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Biodiversity, herbicides and non-target plants

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ABSTRACT

Herbicides provide a useful tool for the farmer, grower and vegetation manager. However, they are capable of affecting non-target plants. Non-target plants may be those outside the target area, or those within the target area of conservation concern or whose control has untoward effects on biological diversity. A number of farmland birds, invertebrates and plants have shown population declines in Europe; changes in agriculture, including herbicides, are implicated. Whilst a better understanding of the impacts of weed control on biological diversity is needed, the new challenge is the development of more ecologically sustainable production, incorporating the maintenance of some weed species within crops. The first-generation genetically modified herbicide-tolerant (GMHT) crops seem unlikely to provide the required flexibility of management. For success, greater selectivity of herbicide chemistry is indicated, together with a range of risk avoidance approaches.

INTRODUCTION

Herbicides are an essential part of the farmer and grower's equipment for crop management. In addition, herbicides can play a useful role in vegetation management in a variety of non-crop situations, ranging from industrial areas to amenity sites (Marshall, 1994) and even nature reserves and conservation areas. For example, herbicides may be an essential part of control strategies for alien invasive species, such as giant hogweed (*Heracleum mantegazzianum*). Nevertheless, a range of environmental problems, including residues in water, has focussed attention on the regulatory process and the impact of herbicides in the environment. There have been a number of recent developments in approaches to risk assessment and risk avoidance for non-target effects of herbicides (Breeze *et al*., 1999). This paper reviews the definition of non-target plants, the use of herbicides and assesses the impacts of herbicides on non-targets and biological diversity. The implications of improved understanding of functional biodiversity and of developments in new technologies are discussed. Finally, a number of requirements for the future approval and use of herbicides are proposed.

DEFINING NON-TARGET PLANTS

The movement of herbicide away from the application area will bring it into contact with plants that are by definition non-targets. This "off-field" movement may be due to droplet drift, vapour movement, leaching and erosion, as well as inappropriate disposal. An extremely wide range of plant species (the national flora) is potentially at risk to such movement. Approaches to risk assessment and risk avoidance in the UK have been reviewed by Marshall *et al*. (2001). Advances in non-target risk assessment have also been made in Europe and North America, aimed at assessing the risks to off-field flora particularly from drift events (Hewitt, 2000).

There are also within-field non-target plants that need consideration. There are two very different scenarios where herbicides are used. In most situations, a herbicide is deployed to control all the plant species present except the single crop species. In the non-crop situation, either all species are targets for total weed control, or there is a single target species and all others present are non-targets. This is a simplification, as herbicide selectivities vary and the target group necessarily may be wider. Likewise, within a crop, there may be a number of unsown plant species present forming a weed assemblage. As many of these species reduce yield, or affect harvesting, storage or crop quality, farmers regard them all as weeds worthy of removal. Nevertheless, amongst these non-crop species, there may be both target and non-target species for weed control. A number of rare weed species, such as broad-leaved cudweed (*Filago pyramidata*), are subject to conservation effort and some are included within UK Biodiversity Action Plans (BAPs), the response to the Rio Convention on Biological Diversity (Anon, 1994). These may be regarded as non-target species. Of greater significance, as they are commoner and often have significant biomass, there is a suite of species that might be targets at higher density, but may be non-targets at low population levels for biodiversity reasons. There are a number of species that are almost invariably targets for control, usually because of their competitive ability, such as wild-oat (*Avena fatua*). The consideration of non-target species within the application area brings a number of potential complications to the regulatory process and to practical management. However, against the environmental background of significant declines in farmland wildlife across Western Europe, this is a challenge to be faced.

HERBICIDE IMPACTS AND NON-TARGET EFFECTS

Agricultural and horticultural habitats do not occur in isolation in the landscape. Field systems occur as mosaics of crop and non-crop habitat (Marshall, 1988) and may be refuges for many plant and animal species. Whilst most species associated with non-crop areas do not commonly pose serious threats to adjacent crops (Marshall, 1989), these areas may be important for the conservation of biological diversity in agricultural landscapes, particularly as production methods have intensified. Extensive studies of land use change and their ecological consequences also indicate that botanical diversity is continuing to decline (Haines-Young *et al*., 2000). Whilst the causal effects are not agreed, they are most likely to be eutrophication and disturbance. Agricultural practices, including fertiliser and herbicide applications, are implicated (Kleijn & Snoeijing, 1997).

