19 Agriolimacidae, Arionidae and Milacidae as Pests in West European Oilseed Rape

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Introduction

Oilseed rape has been bred from several *Brassica* Linnaeus (Brassicaceae) species (Bunting, 1984). The two most important commercial oilseed-rape crops are *Brassica rapa* Linnaeus var. *oleifera* Linnaeus and *Brassica napus* Linnaeus var. *oleifera* Linnaeus, with the latter being the type commonly grown in Europe (Weiss, 1983; Kimber and McGregor, 1995). Oilseed rape is one of the main European oil crops, together with sunflower (*Helianthus annuus* Linnaeus) (Asteraceae) and linseed (*Linum usitatissimum* Linnaeus; Linaceae), with its main use being human consumption as salad oils, cooking oils, margarines and fats (Bowman, 1989). Rape oil also has industrial uses in the manufacture of lubricants, lubricant additives, soaps, detergents, paints and varnishes, as well as acting as chemical feedstock for a wide range of processes (Bowman, 1989). For human consumption, a low concentration of erucic acid in the oil is necessary, whereas high concentrations of this acid are required for industrial lubricants. *Brassica* oilseeds yield 40–42% oil by dry weight and the residual meal is used in livestock or poultry feed (Evans and Scarisbrick, 1994).

The increased acreage of oilseed rape grown in Europe since the mid-1970s has been associated with a move away from spring-sown to autumn-sown cultivars (Ramans, 1989) (the latter often known as winter rape). In order to increase the marketability of rape meal, steps were taken by the European Community in the 1980s to reduce the concentrations of glucosinolates, which were considered to be undesirable in meal due to their antinutritional properties (Ramans, 1989). Thus, cultivars of oilseed rape grown for human consumption contain low concentrations of erucic acid and glucosinolates in the seeds. These are often called 'double-low' cultivars for this reason.

Gastropod damage to oilseed rape, as with most other agricultural crops in western Europe, occurs mainly at establishment. Since gastropods were first identified as important pests of oilseed rape (Mallet and Bougaran, 1970), the extent of gastropod problems and their economic importance have increased considerably in this crop. The principal reasons for this are thought to be largely agronomic, including the growing of more susceptible cultivars, incorporation of crop residues into soil rather than removal by baling or burning, reduced cultivations and the tendency towards autumn sowing. In Great Britain, surveys by the Ministry of Agriculture show that the percentage of the area of oilseed rape treated with molluscicide ranged from 6% to 58% between 1977 and 1996 (Port and Port, 1986; Davis *et al.*, 1993; Garthwaite *et al.*, 1995; Thomas *et al.*, 1997). In western France, rape is routinely treated with molluscicide by a majority of farmers (Mouchart, 1984). The oilseed rape crop is second only to cereals in terms of the area treated with molluscicides in Britain (see Glen and Moens, Chapter 12, Table 12.1, this volume).

The consequences of failure of establishment in winter oilseed rape are more severe than in winter cereals because redrilling of rape is not a viable option, due to the fact that the seed must be sown no later than in the first 2 weeks of September. Thus it is particularly important in rape to maximize establishment success. It is critical that the understanding of gastropod biology and all the factors that could influence damage, are integrated and applied to minimize the seedling losses. Another important aspect of the gastropod problem in oilseed rape is that, as the crop develops, the dense canopy provides gastropods with a moist environment and an abundant food supply. Thus, gastropod populations can increase greatly during a single season when oilseed rape is grown. Winter wheat (*Triticum aestivum* Linnaeus) (Gramineae) normally follows oilseed rape in the crop rotation in western Europe and the first wheat crop after rape is at high risk from gastropod damage, as described by Glen and Moens (Chapter 12, this volume). Spring barley (*Hordeum vulgare* Linnaeus) (Gramineae) after oilseed rape in Norway can be totally defoliated by gastropods (Andersen, 1996).

