SESSION 8C

INDUSTRIAL AND AMENITY WEED CONTROL

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HERBICIDE USE IN INDUSTRIAL AND AMENITY AREAS: CURRENT PRACTICE AND FUTURE PROSPECTS

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ABSTRACT

The current use of herbicides in industrial and amenity situations in the UK is reviewed in the light of evidence of low level herbicide residues in some drinking water supplies, increasing pressure against herbicide use in public places, and curtailment of local authority budgets for weed control.
The consequences of possible withdrawal of triazine herbicides for weed control on non-crop areas is considered; alternative programmes may involve applications of herbicides several times annually. In amenity plantings there is a need for a greater appreciation by landscape planners and spray operators of the properties of the herbicides used, to reduce plant damage problems. Possible means of improving standards with and without the use of herbicides are discussed.

INTRODUCTION

Over the past 30 years herbicides have become an integral part of the management of industrial and amenity land areas. They are used to maintain vegetation-free land on industrial and transport sites, selective control of weeds in ornamental plantings and to maintain the quality of grassed areas. Their adoption has been encouraged by the advantages of cost effectiveness and ease of management. As new weed problems have appeared so new herbicides have been introduced to resolve them. By the mid-1980's, however, this relatively stable situation was facing the wind of change. Since then public pressure against the use of pesticides has continued to increase with particular concern about their use in public places and the possibility of contamination of drinking water. At the same time public demand for acceptable weed management standards for public areas is maintained with outcries over any damage from uncontrolled weeds. This situation is reviewed in this paper as well as prospects for the future use of herbicides to maintain acceptable vegetation management in these areas.

CURRENT HERBICIDE USE ON INDUSTRIAL SITES AND HARD SURFACES IN PUBLIC PLACES

This land is either maintained as bare surfaces with minimal vegetation or with a rough sward. Bare surfaces are required on railways, oil refineries and factory/storage areas to reduce fire risk and give good visibility. Sward, much of it rough, is maintained at airfields, military installations and around industrial and commercial areas. While some use of selective herbicides is required on this sward to prevent domination by broad-leaved perennial weeds, it is the industrial sites maintained largely free of vegetation that receive large doses of herbicides. Over 20 different active ingredients are Approved for this use (Ivens 1991). The normal treatment involves application of mixtures of foliar-acting and residual herbicides in spring to give year-long control. An estimate of herbicide use on amenity and industrial land for 1989 showed that, of the 550 tonnes of active ingredient used, 39% were triazines (atrazine, simazine and terbutryn) (DoE 1991). This value is not surprising since for total weed control these may be used at doses up to 10 times those employed in agriculture or horticulture. Phenoxyalkanoic herbicides comprised 21% of the total and ureas and uracils 13%. Although these figures include amenity uses they probably give a broad indication of relative usage on industrial land.

Greater logistic efficiency in application has been achieved in recent years with the introduction of controlled droplet application (CDA) sprayers for knapsack use and the introduction of high speed spray trains by British Rail (De'Ath & Collins 1991). Repeated annual use of triazine herbicides has lead to the development of triazine-resistant biotypes of some weed species, particularly Canadian Fleabane (*Erigeron canadensis*) on railway land (Clay & West 1988, Clay 1989). Imazapyr has been successfully used to control these resistant weeds.

Against this picture of successful weed management must be set the current public pressure against pesticide use and the occurrence of small quantities of pesticides in drinking water. The latter appears to be linked to the use of triazine herbicides on industrial land. An estimate of the type of non-agricultural land treated with herbicides in 1989 (DoE 1991) indicated that hard surfaces predominate (43% of the total applied to industrial/amenity land) and that power, industry and transport bodies are responsible for over half the usage. Since these are the use situations where high doses of triazines are applied it seems likely that the low-level residues of atrazine and simazine frequently found in drinking water in 1990 in some areas (DWI 1991) have resulted from these applications. This type of information and the public concern it has engendered has lead to the current review of Approvals of triazine herbicides by the Advisory Committee on Pesticides, the announcement by British Rail that they are ceasing atrazine use on their land by the end of 1993 (BRB 1991) and the withdrawal of recommendations for atrazine on non-cropped land by a major UK manufacturer. There is evidence from Switzerland that stopping atrazine use in 1987 on all situations except maize crops has led to an apparent reduction in detectable residues in ground water (Egli 1990).

