JOURNAL OF ECOLOGY AND CONSERVATION
Jul - Sep 2026, VOL. 4, ISSUE 3, pp. 14-21
https://doi.org/10.61577/jec.2026.1000013

REVIEW ARTICLE

Integrated plant protection and agroecological approaches to waste management for sustainable natural resource conservation

Yasser Saeed Cassim[1], Maxwell Ayibasin[1], Aisha Twalibu[2], Ellena Chikhazu[2], Hazel Samartha Mabangwe[2] and Witness Twalibu[3]

[1]Agrarian and Technological Institute, Peoples' Friendship University of Russia, Moscow, Russian Federation

[2]Institute of Environmental Engineering, Peoples' Friendship University of Russia, Moscow, Russian Federation

[3]Lilongwe University of Agriculture and Natural resources (LUANAR), Bunda College Campus, Post Office Box 219, Lilongwe, Malawi

Abstract

Agriculture must control pests, recycle organic residues, maintain yields and conserve soil and water under variable climatic and economic conditions. This integrative review examines how integrated plant protection can be strengthened by ecological diversification, composting, biochar application, nutrient recycling and conservation-oriented soil management. The evidence base comprised 40 DOI-verified original studies published between 1987-2024 and nine supporting agroecology and circularity papers published between 2002-2025. Because the primary studies differed substantially in intervention type, study scale, outcome definition and measurement unit, the evidence was grouped mechanistically and synthesized across comparable outcome families. Study-level extraction retained production context, comparator, direction of effect, quantitative signals when directly reported and stated limitations. The synthesis indicates that diversified habitats, flower strips, push-pull systems and balanced natural-enemy communities can reduce pest pressure while maintaining or improving yield. Compost and biochar may enhance soil biological activity, stimulate plant defenses and suppress soil-borne and foliar diseases, but outcomes depend on feedstock, processing conditions, application rate, pathogen, crop and soil context. Long-term experiments further show that organic amendments, legume rotations, reduced tillage and continuous soil cover can improve aggregation, carbon retention, nutrient-use efficiency and erosion control. However, excessive compost application may increase phosphorus accumulation and leaching. Effective integration requires quality-controlled amendments, crop-matched nutrient budgets, habitat management, pest monitoring, farmer participation and adaptive decision-making. This approach transforms waste management from disposal into a foundation for preventive plant protection and sustainable natural-resource conservation.

KEYWORDS

Agroecology; Integrated plant protection; Compost; Biochar; Circular agriculture; Natural-resource conservation

ARTICLE HISTORY

Received 14 August 2026;
Accepted 11 September 2026;
Published 19 September 2026

Introduction

Agriculture now operates within a difficult contradiction: It must produce reliable harvests while reducing dependence on inputs that can simplify food webs, degrade soil structure, contaminate water and weaken long-term resilience. Agroecology addresses this contradiction by treating the farm as an ecological and social system rather than as a collection of isolated production problems. Its central ideas include recycling, diversity, synergy, efficiency, resilience, co-creation of knowledge and responsible governance of land and natural resources [1,2]. Long-term field evidence shows why these systems view matters. Legume-based rotations can reduce carbon and nitrogen losses; organic management can sustain soil biological activity and organically managed soils can be less vulnerable to erosion than conventionally managed counterparts [3-5]. Integrated plant protection applies the same logic to pests and diseases. Instead of responding only after damage becomes visible, it builds preventive regulation through crop diversity, habitat management, resistant or adapted plant material, biological control, informed monitoring and selective intervention. Landscape structure can influence parasitism and natural pest control, while diverse agricultural landscapes can support stronger suppression of introduced pests [6,7].

Multi-country experiments in rice demonstrated that flowering vegetation and ecological engineering can reduce insecticide dependence without sacrificing production [8]. Similar benefits have been reported where wildlife-friendly habitat was embedded in intensive farmland, where perennial wildflower strips enhanced pest control in wheat and where climate-adapted push-pull systems reduced fall armyworm damage in East African maize [9-11]. Organic waste management creates a second entry point for preventive plant protection. Properly processed crop residues, food waste, yard materials, manures and other biodegradable resources can be converted into compost or biochar rather than lost through uncontrolled dumping or burning. Their value is not limited to nutrient supply. Experiments with multiple composts and pathosystems show that suppressiveness is biologically real but highly variable, while agricultural-waste composts have suppressed diseases caused by *Rhizoctonia solani* and *Sclerotinia minor* [12,13]. Co-composted biochar has been tested as a means of strengthening disease suppression and soil-applied biochar has induced systemic resistance in plants [14,15]. In tomato, wheat-straw biochar reduced bacterial wilt while changing soil chemistry and the rhizosphere bacterial community [16]. In urban production, leaf-mold compost improved soil properties, reduced foliar disease and increased marketable tomato yield [17]. These outcomes make waste valorization directly relevant to integrated plant protection. The remaining challenge is integration. A material can suppress one pathogen yet fail against another; an amendment that improves soil carbon can also create phosphorus surpluses if its nutrient content is ignored.

Conservation tillage can protect aggregates, but its agronomic success depends on weed management, rotation, residue availability and local soil conditions. Field evidence shows that organic and

***Correspondence:** Ms. Aisha Twalibu, Institute of Environmental Engineering, Peoples' Friendship University of Russia, Moscow, Russian Federation. e-mail: 1032255983@rudn.ru

©2026 The Author(s). Published by Reseapro Journals. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

reduced-tillage systems can lower sediment delivery, while repeated farm compost applications can improve soil quality without necessarily increasing nitrogen or phosphorus leaching when rates and management are appropriate [18,19]. Conversely, long-term fertilization studies warn that phosphorus form, loading rate and crop recovery determine leaching risk [20]. Circularity must therefore be managed, not assumed. This manuscript synthesizes evidence on how integrated plant protection, waste valorization and conservation practices can be assembled into a coherent strategy and identifies the conditions, monitoring requirements and trade-offs that determine whether the strategy remains productive and environmentally sound [21]. Thus, these studies indicate that plant protection improves when ecological functions are intentionally designed into fields and landscapes. Based on this, the paper seeks to connect integrated plant protection and agroecological approaches as a means of waste management for sustainable natural resource conservation.

