vrikṣāyurveda offers invaluable ancient frameworks for sustainable, ecologically sensitive cultivation practices. When integrated judiciously with modern agricultural tools and scientific validation, these ancient roots can contribute to resilient and sustainable farming systems. Policy support, research, farmer education, and standardization are needed to bridge the gap between traditional wisdom and modern agricultural growth.

***Keywords**:* Vrikṣāyurveda; sustainable agriculture; organic farming; seed treatment; biodiversity; modern cultivation systems

## Introduction

Agriculture forms the backbone of the Indian economy and society, sustaining over 50% of the population either directly or indirectly [1].Agriculture in India has always been more than mere cultivation—it has been deeply intertwined with culture, philosophy, and a holistic understanding of nature. Among the indigenous systems, Vrikshayurveda stands out as an ancient treatise that embodies a deep knowledge of plant life ("vriksha" = tree/plant, "ayurveda" = knowledge of life). It includes detailed guidance on soil types, seed treatments, plant care, pest control, and sustainable manure usage, reflecting a sophisticated agronomic science developed centuries ago.[2,3]

The ancient Indian treatise on plant science, Vrikshayurveda, dating back to at least 10th century CE, offers a holistic framework for nurturing plants using ecological, organic, and Ayurvedic principles [4]. This system advocates seed treatment, soil enrichment using natural substances, pest control through herbal preparations, and a deep understanding of plant physiology based on the balance of Panchamahabhutas (five elements) and Tridoshas (Vata, Pitta, Kapha). [5]

In contrast, modern agricultural systems are driven by scientific advances in genetics, agrochemicals, irrigation technologies, and mechanization, aiming to maximize crop yield and efficiency. These technologies have enabled the Green Revolution and have significantly contributed to food

security in India and worldwide. However, challenges such as soil degradation, environmental pollution, loss of biodiversity, and health concerns from chemical residues are increasingly recognized. [6]

With the advent of modern cultivation systems—driven largely by the Green Revolution in the mid-20th century—the emphasis shifted toward maximizing yield through high-input agriculture: synthetic fertilizers, chemical pesticides, mono-cropping, mechanization, and often heavy irrigation. While such methods achieved dramatic yield gains and food security for a growing population, they also introduced serious side effects: soil degradation, chemical residues, loss of biodiversity, and dependence on non-renewable inputs.[7,8]

In recent decades, there has been renewed interest in ancient agricultural wisdom—such as Vrikshayurveda—as part of a broader movement toward sustainable, regenerative, and organic farming systems. These approaches attempt to balance productivity with ecological health, honoring natural cycles and minimizing harm to the environment.[9,10] The revival is not simply sentimental; practical studies are now documenting how ancient practices remain relevant, perform well in modern fields, and may help address issues that modern agriculture struggles with.

For example, a field study on *Proso millet (Panicum miliaceum L.)* showed that traditional Vrikshayurveda practices produced yields comparable to those obtained under modern scientific agricultural methods, highlighting that older agronomic knowledge still holds practical utility.[11] Studies on bio-fertilizers such as Panchagavya, Jeevamrutha, and organic manure indicate improvements in soil nutrients, microbial populations, disease resistance, and overall crop health.[12,13] Foliar sprays of Panchagavya plus micro-nutrients in chickpea (Cicer arietinum L.), or combined use with organic inputs in groundnut, are showing that integrating traditional liquid organic preparations can improve yield and reduce dependency on chemical fertilizers.[14]

At the same time, modern cultivation has itself evolved. There is now greater awareness of environmental impacts, soil microbiome, water scarcity, and climate change. Technologies like precision agriculture, sensor agriculture, smart fertilizers, automation, and data-driven decision making are providing tools for making modern farming more efficient, less wasteful, and more sustainable. These innovations can potentially be harmonized with ancient knowledge: for example, using sensor data to optimize the timing and quantity of organic manure applications; or employing contemporary biological research to validate the microbial communities promoted by Panchagavya or Vrikshayurvedic seed treatment techniques.

Vrikshayurveda's ancient insights include sophisticated soil classification (e.g., by fertility, moisture, color, context), seed treatment (soaking, smoking, coating with medicated powders), use of natural manures, herbal pest repellents, and ecological practices of intercropping and companion planting. Its wisdom emphasizes *balance*, *diversity*, and *sustainability*, not simply short-term yield. These are precisely the values the modern agricultural community is increasingly demanding.