Gastropod Species Responsible for Damage

As oilseed rape is grown mainly in rotation with cereals in western Europe, the main gastropod species responsible for damage are similar to those in cereals (see Glen and Moens, Chapter 12, this volume). Gastropods of the slug body form predominate and shelled gastropods (snails) are not considered to be pests, presumably because the latter have lower fitness in the disturbed agricultural ecosystems. The most widespread and abundant species in oilseed rape is *Deroceras reticulatum* (Müller) (Agriolimacideae). In some parts of Western Europe, such as Belgium, this species usually occurs alone in arable systems. Less frequently it is associated with small arionids, such as *Arion distinctus* Mabille and *Arion* *circumscriptus* Johnston. However, in England (Glen and Wiltshire, 1988) and France (Hommay, 1986, 1994; Chabert *et al.*, 1997) *D. reticulatum* is usually sympatric with one or more species of Arionidae in arable fields. Milacidae were found to be more localized in their distribution (Glen and Wiltshire, 1988; Chabert *et al.*, 1997).

Factors Affecting Gastropod Damage to Oilseed Rape

Gastropod damage to oilseed rape depends on three main factors; gastropod population density at establishment, gastropod feeding intensity activity in the seed-bed, and crop vulnerability during germination, emergence and the first-leaf stages.

Gastropod population density

Glen and Moens (Chapter 12, this volume) provide a detailed account of the factors influencing gastropod population density in West European arable fields. *D. reticulatum* and other gastropod species in these arable fields generally live in the upper 8–10 cm of soil, but retreat to greater deapth in the soil in order to survive when the upper layers of soil dry out (see Glen and Moens, Chapter 12, this volume). This can explain gastropod damage to rape seedlings even after dry seasons. The important influence of cultivation on gastropod population density and the percentage of rape seedlings subsequently killed by gastropod feeding has been demonstrated by Glen *et al.* (1996b) and Voss *et al.* (1998). Higher populations were recorded where there was no tillage or where non-inversion tillage was used than where soil was ploughed followed by subsequent cultvations to prepare a seed-bed. In experiments where each plot was subdivided and one subplot on each was treated with molluscicide while the other subplot was left untreated, molluscicide applications generally reduced gastropod activity and increased plant survival. On subplots treated with molluscicide in the experiment described by Glen *et al.* (1996b), there were no significant differences between different cultivation treatments in the numbers of rape seedlings that established. However, on untreated subplots, highly significant differences were observed, with the greatest numbers of plants on ploughed subplots (not significantly lower than on treated subplots), intermediate numbers on untreated subplots cultivated by non-inversion tillage and significantly fewest plants on untreated direct-drilled subplots. In accordance with these results, rape sown preharvest into cereal crops is at high risk of damage, because of high densities of gastropods in this situation (Tebrugge and Wagner, 1996).

In the experiment by Glen *et al.* (1996b), the reduction in numbers and biomass of rape seedlings on the untreated subplots, as a percentage of the value on treated subplots, was positively correlated with the biomass of gastropods m^{-2} recorded in samples from the upper 10 cm of soil in untreated subplots. Glen *et al.* (1996b) compared this relationship with that found for winter wheat in an earlier experiment (Glen *et al.*, 1989). This comparison is of interest because winter wheat is the most important crop affected by gastropod damage in western Europe and is thus the crop in which farmers have most experience in managing damage. In wheat, the relationship between % seed kill and gastropod biomass was strongly influenced by the percentage of fine-soil aggregates in the seed-bed and the depth at which the wheat seeds were sown. However, even in the conditions most conducive to damage to wheat (low % fine-soil aggregates and shallow sowing), the mortality caused by a given biomass of gastropods was substantially less than that caused to oilseed rape. Of course, the level of damage in each study was influenced by a variety of factors and the two studies are not, strictly speaking, directly comparable, However, the results point to a greater susceptibility of rape to gastropod damage in comparison with wheat.

