Landscape Features to Improve Pest Control in Agriculture

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Matthias Tschumi, Agroscope, 2013

Included in fields, strips sown with wild flower mixtures provide excellent resources for natural enemies of pests.

In Brief

Despite wide acceptance of the importance of integrated pest management, pest control in most cropping systems depends on the extensive use of pesticides, with detrimental effects on environmental and human health. These effects have led to many pesticides being removed from use, increasing demands for the rapid development of alternative solutions. Biological pest control aims for control through natural enemies, which significantly reduces and even eliminates pesticide use in crops. The role of noncultivated areas in agricultural landscapes in supporting biodiversity functions, such as the biological control by providing natural enemies with food and refuge, is only partially understood.

Efficient implementation of biological pest control requires a wide range of knowledge and skills, not least those of farmers. Here we suggest the promotion of so called operational groups composed of farmers, scientists (agronomists and ecologists), extension service advisors, agribusiness representatives, and consumer associations to create objectives, strategies, and procedures to be realized at the local, regional, or national level. In this context, it is proposed that farmers will play a crucial role in providing solutions, as well as implementing, and disseminating practical knowledge and the concrete implementation of solutions.

Despite the annual use of approximately three million tons of pesticides,[1] pests destroy more than 40 percent of potential global food production.[2] In some countries, programs to control the exposure of farm workers to pesticides are limited or nonexistent. As a consequence, it has been estimated that as many as 25 million agricultural workers worldwide experience unintentional pesticide poisoning each year. The major types of chronic health effects of pesticides include cancer, neurological, respiratory, and reproductive effects. Furthermore, there is evidence that pesticides can cause sensory disturbances as well as cognitive effects such as memory loss, language problems, and learning impairment.[3]

Pesticides enter air, water, and soil with multifaceted, direct, and indirect detrimental effects.[4] Pesticides can harm other plants and animals ranging from soil microorganisms and invertebrates to fish, birds, and other wildlife. For example, investigations in the US show that more than 90 percent of water and fish samples from all streams contained at least one, but more often several pesticides.[5] Pesticides have also been directly linked to fish mortality.[6] Even when within permissible levels, environmental contamination can have harmful effects. Köck-Schulmeyer and colleagues found that pesticides presented an ecotoxicological risk for aquatic organisms, especially algae and macro-invertebrates in the Llobregat River basin of Spain, even though levels were within the European Union Environmental Quality Standards.[7] Heavy treatment of soil with pesticides also causes the biomass and diversity of beneficial soil microorganisms to decline. Biochemical reactions and enzymatic activity are altered by pesticide use, leading to disturbance of the soil ecosystem and loss of soil fertility.[8]

Bird mortality can result from exposure via pathways such as direct ingestion of pesticide granules and treated seeds, treated crops, direct exposure to sprays, contaminated water, or feeding on contaminated prey, and bait. In the US, nearly 50 pesticides are known to be directly responsible for killing song birds, game birds, seabirds, shorebirds, and raptors.[4]

Key Concepts

- **Modern agriculture is suffering worldwide from damage by numerous pests. A significant alternative to the use of pesticides is the conservation and promotion of natural enemies, usually as part of integrated pest management programs.**
- **Noncultivated habitats including hedgerows, grassy margins of fields, and wildflower strips provide essential resources for natural enemies and insect pollinators.**
- **"Conservation Biological Control" consists of managing noncultivated habitats in agricultural landscapes in such a way that they boost natural enemy populations and thus reduce pests.**
- **Appropriate management of noncultivated habitats and inclusion of targeted measures have the potential to avoid mass pesticide use. This will not only benefit the environment as well as human health but could also provide economic returns.**
- **Agronomic and ecological expertise is required for innovation, involving groups consisting of farmers, scientists, extension service advisors, agribusiness representatives, consumer associations, and others.**

Pesticide application to control pests may also adversely affect the pest's natural enemies as well. However, Pimentel and Burgess have estimated that at least 50 percent of pest control is through natural enemies, with pesticides contributing only 10 percent and the remaining 40 percent a consequence of host–plant resistance.[3] For example, the negative impact of neonicotinoids on honey bees and wild bees is one of the hottest topics around pesticide use. Neonicotinoids have known lethal and sublethal effects on domestic and wild insect pollinators even at extremely low concentrations, often reported in the parts per trillion range.[9] The rate at which honey bee colonies have been declining in the UK may be associated with the application of the neonicotinoid imidacloprid.[10]

The use of pesticides is thus a globally significant environmental and human health issue for which solutions are urgently needed.