Nevertheless, the transition is not straightforward. Ancient practices are often described in non-quantitative terms, context-specific, dependent on local environmental conditions, and difficult to standardize. Modern agriculture generally requires reproducibility, scalability, rigorous measurement, and regulatory compliance. Furthermore, yields under purely traditional systems may lag behind modern high-input systems under certain conditions if resources such as labour, organic material, or knowledge are inadequate.There is also the challenge of integrating traditional practice within modern market demands (post-harvest handling, pest tolerances, consumer expectations, certification for organic produce).

Thus, the current era presents both a challenge and an opportunity: to critically appraise Vrikshayurveda—what works, what needs adaptation, what evidence is missing—and to examine how modern cultivation systems can absorb, complement, or transform those ancient practices to create more resilient agricultural systems.

This article critically examines both Vrikshayurveda and modern cultivation systems, reviews recent agricultural innovations, and discusses integrative approaches currently practiced in India, especially in Karnataka and Maharashtra, which blend traditional wisdom with modern science for sustainable agriculture.

## Principles of Vṛkṣāyurveda

### *Seed Selection, Treatment and Storage (Bijavṛtti / Bījaprayoga)*

Ancient Vṛkṣāyurveda texts put strong emphasis on choosing good quality, mature seeds, extracted in due season, and proper treatment to improve germination, reduce disease, and enhance vitality. Seed treatment methods include soaking in milk, smearing with cow-dung (gomaya), ash, ghee, honey, or herbal pastes; rubbing or scarification of hard-coated seeds; fumigation; drying under shade; and proper storage in dry, cool places away from pests and heat. Example: Seeds of Bakuchi (Psoralea corylifolia Linn.) showed improved germination and better active ingredient profiles when seeds were treated using traditional Vṛkṣāyurvedic methods such as soaking in milk, fumigation with vidanga & ghee, or by applying pastes of Brihati, Tila, Kamala nāla, and honey, compared to untreated controls [15]. Another example: Embelia ribes (bidanga) seeds stored for three months; seeds soaked in cow dung slurry had higher germination compared to controls. [16]Use of Natural Manures and Organic Fertilization (Kunapā, Panchagavya, etc.)

Use of decomposed organic matter, animal waste, herbal concoctions, and preparations like kunapā or panchamula are advocated to enrich soil fertility, improve microbial life in soil, and sustain long-term soil health rather than relying solely on synthetic inputs. Example: In studies with chickpea (Cicer arietinum L.), seed invigoration treatments with Vṛkṣāyurveda-based herbal kunapājala improved seed germination and seedling vigour [17].

### *Biodiversity, Crop Rotation, and Companion Planting*

Vṛkṣāyurveda recognizes that mixing different species, planting companion plants, intercropping, and rotating crops can help maintain soil health, break pest and disease cycles, and improve ecosystem balance. Conservation of indigenous and local varieties is also emphasized. Example: In recent modern trials with Proso millet (Panicum miliaceum L.), adoption of traditional practices (which often include crop rotations, mixed cropping) resulted in yields comparable to modern agricultural practices, showing that these biodiversity-centered practices are effective [18].

**Natural Pest & Disease Management**

Instead of or in addition to synthetic chemicals, Vṛkṣāyurveda endorses use of herbal remedies, smoke or fumigation, botanical extracts, and encouraging natural predators. Practices like fumigation (dhūpan), decoctions from roots, leaves or plant parts (e.g. panchamūla), or application of substances like neem, cow dung, honey etc. to seeds or plants are common. Example: Ancient prescriptions include fumigation of seeds/plants with fumes of animal fats, ghee, horn, or plant materials. Sprays or decoctions of herbal mixtures are used to ward off pests [19].

***Soil and Water Management***

Knowledge of soil types (texture, fertility, moisture retention), proper preparation of soil before sowing, ensuring adequate water supply through traditional irrigation or natural water harvesting, proper drainage to avoid water stagnation, and practices that maintain soil moisture (mulching, organic matter) are part of Vṛkṣāyurveda. Soil is considered a living medium needing nourishment and balance. Example: Vṛkṣāyurveda text mentions soil classification by fertility, dealing with water scarcity via irrigation or using mulches and manures; modern interpretations of Vṛkṣāyurveda also include water conservation techniques [20].

