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Research Article

Integrated Pest Management and Ecological Pest Control in Cereal-Legume Cropping Systems: From Field Ecology to Farmer Decisions

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Abstract

Pests, diseases, and weeds remain among the largest causes of crop loss in cereal-legume systems, yet repeated reliance on chemical pesticides has produced resistance, resurgence, harm to natural enemies, residues, and rising costs. Integrated pest management offers a different logic: prevent pests through system design, monitor populations, protect natural enemies, and intervene only when economic thresholds are crossed, using the most selective option available. This article reviews ecological pest control in cereal-legume cropping systems, covering host-plant resistance, crop diversification, push-pull systems, biological control, habitat management, cultural practices, and the judicious use of selective pesticides and biopesticides. It shows that integrated bundles can reduce pest pressure and pesticide use while maintaining or increasing yield, but that outcomes depend on pest biology, landscape context, timing, farmer knowledge, and access to resistant seed, monitoring tools, and advisory support. The article proposes a practical decision framework based on prevention, monitoring, thresholds, and evaluation, and it identifies research and policy priorities for scaling integrated pest management without increasing labour burdens or inequity.

Keywords: integrated pest management; biological control; push-pull; host-plant resistance; cereal-legume systems; natural enemies; economic threshold

1. Introduction

Insect pests, plant pathogens, and weeds together cause large pre-harvest losses in cereals and legumes, with estimates varying by crop, region, and season but frequently reaching one-fifth to two-fifths of attainable yield when control fails (Oerke, 2006; Savary et al., 2019). For a household that depends on maize, sorghum, cowpea, soybean, or common bean, a severe outbreak is not an abstract statistic. It can mean less food, less seed for the next season, and less cash for school fees, health care, and inputs. The conventional response in many systems has been calendar-based pesticide spraying: apply on a fixed schedule, regardless of pest density, natural enemy activity, or crop stage. This approach can suppress a pest in the short term, but it also selects for resistance, kills predators and parasitoids, can trigger resurgence of the target pest or outbreaks of secondary pests, and leaves residues that concern consumers and export markets (Bottrell and Schoenly, 2018; Pretty and Bharucha, 2015).

Integrated pest management (IPM) was developed to break this cycle. It is not a ban on pesticides, and it is not a single technology. It is a decision system that combines preventive, ecological, cultural, biological, and chemical tools, guided by monitoring and economic thresholds (Stern et al., 1959; Kogan, 1998). The economic injury level is the pest density at which the cost of damage equals the cost of control, and the economic threshold is the lower density at which action should be taken to prevent the population reaching that level. This distinction matters because it reframes pest control from eradication to management: a small pest population that does not threaten profitable yield, and that sustains natural enemies, may be better left alone.

This article focuses on cereal-legume systems because they are widespread, nutritionally important, and ecologically

informative. Cereals and legumes differ in growth habit, pest complexes, nitrogen fixation, and residue quality, and their combination creates opportunities for diversification, habitat provision, and rotation that a cereal monoculture does not offer (Bedoussac et al., 2015; Yu et al., 2016). The review examines how field ecology, crop design, biological control, and farmer decision-making interact, and it proposes a practical framework that extension workers and farmers can use in the field.

2. Ecology of Pests in Diversified Systems

Pest populations are shaped by food, shelter, natural enemies, weather, and movement across the landscape. A large, uniform field of a susceptible variety offers abundant food, easy host-finding, and rapid population growth. A diversified field offers a more complex environment: non-host plants can mask host odours, interrupt movement, provide alternative prey for predators, and offer nectar and pollen that increase parasitoid longevity and fecundity (Landis et al., 2000; Ratnadass et al., 2012). Diversification does not automatically reduce every pest. Some polyphagous pests can use several crops, and some diseases can spread more easily when susceptible hosts are close together. The design question is therefore specific: which diversity, in which arrangement, against which pest, at which stage?

Landscape context adds another layer. Field margins, hedgerows, fallows, trees, and neighbouring fields provide overwintering sites, refuges, and alternative hosts for both pests and natural enemies (Bianchi et al., 2006; Tscharntke et al., 2007). A field surrounded by diverse habitat may receive more natural enemies early in the season, when pest populations are still low and most vulnerable to predation and parasitism. The same landscape can also harbour pests that move into the crop. Research on landscape effects therefore finds context-dependent outcomes: natural enemy abundance often increases with landscape complexity, but pest suppression depends on the identity of the enemies, their dispersal, and the timing of their arrival relative to pest colonisation (Bianchi et al., 2006; Karp et al., 2018).