Basis for a Solution

Increasing agricultural biodiversity and rebalancing basic ecosystem functioning is part of a solution in which seminatural, noncultivated habitats play a major role. Noncultivated/seminatural habitats such as field margins, fallows, hedgerows, and wood lots are relatively undisturbed, temporary, or permanent areas that hold a substantial proportion of the biodiversity in agricultural landscapes. They reportedly act as biodiversity reservoirs, and so landscapes with a higher proportion of them support higher biodiversity than simplified landscapes like those composed of mainly arable fields.[11]

In addition to improving biodiversity, seminatural habitats contribute ecological services in all four categories defined by the Millennium Ecosystem Assessment: provisioning, regulating, habitat, and cultural services.[12,13] Seminatural habitats are used by beneficial organisms for overwintering,[14,15] as source of alternative prey or hosts for natural enemies,[16] for offering food sources for herbivores and decomposers,[17] for providing floral resources to pollinators,[18] and as refuges at times of disturbance. Their critical importance can be seen through exponential declines in pollinator species richness and flower visitation rates with distance from seminatural habitats,[19] while the density and diversity of natural enemies increases where there are more seminatural habitats.[20,21]

Conservation Biological Control: Available Evidence

Management of pest control through noncultivated elements in agricultural landscapes through boosting natural enemies is called "Conservation Biological Control," or CBC. Recent research shows that the sustained effectiveness of seminatural habitats strongly depends on their botanical composition. A wide range of pest-controlling predators and parasitoids depend on specific flowering plants for survival and reproduction.[22–24] In commercial crops, natural enemies are severely food deprived and have very low energy reserves that can be effectively replenished by increasing these flowering plants.[25,26] For example, targeted measures, like sowing selected plant mixtures directly adjacent to or inside the crop, can effectively provide nectar and pollen resources for predators and parasitoids.[26–28] Furthermore, recent and ongoing studies using flower margins with selected flowering plants in the UK and Switzerland are showing the following:

- Increased numbers of predators and parasitoids in the flower margins,
- Enhanced populations of natural enemies spilling over into the adjacent cropland,
- Effective suppression of pests, and
- 10 to 30 percent yield increases in arable (wheat) and horticultural (carrots and peas) crops.

Seminatural habitats can also provide supplementary resources for natural enemies by supporting populations of alternative prey or hosts. These are a valuable resource in promoting fitness and allowing populations to persist in the absence of pest species.[29,30] Although likely to be of greatest significance to generalist predators, there are examples of parasitoid populations being maintained by an alternate host population, which is itself maintained by the introduction of their preferred host plants.[31] In addition to food resources and support for vegetation, such as grass and herbaceous margins and hedgerows, they provide a habitat for overwinter survival of ground-dwelling arthropods that may otherwise suffer from substantial disturbance in annual arable cropping systems. Their biodiversity is also important: species-rich assemblages are more likely to control crop pests than poorer ones, as pest control can be strengthened when natural enemies complement each other.[32]

Enhancing landscape complexity through the re-introduction of seminatural habitats may act to conserve natural enemies via the same mechanisms described above of enhancing resource availability. Spatial processes are also important in the conservation of natural enemies at the landscape scale. For example, habitat fragmentation accompanying land-use intensification has the potential to lead to local extinctions through patch isolation.[33,34] Modelling studies confirm that their populations may be sensitive to habitat fragmentation and connectivity,[35–37] though empirical studies have produced conflicting results on the importance of the spatial configuration of a habitat area.[38,39]

New Practical Solutions Need to be Explored by Farmers

Agri-environment schemes are government programs set up to help farmers manage their land in an environmentally friendly way. They are important for the conservation of farmed environments of high nature value, improved genetic diversity, and protection of agroecosystems, and they offer the potential to improve CBC by including noncultivated elements on farms. The introduction of less intensively managed and beneficial habitats are an important and growing response to the environmental challenges posed by modern agriculture. For example, the introduction of Ecological Focus Areas (EFA) into European agriculture is now enshrined in legislation as part of the EU Common Agriculture Policy. However, to be successful, such schemes must be translated into effective practical measures. Farmers with expertise and first-hand knowledge of the land are best placed to develop effective ways of using and adequately managing EFAs on farms. At the same time, they are sometimes unaware of existing solutions that reduce pesticide inputs and are consequently underused. Adapting farming practices and systems to work with EFAs could provide new solutions incorporating crop rotations, minimal or no-tillage crops, sown understory, and others and should thus be explored. The exploration of habitat management practices for biological pest control should target service delivery by including the following:

- Management of existing permanent noncultivated habitats to promote the supply of alternative hosts and prey, sources of pollen and

Four Categories of Ecosystem Services

Provisioning services are the goods and products obtained from ecosystems such as food, water, timber, or medicines.