**Rejuvenation and Maintenance of Plants (Vṛkṣa-Punarjīvana etc.)**

Just as humans need care, pruning, protection, and periodic treatment for health, ancient agriculture texts prescribe rejuvenation of older trees, protecting trees from diseases, ensuring that plant environment (shade, spacing, nutrients) is maintained, grafting, and general caretaking to extend productive life [20].

***Ecological Harmony and Sustainability***

A core Vṛkṣāyurveda principle is that agriculture should be practiced in harmony with nature: preserving biodiversity, conserving indigenous plant varieties, maintaining soil life, avoiding over-use of chemicals, integrating animals/plants/ecosystem components, and understanding climatic/seasonal conditions. This leads to sustainable productivity. Example: Modern review articles note that Vṛkṣāyurveda emphasizes crop diversity and reduced chemical dependency, which aligns with current organic agriculture and the modern push for sustainable systems [21]

**Additional Illustrative Examples**

In seed treatment of Rajadan (Mimusops hexandra) and Bakul (Mimusops elengi L.), Surpāla's procedures include treating seeds with milk, dusting with herbal powders, fumigation, and then cutting or head-cutting to enhance germination . For Ervaru (Cucumis melo L.) seeds, Vṛkṣāyurveda prescribes wrapping the seeds, treating them with jaggery solution, heating (taptā) for a few days, then sowing; such practices help improve seed viability and germination speed .

Vrikshayurveda's focus on ecological harmony and the use of cow-based inputs have been found to improve soil microbiome diversity and enhance plant immunity, promoting long-term sustainability [22].

***Modern Cultivation Techniques: Advances and Challenges***

**Modern agriculture encompasses:**

- **Genetic Improvement:** Hybrid seeds and genetically modified organisms (GMOs) offer enhanced yield, pest resistance, and stress tolerance [23].
- **Agrochemicals:** Synthetic fertilizers (nitrogen, phosphorus, potassium) and pesticides enable rapid growth and pest management but may cause soil and water pollution [24].
- **Irrigation Technologies:** Drip and sprinkler irrigation optimize water use efficiency [25].
- **Precision Agriculture:** Use of GPS, drones, sensors, and data analytics to monitor crop health, soil parameters, and optimize input use [26].
- **Mechanization:** Tractors, harvesters, and seed drills reduce labor and increase farm efficiency.

Despite these advances, the heavy reliance on chemical inputs has resulted in soil acidification, salinity, reduced microbial diversity, and accumulation of pesticide residues, posing environmental and human health risks [27]. Additionally, monoculture farming has diminished biodiversity, increasing vulnerability to pests and diseases [28].

**Merits and Demerits: Vrikshayurveda vs Modern Cultivation**

| Aspect | Merits of Vrikshayurveda / Traditional Systems | Demerits of Vrikshayurveda / Traditional Systems | Merits of Modern Cultivation Systems | Demerits of Modern Cultivation Systems |
|---|---|---|---|---|
| **Environmental Impact** | Promotes biodiversity, intercropping, companion planting; less chemical runoff, better soil microbiome | Sometimes slower restoration of degraded soil; dependency on local natural resources; may be harder to apply in degraded soils without inputs. | More control over inputs; ability to correct nutrient deficiencies quickly; high productivity per unit land. | Heavy use of synthetic fertilizers/pesticides; water pollution; soil degradation; loss of biodiversity. |
| **Yield / Productivity** | In some cases, traditional practices with Vrikshayurveda methods have produced yields | Generally lower yields, especially in initial phases or in nutrient poor soils; | Very high yield, rapid growth, ability to meet large-scale food demand | Yield gap: many studies show organic / traditional yields are lower on average (e.g. ~80% of |