FUTURE PROSPECTS FOR HERBICIDE USE ON INDUSTRIAL LAND AND HARD SURFACES

The possibility of the withdrawal of triazine herbicides for total weed control on these areas will create considerable problems for land managers since they have been the cornerstone of the weed control programme for many years. It is important to keep the current debate in perspective. The levels of residue detected in water are low and far below those likely to damage human health (DWI 1991). There are also problems in the precision of determinations at such low levels and the need for confirmation by alternative methods has been suggested (Hance 1990). Presence of herbicide residues in drinking water does appear to be associated with regional differences (DWI 1991). The frequent occurrence of detectable residues was largely confined to south and east England where major triazine use coincides with water extraction from bore holes and river sources. In northern and western regions where water is extracted from upland areas detectable residues were infrequent although the triazine usage is appreciable in those regions (DoE 1991). In the absence of satisfactory alternatives there could therefore be a case for continuing use on non-crop land in non- catchment areas.

In the event of withdrawal what control programmes are available? Changing from the triazines to widespread use of another herbicide such as diuron may not be adequate; it has comparable soil mobility characteristics to simazine and residues have been found in water samples in south-east England (DWI 1991). Leaching of this type of herbicide could possibly be reduced by the presence of a vegetation cover at spraying or by annual cultivation of surface soil to destroy fissures and macropores that facilitate leaching but this is unlikely to be practicable. There are a number of strongly adsorbed herbicides approved for annual weed control in agriculture which would be unlikely to leach on non-crop land significantly, but they would probably need to be applied in autumn or winter; at current use rates they are ineffective in dry springs and late application might incur other problems such as photodegradation or volatility. They would generally have little effect on deep rooting perennial weeds.

Control could be achieved by repeated applications of broad spectrum translocated herbicides or mixtures Two or three applications would be needed each year and efficacy can be very dependent on growing conditions and weather. Over dependence on one herbicide such as glyphosate runs the risk of weed species acquiring resistance (Putwain & Mortimer 1989), as well as a build up of species that are inherently more resistant. Whatever the solution it is almost certain that the number of herbicide applications each year will increase, with a corresponding increase in costs. There may be problems with access for repeated applications in sites where security is a problem.

CURRENT HERBICIDE USE IN PLANTED AREAS IN AMENITY LANDSCAPES

Financial pressures have forced reductions in the cost of management of amenity areas, but at the same time an acceptable level of interest and 'tidiness' has to be maintained. Although they were initially slow to appreciate their efficacy and relatively low costs, managers have increasingly turned to herbicides as the best weed control option. Dependence on them is now almost universal. As outlined above, pesticide use poses problems of public acceptance, and public opinion has moved against the use of all 'chemical' aids in recent years. Pressure from the public has led to some Local Authorities banning or restricting the use of some herbicides, not withstanding that those banned are fully approved by MAFF. It is against this background that current practices and future prospects are discussed.

Under the Control of Pesticides Regulations, 1986, only Approved pesticides may be used and the maximum dose given on the label must not be exceeded. There are a large number of Approved commercial products for amenity use available, currently comprising some 17 active ingredients, either alone or in mixtures. There are contact and translocated foliar-applied herbicides, and root-absorbed residual products. Simazine, oxadiazon, propachlor and propyzamide are formulated either as soil-applied granules or for spray application; chloramben and dichlobenil are always formulated as granules. Many of the Approved herbicides are formulated for CDA application at greatly reduced volume rates.

Where a programme of chemical weed control is to be used, this needs to be carefully planned if safe and effective weed control is to be achieved, but it must be planned sufficiently flexibly to allow for unforseen problems such as the onset of herbicide resistance or the appearance of deep rooted and persistent perennial weeds. Their are now about 10 weed species resistant to triazine herbicides and American willowherb (*Epilobium ciliatum*) and annual meadow grass (*Poa annua*) biotypes resistant to paraquat (Clay, 1989). By regularly varying the herbicide used the build up of particular species or the development of resistance can be prevented or delayed. The range of activity and mode of action of the currently-approved herbicides is such that it should be possible to achieve substantial freedom from weeds without permanent or unsightly damage to amenity plants.