Regulating services are the benefits obtained from an ecosystem's control of natural processes, for instance pollination or pest control by natural enemies.

Cultural services are the nonmaterial benefits obtained from ecosystems such as recreation in forests.

Habitat services support the provision of other services by providing habitat.

Agroscope, Switzerland, 2007

Hedgerows in agricultural landscapes are an important source of natural enemies of pests, but need proper management to be effective in delivering pest control ecosystem services.

nectar, and provide shelter and overwintering areas. Elements such as hedgerows or grassy strips need to be managed so that they do not become dominated by a few, potentially unsuitable plant species.

- Sowing of annual within-field and margin elements containing suitable plant mixtures to provide appropriate food and shelter. These should be adapted to the crop–pest systems and not inadvertently increase pest or pathogen populations nor enhance weed pressure. Criteria to select the species include (but are not restricted to) adaptation to local pedoclimatic conditions, adaptation to soil type, quantity, attractiveness, and accessibility of resources provided (e.g., pollen and nectar in accessible flowers, extra-floral nectar), nutritional value of resources, time and duration of resource provision, and plant phenology and morphology (e.g., the ability to provide shelter against harsh weather conditions and hiding places from predators).
- Increasing temporary within-field and permanent habitats. Permanent elements should provide beneficial long-term conditions by increasing species pools and support populations of natural enemies. Within-field strips and field margins complement this by contributing resources close to the crop, thus attracting and supporting natural enemies that provide immediate and annual control of pests.
- Some systems allow permanent features to be introduced within fields. Examples include perennial (fruit) crops and silvo-arable agroforestry. In the latter case, trees are aligned inside the field, providing a perennial habitat directly in contact with the crop. The uncultivated line along the tree row further offers the possibility to sow beneficial plant mixtures.

The management of crops and fields also has a vital role to play in conservation biocontrol, such as the following:

- minimal or no-tillage option,
- decreased nitrogen input and pesticide use,
- varying sowing and harvesting date and plant density,
- intercropping and sown understory, and
- innovative crop rotation, including cover crops and the use of resistant varieties that favor natural enemies as well as directly affecting pest populations.

The success of conservation biocontrol is likely to lie in the combined effects of some or all of these measures and so relies on concerted actions involving farmers, scientists, and relevant stakeholders such as nature conservation organizations, national and local authorities, etc.

M. Waldburger, Agroscope, 2010

Ladybirds are important predators of aphid pests and need landscape features for food when conditions in fields are unfavorable. A single ladybird may consume as many as 5,000 aphids in its lifetime.

Knowledge Required to Fill the Gap

Research focusing on agroecology is poorly funded, comprising only 15 percent of the total USDA Research, Extension, and Economics budget.[40] The measures described here offer innovative solutions to pest control and pesticide use reduction, but a number of uncertainties remain in our understanding of the ecological processes and reliable and effective management in delivering biological pest control. The relationships between crop, managed, and unmanaged noncultivated habitats are complex and possibly antagonistic. Successful service provision also requires the presence of suitable flowering plant species, a sufficient proportion of unmanaged noncultivated habitats, spatial configurations at both farm and landscape scales, and appropriate crop management.

The suitability of plants as floral resources for certain natural enemies is determined by a number of characteristics including phenology, morphology, and biochemistry. Selecting appropriate plant species can yield clear benefits in supporting natural enemy populations. Further investigation is needed to determine which species, mixtures, and proportions of both will benefit the appropriate natural enemies. Two important aspects of this choice are seasonal complementarity between species and the provision of food resources and habitats during the overwintering period, as this is a bottleneck in natural enemy population dynamics. Particular plant species may be required for parasitoids that need their resources at a given time in the year, while others may be more effective in delivering habitats for generalist predators like spiders and carabid beetles. However, most studies on agroecosystems have been carried out during the active growing season, and scientific knowledge on their ecological requirements during overwintering needs to improve. Knowledge is also required around the suitability of plant mixtures for specific soil conditions and technical characteristics for sowing.

Comparative contributions between within-field elements and permanent habitats in CBC is not fully known, although permanent EFAs do play a crucial role for sheltering and sustaining arthropod biodiversity at the landscape scale and also act as a source for recolonization of agricultural fields after disturbances. This reservoir role is of utmost importance for preserving future functional biodiversity, especially under a changed climate, and in allowing natural enemies to move within the landscape. In particular, synergies and synchronization should be studied: the understanding of the influence of local and regional (landscape) population dynamics on the conservation of natural enemies (and pests), and the role of within-field elements and permanent habitats on these. The importance of within-field elements in modifying the behavior of natural enemies should also be considered; can behavioral cues be used to "capture" specific natural enemies from the regional species pool, redirecting them to deliver biocontrol within the crop? Similarly, the synergistic effects of noncultivated elements together with particular farming practices should be investigated.

