ASSESSING PESTICIDE RISKS TO NON-TARGET TERRESTRIAL PLANTS

SECTION FIVE: PESTICIDE IMPACTS ON NON-TARGET PLANTS

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5.1 INTRODUCTION

Plants have a key role in terrestrial ecosystems, providing the primary production upon which food chains are built. Different plant parts may provide a range of resources for associated fauna. Leaves may be browsed by herbivores, 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 apart from providing food for herbivores. They provide cover, reproduction sites and structure, as well as affecting ecosystem function via soil processes and trophic interactions. Non-target plants within spray target areas and in adjacent habitats may be susceptible to pesticides that reach them. These effects may be direct, via toxicity, or indirect, mediated by the responses of other plants, the environment or animals.

In this section, the likely methods of pesticide movement are considered, the available data on drift and susceptibilities of plants are reviewed and the implications for risk assessment and management discussed. The possible direct and indirect effects on individual plants and on whole communities are also discussed and the areas where insufficient information is available are identified.

5.1.1. Pesticide drift and primary off-target movement

Pesticides may drift away from the target site during or after application. This can happen in a variety of forms:

Spray droplets: - of similar composition to the spray solution. Drift in this form generally takes place at the time of application or very soon afterwards.

Evaporated droplets: as small droplets have a high surface area to volume ratio, evaporation of water carrier can be rapid to leave a micro-droplet of the original active ingredient and formulation solution. There appear to be no studies on this type of drift, and its significance remains a question for speculation. Very small droplets like this would nevertheless have the potential to drift considerable distances, further than unevaporated droplets.

Vapour: the active ingredient may evaporate both from droplets and sprayed surfaces during and after application if the saturated vapour pressure is large enough. Usually, only certain types of chemicals behave in this way, and are potentially serious because vapour may travel large distances. Also, the vapour of pesticides may be highly available to affected organisms and rapidly assimilated resulting in toxicity at low doses. Breeze, Simmons and Roberts (1992a) have considered generation of vapour from sprayed surfaces; other aspects of herbicide vapour including phytotoxicity have been reviewed by Breeze (1993). Saturated vapour pressure values for many pesticides in use in the UK are given in by Breeze, Simmons and Roberts (1992b) and for others by Wauchope, Buttler, Hornsby, Augustijn-Beckers and Burt (1992). Responsibility for this form of drift is in the hands of the manufacturer; there is little or nothing that the spray operator can do, apart from applying pesticide in cool conditions, to prevent vapour generation.

Pesticides sorbed onto particles which are small enough to be carried in air. This is unverified in the field but is a potential hazard particularly for soil-applied chemicals.

Pesticides sorbed onto acid mist droplets: this has been demonstrated by Glotfelty, Seiber and Liljedahl (1987). This may be another method for long-distance transport.

Leaching in soil water and subsequent movement to ground and surface waters is a potential problem, although largely relevant to non-target aquatic plants.

Crystallisation of solids onto the spray nozzle during application and consequent movement of particles in air currents; Only one case is recorded of this; that of propanil on rice (University of California, Davis; personal communication to V G Breeze), and is probably the result of inappropriate formulation or incorrect sprayer adjustment.

Of these drift forms, droplet movement is by far the most important and common form of drift, and is not confined to specific active ingredients. It usually occurs as a result of using the wrong sprayer adjustment or operating in a higher than recommended wind speed. Also, droplet drift usually leaves the pesticide in a form that is phytotoxic, unlike some of the other forms of drift such as sorption onto soil particles which may lead to a lower availability of active ingredient.

5.1.2. Secondary movement of pesticides

Following application, pesticides may undergo secondary redistribution with a risk of non-target effects.

Rainfall may redistribute applied pesticide on the plant and result in wash-off to soil.

Pesticide leaching through the soil profile may result in within-soil effects. Pesticide residues are recorded in soil water, in drainage and in potable water supplies. These may result from direct overspraying of watercourses but also movement *via* soils to groundwater. Non-target effects may occur, if pesticide concentrations are high enough.

Vapour redistribution within the plant canopy and further from the target can occur (See earlier comments). Some new fungicides rely on this property to provide plant protection from disease.

5.2 DISTANCES TRAVELLED BY SPRAY DROPLETS AND AMOUNTS OF DRIFT IN FIELD CROPS

Pesticide spraying equipment is designed to apply small droplets of solution over as large an area of crop as possible, as this is the most effective way to deliver the active ingredient to the weed, fungal or insect pest. Generally, droplets of about 250 µm diameter are ideal because these settle rapidly, although some smaller droplets are inevitably produced as well by most systems. Droplets of about 100 µm diameter are prone to drift, as their weight is less; they also have a high surface area to volume ratio, and therefore evaporate rapidly. Once a droplet has reached 10 µm diameter, its rate of fall is so low that it can be considered capable of drifting indefinitely. The volume of spray solution contained in the droplet fraction of <100 µm diameter is important in determining the amount of spray drift that may occur. Typically, this volume will be a few percent of the total volume of spray solution (Western, Hislop, Herrington and Jones, 1989) but is affected by nozzle design, spray pressure and composition of the solution.

The effect of wind speed on droplet drift has been extensively described (e.g. Hartley and Graham-Bryce, 1980); essentially, a droplet settling at a low speed will be carried further in a current of air, and hence will drift. The longer a water solution droplet is airborne, the more water will evaporate; its size declines and so its rate of settling slows.

The shape of the field to which pesticide is being applied, in relation to the wind direction, is also important because drifting droplets may settle on the crop. Wide fields, requiring more passes of the sprayer, may give more contamination along the margins than narrow fields having fewer passes (Breeze, Thomas and Butler, 1992).

Once having drifted onto a non-target site, there is no certainty that the pesticide will have the same toxicity as the original solution. Evaporation of the carrier water or components of the formulation could have small effects; such differences can only be inferred because there are no reliable data. Photodegradation of the active ingredient is possible if there is an appreciable delay between pesticide application and arrival at the target; this topic has been reviewed by Fritz (1993) and other references are given in Breeze, Simmons and Roberts (1992b).

There are two ways to quantify the amount of off-target drift of pesticide, by field measurements and by models. Measurements are difficult to make because one of the principal factors, that of wind speed, cannot be controlled on a large scale. On the other hand, models need to consider many factors with considerable complexity. As no two fields are the same with respect to physical features, it is likely that both models of droplet drift, and relationships derived from field measurements will, at best, be an approximation for the prevailing conditions.

5.2.1 Field measurements of drift

Few reliable data are available for field conditions. A summary of work is given in Appendix One. Recent data from Longley *et al*. (1997) and Longley & Sotherton (1997) show that under recommended spray conditions, drift to field margins is of the order of 3% of field application rates. Rates of deposition in field margins are affected by a variety of factors, including boom height, wind speed and vegetation heights. Nevertheless, higher levels of drift have been recorded on ditch banks in the Netherlands, ranging from 4% to 25%, depending on the type of spray nozzle used (de Snoo & de Wit, 1998). Drift is normally no greater than 4% under recommended field conditions (pers. comm. N. Western). Drift may occur when applications are made under less-than-ideal conditions, which may occur when spray decisions are dictated by time and management pressures.

5.2.2 Predictions of droplet drift from models

There have been several attempts to model droplet drift and some examples are given in Appendix Two.

5.3 IDENTIFYING NON-TARGET EFFECTS ON PLANTS IN THE FIELD

There are three ways in which symptoms of pesticides may be manifest on non-target plants, i) by visible symptoms of damage or by a reduction in rate of growth, ii) by promotion of growth or, iii) in the longer term, on the population structure of a community by the elimination of susceptible species. Whereas the first example is recognised in the field from observations, the other two are usually inferred from laboratory or glasshouse studies.

5.3.1 Pesticide damage

Surprisingly little work has been carried out, or at least is available in the literature, on pesticide damage to plants species, both weed and wild. Herbicide evaluations are generally limited to a ‘dead or alive’ assessment for weeds of economic importance in crops. Nor, unexpectedly, are there any quantitative models describing the response of individual plant species to selected herbicides and, likewise, there are few sets of data describing dose responses. Part of the reason is that the effect of herbicide is confounded by many factors, and industry is largely interested in general effects in the crop. However, it would be difficult to find in the literature a single, thorough set of data describing the effect of herbicide at different plant sizes, a relationship which is of no little practical importance. Bearing in mind that data are few even for weeds, the lack of information for wild plant, non-weed species is perhaps understandable.

Awareness of the general lack of information on herbicide damage to plants becomes only too clear when incidents of pesticide contamination are encountered in the field. Such events are inevitably reported well after the contamination took place and thus can be difficult to verify. Often the type of pesticide is not known because symptoms are not specific and can be confused with other effects unrelated to pesticides, such as waterlogging. Even plant tissue analysis can be inconclusive, as there may be degradation of the original chemical. More importantly, chemical analysis could be difficult to interpret without dose-response data. The type of transport, such as spray or vapour drift, can be uncertain, and with this problem, difficulties may arise about how far the pesticide has travelled. Two illustrated guides to identification of symptoms are available, although both are for a limited number of examples (Meinhardt, 1989; Noye, 1983).

The following cases are typical examples of off-target pesticide contamination which have occurred both in the UK and overseas.