Literature Review

Agroecological foundations of integrated plant protection

Agroecological plant protection begins with the proposition that pest regulation is produced by relationships among crops, non-crop vegetation, natural enemies, soils, farm decisions and surrounding landscapes. The approach does not reject intervention; it changes its sequence and purpose. Prevention, observation and ecological regulation come before broad-spectrum control [22]. At landscape scale, structurally complex surroundings increased parasitism and biological control in early field studies and greater landscape diversity strengthened suppression of soybean aphid in the north-central United States [6,7]. At the community level, evenness among natural enemies was associated with improved pest control in organic systems, while experimental predator assemblages showed that biodiversity can strengthen aphid suppression across prey communities [23,24]. These results support a functional view of biodiversity: The goal is not diversity for its own sake, but the maintenance of organisms, habitats and interactions that interrupt pest population growth.

Field-scale diversification translates that principle into practical design. Flowering vegetation around rice fields supported ecological intensification across several Asian countries [8]. Wildlife-friendly interventions in conventional farms produced yield benefits after ecological functions matured and species-rich wildflower strips reduced cereal leaf beetle pressure and increased adjacent wheat yield [9,10]. Flower plantings can also increase wild-bee abundance and pollination services, showing that habitat interventions may support several functions simultaneously [25]. Push-pull systems combine repellence, attraction, fodder production, soil cover and crop diversification; the climate-adapted version sharply reduced fall armyworm abundance and damage while increasing maize yield [11]. Adoption research adds a necessary social dimension. Kenyan mango studies found that integrated fruit-fly management generated farm, health, environmental and spillover benefits [26-28]. Participatory assessments further show that farmers judge soil, water and pest practices as linked rather than separate and that locally relevant co-design improves the likelihood that complex options will be implemented [29]. Safe-practice adoption nevertheless depends on knowledge, resource access, labor and institutional support [30,31].

Waste valorization, compost, biochar and disease suppression

Compost-mediated disease suppression is one of the clearest links between waste valorization and plant protection. In a comparison of 18 composts against seven pathosystems, suppressiveness varied with both compost and pathogen, demonstrating that the label "compost" does not predict biological performance [12]. Field application nevertheless reduced take-all severity and increased winter-wheat yield in another experiment [32]. Agricultural-waste compost suppressed *R. solani* and *S. minor* under control conditions, while leaf-mold compost produced from an urban waste stream improved soil microbial property, reduced foliar disease and raised tomato productivity [13,17]. Food- and yard-waste compost increased Swiss-chard growth and improved soil organic carbon, nitrogen, available phosphorus and cation-exchange capacity [33]. A three-year tomato experiment similarly showed that food- and green-waste composts can contribute to nitrogen and support yield when integrated with fertilizer management [34]. These benefits are accompanied by a nutrient-balancing requirement: A seven-year urban-garden experiment found that compost applied to meet crop nitrogen demand could oversupply phosphorus and increase leachate losses [35].

Biochar introduces stable carbon, reactive surfaces, altered nutrient retention and new microbial habitats, but its plant-health effects are equally context dependent. Biochar induced systemic resistance to foliar pathogens and a mite pest in tomato and pepper and mediated systemic responses of strawberry to fungal pathogens [15,36]. Wheat-straw biochar suppressed tomato bacterial wilt while shifting rhizosphere bacterial composition, whereas other work linked strawberry-fruit resistance to *Botrytis cinerea* with changes in the rhizosphere microbiome [16,37]. Compost and biochar together altered mycorrhization, tomato root exudation and the development of *Fusarium oxysporum* [38]. Biochar also changed the severity of soybean disease caused by *Fusarium virguliforme*, with outcomes dependent on material and dose [39]. Molecular analysis in tomato connected biochar-mediated growth promotion and resistance to changes in defense pathways and the root-zone environment [40]. Pepper experiments associated biochar control of Phytophthora blight with improvement of the rhizosphere fungal community and combined application of biochar, compost and growth-promoting rhizobacteria reduced tomato early blight [41,42]. Co-composting biochar may therefore be useful, but no single amendment should be treated as a universal pesticide substitute [14].

Soil, water and natural-resource conservation

The conservation literature shows that biological plant protection becomes more reliable when the soil resource is protected. In long-term experiments, legume-based rotations reduced carbon and nitrogen losses relative to input-intensive comparison systems and organic management supported soil fertility and biodiversity with lower external input use [3,4]. Comparisons of organic and conventional soils found lower erodibility and better structural indicators under organic management [5,43]. During an extreme climate year, long-term organic systems displayed greater yield stability than conventional comparison systems, illustrating the importance of soil water-holding capacity and management history [44]. Rainfall-simulation work subsequently showed that reduced tillage within organic farming markedly reduced sediment delivery, especially where living cover protected the surface [18]. Improvement in aggregation has also been measured where organic crop management was combined with reduced tillage and a grass-clover ley [45]. After ten years, conservation of the tillage in organic farming produced clear changes in soil fertility distribution, although responses varied with depth and management [46].