| | | | | |
|---|---|---|---|---|
| | comparable to modern scientific ones (e.g. Proso millet study) under certain conditions. | slower growth; more variable. | | conventional). |
| **Sustainability & Long-Term Soil Health** | Better maintenance of soil structure and fertility; less erosion; use of organic manure etc. supports long-term health. Culture and Heritage+1 | Requires time and labor to maintain; nutrient availability may be limiting unless managed well; may need more land in some cases. | Modern techniques can build soil fertility (e.g., with tailored fertilizer usage, soil amendments), especially when combined with modern conservation methods. | Overuse of chemicals, compaction, salinization, decline of organic matter; long-term soil health may suffer. |
| **Cost & Inputs** | Lower costs for chemical inputs; often uses locally available herbal/manure resources; less dependence on industrial supply chains. | Labour-intensive; preparation of organic manures, seed treatments etc. may require more time and effort; transition period may reduce profit. | Mechanization, chemical fertilizers, high-yielding varieties can reduce labour; higher output per labour input; economies of scale. | High input costs; dependency on synthetic fertilizers / chemicals; environmental externalities often not paid for; risk of input price fluctuations. |
| **Health / Food Safety** | Likely lower pesticide / chemical residues; potentially more nutritious produce in some cases; ecological safety. | Potential for lower uniformity, possible issues with storage or pest damage if not managed well; less oversight in standardization. | Ability to ensure consistent pest control, uniformity, faster harvests; often better control over varieties and market preferences. | Risk of pesticide residues; health risks from chemical exposure; environmental pollution; possible negative effects on non-target organisms. |
| **Scalability & Uniformity** | Traditional systems are well adapted in local contexts; better resilience, cultural acceptance; often more sustainable in marginal lands | Scaling up may be difficult: practices may not translate uniformly; uniformity in output may be lower; may need adaptation. | Very scalable; modern agriculture can be standardized, mechanized, produce uniform product for markets. | Sometimes less resilient in face of climate stresses; overreliance on uniform varieties may reduce adaptation; environmental cost. |
| **Innovation & Knowledge** | Rich traditional knowledge base; wisdom on seed treatment, plant health, ecological interactions; potential for integrating with modern science. | Some knowledge is in ancient language, qualitative; may lack precise quantification; risk of knowledge loss; requires scientific validation. | Modern agriculture builds upon research; uses scientific breeding, biotechnology, precision agriculture, data analytics. | Sometimes knowledge is disconnected from ecology; focus on yield over sustainability; may ignore traditional ecological insights. |

## Recent Research and Advances in Agriculture

### *Precision Agriculture and Digital Farming*

Modern agriculture has increasingly adopted **precision agriculture** using satellite imagery, drones, IoT sensors, and AI-driven analytics for site-specific crop management. This approach enhances resource efficiency, reduces input wastage, and minimizes environmental footprint [29].

### *Biofertilizers and Biopesticides*

Research into **biofertilizers** and **biopesticides** using microbial consortia and plant extracts aligns with the ecological principles of Vrikshayurveda. Recent studies have demonstrated the effectiveness of neem-based biopesticides and microbial inoculants to improve nutrient cycling and plant immunity [30].

### *Climate-Resilient Crops*

Advances in biotechnology focus on developing **drought-tolerant, flood-resistant, and pest-**resistant crop varieties to adapt to climate change. Integration of traditional germplasm with molecular breeding is an emerging area [31].

## Integrative Farming Approaches in India

### *Karnataka: Panchagavya-Based Organic Farming*

In Karnataka, several farmer groups have embraced Panchagavya and Jeevamrutha preparations, which are fermented mixtures of cow products (milk, curd, ghee, urine, dung) and herbal extracts, alongside organic manures such as compost and vermicompost. These biofertilizers enhance microbial activity, soil nutrient availability, and plant immunity, reducing dependence on chemical fertilizers. The University of Agricultural Sciences, Bengaluru, has promoted integrated pest management strategies that combine Vrikshayurveda principles—like the use of neem, garlic, and other herbal extracts—with modern interventions such as soil testing, drip irrigation, and crop rotation. Field reports indicate improved soil fertility, enhanced pest and disease resistance, and sustained yield improvements in crops including maize, turmeric, vegetables, and banana [32,33]. Furthermore, intercropping strategies, such as maize with legumes or turmeric with marigold, have been successfully adopted to reduce pest pressure and improve overall farm resilience.

### *Maharashtra: Organic Cotton and Millet Cultivation*

In Maharashtra, the Sant Tukaram Organic Farmers Association implements Vrikshayurveda-based seed treatments using herbal decoctions and cow-derived preparations, alongside scientific nutrient management for cotton and millet. Farmers apply neem-based bio-pesticides, herbal sprays, and organic mulches to conserve soil moisture and enhance soil microbial diversity. Collaborations with agricultural universities have enabled systematic yield monitoring, pest surveillance using mobile applications, and training on integrated nutrient management. This holistic approach has led to reduced input costs, improved fiber quality in cotton, better grain quality in millet, and greater access to premium organic markets [34,35]. Additionally, crop residue management using bio-decomposers and green manuring has further enhanced soil structure and fertility.