Mecoprop contamination of oilseed rape in the UK: This has been described by Breeze and Timms (1986) and references cited therein (Elliott and Wilson, 1983). Essentially, the herbicide mecoprop *iso*-octyl is slightly volatile and was thought to cause vapour drift to nearby crops of oilseed rape following application to cereals. Subsequently, the herbicide was withdrawn. Two points are of interest. First, the herbicide in question was in use for some time before drift contamination was observed. Oilseed rape was introduced as a crop at about the same time as the herbicide became available, and it was the widespread occurrence of the crop that highlighted the problem. Incidents of drift onto wild plants must have gone unreported beforehand. Second, oilseed rape is not especially sensitive to mecoprop (Breeze, 1993), thus further suggesting that other, unnoticed damage must have taken place. There do not, however, appear to have been reports of damage to non-crop species. The implication is that damage from pesticide drift may be present in wild species without it being observed or attributed to pesticide drift.

Triclopyr vapour drift: Triclopyr is an effective but volatile herbicide and has caused damage to non-target plants over a number of years, especially in warm areas on the Continent but also in the UK (Cooke, 1993). Woody species appear to be susceptible. In most instances this is probably due to vapour movement.

Contamination by phenoxyalkanoic acid herbicides: There are a number of reports of plant damage from this class of herbicides from Australia, the USA and Canada, and most recently, South Africa; these have been summarised and evaluated by Breeze (1993) (see Appendix Three). The South African case demonstrates both the problems with identifying sources of contamination and the ways in which the pesticide was moved in the field. Breeze (1994) also describes the possible risk from dimethylamine salts, which may degrade to release volatile, toxic free acids (Appendix Four).

Recent drift incidents reported by the HSE: Each year, the Health and Safety Executive publishes the number of complaints arising from crop spraying; during 1996/97, 93 complaints were recorded (HSE 1997). In previous years, going back to 1991, between 60 and 100 complaints were recorded. This is clearly not the total number of spray drift events that took place, due to drift being unrecorded and because not all the complaints were confined to drift itself. Nevertheless, it indicates that there are still a considerable number of spray drift incidents taking place each year.

5.3.2 Promotion of plant growth due to low doses of pesticides

It is generally agreed that very low doses of some herbicides can be growth promoting (Ries, 1976), and such treatment might have been advocated as a means of increasing crop yield had not experiments given inconsistent results. Breeze (1994) described experiments using low doses of 2,4-D esters in which field bean plants showed a transient enhancement in the rate of carbon dioxide exchange during exposure to the herbicide, whereas tomato plants showed a rapid decline. In other work, no enhancement of growth or any other process was observed for tomato plants following exposure to vapour of 2,4-D. However, tomato plants exposed to fluroxypyr vapour were up to 20% taller than the controls, although shoot dry weight was not increased. Thus, growth enhancement is specific to certain combinations of plant species and herbicides, but the physiological explanation for this is lacking. Such effects have not been reported following contamination by herbicides, from vapour or spray drift, in the field. It seems very unlikely that the correct conditions have not existed in the field, although entirely possible that the effects have not been recognised because there would need to be unaffected plants close by for comparison.

Promotion of the growth of *Crataegus monogyna* (hawthorn) has been reported following treatment with the herbicide, difenzoquat. It was suggested that the herbicide, which has a chemical formula similar to a number of fungicides, reduced amounts of mildew (Marshall, 1989), allowing enhanced growth over the untreated controls.

5.3.3 Effects of pesticide contamination on species composition in natural communities

Effects of sublethal doses of pesticides on the composition of natural plant communities have been advocated (Breeze, 1993; Breeze, 1994) but not widely studied. Such effects, on one or more plant species, could be either deleterious or growth promoting, leading to changes in the species composition of a community and the possible elimination of desirable species in the long-term. Although there may be few documented examples of this happening following pesticide contamination, it is well-established that application of nitrogen to species-rich meadows can encourage the growth of grasses and so cause other, less vigorous species, to disappear (Marrs, 1993; Willis, 1963). It is possible that certain areas adjacent to highly intensive arable farms might be subjected to frequent but low doses of herbicide from drift, which could cause a cumulative biological effect over a number of seasons. Fertiliser contamination of field boundaries occurs commonly, with effects on the associated herbaceous flora (Tsiouris and Marshall, 1998). Recent work in the Netherlands reports significant impacts of the herbicide fluroxypyr applied at 5% and 10% of field doses on field communities (Kleijn & Snoeijing, 1997). The effects are not always immediate and appear to be mediated by effects on the survival of subordinate species in the community.

5.4 SUSCEPTIBILITIES OF NON-TARGET PLANT SPECIES TO PESTICIDES

5.4.1. Measuring susceptibilities of species and communities

Individual plant species can be affected directly by a pesticide. As part of a plant community made up of many species, a plant species can also be affected indirectly following pesticide 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, notably mycorrhizae (e.g. Carey *et al.*, 1992). Determining the effects of herbicides on plant communities is not straight forward (Cousens *et al.*, 1988). Susceptibility of plants to pesticides is not a constant characteristic, as it is affected by many variables. Application variables, which include dose, timing, spray volume and spray deposition, interact with plant variables, such as growth stage, size and location within the plant canopy.

Direct effects of pesticides are usually measured in terms of susceptibilities to single applications of directly applied pesticide products. A range of doses are often applied, sometimes in order to describe dose-responses. Useful data on species susceptibilities may be provided as part of product efficacy information. Often, similar susceptibilities are found within families of plants. For example, most members of the Asteraceae are susceptible to the herbicide, clopyralid. However, indirect effects are seldom quantified.

Effects of pesticides on plant communities have been described for many active ingredients and for a range of habitats, often as part of the investigation or development of novel methods of vegetation management. These data are scattered through the literature. While such studies do not usually attempt to identify the specific effects at work, they nevertheless provide some useful information on community responses.

5.4.2. Tolerance and susceptibilities of individual species

Herbicide development includes pot and field tests on a range of plant species. Often, however, the range of species is representative of crops and weeds and not non-target species. Enquiries to manufacturers about the tolerance or susceptibilities of non-target species often elicit no information, for example, for uncommon cornfield flowers.

To evaluate the potential adverse effects of herbicides used in adjacent crops on the non-target flora of field boundaries, evaluations of herbicides used in the 1970's and early 1980's were made using pot-grown material. Plants were usually grown from seed and oversprayed at different dose rates (Birnie, 1984; 1985; Marshall and Birnie, 1985). These early evaluations indicated that non-target flora could be adversely affected by drift or accidental over-spraying, though individual species tolerances varied considerably. Effects on any of the 40 species selected under Objective 1 of the present review are summarised in Appendix Five.

A further series of field margin flora were tested against a range of herbicides of non-target species and the results summarised as those species which were severely damaged at six weeks and were unlikely to recover. The results obtained (Appendix Five) indicate that active ingredients had varying effects.

Similar studies but using test plants at different distances from a tractor-mounted sprayer in the field were made by Marrs *et al*. (1989; 1991). A range of species was assessed in terms of safe distances, indicating that a spray buffer zone of between 5 m and 10 m is required adjacent to sensitive habitats. Marrs *et al*. (1989) recorded visual symptoms of herbicides and also effects on flowering and seed production. Drift of the herbicides glyphosate and chlorsulfuron+metsulfuron-methyl in autumn and drift of glyphosate, mecoprop and MCPA in spring, caused reduced flowering and seed production of a number of flower species. It was suggested that drift might affect regeneration within the community and hence species diversity in the longer term.

More accurate assessments of the susceptibilities of plant species to herbicides are given by deriving dose-response curves. Species may then be categorised by their LD_{50}, the dose required to give a lethal dose to half the population, or ED_{50} or ED_{10}, the effective doses in 50% or 10% of the population.

This approach has been used to categorise non-target herbicide effects (Breeze, Thomas and Butler, 1992). The dose responses of 14 wild plant species (two grasses, two legumes, one annual and 9 perennial dicotyledons), not usually recognised as weeds, to four herbicides (asulam, glyphosate, MCPA and mecoprop) were measured in glasshouse experiments. Glyphosate was the most toxic; seven of the species tested had ED_{10} values (measured as shoot dry weight) of <1.0 μg/plant, compared with only one species for MCPA and mecoprop. Asulam was the least toxic. The results for target key species identified in this review are summarised in Appendix Five. Results obtained were used to indicate the risk to each species from drift damage. A model of spray drift, based on that developed by Thompson and Ley (1982) for evaporating droplets, was rescaled to allow for field application rates and used to predict the distances travelled by given doses of herbicide. This gave acceptable agreement with reports for drift damage in the field, and predicted that only glyphosate sprayed at the highest recommended concentration might be unsafe to some of the species examined. The two herbicides sometimes used as volatile formulations (MCPA and mecoprop) did not cause damage at the small doses likely to result from exposure to vapour in the field.

As part of study of the use of graminicides to control weed grasses in newly sown grass margin strips, a pot experiment supported by Willmot Pertwee Limited examined the effects of three herbicides applied at half and a quarter field rates (Marshall, 1995). Three graminicides, fluazifop-P-butyl, cycloxydim and propaquizafop, were applied to 14 different grass species grown in pots. Applications were made at four growth stages, from a main shoot plus one, two, four or six tillers. Herbicides were applied at one quarter and one half of field rates, in order to assess the selectivity between species at reduced rates. Results confirmed that *Festuca rubra* was unaffected by any of the three herbicide treatments. Propaquizafop was effective on most grasses at both rates, with the exception of *Festuca rubra* and *Holcus lanatus*, the latter which recovered successfully. Evidence of selectivity, i.e. the control of weed grasses and lack of effect on desirable grasses, was sparse. *Hordeum secalinum* was an exception, recovering to growth similar to untreated plants. There were indications that at half-rate, fluazifop-P-butyl was safer than cycloxydim on *Anthoxanthum odoratum* and *Cynosurus cristatus*, and possibly *Holcus lanatus* and *Trisetum flavescens*. *Dactylis glomerata* survived better following treatment with cycloxydim, than with fluazifop-P-butyl (see Appendix Five). In this experiment, there was little evidence of differences in effect with growth stage.