Organic residues influence conservation outcomes through both carbon addition and nutrient cycling. Repeated farm compost application increased soil organic carbon and several biological and physical soil-quality indicators without increasing nitrogen and phosphorus leaching in a carefully managed field trial [19]. An eight-year Norwegian systems experiment showed that environmental, fertility, yield and economic outcomes must be evaluated together because no cropping system maximized every indicator [47]. Long-term comparisons of organic and mineral fertilizers confirmed that manure and compost can build soil carbon, but phosphorus loading and sorption determine whether this benefit is accompanied by leaching risk [20]. Food- and green-waste compost can improve crop nitrogen-use efficiency when it is paired with crop demand and fertilizer management, while the seven-year urban study demonstrates the consequence of repeatedly applying compost on a nitrogen basis [34,35]. The circular-economy implication is precise:

© 2026 Reseapro Journals
https://doi.org/10.61577/jec.2026.1000013

biomass to soil can reduce waste and restore ecological function, but nutrient budgets, contamination screening, water pathways and locally adapted decision rules remain essential [21,48]. Broader agroecological syntheses therefore place recycling beside diversity, efficiency, resilience, participation and responsible resource governance rather than treating it as an isolated objective [1,2,49].

Methodology

Review design and evidence base

The study used a structured integrative-review design. A pooled meta-analysis was considered but was not selected because the corpus does not share a single intervention-outcome estimand: It combines landscape ecology, plant pathology, soil science, nutrient management, farm economics and participatory innovation, and includes field, greenhouse, laboratory, long-term systems and farm-household designs. Pooling these unlike outcomes into one standardized effect would obscure rather than resolve the ecological and management heterogeneity. The core evidence base comprised 40 DOI-verified, peer-reviewed original studies published from 1987 through 2024. Nine (9) supporting documents were used to define agroecological principles, circularity, farmer participation and transition context. Supporting reviews and conceptual papers were not used as substitutes for primary outcome evidence. The review was reference-led and bounded rather than presented as an exhaustive systematic search of every bibliographic database. Candidate papers were retained when they reported an original field experiment, greenhouse or laboratory experiment, long-term systems comparison, farm-household impact assessment, or participatory assessment directly related to at least one of three domains: Ecological plant protection; organic-waste valorization and disease suppression; or soil, water, carbon and nutrient conservation. Records were excluded from the outcome synthesis when they lacked a resolvable DOI, did not report original observations, or addressed agricultural sustainability without a direct connection to the review domains.

Data extraction and synthesis

For every primary study, information was extracted on production context, intervention, comparator, measured plant-protection or resource outcome, duration, direction of effect and stated limitation as explained in Table 1. Studies were then organized by mechanism rather than by crop. Ecological-regulation mechanisms included habitat provision, crop diversification, push-pull effects, natural-enemy balance and integrated pest-management packages. Amendment mechanisms included nutrient supply, microbial antagonism, induced resistance, shifts in rhizosphere communities, carbon stabilization and changes in soil physical properties. Conservation mechanisms included ground cover, aggregation, erosion control, nutrient retention, crop recovery and leaching. Evidence was synthesized in four steps: (1) studies were grouped by mechanism and outcome family; (2) direction of effect and any directly reported quantitative signal were extracted; (3) convergence and contradictions were compared within outcome families rather than across unlike metrics; and (4) contextual modifiers and limitations were recorded before cross-study conclusions were drawn. Direction-of-effect mapping was used as an organizing device, not as a statistical-significance test. Contradictory or conditional outcomes were retained, especially for compost and biochar, because amendment identity, dose, processing conditions, soil, crop and pathogen can change the result. Quantitative values were reported only when they came directly from individual studies; no new pooled effect size was calculated.

Table 1. Evidence-extraction and synthesis framework.

Evidence domain	Eligible study designs	Variables extracted	Primary synthesis question	References
Ecological plant protection	Field experiments, landscape studies, IPM impact assessments	Habitat or crop treatment, pest pressure, natural enemies, yield, insecticide use, income or health outcome	Does ecological diversification prevent pest damage while maintaining production?	[6,8,11.24]
Compost & organic-waste valorization	Compost comparisons, pot trials, field trials, urban-agriculture studies	Feedstock, maturity, application rate, disease severity, yield, soil biology, nutrient status	When does recycling organic matter improve plant health rather than transfer risk?	[12,13,34,35]
Biochar-mediated disease regulation	Greenhouse, molecular & rhizosphere experiments	Feedstock, pyrolysis or dose information, pathogen response, plant defense, microbial community	Which material & biological mechanisms are associated with disease suppression?	[15,16,40,42]
Soil, water & nutrient conservation	Long-term systems trials, rainfall simulations, leaching experiments	Soil carbon, aggregation, erosion, nitrogen & phosphorus balance, leachate, yield stability	Do integrated practices conserve resources without creating nutrient surpluses?	[3,18,19,20]

Analytical treatment of heterogeneous evidence

The included studies reported heterogeneous outcomes across ecological plant protection, waste-derived amendments and natural-resource conservation. Ecological plant-protection studies assessed pest abundance, crop damage, natural-enemy activity, insecticide use, yield and socioeconomic outcomes; amendment studies examined disease severity, soil or rhizosphere responses, nutrient status and yield; and conservation studies evaluated soil carbon, aggregation, erosion, nitrogen and phosphorus balance, leaching and yield stability. Study scales ranged from molecular and greenhouse experiments to multi-country field studies and farm-household assessments. Accordingly, studies were grouped by mechanism and comparable outcome family, quantitative values were reported only when directly available, significance-based vote counting was avoided, and heterogeneity and contradictory outcomes were retained in the synthesis. Table 2 presents representative study-level extractions together with the main sources of

© 2026 Reseapro Journals
https://doi.org/10.61577/jec.2026.1000013

methodological and contextual heterogeneity affecting cross-study comparison.

Table 2. Representative study-level evidence extraction and analytical interpretation.