Within agricultural systems, there have been significant declines in both population sizes and ranges of common birds in the UK (Fuller *et al*., 1995). Likewise, there have been significant declines in some taxa of invertebrates found within fields (Aebischer, 1991). The idea that arable fields are “ecological deserts” is ill founded, as there is a range of plant and animal species specifically adapted to the habitat, for example the cornfield flowers.

Individual plant species can be affected directly by a herbicide. As part of a plant community made up of many species, a plant species can also be affected indirectly following herbicide contamination. This can be mediated by competition between species, or by affecting plant recruitment (vegetative or from seed), or by affecting herbivore pressure or symbionts. Determining the effects of herbicides on plant communities is not straightforward (Cousens *et al.*, 1988). Susceptibility of plants to herbicides is not a constant characteristic, as application variables interact with plant variables.

Non-target effects of herbicides may be caused when materials reach situations beyond the target application area and/or reach species not intended to be affected growing within the target area. The direct adverse effects of herbicides can range from outright death of a plant or population, through minor effects, to enhanced growth. The spectrum of direct effects on individuals is matched by a spectrum of indirect effects on associated fauna and flora. Direct effects on plants can appear to be insignificant, for example, reduced flowering. However, such impacts may be of major significance to species where seed production is the key element of the regenerative cycle of the plant. Effects on germination and early recruitment of plant species are believed to be of particular importance at a growth stage that is particularly susceptible to pesticides. Non-target effects may have subtle effects on plant community composition, mediated by plant competition or by effects on the water and chemical environment in the rhizosphere.

It is unclear how important the non-target effects of herbicides are. For example, it is unknown if repeated drift events, or mixtures of herbicides at low doses, can have sub lethal effects on plant recruitment. The “off-field” movements from herbicide application are likely to be the most common cause of non-target effects (Breeze *et al*., 1999). These can result from droplet drift, mist, solid and vapour movement. Of these drift forms, droplet movement is by far the most important and common form. Following application, pesticides may also undergo secondary redistribution with a risk of non-target effects, if pesticide concentrations are high enough.

BIODIVERSITY AND ECOSYSTEM FUNCTION

The reasons for the conservation of biodiversity are moral, aesthetic, social and economic. We steward other organisms for their intrinsic value and because species may be of benefit to human society and have economic value. A culture that encourages respect for wildlife is preferable to one that does not. Biodiversity can be easily lost but is difficult to regain, particularly if species are driven to extinction. Biodiversity, including genetic diversity, may provide economic benefits. Even at the level of landscape, biodiversity may influence tourism and sense of place. Perhaps of greatest concern is that biodiversity has a role in the function of ecosystems (Tilman *et al.*, 1996). Erosion of diversity may thus ultimately result in damage to ecosystem function.

Plants are key components of terrestrial ecosystems, providing the primary production upon which food chains are built. Different plant parts provide a range of resources for associated fauna (Fig. 1). Leaves and stems may be browsed, while pollen and nectar provide resources for pollinating insects. Fruits and seeds are important food for a large number of organisms. Plants have other functions as well as providing food for herbivores. They provide cover, reproduction sites and structure within habitats. Plants also form a substrate for bacteria, fungi etc., both above ground and in the soil.