Although the positive role of targeted landscape management in conserving natural enemies has been shown in several studies,[30,43] less is known about how it translates into pest control and subsequent yield improvements.[44,45] Evidence that habitat diversification leads to effective biological pest control is limited, so before CBC can be established as an alternative to excessive pesticide use, we must be sure to understand how and when reliable pest control can be delivered by it.

Seminatural habitats contribute ecological services in all four categories defined by the Millennium Ecosystem Assessment: provisioning, regulating, habitat, and cultural services.

Studies have typically focused on single aspects of biological control-based pest management, but integrated pest management strategies demand complementarity of different techniques to meet three main objectives as highlighted by Rusch and colleagues: (i) a production purpose (crop performance, yield stability and long term supply, and quality of products), (ii) socio-economic imperatives (farm organization, farm income), and (iii) environmental objectives (limitation of pesticide and nitrogen discharge into the environment, minimization of water, and energy use).[30] Integrative research is required to consider synergies and trade-offs between the three objectives; it is particularly important to conduct economic assessments of the value of biological control and the return on investment of landscape features, as this will largely influence the adoption of CBC by farmers. Although CBC provides one of the highest returns on investment available through IPM, its economic value is rarely estimated.[46]

"Operational Groups" to Devise Solutions

Social networks are key factors in development, extension learning, and the adoption of innovations. In developing and implementing CBC, "Operational Groups" should create networking and collaboration among farmers and other actors. This concept is driven by a new EU initiative that aims to bring people together at local, regional, and national levels to build practical solutions to specific problems, encouraged by a Rural Development policy. Operational groups consisting of several partners with a common interest in a certain project will have an important role to play in applying CBC strategies. Those involved should be from a diverse combination of practical and scientific backgrounds, including farmers, scientists, extension service advisors, agribusiness representatives, NGOs, and others. As each group should combine their skills and expertise to reach the project objectives, the type of people involved can vary depending on the project's theme and objective. In the case of pest control, operational groups should involve farmers, advisors, policy makers, and scientists, as well as industry partners like pesticide manufacturers and providers of seed mixtures. As the most successful agroecological partnerships emerge from prior social networks,[47] these groups could build from existing local groups, such as CIVAM or GIEE in France and LEAF or the Permaculture Association in the UK. Operational groups interested in promoting and using CBC techniques will need to develop innovative solutions to tackle relevant knowledge gaps and other implementation barriers. Innovation topics for operational groups involving farmers, advisors, policy makers, scientists, and industry partners include:

- Improved identification, development, and selection of plant mixtures and habitat characteristics that promote natural enemies
- Development of deployment strategies that benefit the conservation of natural enemies at the regional/landscape scale
- Development of measures to ensure delivery of biocontrol and yield enhancement
- Development of scouting techniques for farmers, screening for presence of pests as well as natural enemy populations in different crops, and taking the result into account for decisions on spraying management
- Identification of integrated farming practices that decrease pest pressure and enhance natural enemy populations, including which species function as intermediate host for pests in field crops and should be avoided in non-cultivated habitats
- Development of management techniques for within-field, buffer strips, and landscape features in order to control weeds
- Identification of farming practices that provide synergies between pest control and other environmental challenges (biodiversity, soil, and water conservation)

- Monitoring in fields with control situation (with no within-field or buffer strips) in order to quantify the economic result of advised implementations
- Development of intervention threshold based on pest/predator ratios
- Discussion groups involving farmers, retailers, grocers, consumer associations, etc. to debate on the level of food product damage acceptance, and to develop new pathways for selling "second quality" consumable products showing damages from pests but labelled no (or less) pesticide (including organic)

Improving Farmer Acceptance and Adoption

Despite growing literature on the principles behind CBC and ways to achieve success, acceptance and adoption remain small.[47] Some of the failure to adopt similar environmental schemes in the past have been as a result of the perception of farmers that innovative management options might present a risk, and the fact that prescriptive policies rob the farmers of inclusion in the process and therefore return little symbolic capital to them.[48] More importantly, the chasm between farmers' professional knowledge and scientific knowledge has been shown to hamper adoption of environmental schemes,[49] in particular those pertaining to biodiversity conservation. Persistent barriers to adopting of new farming practices also include limited availability of and access to information and limited knowledge of alternative practices.[50,51] For example, in England, a review of the Environmental Stewardship scheme found low uptake of habitats for which there was the strongest evidence of a benefit to biocontrol,[52] despite the apparent awareness among farmers of their value.[53] Primary explanations given by farmers for not adopting the scheme were its inflexibility, the volume of paperwork and amount of information to assimilate the application process, costs of the plan and its implementation not being covered by payments, and costs of capital works not being met due to rising labor and material costs. Farmers were also unwilling to adopt the scheme if habitats had to be newly planted on their farm, such as hedgerows.