Study & context	Intervention or comparison	Extracted outcome signal	Interpretive limitation / source of heterogeneity	Reference
Multi-country rice field experiments	Flowering vegetation/ecological engineering	Reduced insecticide dependence while production was maintained	Country, vegetation, & landscape context varied; outcome metrics were not identical.	[8]
Wheat field study	Perennial species-rich wildflower strips	Lower cereal leaf beetle eggs, larvae, & crop damage; yield increased near strips	Response depends on distance from habitat, species composition, & establishment time.	[10]
East African maize	Climate-adapted push-pull vs. maize monocrop	Fall-armyworm larval abundance reduced by 82.7%, plant damage reduced by 86.7%, & grain yield was 2.7 times higher	Crop- and pest-specific response; requires suitable companion plants & management knowledge.	[11]
18 composts × 7 patho-systems	Compost suppressiveness comparison	Disease suppression varies by compost & pathogen	No single compost effect exists across feedstocks & patho-systems; this provides direct evidence of heterogeneity.	[12]
Soil-borne disease experiments	Agricultural-waste composts	Suppressed *R. solani & S. minor*	Controlled conditions & pathogen-specific responses limit direct pooling with field disease studies.	[13]
Compost-biochar comparison	Biochar added during composting vs. component treatments	Adding biochar did not consistently improve disease suppression across tests	Combination effects were not uniformly synergistic & depended on the final product & disease system.	[14]
Tomato bacterial-wilt system	Wheat-straw biochar	Reduced bacterial wilt with changes in soil chemistry & rhizosphere bacterial community	Single biochar patho-system combination; feedstock & dose matter.	[16]
Managed field trial	Farm compost plus non-inversion tillage	Improved soil quality without increased N or P leaching under the tested regime	Rate, soil, & management conditions govern transferability.	[19]
Long-term silt-loam fertilization trial	Organic & mineral fertilizer treatments	Soil P & C, yield, & P-leaching responses depended on P loading & sorption	Long-term nutrient history & soil properties determine risk.	[20]
Winter-wheat field experiment	Compost application	Take-all severity decreased & winter-wheat yield increased	Single crop-pathogen-site combination; not a universal compost effect.	[32]
Three-year irrigated tomato study	Food- & green-waste compost integrated with fertilizer management	Compost contributed N & supported yield	Effect depends on crop demand & the accompanying fertilizer regime.	[34]
Seven-year urban-garden study	Repeated compost application	Applying compost to meet N demand could oversupply P & increase leachate losses	Long-term repeated loading & the urban-garden context are key boundary conditions.	[35]

Results

Across the 40 primary studies, the evidence was most interpretable as mechanism-specific patterns rather than as one pooled effect. Table 2 provides representative study-level extractions, while Table 3 summarizes cross-study directional patterns and the conditions that explain variation in response.

© 2026 Reseapro Journals
https://doi.org/10.61577/jec.2026.1000013

Ecological regulation of pests and production

The evidence consistently showed that non-crop habitat and crop diversification can strengthen biological regulation, but benefits depend on ecological design and time. Landscape complexity increased biological control and multi-country rice experiments showed that flowering vegetation could reduce reliance on insecticides while maintaining production [6,8]. In wheat, perennial wildflower strips reduced cereal leaf beetle eggs, larvae and crop damage and were associated with a yield increase near the strips [10]. The strongest crop-specific response occurred in the climate-adapted push-pull study: Compared with maize monocropping, the system reduced average fall-armyworm larval abundance by 82.7%, plant damage by 86.7%, and produced 2.7 times the grain yield [11]. These studies indicate that preventive plant protection is most effective when habitat resources, companion plants and crop arrangement are selected for a known ecological function. The evidence also showed that ecological intensification is not merely a biophysical intervention. IPM packages perform through knowledge, coordination and repeated use. Natural-enemy diversity can stabilize suppression but adoption and continued implementation depend on whether farmers observe benefits, can obtain inputs and can fit monitoring and sanitation into existing labor routines [24]. Consequently, field design and farmer decision-making are inseparable components of integrated plant protection.

Disease suppression through recycled organic materials

Compost and biochar frequently improved plant health, but the synthesis did not support a universal suppressive effect. The 18-compost comparison produced variable responses across seven pathosystems [12]. In contrast, compost reduced take-all severity and increased winter-wheat yield in a field experiment and agricultural-waste composts suppressed *R. solani* and *S. minor* [13,32]. Adding biochar during composting did not guarantee superior disease control across every test, reinforcing the importance of validating the final product rather than assuming synergy [14]. Biochar-mediated suppression was more convincing where studies linked disease outcomes to plant defense or microbial change. Wheat-straw biochar suppressed tomato bacterial wilt and shifted the rhizosphere bacterial community, while molecular work connected tomato resistance to *Fusarium* crown and root rot with biochar-mediated changes in growth and defense [40]. A combined biochar-compost-rhizobacteria treatment also reduced early blight in tomato [16,42].

Conservation outcomes and nutrient trade-offs

Table 3. Cross-study outcome patterns and boundary conditions identified in the primary evidence.

Practice or intervention	Plant-protection outcome	Production or resource outcome	Important condition or limitation	References
Flowering habitat & landscape diversification	Greater natural-enemy activity & lower pest pressure	Yield maintained or locally increased	Plant species, landscape context, distance & establishment time affect response	[6,8,10]
Climate-adapted push-pull	Strong reduction in fall-armyworm larvae & damage	Maize yield increased relative to monocrop	Requires suitable companion plants, seed access & management knowledge	[11]
Mature, biologically active compost	Suppression of selected soil-borne diseases	Improved yield & soil biological activity in responsive systems	Suppressiveness varies by feedstock, maturity, dose & pathogen	[12,13, 32]
Biochar or biochar-biological combinations	Induced resistance or rhizosphere-mediated suppression in several pathosystems	Carbon addition & improved soil conditions may accompany control	Responses may be neutral or adverse; feedstock & dose must be tested	[14,16, 40,42]
Legume rotations, organic management & reduced tillage	Healthier root-zone environment & reduced disturbance	Lower C & N losses, greater biological fertility & less erosion	Weed control, rotation design, soil type & surface cover influence performance	[3,4,18, 19]