Arion lusitanicus Mabille has been found in high abundance in wild-flower strips and grass headlands, with the large adults being present at the time of rape establishment in late August–early September (Frank, 1998b,c,d). Adults of this species can travel net mean distances of 3–8 m per night (Grimm *et al.*, 2000) while abundance declines with increasing distance from headlands (Frank, 1998a,b,c), they can be prevalent in rape during crop establishment. *A. lusitanicus* forage into rape fields at night, causing severe damage within 1–2 m of the edge of wild-flower strips (Frank, 1998c,d). By the time that wheat is sown, later in the autumn, the *A. lusitanicus* populations comprise, only juveniles (which are thought to be less mobile) and the trend of greater damage close to wild-flower strips is no longer apparent (Frank, 1998a). In most cases, *D. reticulatum* did not show a decline in densities at increasing distances from strips of semi-natural vegetation retained within the field (Frank, 1998a,c,d) except in one study where rape bordered two grass strips (Frank, 1998b).

Davies *et al.* (1997) found a positive relationship between the severity of gastropod damage to oilseed rape in autumn and overall weed ground cover. They also reported positive correlations of such damage with 5 years' set-aside and oilseed rape as a previous crop. It is likely that all three correlations with previous vegetative cover are indicative of conditions that favour high gastropod population densities.

Gastropod feeding activity

As explained earlier, modern cultivars of oilseed rape have been intentionally bred with low concentrations of glucosinolates in the seeds, in order to increase the palatability of the residue left after oil extraction as feed for farm animals (Ramans, 1989). For oilseed rape, the number of seedlings attacked and the leaf area destroyed by *D. reticulatum* has been shown to be inversely related to the concentration of glucosinolates in the seeds and their concentration in seedlings at the cotyledon stage (Glen *et al.*, 1990a; Moens *et al.*, 1992a). Glen *et al.* (1990a) found a strong correlation between the total concentration of glucosinolates in seeds and that in seedlings (hypocotyl and cotyledons). This suggests that glucosinolates in the seeds were transferred to the seedlings with little change in overall concentration, although there were increases and decreases in concentrations of certain individual glucosinolates (Glen *et al.*, 1990a). It is possible that certain individual glucosinolates may have more or less influence than others on palatability to *D. reticulatum*. However, cultivars with low overall concentrations of glucosinolates in the seed (6–12 mg g^{-1} of seed) were highly susceptible to damage, whereas cultivars with high glucosinolate concentrations (70–89 mg g^{-1} seed) were highly resistant. These observations strongly suggest that an important function of glucosinolates in rape seeds is to protect the young seedlings from being eaten by generalist herbivores, such as *D. reticulatum* and rabbits (*Oryctolagus cunniculus* Linnaeus; Leporidae) (Giamoustaris and Mithen, 1995).

Interestingly, Glen *et al.* (1990a) noted that counts of seedlings emerging in the presence or absence of gastropods indicated that the number of seedlings consumed in the initial stages of germination was not influenced by glucosinolate concentration. They proposed that gastropods did not initially avoid feeding on seedlings with a high concentration of glucosinolates, although they did so after a few days and with a high degree of discrimination. An alternative explanation for this initial feeding, that concentrations of glucosinolates were initially low in seedlings, is unlikely, because both seeds and young seedlings consist mainly of the cotyledons, which contain glucosinolates. The strength of the feeding deterrence to gastropods provided by glucosinolates in oilseed rape is indicated by the fact that, in the experiments of Glen *et al.* (1990a) and Moens *et al.* (1992a), *D. reticulatum* largely avoided feeding on seedlings with high glucosinolate concentrations, even when no alternative food was available. Indeed, damage to rape was not influenced by the presence of alternative food in the form of barley seedlings, which would often be available to gastropods feeding on winter oilseed rape in the field, as barley often precedes winter rape in the crop rotation (Glen *et al.*, 1990a). Byrne and Jones (1996) noted that high concentrations of glucosinolates in rape reduced feeding by *D. reticulatum* more rapidly than feeding by the non-pest species *Limacus pseudoflavus* (Evans) (Limacidae). *D. reticulatum* gained weight when fed on seedlings of rape with low concentrations of glucosinolates, but lost weight when fed on seedlings with high concentrations. *L. pseudoflavus* lost weight when fed on either type of rape.