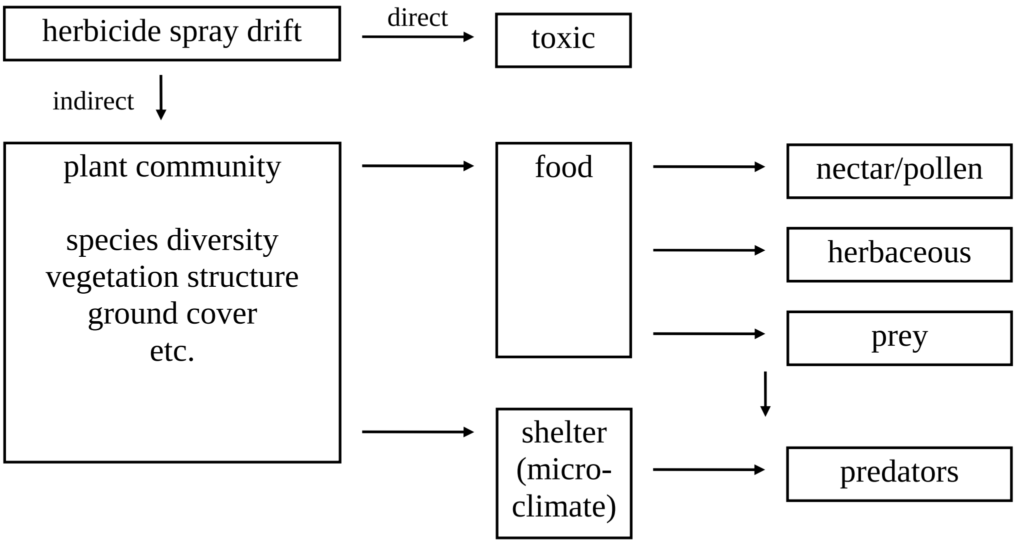

Figure 1. Potential ecological effects of herbicide spray drift on invertebrates - from Breeze *et al.*, (1999)

Even non-crop plants or weeds may play a role in the function of the ecosystem and in supporting many other species. As an example, the grey partridge (*Perdix perdix*) requires insects as chick food during the first ten weeks of rearing. Many of these insects are associated with annual dicotyledonous weeds in cereal crops in the UK. Adult partridges also feed on plants, particularly within arable crops. Management of the crop with pesticides and herbicides is therefore likely to have had a major impact on partridge populations, explaining the major declines in population of this bird species in the twentieth century (Potts, 1991).

Interactions between weed diversity and biodiversity

A comparison of herbicide-treated and untreated plots in the headlands of winter cereal fields in southern England (Moreby & Southway, 1999) has clearly demonstrated that untreated plots had greater weed density and diversity and significantly higher numbers of many invertebrate taxa, notably those that are important in the diet of farmland birds. Studies of the insects associated with soybean in Iowa, USA, indicate that weedier fields have generally higher insect densities. Weed management in herbicide-resistant soybean generally gave fewer insects (Buckelew *et al.*, 2000). The effects were indirect, mediated through the weed flora. Several initiatives, notably for integrated crop management, indicate there are implications for biological diversity within fields from different approaches to weed control. The protection of the farmers' investment and avoidance of risk have been the driving forces for efficient weed control in the past. However, an emerging new paradigm is to match crop production with conservation of biological resources (Paoletti *et al.*, 1992) and the development of more sustainable systems. This may require the maintenance of some weeds within fields.

NEW TECHNOLOGIES FOR WEED MANAGEMENT

Genetically Modified Herbicide-Tolerant (GMHT) crops

The introduction and testing of GMHT crops, whilst widely accepted in North America, has been opposed by many interest groups in Europe. Current work on the field-scale evaluation of the biodiversity impacts of these crops in the UK is examining the likely impact of modified herbicide use within the crop (Firbank *et al*., 1999). The first generation of GMHT crops are engineered for tolerance to broad-spectrum herbicides, notably glyphosate and glufosinate. These *may* allow greater flexibility in weed management, but there may be effects on biodiversity as a result.

Watkinson *et al*. (2000) simulated the effects of the introduction of GMHT crops on weed populations and the consequences for seed-eating birds, using fat-hen as the model weed. They predicted that weed populations might be reduced to low levels or practically eradicated, depending on the exact form of management. Consequent effects on the local use of fields by birds might be severe, because such reductions represent a major loss of food resources. Buckelew *et al*. (2000) have shown that herbicide-resistant soybean crops tend to have lower insect population densities, associated with fewer weeds.