Long-term studies showed that soil protection is cumulative. Legume-based systems reduced carbon and nitrogen losses, organic systems supported soil biological fertility and reduced tillage with organic management lowered rainfall-driven sediment loss [3,4,18]. Repeated farm compost improved soil carbon, microbial biomass, aggregate stability and other soil-quality indicators without increasing nitrogen or phosphorus leaching under the tested management regime [19]. These outcomes support the use of rotations, living cover, reduced disturbance and planned organic inputs as a connected conservation package. The same evidence identified a boundary condition: recycling does not remove the need for nutrient accounting. Compost contains carbon and plant nutrients in ratios that may not match crop demand. When compost is repeatedly applied to satisfy nitrogen demand, phosphorus can accumulate faster than crops remove it, increasing the risk of loss to water. Product testing, soil analysis, crop nutrient budgets and rate adjustment are therefore central components of circular agriculture, not administrative additions.

Discussion

Integrating plant protection with circular soil management

The evidence suggests that the strongest strategy is not a larger menu of independent practices, but a sequence of mutually supporting functions. Landscape diversity and balanced natural-enemy communities provide above-ground regulation [7,23,24]. Flower plantings and wildlife-friendly habitat add nectar, pollen, shelter and pollination services [9,25]. Below ground, compost and biochar can add organic substrates, alter microbial communities and stimulate defense [14,15,37]. Leaf-mold compost illustrates how a municipal residue can simultaneously improve soil properties, support beneficial microbes, reduce foliar disease and increase marketable yield [17]. At the systems level, rotations and reduced tillage protect the carbon, aggregation and water relations needed for those biological functions to persist [3,19,45]. Integration is therefore mechanistic: Each component should be selected for a function that supports the next component. This interpretation also changes the meaning of "integrated." Combining interventions is not automatically beneficial. If an amendment raises salinity, contains unstable organic

© 2026 Reseapro Journals
https://doi.org/10.61577/jec.2026.1000013

immobilizes nitrogen, or oversupplies phosphorus, it can undermine plant health. If flowering habitat supports the wrong organisms or is poorly timed, it may not improve control. Evidence from long-term fertilization and conservation experiments shows that responses depend on placement, rate, soil depth, crop sequence and monitoring [20,46,47].

Table 4. Decision matrix for implementing an integrated agroecological package.

Management objective	Recommended intervention package	Expected co-benefit	Risk indicator & monitoring need	References
Reduce insecticide-dependent pest control	Crop diversification, flowering margins, natural-enemy conservation & threshold-based monitoring	Pollination, biodiversity & improved field resilience	Track pest & natural-enemy abundance, crop damage & any non-target pest increase	[6,8,11, 24]
Convert biodegradable waste into a plant-health input	Source separation, controlled composting, maturity testing & crop-specific application	Waste diversion, nutrient return & microbial activity	Test EC, pH, stability, nutrients, contaminants & pathogen-specific suppressiveness	[12,13, 34,35]
Use biochar for disease management & carbon retention	Characterized biochar at validated dose, optionally combined with compost or beneficial microbes	Stable carbon, nutrient retention & rhizosphere habitat	Record feedstock, processing temperature, dose, soil response & disease severity	[15,16, 40,42]
Conserve soil & water	Legume or grass-clover rotation, continuous cover, reduced tillage & organic inputs	Aggregation, infiltration, carbon retention & lower sediment loss	Monitor ground cover, aggregate stability, runoff, erosion & weed pressure	[3,18,1 9,46]

Transferability, adoption and safeguards

The principal limitation to transfer is context. Compost suppressiveness varied across pathosystems, biochar effects differed with material and disease and landscape interventions were shaped by surrounding land use and crop ecology [12,14,39] . Socioeconomic studies of mango IPM show that benefits can extend to income, health and neighboring crops, but adoption still depends on information, access and collective action [26-28]. Participatory work in Kenya found that farmers preferred practices that addressed several soil, water and pest functions, yet their choices reflected local labor, resource and biophysical constraints [29]. Safeguards are equally important. Organic residues should be source-separated where possible and tested for maturity, pathogens, metals, salinity and other contaminants before agricultural use. Application should follow both nitrogen and phosphorus budgets, with soil and water monitoring where repeated inputs create accumulation risk [20,35]. Conservation packages should maintain sufficient cover to control erosion, while reduced tillage should be paired with viable weed-management and rotation strategies [18,46]. At landscape scale, habitat measures should be designed around target pests, natural enemies, crop phenology and farmer maintenance capacity. Circular food system thinking can guide resource flows, but it should not obscure unequal access to biomass, water, land, knowledge and markets [21]. Table 4 presents representative evidence from the included studies, emphasizing key outcomes and methodological and contextual heterogeneity across the evidence base.

Research gaps and priorities

Five recurring research gaps emerged from the evidence. First, compost and biochar studies need standardized characterization of feedstock, maturity or processing conditions, dose, contaminant status and disease-assay methods so that future effect estimates are more comparable across sites [12,14,39]. Second, more factorial field experiments should test habitat diversification, waste-derived amendments and conservation practices together rather than as isolated interventions, because the current evidence is strongest for individual mechanisms. Third, longer-term studies should track both plant-protection benefits and environmental liabilities, especially phosphorus accumulation, leaching and contaminant transfer under repeated organic inputs [20,35]. Fourth, adoption research should pair biophysical outcomes with labor, cost, access and collective-action variables to explain persistence beyond short projects [26-31]. Fifth, cross-region replication is needed to determine which responses transfer across soils, climates, crop systems and pest or pathogen complexes. These gaps define a future research program that can generate standardized datasets suitable for domain-specific meta-analysis rather than forcing one pooled estimate across incompatible outcomes.