Applications of full and half-rates of 17 herbicides and plant growth regulators (PGRs) to four shrub species (Marshall, 1989), revealed different susceptibilities. Some products, such as glyphosate, were active against all four species. Other compounds had unpredictable effects. For example, elder (*Sambucus nigra*) was susceptible to clopyralid, while hawthorn (*Crataegus monogyna*) growth was enhanced by difenzoquat, probably as an indirect effect of mildew suppression (Marshall, 1989). Results on *C. monogyna* are summarised in Appendix Five.

Willmot Pertwee Limited, in collaboration with the Forestry Commission, examined the effects of a range of agricultural herbicides on tree species to be used in farm woodland planting schemes (Nowakowski *et al.*, 1994). The data include effects on hazel and hawthorn, two key species selected in this review (see Appendix Five). Young plants of these two species were moderately susceptible to most herbicides tested.

Whilst some information on the effects of herbicides is available in the literature, it is clear that:
a) there is insufficient dose-response data
b) many new herbicides are now used commercially which have not been subject to tests on non-target species
c) effects of pesticides on regeneration in plant species requires further study

5.4.3. Direct applications of pesticides to communities

Studies of the use of herbicides and plant growth regulators (PGRs) for diversifying amenity grassland swards indicated a variety of susceptibilities within communities and a range of responses (Marshall, 1983). Modifying doses and the time of year (growth stage of plants) of application, can result in different responses.

Studies of the impact of herbicide drift on native flora have been made using artificial communities or mesocosms (Marrs and Frost, 1997; Marrs *et al*., 1991) exposed to drift at different distances from a sprayer. Results indicate that distances for no measurable effect are in excess of 6 m for the herbicides studied, but that a 6 m buffer is sufficient under most conditions. The herbicide glyphosate was particularly active against non-target species (Marrs *et al*., 1991).

Kleijn & Snoeijing (1997) have made detailed studies of the effects of low levels of herbicide and fertiliser on field margin communities. Field experiments on a natural and a sown community were treated with a range of doses of fluroxypyr (0-50% of field rate) and fertiliser. Fertiliser contamination is likely to be a more important and more predictable factor in reducing botanical diversity in adjacent non-target areas, than herbicide drift. However, drift also resulted in reduced species richness, enhancing grass biomass and reducing biomass of flower species, notably the subordinate, lower-growing ones. Most significant effects were noted with the 50% rate, but 5% and 10% doses reduced biomass of colonising herbs and increased extinctions. The herbicide had different effects on different species (Kleijn & Snoeijing 1997). In addition to the field experiments, conventional pot experiments were made to test the effects of the different rates of herbicide on a range of the plant species. Results of the pot experiment did not correspond well with the field results. They concluded that extrapolation of the results of pot experiments to normal field conditions is difficult and inappropriate. There are important implications here for regulatory testing, which are often based on pot tests for ease of operation.

Some herbicides can be used to enhance diversity of grassland recreated using grass and wild flower seed mixtures (Marshall and Nowakowski, 1991; 1992; 1994), by suppressing competitive weeds in the establishment phase. Some PGRs can also be used to modify the composition of grassland communities. Mefluidide applied annually at high rates can suppress the growth and flowering of grass species, encouraging the growth of dicotyledenous species in the sward (Marshall, 1988).

5.4.4. Effects of modified pesticide use in arable fields on weed seedbanks

Under the Boxworth Project (Greig-Smith *et al*., 1992), studies were made of the responses of the weed seedbank in 11 fields receiving three levels of pesticide use. The fields had a history of intensive arable management and had low seed densities (Marshall & Arnold, 1994). There was marked field-to-field variation in seedbank composition, such that differences over a five year period could not be attributed to differences in herbicide pressure. The occurrence of a break crop, winter oilseed rape, in the rotation allowed quantitative, but not qualitative, changes in the seedbank, as certain species which survived herbicide application were allowed to set seed.

Recent studies of weed seedbanks as part of the TALISMAN project (Squire *et al*. 1998) showed large increases in the abundance of dominant species under relaxed herbicide use over a six-year period. Reducing herbicide inputs did result in increased numbers of species in the seed banks, but accompanied by greatly increased total number of seeds, which constituted a threat to following crops. Only under circumstances where inputs were already high and with competitive crops, could herbicide use be reduced and there be little effect on the seedbank.

These studies indicate that herbicides do affect seedbanks by preventing or allowing species to complete their life cycles and return seed to the soil.

5.4.5. Effects of modified pesticide use in arable fields on non-target plant communities

Some attempts to evaluate the non-target impact of pesticides applied in arable fields have been made. Under the Boxworth Project (Greig-Smith *et al*., 1992), studies were made of the flora of the boundaries of fields receiving three levels of pesticide input over a five-year period (Marshall, 1992). No effects consistent with the levels of pesticide use in the adjacent field were found. In this situation, a relaxation of herbicide use might have resulted in a more diverse flora. The lack of this effect might have reflected the initial depauperate state of the boundary flora and an inability to recover to become more diverse. Alternatively, field applications were not affecting boundary flora.

A similar interim result has been found for a 2 m sown margin strip at the edges of a field-scale comparison of conventional and integrated (ICM) arable production systems, the LIFE project (Jordan and Hutcheon, 1995). Over a period of three cropping seasons following sowing, there were no significant differences in the developing margin flora associated with the different adjacent farming systems, although there were significant differences in pesticide and fertiliser use (Marshall, 1997).

Nevertheless, large-scale evaluation of land use changes under the UK Countryside Surveys have demonstrated that field margins are the sources of botanical diversity in lowland landscapes (Barr *et al*., 1993). Further, re-examination of a sample of field margins demonstrates that diversity continues to decline in field margins associated with intensive arable production (pers. comm. R.G.H. Bunce). The mechanisms for this deterioration are not identified, though pesticides and fertilisers are implicated.

5.4.6. Impacts of pesticides on the reproduction of non-target plant species

Field experimentation has shown that herbicide drift can affect flowering and seed production in non-target plant species (Marrs *et al*., 1989). The implication has been drawn that this will affect recruitment within plant communities, leading to changes in diversity. Effects of direct applications of herbicides and plant growth retardants (PGRs) on flowering are reported for a number of products and species. For example, the compound mefluidide inhibits flowering in grasses (Price, 1984; Marshall, 1988). Kleijn & Snoeijing (1997) note that low doses of herbicide, similar to those that might be expected under drift conditions, can impact on non-target plants. They noted that such effects were likely to reduce the fitness of so-called subordinate species in communities, leading to species loss over time.

While these impacts of pesticides on reproduction (and competitive ability) in plants are likely in non-target situations, the significance of these effects on community composition and species persistence is less clear. Plant species have a range of reproductive strategies (see Section 2.3.), based on seeds and vegetative spread. Monocarpic species flower only once and then die. Polycarpic species may flower many times and live many years. Polycarpic species often have adaptations for vegetative propagation and are less reliant on seed. Seed of perennial polycarpic species are often only short-lived (transient seed bank – Section 2.3.). Monocarpic species are dependent on seed for species persistence. Often, these species produce many seeds, which are adapted to dispersal in space (e.g. wind-blown seeds), or dispersal in time (i.e. they have a persistent seed bank of dormant seed). These adaptations usually allow the species to re-establish when suitable conditions are available.

The threats of sub-lethal non-target pesticide effects on plants are likely to be relatively small for low-dose incidents. Monocarpic species that do not set seed are likely to re-establish from the seedbank. Polycarpic species that are not killed are likely to recover the following season. However, there is a need to confirm this assertion, bearing in mind the results given by (Kleijn & Snoeijing, 1997). There is also very little information on the longer-term impacts of drift events on subsequent flowering, seed production and vegetative propagation of non-target species. There is also a valid concern, bearing in mind the continuing decline in botanical diversity of non-target habitats adjacent to farmland, that sub-lethal effects of pesticides are having a long-term (chronic) impact on plant communities. There is a need to investigate the effects of cumulative non-target contamination with pesticides on non-target plant communities.

From a regulatory viewpoint, the effects of pesticides on the recruitment behaviour of plant species can be mediated at several points in the life cycle. The established plant may show inhibition of flowering, seed production or vegetative propagation. The seed may have its viability affected. Pesticides may affect germination and dormancy breakage. The seedling may also be more susceptible to pesticides than the adult growth stages. Each stage may be of significance in the recruitment of a plant population. As and example of likely non-target pesticide risks for a single species, the life cycle of the biennial *Alliaria peteolata* (Garlic mustard) is illustrated in the following table, with the processes at risk from pesticide contamination:

Month	**Cohort 1 growth stage**	**Processes at risk**	**Cohort 2 growth stage**	**Processes at risk**
J		Seed dormancy	Rosette	Growth
F	Seedling	Germination	Rosette	Flower initiation
M	Seedling	Germination	Mature rosette	Flower initiation
A	Seedling	Seedling growth	Flowering	Flowering
M	Rosette	Seedling growth	Flowering	Seed formation
J	Rosette	Growth	Flowering	Seed formation
J	Rosette	“	Seeding	Seed formation
A	Rosette	“	Seeding	Seed dispersal
S	Rosette	“		Seed dispersal
O	Rosette	“		Seed survival
N	Rosette	Survival		Seed survival
D	Rosette	“		Seed survival
J	Rosette	Growth		
F	Rosette	Flower initiation		
M	Mature rosette	Flower initiation		

A	Flowering	Flowering		
M	Flowering	Seed formation		
J	Flowering	Seed formation		
J	Seeding	Seed formation		
A	Seeding	Seed dispersal		
S		Seed dispersal		
O		Seed survival		
N		Seed survival		
D		Seed survival		

The table illustrates the fact that a non-target drift event may impact on different processes within one species, because parts of the population can be at different life stages. To test effects on reproduction is undoubtedly an important part of the evaluation of non-target effects. Further work is required to refine which are the key stages that affect subsequent recruitment. A caveat that should be noted is that tests of non-target impacts in pot-grown material is not necessarily the same as that in natural plant communities in the field (Kleijn & Snoeijing, 1997).