The potential of CBC should be communicated in multiple ways in order to reach the widest possible range of farmers. These could include fact sheets (digital and print), on-station/farm demonstration, and participatory research. Since the effect of biocontrol is less dramatic than the effect of pesticides, tools to help farmers visualize the presence of natural enemies or even monitor the level of service they provide would improve awareness. Such tools might be as simple as pitfall traps with simplified identification keys for the most abundant ground-dwelling natural enemy species in the region, or they could be more elaborate, like predation cards where prey bait are exposed to potential predation with a subsequent evaluation of the numbers eaten.

Training and advisory systems should first raise awareness and stimulate interest in alternative methods of pest management, then provide farmers access to the necessary tools to implement the appropriate measures.

To address these problems, training and advisory systems should first raise awareness and stimulate interest in alternative methods of pest management, then provide farmers access to the necessary tools to implement the appropriate measures. Educational programs are of particular value in addressing complex issues such as pest regulation, where there are uncertainties regarding the efficacy or environmental effects of alternative crop protection methods and when solutions rely on the integration of multiple approaches. Another knowledge exchange could be free of subsidized advisors to provide advice complementary to IPM. Moreover, advisory services should support the implementation of farmers' groups that are able to share the costs and to coordinate management at landscape scale. Additionally, demonstration farms are often highly appreciated by farmers' communities and considered to be very valuable for both knowledge exchange between research, advisors, and farmers and for efficient dissemination to other farmers.

Participatory development in new technologies is also important. Farmers are more likely to adopt if they are involved in the development of the technology and practice and if benefits are clear, uncertainty is reduced, the need for exploration and testing is low, risk is limited, and a financial return can be realized relatively quickly.[47]

There is evidence that CBC can be economically viable, but it does require the implementation of new technologies and farm practices that have investment and operational costs. Cost–benefit analyses of potential projects should be designed to show the difference between increased economic costs of implementation (e.g., loss of productive area or more expensive technologies) and the benefits from reduced pesticide use and added value for new or enhanced products with CBC. The latter could be strongly reinforced with labels and certifications. Understanding the financial impact of going beyond existing labels for products made under IPM (e.g., IP-Suisse system in Switzerland) and potentials in increased pricing for sustainably produced agricultural goods should also be included. Finally, in assessing the decision making process associated with CBC adoption it is necessary to account for farmer's attitudes, their perception of risk, and all benefits, including nonmonetary aspects of cultural ecosystem services such as aesthetic, recreational, and tourism values.

M. Waldburger, Agroscope, 2012

Spiders are generalist predators and exist exclusively on live preys. In addition to the consumption of pest species, they require supplementary and alternative prey supplied by landscape features. A spider population may consume more than seven million individuals per hectare during its biological life cycle.

Moving Forward

The last 20 years of researching and implementing environmentally friendly practices in agriculture have essentially only been targeting general biodiversity, and have only partly succeeded in achieving these goals. At the same time, various means to ensure and increase production have been applied, mostly by intensifying management and pesticide use. While some systemic approaches like IPM have been implemented, pests and pesticides continue to be a problem for reducing crop production and harming human and environmental health, respectively.

CBC seeks to rebalance the part of the agricultural ecosystem that supports natural enemies, while increasing resources that natural enemies depend on, yet have been lost through agricultural intensification. Though we are learning how to conserve certain natural enemy types, managing ecological processes through CBC is a challenge with many aspects still to be understood before reliable methods to achieve pest control and yield improvement are established.

To be effective, CBC must provide system-level solutions, account for interactions between organisms and scales, and produce positive environmental, social, and economic outcomes. This challenge requires collective expertise from a wide range of actors including science, industry, governments, and farmers. Drawing together such diverse yet relevant actors is an important element of operational groups, which are now being pursued as a practical, sustainable, and environmentally friendly way forward to address key problems regarding pests and pesticides. S

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Landscape features such as wild flower strips support natural enemies of pests in agricultural landscapes.

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