Soil and plant health also influence pest dynamics. Plants under nutrient stress, drought stress, or waterlogging can be more susceptible to some pests and diseases, while well-nourished plants can tolerate more herbivory without yield loss (Altieri and Nicholls, 2003). Excess nitrogen can increase aphid fecundity and disease severity in some systems, which is one reason why integrated nutrient management and IPM should be planned together rather than in separate programmes (Vanlauwe et al., 2015). Understanding these interactions helps farmers avoid a narrow focus on killing pests and instead build a system that is harder for pests to colonise, slower for them to exploit, and richer in the organisms that suppress them.

3. Host-Plant Resistance and Seed Systems

Host-plant resistance is often the most cost-effective and farmer-friendly component of IPM because it requires no extra labour after planting and no spray equipment (Painter, 1951; Smith, 2005). Resistance can operate through antixenosis, in which pests avoid or fail to colonise the plant; antibiosis, in which plant chemistry reduces pest survival, growth, or reproduction; and tolerance, in which the plant maintains yield despite infestation. Modern breeding has produced varieties with resistance to stem borers, aphids, leafhoppers, rusts, blights, and viruses in several cereals and legumes, although resistance is rarely complete and can break down when pest populations evolve (Smith, 2005; Ceccarelli, 2015).

The value of a resistant variety depends on whether farmers can obtain it, whether it performs well for yield, grain quality, cooking, and market traits, and whether resistance is durable under local pest pressure. A variety that resists one pest but is susceptible to another may simply shift the pest problem. A variety that resists a pest but yields poorly or tastes poorly will not be adopted, however strong its resistance. Seed systems therefore matter as much as breeding. Community seed multiplication, participatory variety selection, and clear information about resistance traits can increase adoption, while reliance on a single resistant variety over a large area can accelerate resistance breakdown (Ceccarelli, 2015; Pretty et al., 2018). Rotating resistance genes, combining resistance with other IPM tools, and monitoring pest populations for virulence shifts are practical ways to prolong the useful life of resistant varieties.

4. Biological Control: Predators, Parasitoids, and Pathogens

Biological control uses living organisms to suppress pests. Conservation biological control protects and enhances the natural enemies already present by reducing broad-spectrum pesticide use, providing habitat, and timing interventions to avoid enemy activity (Landis et al., 2000). Classical biological control introduces a natural enemy from the pest's region of origin to control an invasive pest, with careful host-specificity testing. Augmentative biological control releases mass-reared predators, parasitoids, or pathogens at critical times, for example Trichogramma parasitoids against stem borers or entomopathogenic fungi and bacteria against caterpillars and aphids (van Lenteren et al., 2018; Lacey et al., 2015).

Evidence for biological control is strong in many systems, but it requires knowledge and patience. Natural enemies often act with a lag: parasitoids must find hosts, lay eggs, and complete development before pest mortality is visible. A farmer who expects an immediate knockdown may conclude that biological control has failed and spray a broad-spectrum insecticide, killing the very enemies that were about to suppress the pest. Farmer field schools and participatory monitoring have been effective at building this patience because farmers can observe parasitised eggs, mummified aphids, and predator activity directly (Pretty and Bharucha, 2015; van den Berg and Jiggins, 2007). Biopesticides based on Bacillus thuringiensis, Beauveria bassiana, Metarhizium anisopliae, and nucleopolyhedroviruses can provide more targeted control than broad-spectrum chemicals, but their efficacy depends on strain, formulation, storage, timing, and coverage, and quality control in local markets remains a challenge (Lacey et al., 2015).

5. Push-Pull and Habitat Management

Push-pull is one of the best-documented ecological pest management systems for cereal-legume systems in sub-Saharan Africa. It combines a repellent intercrop that pushes stem borers away from the main cereal with a trap crop around the field that pulls them toward oviposition on a plant where larvae survive poorly (Khan et al., 2014; Midega et al., 2018). In the classic East African system, Desmodium is intercropped with maize or sorghum and Napier grass is planted as a border. Desmodium also fixes nitrogen,

suppresses Striga, provides fodder, and improves soil cover, so the system delivers multiple benefits beyond pest control (Khan et al., 2014; Midega et al., 2018). Studies have reported substantial reductions in stem borer damage and Striga emergence, and increases in maize yield and farm income, although outcomes depend on rainfall, soil fertility, seed availability, and management of the companion plants.