In later stages (Zadok's growth stages > 25), older leaves of oilseed rape become less attractive and are less palatable to gastropods. Seedling vulnerability is very high during early stages of germination and emergence (GS 02–14). Indeed, at this stage, cutting of the hypocotyl or consumption of small quantities of plant tissue from the growing point or cotyledons causes the death of seedlings and gastropods can destroy many plants. Vulnerability decreases progressively during the first-true-leaf stages, because gastropods no longer attack vital organs, but they make holes in the leaves. Damage at this stage is serious when grazing is not compensated for by growth. In later stages GS (> 25 = formation of large leaves), seedlings are less palatable and attacks are generally limited to older leaves, so that plants are less susceptible to damage.

The duration of vulnerable seedling stages (germination, emergence and first-leaf stages) is prolonged by adverse weather and poor soil conditions (coarse macrostructure or 'capped' soils), but can be influenced by cultivar; slow-growing cultivars are at greater risk than cultivars that develop more quickly through susceptible stages (Moens *et al.*, 1992a). Crops with a low plant density (crops sown at a low drilling rate, or thinned by adverse weather or disease) are more vulnerable than densely sown healthy crops, which have the capacity to compensate for seedling losses. Thus, factors compromising plant fitness, such as late drilling or adverse growing conditions, will have an important influence on the severity of gastropod damage.

For cereal crops, especially wheat, accessibility of the seeds and the growing points of young shoots can be diminished if the seed is sown in a fine seed-bed favouring closure of the drill furrow. Under these conditions the gastropods are unable to readily locate the most vulnerable stages of the wheat crop (Glen and Moens, Chapter 12, this volume). Rape seeds, however, are protected in the first stages of germination (GS 00–02) by a strong outer coat; but the seedlings become progressively more accessible when the outer seed-coat is broken and the cotyledons and the growing point are pushed up to and above the soil surface (GS 03–14) (Moens, 1989). This pattern of vulnerability is consistent with the observation by Frank (1998d) that above-ground feeding by gastropods was of greater consequence than initial feeding below ground at the time of rape establishment. In contrast to monocotyledons, such as cereals, little can be done in terms of cultural measures to avoid gastropods gaining access to the vital organs, once seeds have germinated.

In laboratory experiments with 77 plant species, Briner and Frank (1998) found *A. lusitanicus* to prefer rape to all other species. Subsequent laboratory tests by Frank and Friedli (1999), with both *A. lusitanicus* and *D. reticulatum*, showed that rape was equalled only by *Capsella bursa-pastoris* (Linnaeus) Medikus (Brassicaceae) in vulnerability to defoliation. For *A. lusitanicus* only, *Taraxacum officionale* Weber (Asteraceae) was similar to rape in seedling vulnerability. In addition, the presence of *Veronica persica* Poiret (Scrophulariaceae) and *G. bursa-pastoris* significantly reduced the number of rape plants killed by both *A. lusitanicus* and *D. reticulatum* (Frank and Friedli, 1999). When exposed to a low density of *D. reticulatum* (10 m^{-2}) in the field, significantly more rape seedlings survived the first 4 weeks after emergence when seedlings of either

C. bursa-pastoris or *Stellaria media* (Linnaeus) Cirillo (Caryophyllaceae) were present than when rape seedlings were present alone (Frank and Barone, 1999). However, with *D. reticulatum* at a density of 20 m^{-2}, almost no rape plants survived, even in the presence of weeds.

Management of Gastropod Damage to Oilseed Rape

Integrated control of gastropod damage to rape seedlings can be achieved by means of cultural practices supported by chemical treatments. Biological control, especially predation by carabid beetles, is also relevant and is discussed below.

Cultural control

The following cultural practices are known to decrease the risk of gastropod damage: avoidance of crops favourable to gastropods in rotations, clearing of crop residues from fields after harvest, improvement of soil structure, seed-bed preparation and drilling in optimal circumstances and, finally, cultivation of less susceptible cultivars. Some of these practices are more desirable than others. Their advantages and disadvantages are discussed below.