Limitations of the synthesis

This review is deliberately integrative rather than meta-analytic. The evidence base covers different climates, soils, crops, pathogens, spatial scales, amendment types, study designs and outcome measures. Directional convergence can therefore be identified within mechanistically comparable outcome families, but a single average effect across the full corpus would hide important differences among systems. The reference-led design also means that the corpus is bounded and should not be interpreted as an exhaustive inventory of every relevant publication. Accordingly, the review does not claim systematic-review completeness or formal certainty grading. Future work should use preregistered database searches, common reporting standards for compost and biochar, longer field trials that measure both plant protection and nutrient losses, and participatory comparisons that record labor, cost, gendered access and adoption over time. Where sufficiently homogeneous intervention-outcome families emerge, domain-specific meta-analysis should use comparable effect measures and associated uncertainty rather than combine unrelated endpoints.

Conclusion

Integrated plant protection becomes more durable when it is built into the management of biodiversity, organic residues, soil, water and nutrients rather than operated as a separate response to outbreaks. The evidence reviewed here shows that diversified landscapes, flowering habitats, balanced natural-enemy communities and push-pull arrangements can prevent damaging pest growth while maintaining or improving crop production. Their effectiveness depends on ecological fit, farmer knowledge, timely monitoring and continuity across seasons. Waste valorization can reinforce this preventive foundation. Mature compost carefully produced biochar and compatible beneficial microorganisms can improve soil structure, nutrient availability, microbial activity and plant defense. They can also suppress

© 2026 Reseapro Journals
https://doi.org/10.61577/jec.2026.1000013

important soil-borne and foliar diseases. These outcomes are not automatic. Feedstock identity, processing conditions, amendment maturity, application rate, soil characteristics, crop species and pathogen biology determine whether a material is beneficial, ineffective, or harmful. Quality assurance and local validation must therefore precede recommendation. Natural-resource conservation provides the longer-term setting in which these biological processes can persist. Rotations containing legumes or temporary leys, continuous soil cover, reduced disturbance and planned organic inputs can conserve carbon, strengthen aggregation, improve water relations and reduce erosion. Nutrient recycling must nevertheless follow crop demand. Repeated compost application based only on nitrogen requirements can accumulate phosphorus and create a pathway to water pollution. A workable strategy should begin with diagnosis, then combine habitat management, crop diversification, validated waste-derived amendments, conservation tillage, nutrient budgeting and threshold-based plant-protection decisions. Farmers should participate in selecting, testing and revising the package because labor, land, biomass, water, knowledge and market conditions shape its performance. Monitoring should include pests, natural enemies, disease, yield, soil carbon, ground cover, nutrient balances and potential losses. When these elements are connected through adaptive management, agricultural waste becomes a resource, plant protection becomes preventive and conservation becomes part of production rather than a competing objective. The review therefore identifies specific reporting and design gaps that must be closed before robust, domain-specific meta-analyses can be undertaken across comparable intervention-outcome families.

Data Availability Statement

No datasets were generated or analyzed during the current study because this article is a review based on previously published literature.

Funding Statement

The authors received no specific funding for this work.

Ethics Declaration

Ethical approval was not required for this study because it is a review of previously published literature and did not involve human participants, animals, or the collection of primary data.

Author Contribution Statement

All authors contributed equally to the conception, development, review, and preparation of the manuscript. All authors read and approved of the final manuscript.