5.5 IMPLICATIONS FOR RISK ASSESSMENT AND RISK MANAGEMENT

Risk associated with the use of pesticides can be evaluated on the basis of the effects of the pesticide (susceptibility of target and non-targets to direct and indirect effects), coupled with the exposure that will occur. Simply:

Risk = susceptibility x exposure

Risk assessment is thus a process of evaluating likely susceptibilities and likely exposures. Attempts to assess risk for regulatory purposes have been made in Canada (Freemark and Boutin, 1994), following reviews of the likely non-target effects in farmland (Freemark and Boutin, 1995).

5.5.1. Susceptibilities

In the case of herbicides and PGRs, some data is available on the effects of target weeds and crops and some on non-target species for older, out-of-patent compounds. Crop tolerance and the spectrum of weeds controlled are key economic characteristics of products and are usually well known, particularly by manufacturers. However, data on effects on non-target species are not widely available or necessarily easy to obtain.

Susceptibilities are often reported simply on a four point scale (resistant, moderately resistant, moderately susceptible, susceptible) for a pesticide product at the recommended field rate. In reality, the susceptibility of a population is best described by a dose-response curve for a given growth stage. Susceptibility may change with plant size and maturity, which will reflect application time during the year. Pre-emergence herbicides may not have any significant effects on mature plants.

Some constancy of effect within plant families is reported. For example, most Asteraceae are susceptible to the herbicide clopyralid. However, there are many exceptions, for example in the Poaceae (Gramineae), where crop tolerance is found with many grass weed herbicides. The resistance of *Festuca rubra* to fluazifop-P-butyl is a useful exception that may be exploited in controlling grass weeds in sown field margin strips (Marshall and Nowakowski, 1991).

It is clear that there is insufficient information on which to judge susceptibilities of many non-target plant species. The quality of data is poor and largely available for older compounds. Newer herbicides, such as diflufenican and many of the sulfonylureas, have not been investigated on many non-target species. Dose responses are required for key life history stages (germination, early growth and maturity).

5.5.2. Exposure

Opportunities for exposure to pesticides are governed by many factors. The timing of application in the field has a profound influence, because plants are at different growth stages at different times of year. Applications of pre-emergence herbicides in the autumn are typically made using large droplet spray spectra, minimising drift. Pre-emergence herbicides will typically affect germinating plants, but not affect established growth stages. Such herbicides are usually applied when many non-target species are regarded as dormant. However, adult plants of non-target species are inevitably present in adjacent non-crop areas of field margins etc. A full assessment of non-target effects of pre-emergence products will be necessary.

The spray droplet spectrum of a field application and its behaviour in terms of penetration within plant canopies will affect its propensity to drift. The goal must be precise application to targets, with no movement to non-target environments. Many techniques have been introduced to limit drift and to better target pesticide applications, but further work is required, considering the considerable losses that occur between the sprayer and the site of biochemical action within the organism. It has been estimated, for example, that only 1% of active material of fluazifop-P-butyl that is deposited on the leaves of *Setaria viridis*, a grass weed, reaches the active sites within the meristem (Boydston, 1992). Significant drift can occur using hydraulic sprayers under unsuitable wind conditions, e.g. (Western *et al*., 1989). Losses between the sprayer and the target surface (leaf) must also be large.

5.5.3. Risk management

Risk management needs to address susceptibility and exposure. Exposure can be most easily manipulated, though susceptibility may be influenced, for example by protectants. The following areas require consideration:

1. Choice of pesticide. Use compounds with high specificity, rather than broad-spectrum; use pesticides with low mobility in soils; low volatility

2. Optimum dose. Reduced doses may be adequate to achieve commercial control levels

3. Timing of application. Pre-emergence herbicides can be applied to soils with large droplets, minimising drift

4. Selective application. Patch spraying, rather than overall; weed detection; weed wiping, etc.

5. Application technology. Air-assistance, electrostatic, droplet production

6. Formulation. Adjuvants to increase effectiveness and reduce doses

7. Drift protection. Buffer strips to limit drift

5.6 CONCLUSIONS AND IMPLICATIONS

Although there are several ways in which pesticides may contaminate non-target plants, in practice, only spray and vapour phase drift are of major concern. Spray drift is essentially a technical problem, and may be prevented by applying pesticide in the correct conditions with the appropriate equipment. Nevertheless, drift occurs causing biological effects. Vapour movement, on the other hand, is far less predictable and many questions remain. In the recent past it might have been unlikely that new herbicides with the potential for vapour production would be developed. However, new generation fungicides, such as quinoxyfen (Dow-Elanco), give persistent control of powdery mildew in cereals, mainly attributed to volatilisation and redistribution within the crop canopy (pers. com. D. Bartlett). These attributes may be more common than previously understood. There may be future non-target problems that will be unrecognised until after the widespread introduction of the compounds.

The evidence for pesticide drift from the field is poorly reported, as suggested by the case of mecoprop drift in the UK and the lack of descriptions of growth promotion due to drift predicted from laboratory studies but never noted outside. In addition, cases where there is almost certainly pesticide contamination, such as in Natal, South Africa, are very difficult to confirm due to lack of basic knowledge about pesticide effects and atmospheric transport.

Disregarding such exceptions, the general problem of spray drift probably gives rise to contamination to about 10m from the site of application of about 1% of the field rate. Further distances give lower doses. Field margins, at 1 m from spray applications, probably receive drift at 2% to 4% of field rates. However, this contamination is repeated during the season and almost certainly over a number of years, until there is a change in the cropping or the field is put into set-aside or pasture. Such repeated applications, either on single species or plant communities, have not been investigated to the point where useful information on effects is available. Nevertheless, experimental work demonstrates the effects of sublethal doses of herbicides and fertiliser in plant communities. Thus, although the amounts of pesticide reaching non-target plants can be predicted in many instances with reasonable certainty, its biological effect both at species and community level is uncertain. It seems likely that non-target habitat immediately adjacent to intensively managed fields may become adapted to irregular disturbance events and may become dominated by a species-poor assemblage of resilient plants. This requires detailed testing in species-rich situations.

Whilst some information on the effects of herbicides is available in the literature, it is clear that a) there is insufficient dose-response data and b) many new herbicides are now used commercially which have not been subject to tests on non-target species. Novel compounds are being developed, particularly fungicides, which exploit activity in the vapour phase. The non-target effects of such compounds are largely unknown. One feature of the literature is the susceptibility of a wide range of plant species to broad-spectrum herbicides, notably glyphosate. In terms of non-target effects, such products are most likely to pose risks to non-target species. The present approach of incorporating broad-spectrum herbicide resistance genes into crops will result in greater use of such compounds and a consequently greater risk of non-target effects. Agrow No. 307 (p.14) 26 June 1998 reports a 72% increase in the use of glyphosate in the USA, coincident with the introduction of Roundup Ready soybeans.

5.9 REFERENCES

Bache D H (1985). Prediction and analysis of spray penetration into plant canopies. *BCPC Monogram No. 28 - Application and Biology* (ed. E S E Southcombe) pp.183-190. BCPC Publications, Croydon.

Barr, C.J., Bunce, R.G.H., Clarke, R.T., Fuller, R.M., Furse, M.T., Gillespie, M.K., Groom, G.B., Hallam, C.J., Hornung, M., Howard, D.C. and Ness, M.J. (1993). *Countryside Survey 1990. Main Report*. Department of the Environment.

Beer P R de, Smit C and Dyk LP van (1992). Air monitoring for pollution by auxin-type herbicides. *Chemosphere* **24**, 719-733.

Behrens R and Lueschen W E (1979). Dicamba volatility. *Weed Science* **27**, 486-493.

Bennet R J (1990). The volatilization of formulated ester, amine and K salt derivatives of phenoxyalkanoic herbicides: Evidence to connect herbicide activity with plant nutrient status of tomato (*Lycopersicon esculentum* Mill) plants. *South African Journal of Plant and Soil* **7**, 96-100.

Birnie, J.E. (1984). *A preliminary study on the effect of some agricultural chemicals on a range of field margin flora.* (Technical Report No. 79, 16 pp.). Agricultural and Food Research Council Weed Research Organization.

Birnie, J.E. (1985). *A further study of the effect of six cereal herbicide treatments on a range of broad-leaved field margin plants.* (Technical Report No. 88, 19 pp.). Agricultural and Food Research Council, Long Ashton Research Station.

Boydston, R.A. (1992) Drought stress reduces fluazifop-P activity on green foxtail (*Setaria viridis*). *Weed Science,* **40**(1), 20-24.

Breeze V G (1988). Effects of low concentrations of the phenoxyalkanoic herbicide 2,4-D butyl on growth of tomato plants. *Pesticide Science* **22**, 251-261.

Breeze V G (1993). Phytotoxicity of herbicide vapor. *Reviews of Environmental Contamination and Toxicology* **132**, 29-54.

Breeze V G (1994). Herbicide vapour phytotoxicity: laboratory facts and field speculation. In ‘Comparing glasshouse and field pesticide performance II’, 1994 *BCPC Monograph No*. **59**, 85-95.