Habitat management more broadly includes field margins, flower strips, beetle banks, and intercrops that provide nectar, pollen, shelter, and alternative prey for natural enemies (Landis et al., 2000; Ratnadass et al., 2012). Flowering legumes and other plants can increase parasitoid longevity, but they can also attract pests if species and timing are poorly chosen. The design principle is to select plants that benefit enemies more than pests, that do not compete excessively with the main crop for water and nutrients, and that provide additional food, fodder, or income. In cereal-legume systems, the legume itself can serve this role when its flowering period overlaps with the period when natural enemies need resources.

6. Cultural, Mechanical, and Selective Chemical Tools

Cultural practices are often the oldest and most accessible IPM tools. Crop rotation breaks pest and disease cycles by removing the host for a season or more. Early or timely planting can allow the crop to escape peak pest pressure, while adjusting plant density and spacing can change canopy humidity and disease severity. Sanitation, including removal and destruction of infested residues, can reduce carry-over of stem borers and pathogens, although residues also provide soil cover and feed, so trade-offs must be considered (Giller et al., 2009). Intercropping cereals with legumes can reduce pest colonisation and increase natural enemy activity, while also improving land productivity and dietary diversity (Bedoussac et al., 2015; Yu et al., 2016).

Mechanical control includes hand-picking, trapping, and use of light and pheromone traps for monitoring and mass trapping. Pheromone traps are especially useful for monitoring moth flights and timing interventions, and for mating disruption in some systems. When pesticides are needed, selectivity is the key principle: choose products with low toxicity to natural enemies, pollinators, and people; apply at the correct dose, timing, and coverage; use spot or border treatments where possible; and rotate modes of action to delay resistance (Bottrell and Schoenly, 2018; Kogan, 1998). Personal protective equipment, safe storage, and safe disposal are essential, and women and children who often handle or are exposed to pesticides need particular protection (Pretty and Bharucha, 2015). Figure 1 summarises the pattern from the cited syntheses: integrated bundles tend to reduce pest pressure more than single tools while maintaining or increasing yield.

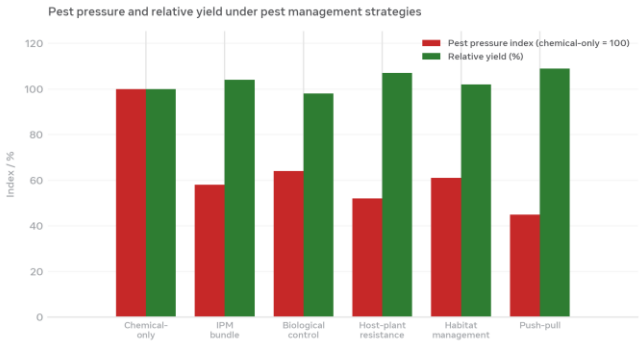

Figure 1. Pest pressure and relative yield under pest management strategies, based on synthesis of the meta-analyses and reviews cited in the text. Values vary by pest, crop, landscape, and management.

7. Monitoring, Thresholds, and Farmer Decisions

Monitoring is the foundation of IPM because decisions without data revert to calendar spraying. Simple monitoring tools include weekly scouting of a fixed number of plants per field, counting pests and natural enemies, checking pheromone traps, and recording crop stage and weather (Kogan, 1998; Pretty and Bharucha, 2015). A farmer who scouts regularly can detect a rising pest population early, when a selective intervention is still effective, and can avoid spraying when natural enemies are already suppressing the pest. Digital tools, including mobile phone images, pest identification apps, and decision support systems, can help, but they must be validated locally and presented in languages and formats farmers can use (Fabregas et al., 2019).

Thresholds must be adapted to local conditions. A threshold developed for a high-yielding, irrigated system may be too low or too high for a rain-fed, low-input system where the cost of spraying is high relative to the value of the crop. Thresholds also need to account for crop stage: the same pest density may be tolerable at vegetative growth but damaging at flowering or pod filling. Participatory development of thresholds, in which farmers and researchers test different action levels together, can increase trust and adoption (van den Berg and Jiggins, 2007). The goal is not perfect precision, but a clear, usable rule: scout, count, compare to a threshold, act only if needed, and record the result.

8. Economics, Labour, and Equity

IPM can reduce pesticide costs and health risks, but it can also increase labour and knowledge demands. Scouting, habitat management, and push-pull establishment require time, and time is not free, especially for women who already carry heavy domestic and farm workloads (Farnworth et al., 2017). A system that is ecologically sound but labour-intensive may be adopted by larger farmers and abandoned by smaller ones unless labour-saving adaptations are developed. Economic evaluation should therefore include labour, seed, and learning costs, not only pesticide savings and yield. It should also consider risk: a farmer who tries a new IPM bundle in a bad year may lose confidence even if the bundle would have performed well on average.