### *Other Regions: Holistic Farming Models*

In Punjab and Kerala, pilot projects have demonstrated the potential of integrating Ayurvedic farming inputs with precision agriculture technologies. Farmers have adopted soil sensors, drone-based field monitoring, and automated irrigation systems while applying Vrikshayurveda formulations such as Jeevamrutha, Panchagavya, and herbal pest repellents. This approach allows real-time monitoring of soil moisture, nutrient levels, and pest infestation, thereby optimizing resource use and minimizing ecological impact. The National Innovation Foundation has documented numerous indigenous practices that combine traditional Ayurvedic inputs with mechanization and modern irrigation techniques, illustrating the scalability and adaptability of integrative farming approaches across diverse agro-climatic zones [36,37]. Crops such as paddy, wheat, pulses, and vegetables have shown improved resilience, lower pest incidence, and higher market value under these models.

## Discussion

Vṛkṣāyurveda, the ancient science of plant life and agriculture, emphasizes a holistic and ecological approach to farming, prioritizing seed quality, soil fertility, biodiversity, and plant health management. One of the foundational principles in Vṛkṣāyurveda is the meticulous selection, treatment, and storage of seeds (Bijavṛtti / Bījaprayoga). Ancient texts emphasize the use of mature, high-quality seeds, harvested at the proper season to ensure optimal germination, vitality, and disease resistance. Various traditional methods are prescribed to enhance seed quality, including soaking in milk, smearing with cow-dung (gomaya), ash, ghee, honey, or herbal pastes; scarification of hard-coated seeds; fumigation; and storage in dry, cool conditions away from pests. For instance, seeds of Psoralea corylifolia treated with milk, fumigation using vidanga and ghee, or application of herbal pastes such as Brihati and Tila demonstrated improved germination and enhanced bioactive content compared to untreated seeds [15]. Similarly, Embelia ribes seeds soaked in cow-dung slurry before storage showed higher germination after three months, illustrating the effectiveness of traditional seed treatment techniques [16].

Soil fertility management is another cornerstone of Vṛkṣāyurveda. Instead of relying solely on chemical fertilizers, the texts advocate for organic manures and herbal preparations such as kunapā, Panchagavya, and Panchamula-based mixtures to sustain long-term soil health. These inputs improve microbial activity, nutrient availability, and plant vigor. Contemporary studies have validated these traditional practices; for example, the use of Vṛkṣāyurveda-based kunapājala for chickpea seeds enhanced germination rates and seedling vigor, highlighting the enduring relevance of these ancient approaches [17].

Vṛkṣāyurveda also strongly promotes biodiversity, crop rotation, and companion planting as a means to maintain ecological balance and soil fertility while reducing pest and disease pressure. Intercropping, planting companion species, and conserving indigenous varieties were common practices in traditional systems. Modern research supports these methods; in trials with Proso millet (Panicum miliaceum), traditional practices including mixed cropping and rotations yielded results comparable to modern agricultural methods, demonstrating the efficacy of biodiversity-centered approaches [18]. Such systems foster resilience against climatic variability and minimize the ecological footprint of agriculture.

Natural pest and disease management is a further critical aspect of Vṛkṣāyurveda. Ancient agronomists recommended fumigation using plant materials, animal fats, and ghee, application of herbal extracts, and encouragement of natural predators instead of relying on synthetic pesticides. Decoctions from roots, leaves, or entire plants (e.g., panchamūla) and application of substances like neem, cow dung, and honey have been used to safeguard seeds and crops [19]. This integrated approach not only controls pests but also enhances soil and plant health, maintaining an ecological equilibrium.

Soil and water management principles in Vṛkṣāyurveda recognize soil as a living medium requiring nourishment, aeration, moisture balance, and fertility management. Techniques include classification of soil types, proper tillage, mulching, organic matter incorporation, and water conservation

through irrigation and natural harvesting methods. These practices are instrumental in maintaining soil structure, preventing erosion, and ensuring sustainable water use [20].