Breeze V G and Rensburg E van (1991). Vapour of the free acid of the herbicide 2,4-D is toxic to tomato and lettuce plants. *Environmental Pollution* **72**, 259-267.

Breeze VG and Rensburg E van (1992). Uptake of the herbicide [^{14}C] 2,4-D iso-octyl in the vapour phase by tomato and lettuce plants and some effects on growth and phytotoxicity. *Annals of Applied Biology* **120**, 493-500.

Breeze V G, Simmons J C and Roberts M O (1992a). Evaporation and uptake of the herbicide 2,4-D butyl applied to barley leaves. *Pesticide Science* **36**, 101-107.

Breeze V G, Simmons J C and Roberts M O (1992b). Vapour drift of pesticides. In '*Environmental Impact of Pesticide Drift'* (ed. B N K Davis). Report of commissioned study to the Institute of Terrestrial Ecology (NERC).

Breeze V G, Thomas G and Butler R (1992). Use of a model and toxicity data to predict the risks to some wild plant species from drift of four herbicides. *Annals of Applied Biology* **121**, 669-677.

Breeze V G and Timms L D (1986). Some effects of low doses of the phenoxyalkanoic herbicide mecoprop on the growth of oilseed rape (*Brassica napus* L.) and its relation to spray drift damage. *Weed Research* **26**, 433-439.

Byass J B and Lake J R (1977). Spray drift from a tractor-powered sprayer. *Pesticide Science* **8**, 117-126.

Carey, P.D., Fitter, A.H. and Watkinson, A.R. (1992) A field-study using the fungicide Benomyl to investigate the effect of mycorrhizal fungi on plant fitness. *Oecologia*, **90**(4), 550-555.

Cooke A S (1993). Conservation and pesticide drift. In: *The environmental effects of pesticide drift.* (ed. A S Cooke), English Nature, Peterborough, pp. 93.

Cousens, R., Marshall, E.J.P. and Arnold, G.M. (1988) Problems in the interpretation of effects of herbicides on plant communities. *BCPC Monograph No.**40**. Field Methods for the Study of Environmental Effects of Pesticides*, (ed. Greaves, M.P., Smith, B.D. and Greig-Smith, P.W.), pp. 275-282. British Crop Protection Council.

Crosby D G and Bowers J B (1985). Composition and photochemical reactions of a dimethylamine salt formulation of (4-chloro-2-methylphenoxy)acetic acid (MCPA). *Journal of Agricultural and Food Chemistry* **33**, 569-573.

Davis B N K and Williams C T (1993). Principles of droplet drift and safe distances. In *'The environmental effects of pesticide drift'* (ed. A S Cooke), English Nature, Peterborough, pp. 93.

de Snoo, G.R. & de Wit, P.J. (1998) Buffer zones for reducing pesticide drift to ditches and risks to aquatic organisms. *Ecotoxicology and Environmental Safety,* **41**, 112-118.

Elliott J G and Wilson B J (1983). The influence of weather on the efficiency and safety of pesticide application. The drift of herbicides. *British Crop Protection Council Occasional Publication No 3*. BCPC Publications, Croydon, UK.

Farwell S O, Robinson E, Powell W J and Adams D F (1976). Survey of airborne 2,4-D in south-central Washington. *Journal of the Air Pollution Control Association* **26**, 224-30.

Freemark, K. and Boutin, C. (1994) Nontarget-plant risk assessment for pesticide registration. *Environmental Management*, **18**(6), 841-854.

Freemark, K. and Boutin, C. (1995) Impacts of agricultural herbicide use on terrestrial wildlife in temperate landscapes: a review with special reference to North America. *Agriculture, Ecosystems and Environment,* **52**, 67-91.

Fritz R (1993). Pesticides in the atmosphere. *Pflanzenschutz-Nachrichten Bayer* **46**, 229-263.

Ganzelmeier H, Rautmann D, Spangenberg R, Streloke M, Herrmann M, Wenzelburger H-J and Walter H-F (1995). *Studies on the spray drift of plant protection products*. Mitteilungen aus der Biologischen Bundesanstals fur Land- und Forstwirtschaft, Blackwell, Berlin.

Gilbey D J, Ralph C M, Scott A N, Ebell G F and Horne R W (1984). Airborne 2,4-D and tomato damage at Geraldton, Western Australia. *Australian Weeds* **3**, 57-69.

Glotfelty D E, Seiber J N and Liljedahl L A (1987). Pesticides in fog. *Nature* **325**, 602-605.

Greig-Smith, P.W., Frampton, G.W. and Hardy, A.R. (ed). (1992) *Pesticides, Cereal Farming and the Environment: The Boxworth Project*. H.M.S.O., London. 288 pp.

Grover R, Kerr L A, Wallace K, Yoshida K and Maybank J (1976). Residues of 2,4-D in air samples from Saskatchewan: 1996-1975. *Journal of Environmental Science and Health B* **11**, 331-347.

Hartley G S and Graham-Bryce I J (1980) *Physical Principles of Pesticide Behaviour.* Vol. 1 and 2. Academic Press, London.

Health and Safety Executive (1997). *Pesticide Incidents Report 1996/97*. Health and Safety Executive, Nottingham.

Jordan, V.W.L. and Hutcheon, J.A. (1995) Less-intensive Farming and the Environment: an integrated farming systems approach for UK arable crop production. *Ecology and Integrated Farming Systems* (ed Glen, D.M., Greaves, M.P. and Anderson, H.M.), pp. 307-318. John Wiley and Sons, Chichester.

Kleijn, D. & Snoeijing, G.I.J. (1997) Field boundary vegetation and the effects of agrochemical drift: botanical change caused by low levels of herbicide and fertilizer. *Journal of Applied Ecology*, **34**, 1413-1425.

Longley, M., Çilgi, T., Jepson, P.C. & Sotherton, N.W. (1997) Measurements of pesticide spray drift deposition into field boundaries and hedgerows: 1. Summer applications. *Environmental Toxicology and Chemistry*, **16**, 165-172.

Longley, M. & Sotherton, N.W. (1997) Measurements of pesticide spray drift deposition into field boundaries and hedgerows: 2. Autumn applications. *Environmental Toxicology and Chemistry*, **16**, 173-178.

Marrs, R.H. (1993) Soil fertility and nature conservation in Europe: theoretical considerations and practical management solutions. *Advances in Ecological Research*, **24**, 241-300.

Marrs, R.H. and Frost, A.J. (1997) A microcosm approach to the detection of the effects of herbicide spray drift in plant communities. *Journal Of Environmental Management*, **50**(4), 369-388.

Marrs, R.H., Frost, A.J. and Plant, R.A. (1991) Effects of herbicide spray drift on selected species of nature conservation interest - the effects of plant age and surrounding vegetation structure. *Environmental Pollution*, **69**, 223-235.

Marrs, R.H., Williams, C.T., Frost, A.J. and Plant, R.A. (1989) Assessment of effects of herbicide spray drift on a range of plant species of conservation interest. *Environmental Pollution*, **59**, 71-86.

Marshall, E.J.P. (1983). *A feasibility study of the use of chemicals for rural amenity areas.* Technical Report No. 71. Agricultural Research Council Weed Research Organization.

Marshall, E.J.P. (1988) Some effects of annual applications of three growth-retarding compounds on the composition and growth of a pasture sward. *Journal of Applied Ecology*, **25**, 619-630.

Marshall, E.J.P. (1989) Susceptibility of four hedgerow shrubs to a range of herbicides and plant growth regulators. *Annals of Applied Biology*, **115**, 469-479.

Marshall, E.J.P. (1992) Patterns of distribution of plant species in the fields and their margins. *Pesticides, Cereal Farming and the Environment: The Boxworth Project* (ed Greig-Smith, P., Frampton, G. and Hardy, A.), pp. 68-81. HMSO, London.

Marshall, E.J.P. & Arnold, G.M. (1994) Weed seed banks in arable fields under contrasting pesticide regimes. *Annals of Applied Biology*, **125**, 349-360.

Marshall, E.J.P. (1995). *Predicting the effects of graminicides on desirable and weed grass species.* Confidential Report to Willmot Pertwee Limited. IACR - Long Ashton Research Station.

Marshall, E.J.P. (ed). (1997) *Field Boundary Habitats for Wildlife, Crop and Environmental Protection.* Final Project report of Contract AIR3-CT920476. Commission of the European Communities. 313 pp. + appendices. IACR-Long Ashton Research Station, Bristol.

Marshall, E.J.P. and Birnie, J.E. (1985) Herbicide effects on field margin flora. *1985 British Crop Protection Conference - Weeds*, pp. 1021-1028. British Crop Protection Council, Thornton Heath, Surrey.

Marshall, E.J.P. and Nowakowski, M. (1991) The use of herbicides in the creation of a herb-rich field margin. *1991 Brighton Crop Protection Conference - Weeds,* pp. 655-660. British Crop Protection Council, Thornton Heath, Surrey, UK.

Marshall, E.J.P. and Nowakowski, M. (1992) Herbicide and cutting treatments for establishment and management of diverse field margin strips. *Aspects of Applied Biology* ***29*** *- Vegetation management in forestry, amenity and conservation areas*, pp. 425-430. Association of Applied Biologists, Wellesbourne, UK.

Marshall, E.J.P. and Nowakowski, M. (1994) The effects of fluazifop-P-butyl and cutting treatments on the establishment of sown field margin strips. *Field Margins - Integrating Agriculture and Conservation*, Monograph No. **58** pp. 307-312. British Crop Protection Council, Thornton Heath, Surrey, UK.

Meinhardt H R (1989). *Guidelines for assessing hormone herbicide damage on vegetables*. Department of Agriculture and Water Supply, Republic of South Africa.