References

1. Altieri MA. Agroecology: The science of natural resource management for poor farmers in marginal environments. Agric Ecosyst Environ. 2002;93(1-3):1-24. https://doi.org/10.1016/S0167-8809(02)00085-3
2. Barrios E, Gemmill-Herren B, Bicksler A, Siliprandi E, Brathwaite R, Moller S, et al. The 10 elements of agroecology: Enabling transitions towards sustainable agriculture and food systems through visual narratives. Ecosyst People. 2020;16(1):230-247. https://doi.org/10.1080/26395916.2020.1808705
3. Drinkwater LE, Wagoner P, Sarrantonio M. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature. 1998;396(6708):262-265. https://doi.org/10.1038/24376
4. Mäder P, Fliessbach A, Dubois D, Gunst L, Fried P, Niggli U. Soil fertility and biodiversity in organic farming. Science. 2002;296(5573):1694-1697. https://doi.org/10.1126/science.1071148
5. Reganold JP, Elliott LF, Unger YL. Long-term effects of organic and conventional farming on soil erosion. Nature. 1987;330(6146):370-372. https://doi.org/10.1038/330370a0
6. Thies C, Tscharntke T. Landscape structure and biological control in agroecosystems. Science. 1999;285(5429):893-895. https://doi.org/10.1126/science.285.5429.893
7. Gardiner MM, Landis DA, Gratton C, DiFonzo CD, O'Neal M, Chacón JM, et al. Landscape diversity enhances biological control of an introduced crop pest in the north-central USA. Ecol Appl. 2009;19(1):143-154. https://doi.org/10.1890/07-1265.1
8. Gurr GM, Lu Z, Zheng X, Xu H, Zhu P, Chen G, et al. Multi-country evidence that crop diversification promotes ecological intensification of agriculture. Nat Plants. 2016;2(3):16014. https://doi.org/10.1038/nplants.2016.14
9. Pywell RF, Heard MS, Woodcock BA, Hinsley S, Ridding L, Nowakowski M, et al. Wildlife-friendly farming increases crop yield: Evidence for ecological intensification. Proc Biol Sci. 2015;282(1816):20151740. https://doi.org/10.1098/rspb.2015.1740
10. Tschumi M, Albrecht M, Bärtschi C, Collatz J, Entling MH, Jacot K. Perennial, species-rich wildflower strips enhance pest control and crop yield. Agric Ecosyst Environ. 2016;220:97-103. https://doi.org/10.1016/j.agee.2016.01.001
11. Midega CAO, Pittchar JO, Pickett JA, Hailu GW, Khan ZR. A climate-adapted push-pull system effectively controls fall armyworm, Spodoptera frugiperda (J E Smith), in maize in East Africa. Crop Prot. 2018;105:10-15. https://doi.org/10.1016/j.cropro.2017.11.003
12. Termorshuizen AJ, van Rijn E, van der Gaag DJ, Alabouvette C, Chen Y, Lagerlöf J, et al. Suppressiveness of 18 composts against 7 pathosystems: Variability in pathogen response. Soil Biol Biochem. 2006;38(8):2461-2477. https://doi.org/10.1016/j.soilbio.2006.03.002
13. Pane C, Piccolo A, Spaccini R, Celano G, Villecco D, Zaccardelli M. Agricultural waste-based composts exhibiting suppressivity to diseases caused by the phytopathogenic soil-borne fungi *Rhizoctonia solani* and *Sclerotinia minor*. Appl Soil Ecol. 2013;65:43-51. https://doi.org/10.1016/j.apsoil.2013.01.002
14. Debode J, Ebrahimi N, D'Hose T, Cremelie P, Viaene N, Vandecasteele B. Has compost with biochar added during the process added value over biochar or compost to increase disease suppression? Appl Soil Ecol. 2020;153:103571. https://doi.org/10.1016/j.apsoil.2020.103571
15. Elad Y, David DR, Harel YM, Borenshtein M, Kalifa HB, Silber A, et al. Induction of systemic resistance in plants by biochar, a soil-applied carbon-sequestering agent. Phytopathology. 2010;100(9):913-921. https://doi.org/10.1094/PHYTO-100-9-0913
16. Gao Y, Lu Y, Lin W, Tian J, Cai K. Biochar suppresses bacterial wilt of tomato by improving soil chemical properties and shifting the soil microbial community. Microorganisms. 2019;7(12):676. https://doi.org/10.3390/microorganisms7120676
17. Richardville K, Egel D, Flachs A, Jaiswal A, Perkins D, Thompson A, Hoagland L. Leaf mold compost reduces waste, improves soil and microbial properties and increases tomato productivity. Urban Agric Reg Food Syst. 2022;7(1):e20022. https://doi.org/10.1002/uar2.20022
18. Seitz S, Goebes P, Loaiza Puerta V, Pujol Pereira EI, Wittwer R, et al. Conservation tillage and organic farming reduce soil erosion. Agron Sustain Dev. 2019;39(1):4. https://doi.org/10.1007/s13593-018-0545-z
19. D'Hose T, Ruysschaert G, Viaene N, Debode J, Vanden Nest T, Van Vaerenbergh J, et al. Farm compost amendment and non-inversion tillage improve soil quality without increasing the risk for N and P leaching. Agric Ecosyst Environ. 2016;225:126-139. https://doi.org/10.1016/j.agee.2016.03.035
20. Vanden Nest T, Vandecasteele B, Ruysschaert G, Cougnon M, Merckx R, Reheul D. Effect of organic and mineral fertilizers on soil P and C levels, crop yield and P leaching in a long term trial on a silt loam soil. Agric Ecosyst Environ. 2014;197:309-317. https://doi.org/10.1016/j.agee.2014.07.019
21. van Rooyen A, Bjornlund H, Moyo M, Pittock J, Parry K, Mujeyi A. Agroecology and circular food systems: Decoupling natural resource use from rural development in sub-Saharan Africa? Int J Water Resour Dev. 2025;41(2):489-511. https://doi.org/10.1080/07900627.2024.2449224
22. Belmain SR, Tembo Y, Mkindi AG, Arnold SEJ, Stevenson PC. Elements of agroecological pest and disease management. Elementa Sci Anthropocene. 2022;10(1):00099. https://doi.org/10.1525/elementa.2021.00099
23. Crowder DW, Northfield TD, Strand MR, Snyder WE. Organic agriculture promotes evenness and natural pest control. Nature.