Crop rotations have to be designed to fulfil multiple aims principally profitability but also maintenance of soil fertility, minimization of the risk of attack by diseases and pests, and to achieve efficient weed control (Jordan and Hutcheon, 1996). For this reason, farmers may well choose rotations with greater risks of gastropod damage than would be the case if gastropods were the only consideration (Glen *et al.*, 1996b). Oilseed-rape crops are normally grown in cereal-dominated crop rotations. Where cereal straw is incorporated, especially by non-inversion tillage, cereal-dominated rotations are favourable to gastropods (Glen *et al.*, 1996b). Because winter barley is harvested earlier than other cereals, it is often favoured as a crop to precede winter oilseed rape, which must be sown in late August or early September. Spring rape is generally at less risk than winter rape, but Jordan and Hutcheon (1996) reported that gastropod damage to spring oilseed rape was severe where cover crops had been grown over winter. As a result, they avoided growing cover crops before spring oilseed rape, despite the value of cover crops in restricting nitrogen losses from soil.

Removal of vegetation cover (weeds and volunteer seedlings germinating from the previous crop) and crop residues after harvest drastically decreases the food and shelter for gastropods. Moreover, a proportion of gastropods are destroyed when weeds and plant residues are physically removed from the soil surface by soil cultivations. As described by Glen and Moens (Chapter 12, this volume), incorporation of crop residues into soil provides a supplementary supply of food and shelter, which results in increased gastropod populations. While increased favourability for gastropods is a negative outcome from the perspective of pest management, the improvements in soil structure mean that incorporation is the preferred method of disposing of crop residues in integrated farming systems designed to combine profitable farming with environment protection (Jordan and Hutcheon, 1995). Improvements in soil structure also make it possible to prepare finer seed-beds. This is particularly important on heavy soils, where crevices and coarse aggregates furnish excellent shelter for gastropods. High-risk patches are located where there is a high clay content close to the surface – for example, on hillsides where the loam topsoil is thin, so that heavy clay is ploughed to the surface. In this context, non-inversion tillage methods may help to improve seed-bed structure and thus reduce the risk of poor establishment, even though such methods, as described earlier, may result in higher gastropod densities in the seed-bed compared with ploughing.

It follows from the above point that on heavy soils additional cultivations before drilling, and soil consolidation after drilling, are necessary to provide a finer and firmer seed-bed, which reduces gastropod activity and accelerates germination and growth. It should be borne in mind that consolidation is beneficial only when done on spongy, well-structured soils and in good weather conditions. Because of their small size, rape seeds are sown at shallow depth, just covered by soil or a little deeper in dry conditions (Pouzet, 1995). This contrasts with cereal seeds, which are normally sown at 30 mm depth (Wibberley, 1989). Because rape seeds are not vulnerable to gastropod damage, shallow sowing is not thought to increase the damage risk and may, by speeding germination, reduce the risk for rape. On coarse-textured seed-beds, a higher drilling rate is advisable, although this measure provides little protection during germination and emergence, as seedlings in these early stages are extremely vulnerable. In later stages, a dense vegetation cover is better able to resist gastropod attack because more leaves are produced and plants can thus compensate for leaf destruction. Optimal plant fitness in well-prepared seed-beds also maximizes the rate of leaf production and decreases crop vulnerability.

As discussed earlier, the palatability of oilseed-rape seedlings to gastropods is inversely related to the concentration of glucosinolates in seeds and seedlings. As modern cultivars contain low concentrations of glucosinolates, they are highly susceptible to gastropod damage. Selection of cultivars with rapid germination and growth, reducing the duration of the most critical stages, is the most appropriate response (Moens *et al.*, 1992a).

Observations on gastropod damage to oilseed rape (Speiser, 1999) suggested that fresh, anaerobically digested organic material from a biogas production plant was molluscicidal. Laboratory studies confirmed that fresh material killed *A. lusitanicus*, *A. distinctus* and *D. reticulatum* in the laboratory. However, molluscicidal properties were rapidly lost in storage and also after application in the field, and this is not considered to be a reliably effective, practical method of control.