Nowakowski, M., Bridge, M.C. and Marshall, E.J.P. (1994). *Willmot Pertwee Ltd 1993 Conservation Programme Report* 1993. Willmot Pertwee Limited.

Noye G (1983). Sensitivity of pot plants to wind drift from foliage applied herbicides. Report, Institut for Ukrudtsbekaempelse, Flakkeberg, Denmark, Publication number S 1657.

Price, I.K. (1984) Mefluidide: a novel broad spectrum growth regulator. *Aspects of Applied Biology 5, Weed Control and Vegetation Management in Forests and Amenity Areas*, pp. 37-44. Association of Applied Biologists, Wellesbourne, UK.

Que Hee S S and Sutherland R G (1981). *The Phenoxyalkanoic Herbicides* Vol. 1. CRC Press, Boca Raton.

Rensburg E van and Breeze V G (1990). Uptake and development of phytotoxicity following exposure to vapour of the herbicide ^{14}C 2,4-D butyl by tomato and lettuce plants. *Environmental and Experimental Botany* **30**, 405-414.

Ries S K (1976). Subtoxic effects on plants. In: Audus L J (ed) *Herbicides: Physiology, Biochemistry, Ecology*. 2nd Ed. Academic Press, London, pp 313-344.

Sandmann E R I C, Beer P R de and Dyk L P van (1991). Atmospheric pollution by auxin-type herbicides in Tala Valley, Natal. *Chemosphere* **22**, 137-145.

Squire, G.R., Rodger, S. & Wright, G. (1998) Weed seedbanks in TALISMAN. *TALISMAN Conference Abstract*. 3pp.

Thompson N and Ley A J (1982). The quantification of spray drop drift. *Proceedings of the 1982 British Crop Protection Conference - Weeds* **3**, 1039-1044. BCPC Publications, Croydon.

Tsiouris, S. and Marshall, E.J.P. (1998) Observations on patterns of granular fertiliser deposition beside hedges and its likely effects on the botanical composition of field margins. *Annals of Applied Biology*, **132**, 115-127.

Wauchope R D, Buttler T M, Hornsby A G, Augustijn-Beckers P W M and Burt J P (1992). The SCS/ARS/CES pesticide properties database for environmental decision-making. *Reviews of Environmental Contamination and Toxicology* **123**, 1-155.

Western, N.M., Hislop, E.C., Herrington, P.J. and Jones, E.I. (1989) Comparative drift measurements for BCPC reference hydraulic nozzles and for an Airtec twin-fluid nozzle under controlled conditions. *1989 Brighton Crop Protection Conference - Weeds*, pp. 641-648. BCPC.

Willis, A.J. (1963) Braunton Burrows: the effects on the vegetation of the addition of mineral nutrients to the dune soils. *Journal of Ecology*, **51**, 353-374.

Woodrow J E, McChesney M M and Seiber J N (1990). Modelling the volatilization of pesticides and their distribution in the environment. In: Kurtz DA (ed) *Long range transport of pesticides*. Lewis Publishers Inc, Chelsea, Michigan. pp 61-81.

Worthing C R and Hance R J (eds) (1991). *The Pesticide Manual, A World Compendium*, 9th ed. British Crop Protection Council, Unwin Brothers Ltd, Old Woking, Surrey, UK.

SECTION FIVE: APPENDIX ONE

Field measurements of droplet drift

One of the most extensive sets of data on droplet drift has been obtained by Ganzelmeier *et al*. (1995). Unfortunately, these data have not been fully interpreted. Essentially, they found that at about 10m from the edge of the crop, the amount of pesticide deposited was about 0.4% of the field application rate in the case of a field crop. The values were much greater for fruit trees and hops. However, such values alone are not informative because the amount of drift depends on many factors, including the width of field. Further interpretation is presumably in progress and will provide a useful indication of the extent to which various factors affect drift.

Davis and Williams (1993) have summarised several reports of the distances travelled by drifting droplets both from ground and aerial spraying. The values they give are in some cases larger than those from Ganzelmeier *et al*. (1995), being 1% of the field rate at 10m.

Longley et al. (1997) and Longley & Sotherton (1997) measured drift into field margins in summer and autumn. Drift differed from the front to the back of the margin, but under recommended application conditions (< 3m/s wind speed) only about 3% of field rates drifted to the margin. An unsprayed crop margin (conservation headland) would significantly reduce this amount of drift reaching non-target habitat. A similar conclusion was found by de Snoo & de Wit (1998) for ditch habitats in The Netherlands. These workers measured drift rates of between 4% and 25% of field rates on ditch banks at wind speeds of 3 m/s, depending on the type of spray nozzle used. A series of factors affected drift, including wind speed, height of spray boom, vegetation structure and nozzle type.

SECTION FIVE: APPENDIX TWO

Models of pesticide droplet drift

In view of both the practical importance of minimising spray drift damage, as well as the problems of obtaining information on the distances travelled by spray droplets, it seems surprising that there have been few attempts to incorporate toxicity data into models of spray drift in order to indicate safe spraying distances. In one attempt, Breeze, Thomas and Butler (1992) have modified and extended a model originally devised by Thompson and Ley (1982) to calculate the width of boundary zones for safe spraying. This model predicts the distance travelled by droplets of initial diameter 100 μm released 50 cm above a crop for a wind speed of 5 m/s (measured at a height of 10 m). Thompson and Ley (1982) deduced this relationship for several different sets of conditions and for both evaporating and non-evaporating droplets; in practice, aqueous herbicide spray solutions would give evaporating droplets. Drift distances of <10 m are not considered in this model. A boundary zone of 10 m width would generally be used even if there was little risk from drift.

The number of drifting droplets has to be calculated for a typical spray nozzle in order to apply the drift model to the field. Western, Hislop, Herrington and Jones (1989) found that 2.9% of the solution sprayed by a Lurmark Kemetal 110° flat fan nozzle operated at 1.44 litres/min and 2.6 bar was in the size range 50-100 μm diameter. This is equal to 1.107×10^6 droplets/m^2 of 100 μm diameter for a solution applied at 200 litres/ha. Thompson and Ley (1982) based their calculations on 10 000 drifting droplets originating from a line source one metre in length; their values have therefore been rescaled by 110.7 times. As the original model only gave the number of drifting droplets from one point of application (the line source), it has been assumed that the line source of one metre length could be converted to an area of one square metre. The calculation of droplet deposition has therefore been repeated for the width of the sprayed area, but each time taking into account the increased distance required to drift to the target. A high-order polynomial was fitted by least squares to the results given in Fig. 1 of Thompson and Ley (1982). This predicted the number of droplets deposited per m^2 to be approximately antilog_{10} (y), where

$$y = - 7.897 + 31.90\,x - 35.13\,x^2 + 17.13\,x^3 - 3.975\,x^4 + 0.3574\,x^5$$

and $\underline{x}$ is the distance downwind, for evaporating droplets of zero reflection coefficient, of initial diameter 100 μm, released 0.5 m above a crop in unstable conditions with a wind speed of 5 m/s at 10 m height. The predicted deposition (number of droplets per m^2) at a given distance from the edge of the sprayed area was then the sum of the contributions from each of the 1 m^2 plots across the field. The number of droplets per m^2 (y) were corrected for the spray volume and the percentage volume of sprayed solution containing 100 μm droplets. Thus, the revised version of the model is different from the original both because actual spraying solution volumes are used and the width of the sprayed field is included in the calculation.

Breeze, Thomas and Butler (1992) used this model to calculate safe spraying distances, based on the ED_{10} and ED_{50} values derived from dose-response data, for two concentrations of spray solution of each of four herbicides. The concentrations were the one in general use and the highest recommended concentration. The values were 17.6, 6.4, 6.7 and 10.1 g/litre for general use of asulam, glyphosate, MCPA and mecoprop, respectively, and 44, 27, 16.6 and 16.5 g/litre for the highest concentration. The number of 100 μm diameter droplets containing the amount in each ED_{10} or ED_{50} was calculated. The number of target plants was 1000/m^2. Dose response data were obtained from glasshouse experiments for the following species: Cardamine pratensis L.; Centaurea nigra L.; Cynosurus cristatus L.; Galium mollugo L.; Geum urbanum L.; Hypericum perforatum L.; Leontodon hispidus L.; Lolium perenne L.; Lotus corniculatus L.; Lychnis flos-cuculi L.; Ranunculus acris L.; Stachys officinalis (L.) Trevisan; Torilis japonica (Houtt.) DC; and Trifolium pratense L..

The model indicated that asulam, MCPA and mecoprop posed little risk to any of the species tested from spray drift. At a spray concentration of 44 g/litre, asulam could cause a 10% reduction in shoot dry weight to C. cristatus and L. flos-cuculi at 15 m from the edge of a 100 m wide field. Similarly, MCPA used at 6.7 g/litre could cause a 10% reduction in shoot dry weight to C. nigra at 13 m from the site of spraying, and at 16.6 g/litre for the same conditions, this species would be at risk up to 25 m away. S. officinalis could receive a dose at the ED_{10} level from MCPA at the highest rate of application up to 12 m away. Only one of the species tested, S. officinalis, could be at risk from spray drift of mecoprop; a dose at the ED_{10} level could be received by plants at 18 m from the edge of the field during application of a solution of 10.1 g/litre, or at 24 m for a solution of 16.5 g/litre.

Plants are at a much greater risk of damage from glyphosate spray drift with six of the species examined being susceptible to a dose at the ED_{10} level from the concentration in general use (6.4 g/litre).