Whilst it may be argued that GMHT crops offer the opportunity to delay weed control, some crops, most notably maize, are particularly susceptible to early weed competition. Such crops are likely to be treated with herbicide around the time of crop emergence to eliminate weeds early in the life of the crop. The technology offers reduced risk to the farmer, with opportunities for repeated application, should this become necessary. Environmentally, the technology offers the possibility of clean crops and thus adverse biodiversity effects, as well as the unknown, if low, possibility of gene transfer to wild relatives. Nevertheless, it must be accepted that in the developing world, where weeds are the primary source of crop loss, this first-generation technology may have an important role.

Integrated Weed Management

Approaches to weed management over recent years have taken an holistic view of the crop rotation as a whole, rather than simply in single crops, as part of integrated crop management (ICM). ICM considers fertiliser use, targeted pesticide use, alternative control techniques, forecasting and modelling, as well as crop rotation (Jordan & Hutcheon, 1995). Economic pressures have also forced farmers and growers to consider the number of herbicide applications made and the dose of active ingredients used. Reduced dose applications have become common. Within ICM, the manipulation of crop architecture, tillage regimes, mechanical weed control, allelopathy, mulching, biological control may all contribute to "integrated weed management".

However, "*devising integrated weed management strategies that address a diversity of weed species with a diversity of life history traits is difficult*" (Mortensen *et al*., 2000). A sound understanding of species, population and community ecology can contribute to weed management. Advances include population equilibria, density-dependent effects, crop competition models and integration with herbicide dose-response studies.

RISK MANAGEMENT

Risk management needs to address herbicide susceptibility and exposure. Exposure can be most easily manipulated, though susceptibility may be influenced, for example by protectants. The key to risk avoidance must be in targeting only those plant species or populations that require control. This means that precision in chemistry, i.e. selectivity of herbicide, and precision of application, i.e. only to the target plants, offers the most robust way forward. Aspects of dose, formulation, application timing and application technology may be usefully modified within a sound weed forecasting and decision-support framework. There may nevertheless be opportunities for spatial approaches to biodiversity maintenance. For example, conservation headlands, in which limited pesticide applications are made to the outside 6m or 12m of crop, allow sufficient weeds and invertebrates to survive for grey partridge populations to switch from decline to increase (Rands & Sotherton, 1987).

NEW DIRECTIONS FOR HERBICIDE USE AND WEED BIODIVERSITY

Ecologically, there is a requirement for greater specificity of herbicide action for minimising environmental and non-target effects. This runs against the trend for more broad-spectrum products produced by manufacturers. In order to cover the high costs of product development, manufacturers require products that will sell into global markets. This has resulted in herbicides with wide weed spectra coming to market, with more selective products rarely being commercialised. Greater herbicide selectivity is not without practical and financial difficulties. The inertia of commercial development could only be mobilised by legislative and regulatory requirements, possibly backed up by redirected farm support to growers. In addition, there could be difficulties if there are insufficient product options, e.g. herbicide resistance. Nevertheless, there could be opportunities for specialist market development, if agricultural support is redirected from production to environmental support. Non-crop vegetation management could provide a diversity of niche markets.

Clearly, where selectivity in chemistry is limited, there are opportunities for achieving selectivity by exploiting application technology and spatial methods, as well as manipulating crop phenology and growth characteristics. Further work on the opportunities for arable biodiversity areas, such as conservation headlands, is required.

Under the regulatory regimes for pesticides, there is a need to consider non-target, indirect effects that occur within the target crop area. This will require testing on a wider range of plant species representative of the diverse flora of arable and horticultural fields.

Current integrated weed management programmes might be further developed and modified to maintain adequate populations of the most important weed species for biodiversity, while controlling the most damaging. There is some possibility of relaxing weed control either rotationally or in limited areas of fields. Nevertheless, the major constraint is that the most fecund and often the most competitive weed species respond best to reduced control. Therefore, relaxed weed control would need to be managed carefully to allow the less common and less competitive species to increase, while controlling the competitive species. This may indicate a new approach to weed management, with the explicit aim of maintaining specific weed assemblages. These might be more traditional assemblages that were common

100 years ago, or tailored to maintaining beneficial invertebrate species, or for biodiversity more generally. An understanding of the selection pressures applied by management, including the use of herbicides, and their effects on diversity, ranging from genetic to community levels, is needed.

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