Biological control

Natural enemies (predators, parasites and pathogens) of gastropods are described by Moens *et al.* (1992b) and in a related volume (Barker, 2002). Mass rearing of predators such as carabid beetles to control gastropod damage in oilseed rape would not be practical. Such predators can best be exploited by providing them with conditions under which they can have a maximum impact on gastropod populations. However, greater understanding is needed of the interactions between these beetles and their prey before the contribution of these generalist predators to integrated control of gastropods can be achieved. Studies in an oilseed rape crop in July–September, before and after harvest, have shown that gastropods are important prey for adults of *Pterostichus melanarius* (Illiger) (Symondson *et al.*, 1996). This species is probably the commonest and most widespread large carabid beetle in arable land in western Europe. Further information on the impact of carabid beetles on gastropod populations in arable fields is given by Glen and Moens (Chapter 12, this volume). It is important to note here that the main period of activity of adult *P. melanarius* is from June to September, i.e. for *c.* 3 months up to the time when winter oilseed rape crops are sown in late August/early September and for *c.* 1 further month during the critical period of crop establishment. For this reason, and based on the evidence reviewed by Glen and Moens (Chapter 12, this volume), conservation measures for *P. melanarius* could be particularly valuable in integrated control of gastropod damage to oilseed rape. Since carabid beetles are killed by methiocarb-based molluscicides, whereas metaldehyde-based molluscicides are harmless (Kennedy, 1990), it may be preferable to use the latter molluscicide at establishment of winter rape.

One possible selective means of controlling gastropod damage is the inundative application of the gastropod-parasitic rhabditid nematode *Phasmarhabditis hermaphrodita* (Schneider) to soil. The biology of this nematode and its use as a biological control agent are summarized by Glen *et al.* (1996a), Glen and Wilson (1997) and Morand *et al.* (2002). The nematode can significantly reduce gastropod damage to oilseed rape when it is applied to soil at the time of sowing or 1–2 weeks before sowing rape (Wilson *et al.*, 1995; Speiser and Andermatt, 1996). Because this nematode requires moisture for survival and because the soil surface often dries rapidly during and after seed-bed preparation for oilseed rape, there may be reduced efficacy of nematodes applied to the soil surface (Wilson *et al.*, 1995, 1996). However, this problem can be diminished by working the soil to a depth of 5–10 cm immediately after nematodes are applied, in order to incorporate them into the surface-soil layers (Wilson *et al.*, 1996). This mixing of nematodes with soil can be done during normal cultivations for seed-bed preparation and does not require any additional operations. Despite the technical feasibility of using this nematode for control of gastropod damage in oilseed rape, its high cost in comparison with chemical molluscicides will preclude its use for control of gastropod damage in arable crops until the economics of usage change significantly (Wilson *et al.*, 1995; Glen and Wilson, 1997). Application of *P. hermaphrodita* to soil when rape was sown did not affect the subsequent development of gastropod populations in rape crops (Wilson *et al.*, 2000). Thus, inoculative application of nematodes to prevent build-up of gastropod populations in rape crops does not seem to be feasible.

Chemical control

Chemical molluscicides should be used as part of an integrated-control approach to gastropod damage on oilseed rape in order to avoid or reduce the severity of gastropod attacks during the crucial vulnerable early growth stages (GS 02–25). In high-risk situations, molluscicidal baits should be broadcast immediately after drilling or just before susceptible growth stages appear in order to kill the gastropods active on the soil surface during this vulnerable phase of the crop. The importance of this is demonstrated by the results of a trial in France (Anon., 1995). Molluscicidal bait pellets applied at crop emergence increased the number of surviving plants from 3 m^{-2} to 15 m^{-2}. Pellets applied at drilling gave better results (33 plants m^{-2}), while pellets applied at drilling and crop emergence gave the best results (42 plants m^{-2}). Treatments before cultivation are likely to be less effective, as they are for wheat (see Glen and Moens, Chapter 12, this volume). In France (Anon., 1997), it is recommended that, in high-risk areas, treatment at sowing should be followed by surveillance at 5–6-day intervals until the crop four-leaf stage, with molluscicide applications repeated as necessary. Similar recommendations have been made by Voss *et al.* (1998).