The effect of field width can be important for species which are very sensitive to herbicide. For G. urbanum and S. officinalis, enough glyphosate would drift to cause a 10% reduction in shoot weight more than 100 m from the edge of a 250 m wide field sprayed with 27 g/litre. However, if the strip was 25 m wide, plants 32 m away would receive the same dose. The model predicts distances of 80, 58, 41 and 25 m for field widths of 500, 250, 100 and 25 m under the same conditions, for a solution of 6.4 g/litre (i.e. the concentration in general use).

One advantage of using a model to predict droplet drift distances is that information can be obtained even if no precise phytotoxicity data are available. Plant species sensitive to 10 μg or more herbicide are not likely to be susceptible to spray drift from a field 100 m wide. However, if a species is damaged by a dose of 0.1 μg/plant and less, it is likely to be at risk. Two species (G. urbanum and S. officinalis) had ED_{10} values of 0.1 μg glyphosate/plant, and probably showed at least some symptoms at doses lower than this. Whether the model over-estimates drift at long distances is not known, but results suggest that damage is possible in some conditions at distances of >50 m from the site of spraying. However, Byass and Lake (1977) detected droplet drift at distances of >100 m from a sprayed field, and so the predictions may not be unreasonable.

This approach represents plant leaves which are directly exposed to droplet deposition, but in a crop or wild communities there may be interception by other leaves of species. Attempts have been made to quantify this (Bache 1985), although prediction of droplet interception becomes less precise with a greater number of species in the canopy.

SECTION FIVE: APPENDIX THREE

Contamination by phenoxyalkanoic acid herbicides

Data for herbicide vapour concentrations in air have been reviewed by Que Hee and Sutherland (1981) and Breeze (1988). All available data are for phenoxyalkanoic herbicides, and of these, 2,4-D has been the most commonly investigated. Farwell *et al*. (1976) used a midget impinger collector, which trapped aerosol droplets smaller than 3 μm diameter, to analyse air of South Central Washington State. They found 2,4-D esters, of high and low molecular weight, at concentrations of 20-130 pg/l (average of 80 pg/l) during May and June 1973, and 230-1140 pg/l (average of 460 pg/l) during April to June 1974. Grover *et al.* (1976) used cold toluene or silica gel traps (giving total amounts of airborne herbicide) and high volume air samplers (for solid particles only). The 2,4-D in the form of solid particles (dust or crystals of amine salts) amounted to <1 pg/l during the sampling period; presumably that in the traps was vapour. About 30% of samples contained <10 pg 2,4-D per litre. Average daily concentrations of 2,4-D esters were 10-1220 pg/l for the iso-propyl ester, 10-13500 pg/l for butyl esters, and 10-590 pg/l for the iso-octyl ester. The maximum value for all esters was 23140 pg/l, but only 10% of all samples contained >1000 pg/l. Vapour concentrations of 2,4-D esters were found to be about 10 pg/l in Western Australia (Gilbey *et al.*, 1984).

Suspected herbicide damage to vegetable crops in Natal, South Africa, has led to an extensive investigation of atmospheric concentrations of several herbicides. Sandmann, Beer and Dyk (1991) found no esters of 2,4-D in air samples, although polar forms were present. As 2,4-D iso-octyl ester was widely used on sugar cane crops in the region, it seems likely that the vapour was hydrolysed to the acid and condensed to the solid phase or adsorbed onto suspended particulate matter (Beer, Smit and Dyk (1992). There is, however, no direct evidence for the fate of the iso-octyl ester, and the possibility remains that the polar forms trapped in the air were evaporated spray drift particles of 2,4-D salts applied outside the sugar cane-growing area. In this case, it is unclear why no 2,4-D iso-octyl ester was trapped in Natal. Nor is it known why the results from Natal are different from those obtained both by Grover *et al*. (1976) and by Farwell *et al*. (1976).

The concentrations of herbicide vapour measured in the air and found to be associated with phytotoxicity are thus in the range 10-1000 pg/l or more for 2,4-D esters. This result is in agreement with laboratory studies (Rensburg and Breeze 1990; Breeze and Rensburg 1992), although exposure periods in the field are unknown. Vapour concentration measurements do not predict phytotoxicity both because they do not indicate dose and because they are usually an average value from an integrating sampler. Short-term fluctuations of concentration have not been investigated due to the very large number of analyses required. There can be little doubt that identifying the sources of herbicide damage to plants in the field is a formidable problem, as experience in the State of Washington and Natal has shown.

SECTION FIVE: APPENDIX FOUR

Risk from dimethylamine salts of herbicides

It is unclear why there appear to have been no instances of vapour damage following application of amine salts of 2,4-D or other phenoxyalkanoic acid herbicides. It appears that MCPA DMA salt can give rise to the free acid of MCPA (Crosby and Bowers, 1985; Woodrow, McChesney and Seiber, 1990) following application to plant and soil surfaces. This occurs because dimethylamine can be lost as gas, thus removing the cation. 2,4-D has a moderately strong acidic reaction (Worthing and Hance, 1991) with a pK_a value of 2.8 (Wauchope *et al*., 1992) and so would be expected to hydrate readily. However, although dicamba ($pK_a = 1.9$; Wauchope *et al*., 1992) is a stronger acid than 2,4-D, it can apparently be found in the field as the free acid following decomposition of the DMA salt (Behrens and Lueschen, 1979). There may be some need to re-examine this finding in view of the very low pK_a of dicamba. Only in one study is there the possibility that 2,4-D DMA salt released the free acid of 2,4-D as vapour (Bennet, 1990). Amine salts have replaced esters in commercial use in order to avoid the risk of vapour drift because they are considered to be non-volatile (Que Hee and Sutherland, 1981). The 2,4-D free acid is phytotoxic in the laboratory (Breeze and Rensburg, 1991) but appears not to be a problem if the field, in spite of it having a higher pK_a than dicamba which is suspected to break down to the volatile free acid from the DMA salt. This indicates that further investigation is required.

SECTION FIVE: APPENDIX FIVE.

Effects of pesticides on key plant species of agricultural habitats.

1. Pot tests of herbicides on field margin flora.

A series of pot tests were carried out in the early 1980s at the Weed Research Organization and Long Ashton Research Station (Birnie, 1984; Birnie, 1985; Marshall and Birnie, 1985). Using a standard 0 - 9 vigour score, effects on plants were assessed:

0 = dead	5 = obvious growth defect, e.g. epinasty
1 = moribund, not all tissue dead	6 = slight growth differences, e.g. wilting, chlorosis
2 = live, some green tissue, further growth unlikely	7 = colour difference, yellowing or darkening
3 = gross inhibition of growth, recovery unlikely	8 = slight detectable growth difference
4 = slight growth inhibition	9 = indistinguishable from control

Vigour scores five weeks after treatment at field rates. Figures in bold are significantly different to controls (from (Birnie, 1984; Birnie, 1985; Marshall and Birnie, 1985)).

Herbicide

Species	Mecoprop	Isoproturon	Chlorsulfuron	Diclofop-methyl	Clopyralid	Ioxynil + Bromoxynil	Flamprop-M-isopropyl
Herbicide dose (kg a.i./ha)	2.4	1.88	0.02	1.14	0.20	0.76	0.60
Galium aparine 5 branches	**0**	8.0	**0**	8.5	7.5	9.0	9.0
Alliaria peteolata Flowering	**1.0**	8.0	**5.0**	**5.5**	7.5	**3.5**	9.0
Carduus crispus Mature rosette	**0**				**0**	**0**	
Cirsium arvense 10cm	**4.0**	**0**	**3.0**	9.0	**1.0**	7.0	
Convolvulus arvensis *(*Pre-flowering	**1.5**						
Urtica dioica 22cm	**3.0**	**0**	**2.5**	9.0	**3.0**	8.0	
Leucanthemum vulgare (5cm rosette)	**4.5**	**1.5**	6.0	7.5	**1.5**	7.5	9.0
Ranunculus repens Flowering	**0**	**1.5**	**2.0**	9.0	**5.0**	7.0	
Trifolium repens Pre-flowering	**4.5**				**2.0**	9.0	
Agrostis stolonifera *Well-tillered*	**3.5**	**0**	6.0	7.0	**5.5**	9.0	7.0
Brachypodium sylvaticum (3 leaves)	**1.5**	**1.0**	6.5	8.0	9.0	9.0	8.5
Dactylis glomerata 5 tillers	7.0	9.0	6.0	**3.0**	8.5	9.0	**4.0**
Festuca rubra 8 tillers	8.0	7.5	6.0	**4.0**	9.0	9.0	6.0

2. Established plants of field margin plant species which were severely damaged (scored 4 or less, on a 0-9 scale, six weeks after treatment at field rates) and unlikely to recover. (Data: EJP Marshall, unpublished). Herbicide doses are given as kg a.i./ha.