The rejuvenation and maintenance of plants (Vṛkṣa-Punarjīvana) is akin to human healthcare. Traditional texts prescribe pruning, grafting, disease protection, and periodic treatment of trees to extend productive life. Ensuring appropriate plant environment through spacing, shade management, and nutrient supplementation further sustains vitality [20]. Additionally, the principle of ecological harmony is deeply embedded in Vṛkṣāyurveda, advocating for sustainable interaction with nature through biodiversity preservation, reduction of chemical inputs, and integration of animals, plants, and ecosystem components [21]. For example, treatment of seeds of Mimusops hexandra and Mimusops elengi using milk, herbal powders, fumigation, and head-cutting improved germination rates, demonstrating the efficacy of these ecologically attuned practices. Similarly, practices involving cow-based preparations enhance soil microbiome diversity and plant immunity, promoting long-term sustainability [22].

In contrast, modern cultivation techniques emphasize yield maximization through technological advancements. Genetic improvement via hybrid seeds and GMOs provides enhanced productivity, pest resistance, and stress tolerance [23]. Agrochemicals, including synthetic fertilizers and pesticides, facilitate rapid crop growth but carry risks of soil and water pollution [24]. Advanced irrigation systems, such as drip and sprinkler methods, optimize water use [25], while precision agriculture utilizes GPS, drones, and sensors to monitor crops and soil parameters, improving input efficiency [26]. Mechanization reduces labor intensity and increases operational efficiency. Despite these advantages, the overreliance on chemical inputs has led to soil degradation, salinization, reduced microbial diversity, pesticide residues, and environmental pollution [27]. Additionally, monoculture practices diminish biodiversity and increase vulnerability to pests and diseases [28].

A comparison between Vṛkṣāyurveda and modern cultivation systems highlights distinct merits and demerits. Traditional methods excel in promoting biodiversity, long-term soil health, and ecological sustainability, with lower chemical residues and potential health benefits. However, they are labor-intensive, slower in productivity, and may require larger areas for equivalent output. Modern systems offer higher yields, scalability, uniformity, and efficiency but can compromise environmental integrity and long-term soil fertility. Integrative approaches that combine the ecological wisdom of Vṛkṣāyurveda with modern tools can harness the strengths of both systems while mitigating weaknesses.

Recent agricultural innovations resonate with Vṛkṣāyurveda principles. Precision agriculture integrates satellite imagery, drones, IoT sensors, and AI to optimize input use and reduce environmental impact [29]. Biofertilizers and biopesticides, including neem-based formulations and microbial inoculants, improve nutrient cycling, plant immunity, and soil health, aligning with traditional practices [30]. Advances in climate-resilient crop development also combine conventional germplasm with molecular breeding to address drought, flood, and pest stress [31].

Integrative farming approaches in India illustrate the practical application of Vṛkṣāyurveda alongside modern techniques. In Karnataka, farmers employ Panchagavya and Jeevamrutha along with organic manures, intercropping, drip irrigation, and soil testing to enhance productivity and soil health [32,33]. Maharashtra's organic cotton and millet cultivation utilizes herbal seed treatments, neem-based bio-pesticides, and organic mulches, supported by university-led training programs, improving fiber quality, grain yield, and market access [34,35]. Pilot projects in Punjab and Kerala demonstrate the synergy of Ayurvedic inputs with precision agriculture, utilizing soil sensors, drones, and automated irrigation systems to optimize resource use, reduce pests, and improve crop resilience [36,37]. These integrative models validate the potential of combining traditional ecological knowledge with modern technology for sustainable agricultural development.

Overall, Vṛkṣāyurveda offers a time-tested framework for ecologically sustainable, resilient, and health-promoting agriculture. While modern agriculture delivers high efficiency and rapid productivity, its ecological costs necessitate the adoption of integrative strategies that balance yield goals with environmental and social sustainability. The convergence of ancient wisdom with modern scientific tools presents a pathway toward resilient, sustainable, and productive agricultural systems for the 21st century.

## Conclusion

In conclusion, the synthesis of Vṛkṣāyurveda principles with modern agricultural innovations offers a promising model for sustainable food production. This integrative approach fosters ecological resilience, reduces reliance on chemical inputs, enhances crop quality, and safeguards soil and water resources. Adoption and scaling of such systems can contribute significantly to global efforts in achieving sustainable agriculture, climate adaptability, and food security for future generations.

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