Where there is a lower risk of gastropod damage, it is possible to wait until seedling emergence to assess the degree of gastropod damage before pellets are applied. However, the danger of waiting until emergence is that gastropods may eat off all growing points and cotyledons as soon as they appear, so that severe gastropod damage may be mistaken for slow emergence. Moreover, severe gastropod damage can be caused by relatively few gastropods, as described earlier. Some crops drilled at high densities in optimal conditions and covering the soil with a dense luxuriant canopy can resist moderate gastropod attacks without treatment, because seedling destruction and leaf consumption are compensated for by growth. In such cases, it will be important to assess regularly the severity of gastropod attack, with control decision depending on damage severity and plant fitness: experience indicates that treatment is not justified if more than 50 healthy seedlings m^{-2} are present.

As explained earlier, oilseed rape bordering wild-flower strips has been shown to be at particular risk from gastropod damage, especially by *A. lusitanicus*. Severe damage close to wild-flower strips can be effectively controlled by broadcasting molluscicide pellets (Frank, 1998c) and their use can be restricted to a band 50 cm wide adjacent to the strips (Friedli and Frank, 1998).

Methanol extracts of two plant species, *Saponaria officionalis* Linnaeus (Caryophyllaceae) and *Valerianella locusta* (Linnaeus) Laterrade (Valerianaceae), applied to the cotyledons of oilseed rape, have been shown to deter feeding by *A. lusitanicus* (Barone and Frank, 1999). This suggests that antifeedant plant extracts could make a useful contribution to integrated control of gastropod damage to oilseed rape, but problems of volatility, persistence and cost need to be solved (Barone and Frank, 1999). As mentioned previously, Frank and Barone (1999) found that the presence of either *C. bursa-pastoris* or *S. media* protected rape seedlings from attack by *D. reticulatum* at low density (10 m^{-2}), but not at 20 m^{-2}. In contrast, the efficacy of metaldehyde pellets was independent of *D. reticulatum* density over this range.

Conclusions

The severity of gastropod damage to oilseed rape at establishment in western Europe has increased since the 1970s for a number of reasons. Among the most important of these has been the European Community (EC) policy to favour cultivars with low concentrations of glucosinolates in the seeds, which has substantially diminished this crop's natural chemical defences and thus rendered the seedlings considerably more palatable to the main pest species, *D. reticulatum*. Over the same period, other agronomic changes have provided favourable conditions for gastropod populations. These practices include incorporation of residues of the previous crop into the soil (rather than burning *in situ* or removal), cover cropping (to reduce nitrate leaching) and the deployment of techniques of reduced or zero tillage. Improved weed control may also have contributed to increased damage, by removing weed seedlings, some of which are alternative foods for gastropods. Weather conditions in recent years (mild winters and wet summers) have also been favourable to high gastropod population densities.

Optimum control of gastropod damage to oilseed rape is achieved through integrated cultural and chemical control. Cultivation, especially by ploughing, decreases gastropod populations and therefore damage potential. Preparation of fine, firm seed-beds reduces gastropod population densities and promotes rapid germination of oilseed rape. Choice of faster-growing cultivars reduces the time period during which crops are at greatest risk. Molluscicidal treatments should be applied only when necessary and should be cost-effective. However, it is difficult for farmers and their advisers to take rational decisions on the need for control measures because, for best results, it is necessary to apply molluscicide before damage is visible. However, it is not possible at present to forecast accurately the severity of gastropod damage. Moreover, there are few data on the influence of gastropod damage on yield of oilseed rape. Predictions of gastropod damage risk and the need for control measures need to be considerably improved, with a system based on weather data, gastropod population densities, soil type, cultural practices and other important parameters.

In crops with a high risk of gastropod damage, molluscicidal bait pellets should be applied at drilling or, at latest, before germinating seedlings have started to emerge. The crop should then be monitored at 5–6-day intervals until the fourth-true-leaf stage, in order to assess whether further treatments may be beneficial. While inundative biological control of pests in oilseed rape is technically feasible, it is not economically viable at present. However, recent results suggest that natural biological control by predatory carabid beetles, especially *P. melanarius*, may restrict the growth of gastropod populations during the summer period (June to August) immediately before winter oilseed rape crops are established. Since *P. melanarius* are still active at the time of rape establishment, it may be beneficial to use metaldehyde-based molluscicides for control of gastropod damage to rape, as such molluscicides are known to be harmless to carabid beetles.

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