Herbicide and dose (kg a.i./ha)	Species	
Isoproturon 2.02	*Bromus erectus* *Rumex obtusifolius*	*Hordeum murinum*
Mecoprop 2.4	*Ballota nigra* *Linaria vulgaris* *Primula vulgaris* *Vicia cracca*	*Geum urbanum* *Potentilla reptans* *Torilis japonica* *Viola riviniana*
Diclofop-methyl 1.14	*Dactylis glomerata*	
Chlorsulfuron 0.015	*Conium maculatum* *Malva sylvestris* *Rumex sanguineus* *Trifolium repens*	*Cirsium vulgare* *Rumex obtusifolius* *Silene alba* *Viola riviniana*
Clopyralid 0.2	*Centaurea scabiosa* *Tragopogon pratensis*	*Leontodon autumnalis* *Vicia cracca*
Ioxynil + bromoxynil 0.76	*Malva sylvestris*	*Viola riviniana*
Ethofumesate 2.0	*Urtica dioica*	*Trifolium repens*
Metsulfuron-methyl 0.006	*Convolvulus arvensis* *Primula vulgaris* *Trifolium repens*	*Digitalis purpurea* *Rumex obtusifolius* *Urtica dioica*
2,4-D 0.7	*Plantago lanceolata* *Ranunculus repens* *Vicia cracca*	*Potentilla reptans* *Rumex obtusifolius* *Urtica dioica*
Fluroxypyr 0.2	*Convolvulus arvensis* *Potentilla reptans* *Rumex obtusifolius* *Trifolium repens*	*Hypericum perforatum* *Ranunculus repens* *Rumex sanguineus* *Urtica dioica*
Difenzoquat 1.0	*Viola reichenbachiana*	
Flamprop-M-isopropyl 0.6	*Dactylis glomerata*	
Methabenzthiazuron 1.6	*Leucanthemum vulgare* *Mercurialis perennis*	*Geum urbanum*

3. Susceptibilities of pot-grown, established plants of field margin flora to field rates of a range of herbicides and PGRs. (Unpublished data from EJP Marshall and Y Craine)

Herbicide or PGR treatment

Species	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Achillea millefolium			S	S		S	x	x	x	x	x	x	x	x	x	x
Anthriscus sylvestris						S	x	x	x	x	x	x	x	x	x	x
Ballota nigra	S	x	x	x	x											
Centaurea scabiosa			x	S	x	x	x	x	x	x	x	x	x	x	x	x
Convolvulus arvensis	x	x	x	x	x	x	x	x	x	x	S	x	S	x	x	x
Cirsium arvense	S		S	S		S	x	x	x	x	x	x	x	x	x	x
Cirsium vulgare		x	x	x	x	S	x	x	x	x	x	x	x	x	x	x
Conium maculatum	S	S	S			S	x	x	x	x	x	x	x	x	x	x
Digitalis purpurea	x	x	x	x	x	x	x	x	x	x	S	x				
Galium aparine						S		x	x	x	x	x	x	x	x	x
Galium verum	S	x	x	x	x	x	x	x	x							
Geum urbanum	S	x	x	x	x	x	x	x	x	x	x	x	x	S	x	x
Hypericum perforatum						x	x	x	x	x	x	x	S	x	x	x
Leontodon autumnalis	x	x	x	S	x	x	x									
Leucanthemum vulgare			S	S				x	x	x	x	x	x	x	x	x
Linaria vulgaris	S	x	x	x	x	x	x	x	x	x	x					
Mercurialis perennis	x	x	x	x	x	x	x	x	x	x	x	x	x	S	x	x
Malva sylvestris	x	S	x	x	x	S	x									
Plantago lanceolata	S			S				x	x	x	x	S	x	x	x	x
Potentilla reptans	S	x	x	x	x	x	x	x	x	x	x	S	S	x	x	x
Primula vulgaris	S	x	x	x	x	x	x	x	x	x	S	x	x	x	x	x
Ranunculus repens	S		S			x	x	x	x	x	x	S	S	x	x	x
Rumex obtusifolius			S		x	S	x	x	x	x	S	S	S	x	x	x
Rumex sanguineus	S		S			S	x	x	x	x	x	x	S	x	x	x
Silene alba	S		S			S	x	x	x	x	x	x	x	x	x	x
Torilis japonica	S	x														
Tragopogon pratensis	x	x	x	S	x	x	x		x	x	x	x	x	x	x	x
Trifolium repens			x	S	x	S	x	S	x	x	S	x	S	x	x	x
Urtica dioica	S		S				x	S	x	x	S	S	S	x	x	x
Veronica persica		S						x	x	x	x	x	x	x	x	x
Vicia cracca	S	x	x	S	x	x	x	x	x	x	x	S	x	x	x	x
Viola reichenbachiana	x	x	x	x	x	x	x	x	x	x	x	x	x	x	S	x
Viola riviniana	S	S	x	x	x	S	x	x	x	x	x	x	x	x	x	x
Agrostis stolonifera	S		S							x	x	x	x	x	x	x
Arrhenatherum elatius			S		S		S			x	x	x	x	x	x	x
Brachypodium sylvaticum	S		S							x	x	x	x	x	x	x
Bromus erectus	x		S	x	x		x									
Bromus sterilis										x	x	x	x	x	x	x
Dactylis glomerata	x	x	x	x	S	x	S			x	x	x	x	x	x	x
Elymus repens										x	x	x	x	x	x	x

Species	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P

Festuca rubra					S					x	x	x	x	x	x	x
Hordeum murinum	x		S		x		x									
Lolium perenne			S		S					x	x	x	x	x	x	x
Poa pratensis			S							x	x	x	x	x	x	x

S= susceptible; x = largely unaffected.

The compounds applied were as follows:

Herbicide	Product (Tradename - Company)	Dose kg(a.i.)/ha	Formulation
A Mecoprop	Compitox extra-M & B	2.4	K$^+$ salt
B Ioxynil and bromoxynil	Deloxil-Hoechst	0.76	ester e.c.
C Isoproturon	Arelon Liquid-Shell	2.02	s.c.
D Clopyralid	Format-Murphyshield	0.2	Amine salt
E Diclofop-methyl	Hoegrass-Hoechst	1.14	e.c.
F Chlorsulfuron	Glean dF 20-DuPont	0.015	w.p.
G Flamprop-m-isopropyl	Commando-Hoechst	0.6	e.c.
H Ethofumesate	Nortron - FBC	2.0	
I Mefluidide	Embark-3M Company	1.6*	e.c.
J Paclobutrazol	PP333 - ICI	1.0	f.c.
K Metsulfuron-methyl	Ally - DuPont	0.006	w.p.
L 2,4-D		0.7	
M Fluroxypyr	Starane-2-Dow	0.2	
N Methabenzthiazuron	Tribunil - Bayer	1.6	
O Difenzoquat	Avenge - Cyanamid	1.0	
P Chlormequat	5C Cycocel - BASF	0.91	Cl$^-$ salt

* Four times the recommended field rate

4. Dose-response studies on non-target flora.

Results of dose-response analysis of four herbicides on a range of plant species, expressed as ED_{10} and ED_{50}s (µg/plant) from (Breeze, Thomas & Butler, 1992).

	Asulam		Glyphosate		MCPA		Mecoprop	
	ED_{10}	ED_{50}	ED_{10}	ED_{50}	ED_{10}	ED_{50}	ED_{10}	ED_{50}
Cardamine pratensis	17	220	3.9	23	4.7	22	2.9	19
Centaurea nigra	71	88	2.0	6.0	0.6	5.8	7.0	32
Cynosurus cristatus	3.5	13	0.3	0.7	12	>1000	49	>1000
Galium mollugo	710	980	4.6	36	470	930	590	>1000
Geum urbanum	*	*	0.1	9.4	*	*	14	120
Hypericum perforatum	110	>1000	5.6	14	640	>1000	87	>1000
Leontodon hispidus	42	170	0.5	5.9	15	68	39	140
Lolium perenne	12	86	0.3	1.3	3.8	>1000	560	900
Lotus corniculatus	200	960	8.6	93	4.2	>1000	49	>1000
Lychnis flos-cuculi	3.4	40	0.8	2.4	25	69	4.7	21
Ranunculus acris	22	250	0.9	3.8	42	120	35	220
Stachys officinalis	*	*	0.1	1.7	1.8	32	18	86
Torilis japonica	*	*	5.8	16	17	65	0.6	7.8
Trifolium pratense	6.9	65	4.1	21	38	160	46	120

* = not measured

5. Pot studies on the susceptibility of weed and sown grasses to three graminicides.

Mean percentage survival of two grass species 12 weeks after treatment with three graminicides applied at two rates to four different growth stages (GS) ranging from one to six tillers (Marshall, 1995).

Species	GS	Fluazifop-P-butyl Fusilade		Cycloxydim Laser		Propaquizafop Falcon		Control
		Rate (l/ha product)						
		0.25	0.5	0.19	0.38	0.3	0.6	
Dactylis glomerata	1	69	13	56	6	19	0	100
	2	50	0	100	94	6	6	100
	4	19	0	6	13	0	0	100
	6	0	0	56	0	0	0	100
Festuca rubra	1	100	100	100	100	100	100	100
	2	100	100	100	100	100	100	100
	4	100	100	100	100	100	100	100
	6	100	100	100	100	100	100	100

6. Willmot Pertwee Limited (UAP) and Forestry Commission studies on farmland trees.

Effects of agricultural herbicides applied to actively-growing, young plants of hazel and hawthorn, as examples of farm woodland planting schemes. (Nowakowski *et al*., 1994). Herbicide doses are in kg active ingredient/ha.

Herbicide Product Active (Dose in kg a.i./ha)	Hazel *Corylus avellana*	Hawthorn *Crataegus monogyna*
Basagran; bentazone (1.44)	MS	MS
Ally; metsulfuron-methyl (0.006)	S	S
Benazolox; benazolin + clopyralid (0.69 + 0.115)	S	MS
Lentagran; pyridate (0.9)	MS	MS
Tropotox; MCPB (1.2)	S	MS
Fortrol; cyanazine (1.4)	MS	S
Coupler; cyanazine + clopyralid (0.31 + 0.05)	MS	MS
Dow Shield; clopyralid (0.1)	R	MS
Asulox; asulam (2.0)	S	MS
DPX53; thifensulfuron-methyl (0.0675)	MS	S
DPX63; tribenuron-methyl (0.12)	S	MS

R = resistant; MS = moderately susceptible; S = susceptible.