© 2026 Reseapro Journals
https://doi.org/10.61577/jec.2026.1000013

24. Snyder GB, Finke DL, Snyder WE. Predator biodiversity strengthens aphid suppression across single- and multiple-species prey communities. Biol Control. 2008;44(1):52-60. https://doi.org/10.1016/j.biocontrol.2007.09.006
25. Blaauw BR, Isaacs R. Flower plantings increase wild bee abundance and the pollination services provided to a pollination-dependent crop. J Appl Ecol. 2014;51(4):890-898. https://doi.org/10.1111/1365-2664.12257
26. Githiomi C, Muriithi B, Irungu P, Mwungu CM, Diiro G, Affognon H, et al. Economic analysis of spillover effects of an integrated pest management (IPM) strategy for suppression of mango fruit fly in Kenya. Food Policy. 2019;84:121-132. https://doi.org/10.1016/j.foodpol.2019.03.006
27. Midingoyi SKG, Kassie M, Muriithi B, Diiro G, Ekesi S. Do farmers and the environment benefit from adopting integrated pest management practices? Evidence from Kenya. J Agric Econ. 2019;70(2):452-470. https://doi.org/10.1111/1477-9552.12306
28. Muriithi BW, Affognon HD, Diiro GM, Kingori SW, Tanga CM, Nderitu PW, et al. Impact assessment of an integrated pest management strategy for suppression of mango-infesting fruit flies in Kenya. Crop Prot. 2016;81:20-29. https://doi.org/10.1016/j.cropro.2015.11.014
29. Kuria AW, Bolo P, Adoyo B, Korir H, Sakha M, Gumo P, et al. Understanding farmer options, context and preferences leads to the co-design of locally relevant agroecological practices for soil, water and integrated pest management: A case from Kiambu and Makueni agroecology living landscapes, Kenya. Front Sustain Food Syst. 2024;8:1456620. https://doi.org/10.3389/fsufs.2024.1456620
30. Akanmu AO, Akol AM, Ndolo DO, Kutu FR, Babalola OO. Agroecological techniques: Adoption of safe and sustainable agricultural practices among the smallholder farmers in Africa. Front Sustain Food Syst. 2023;7:1143061. https://doi.org/10.3389/fsufs.2023.1143061
31. Altieri MA, Nicholls CI, Montalba R, Vieli L, Vazquez LL. Agroecology and the limits to resilience: Extending the adaptation capacity of agroecosystems to drought. Front Agron. 2025;7:1534370. https://doi.org/10.3389/fagro.2025.1534370
32. Tilston EL, Pitt D, Fuller MP, Groenhof AC. Compost increases yield and decreases take-all severity in winter wheat. Field Crops Res. 2005;94(2-3):176-188. https://doi.org/10.1016/j.fcr.2005.01.003
33. Kebede T, Diriba D, Boki A. The effect of organic solid-waste compost on soil properties, growth and yield of Swiss chard (*Beta vulgaris L.*). ScientificWorldJournal. 2023;2023:1-10. https://doi.org/10.1155/2023/6175746
34. Haas SM, Horwath WR, Zhu-Barker X. Effects of food waste and green waste composts on yield and nitrogen-use efficiency in irrigated tomato crops. Agron J. 2024;116(4):1717-1729. https://doi.org/10.1002/agj2.21587
35. Small GE, Shrestha P, Zeiner C, Barabás G, Metson GS. Phosphorus recycling and loss from compost-amended urban gardens: Results from a 7-year study. Urban Agric Reg Food Syst. 2024;9(1):e20055. https://doi.org/10.1002/uar2.20055
36. Meller Harel Y, Elad Y, Rav-David D, Borenstein M, Shulchani R, Lew B, et al. Biochar mediates systemic response of strawberry to foliar fungal pathogens. Plant Soil. 2012;357(1-2):245-257. https://doi.org/10.1007/s11104-012-1129-3
37. De Tender C, Vandecasteele B, Verstraeten B, Ommeslag S, Kyndt T, Debode J. Biochar-enhanced resistance to Botrytis cinerea in strawberry fruits (but not leaves) is associated with changes in the rhizosphere microbiome. Front Plant Sci. 2021;12:700479. https://doi.org/10.3389/fpls.2021.700479
38. Akhter A, Hage-Ahmed K, Soja G, Steinkellner S. Compost and biochar alter mycorrhization, tomato root exudation and development of *Fusarium oxysporum f.* sp. lycopersici. Front Plant Sci. 2015;6:529. https://doi.org/10.3389/fpls.2015.00529
39. Rogovska N, Laird D, Leandro L, Aller D. Biochar effect on severity of soybean root disease caused by *Fusarium virguliforme*. Plant Soil. 2017;413(1-2):111-126. https://doi.org/10.1007/s11104-016-3086-8
40. Jaiswal AK, Alkan N, Elad Y, Sela N, Philosoph AM, Graber ER, et al. Molecular insights into biochar-mediated plant growth promotion and systemic resistance in tomato against Fusarium crown and root rot disease. Sci Rep. 2020;10(1):13934. https://doi.org/10.1038/s41598-020-70882-6
41. Wang G, Ma Y, Chenia HY, Govinden R, Luo J, Ren G. Biochar-mediated control of Phytophthora blight of pepper is closely related to improvement of the rhizosphere fungal community. Front Microbiol. 2020;11:1427. https://doi.org/10.3389/fmicb.2020.01427
42. Rasool M, Akhter A, Soja G, Haider MS. Role of biochar, compost and plant growth promoting rhizobacteria in the management of tomato early blight disease. Sci Rep. 2021;11(1):6092. https://doi.org/10.1038/s41598-021-85633-4
43. Siegrist S, Schaub D, Pfiffner L, Mäder P. Does organic agriculture reduce soil erodibility? The results of a long-term field study on loess in Switzerland. Agric Ecosyst Environ. 1998;69(3):253-264. https://doi.org/10.1016/S0167-8809(98)00113-3
44. Lotter DW, Seidel R, Liebhardt W. The performance of organic and conventional cropping systems in an extreme climate year. Am J Altern Agric. 2003;18(3):146-154. https://doi.org/10.1079/AJAA200345
45. Loaiza Puerta V, Pujol Pereira EI, Wittwer R, van der Heijden M, Six J. Improvement of soil structure through organic crop management, conservation tillage and grass-clover ley. Soil Tillage Res. 2018;180:1-9. https://doi.org/10.1016/j.still.2018.02.007
46. Peigné J, Vian JF, Payet V, Saby NPA. Soil fertility after 10 years of conservation tillage in organic farming. Soil Tillage Res. 2018;175:194-204. https://doi.org/10.1016/j.still.2017.09.008
47. Eltun R, Korsæth A, Nordheim O. A comparison of environmental, soil fertility, yield and economical effects in six cropping systems based on an 8-year experiment in Norway. Agric Ecosyst Environ. 2002;90(2):155-168. https://doi.org/10.1016/S0167-8809(01)00198-0
48. Khanal N, Thapa S. Agroecological approach to agricultural sustainability, food sovereignty and endogenous circular economy. Nepal Public Policy Rev. 2023;3(1):49-78. https://doi.org/10.59552/nppr.v3i1.57
49. Vikas, Ranjan R. Agroecological approaches to sustainable development. Front Sustain Food Syst. 2024;8:1405409. https://doi.org/10.3389/fsufs.2024.1405409
50. Campbell M, McKenzie JE, Sowden A, Katikireddi SV, Brennan SE, Ellis S, et al. Synthesis without meta-analysis (SWiM) in systematic reviews: reporting guideline. BMJ. 2020;368:l6890. https://doi.org/10.1136/bmj.l6890

© 2026 Reseapro Journals
https://doi.org/10.61577/jec.2026.1000013