Equity affects who benefits from IPM. Women farmers may have less access to extension, credit, and inputs, and less

control over decisions to spray or not to spray, even when they do much of the scouting and harvesting (Farnworth et al., 2017; Huyer et al., 2015). Youth and tenant farmers may have less secure tenure and therefore less incentive to invest in habitat or soil-building practices whose benefits accrue over several seasons. Programmes that involve women and youth in farmer field schools, that schedule training at accessible times and places, and that ensure that income from IPM crops is shared fairly are more likely to produce durable adoption. Table 1 summarises IPM bundles and their main mechanisms, while Table 2 proposes indicators for monitoring IPM.

Tables

Table 1. Integrated pest management bundles and their main mechanisms.

Bundle	Core practices	Main mechanism	Likely outcome
Prevention-first bundle	Resistant variety, rotation, timely planting	Reduced colonisation, broken pest cycles	Lower pest pressure, steadier yield
Push-pull bundle	Desmodium intercrop, Napier border, legume rotation	Repulsion, trapping, Striga suppression	Lower borer and Striga damage
Biological control bundle	Conserve enemies, flower strips, biopesticide	Predation, parasitism, disease	Lower pesticide use, more enemies
Monitoring-led bundle	Weekly scouting, traps, thresholds	Action only when needed	Lower cost, less resistance

Table 2. A balanced indicator set for integrated pest management.

Dimension	Indicator	Practical measurement
Pest pressure	Pest counts, damage score	Weekly scouting records
Natural enemies	Predator and parasitoid counts	Scouting, trap records
Pesticide use	Sprays per season, active ingredient	Input records
Yield and income	Grain yield, gross margin	Harvest and cost records
Health and environment	Exposure, residues, biodiversity	Farmer recall, field observations
Equity and labour	Workload by gender, adoption persistence	Household survey, panel records

9. Future Research and Policy Priorities

Future research should report pest, natural enemy, yield, cost, labour, and health outcomes together, rather than pest mortality alone. Long-term, landscape-scale studies are needed to understand how habitat, rotation, and pesticide use interact across seasons and across neighbouring fields. Research on low-cost monitoring, including simple scouting protocols, image-based identification, and community pest alerts, is more valuable for smallholders than complex models that require data farmers cannot collect (Fabregas et al., 2019; Pretty and Bharucha, 2015). Breeding should continue to combine resistance with yield, quality, and climate tolerance, and resistance should be monitored for breakdown (Smith, 2005; Ceccarelli, 2015). Policy should support IPM through extension, farmer field schools, seed systems for resistant varieties and companion plants, quality control for biopesticides, and regulation that restricts highly hazardous pesticides and rewards selective, low-risk options. Subsidies that make broad-spectrum pesticides artificially cheap can undermine IPM, while public investment in knowledge, monitoring, and habitat can make IPM the rational choice for farmers.

10. Conclusion

Integrated pest management is not a fixed package and not a rejection of all pesticides. It is a disciplined way of designing a cropping system that is hard for pests to exploit, rich in natural enemies, monitored regularly, and intervened in only when thresholds are crossed. In cereal-legume systems, the combination of resistant varieties, diversification, push-pull and habitat management, biological control, cultural practices, and selective pesticides can reduce pest pressure and pesticide use while maintaining or increasing yield. The priority now is practical: scout weekly, protect natural enemies, use thresholds, record results, and learn from each season. When knowledge, seed, monitoring, and policy support align, ecological pest control becomes not only environmentally sound but also economically and socially durable.

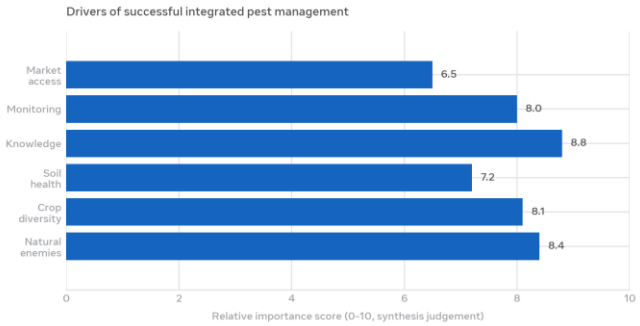

Figure 2. Drivers of successful integrated pest management, based on synthesis judgement from the cited evidence. Knowledge, natural enemies, and diversity are central.

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Conflict of Interest

The authors declare no conflict of interest.

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