Application is generally by small hand-held or pedestrian-controlled equipment, both for sprays and granules. There are some advantages in using spinning disc sprayers (CDA) that produce relatively large drops of 200-300 μm at a much reduced volume rate of around 20 l ha^{-1}. With some of this equipment for instance, the operator only needs to clip on a container holding ready-mixed herbicide and apply it , thus eliminating what can be the most hazardous part of the spraying operation. The greatly reduced volume rate means less physical work, and this helps the operator remain fresh and attentive for his task. In addition, because almost all the drops reach the target, there is less operator contamination (Merritt 1989) so protective clothing requirements are less. However, not all herbicides can be formulated for this application system and CDA formulations are frequently more expensive. The invisibility of the spray is a disadvantage which may be alleviated by including a dye in the spray liquid or formulating as an oil emulsion. Another drawback is the inherently uneven distribution across the spray swath (BCPC 1986); there is an considerable increase in spray volume at the swath edges, as with a hollow cone jet, unless the head is shielded to prevent this. With shielded heads there may be problems with excess liquid being deposited as larger droplets. Unshielded heads, depending on application speed, will result either in under-dosing at the swath centre or overdosing at the edges. This may lead to waste of herbicide, particularly if spot treating narrow bands of weeds, or greater risk of damage when used amongst low-growing crops.

A continuing problem in amenity areas is the occurrence of damage to plantings from careless use of herbicides. There are particular problems with the use of glyphosate because of its translocation from sprayed to unsprayed branches and the insidious carry-over of damage from summer and autumn spraying to the following growing season. This problem should be reduced by the Certification requirements of COPR 1986, the introduction of official standards and codes of practice for pesticide use in amenity plantings and conservation areas. Tighter specifications by contracting bodies will also help, if they ensure that crop health be maintained as well as weed control standards. All these developments should result in sprayer operatives being better informed about the properties of their herbicides, the correct use of their equipment and the conditions leading to damage or failure.

Organic mulches provide an alternative method of weed control to herbicides or mechanical methods in shrub plantings. They are generally of coarse grades of bark and to be effective need to be maintained at least 7.5 cm deep. They must be kept free of contaminating soil in which weed seeds would germinate; they will not control most types of perennial weed that are already present so contact herbicides are needed to supplement their use. Bark also tends to be scattered by birds and blown away in wind. Mineral mulches are now being introduced with comparable effects on annual weeds. Plastic sheet mulches are little used in amenity plantings in Britain although used successfully for this purpose elsewhere in Europe and in commercial horticulture in the UK. When covered with a layer of bark or stones they can be visually acceptable and effective. They are particularly effective on light soil sites but can lead to problems with anaerobic conditions on poorly drained sites (Davies 1987). Flame and infra-red weeding is now being promoted as an alternative to herbicide use and modern propane burners meet the most stringent European standards; their use in amenity areas is restricted to hard surfaces or amongst well-spaced trees.

FUTURE PROSPECTS FOR HERBICIDE USE IN AMENITY PLANTINGS

Already amenity horticulture is heavily influenced by the need to cut costs and also by public opinion. Local Authority maintenance work is progressively being made available for tender from the private sector or from Direct Labour Organisations from the former Parks Departments with the object of containing costs. The danger is that this could lead to falling standards of weed control particularly if local public pressure insists that no herbicides are used and budgets do not allow the expense of handweeding. Data from the Forestry Commission illustrate the increase in cost of mechanical compared with chemical weeding (Williamson & Mason 1990). People in areas where weeds are not controlled will have to accept the sight of weeds in public places, as is happening now in some European cities.

There are a number of developments that might help maintain and potentially improves weed control standards in amenity areas. If less toxic herbicides were available spray operators would not have to wear conspicuous protective clothing and this would reduce public fears. The development of the sulphonylurea herbicides for agricultural use shows that effective, low-dose, low mammalian toxicity herbicides can be found. The possibilities of using herbicides at times of year when crops are more tolerant needs exploring; glyphosate appears to be safe as a winter spray over some species (Skroch 1987). Where specific weed problems develop more use could be made of foliar-acting herbicides with good tolerance to many crop species e.g. selective couch grass (*Elymus repens*) herbicides, clopyralid for creeping thistle (*Cirsium arvense*) control, metazachlor on seedlings of a number of important species. For this a combined approach to obtain any necessary on or off-label Approvals and to educate users on effective and safe treatments will be required. In the long-term the possible development of herbicide-resistant ornamental species is a possibility.

The drawbacks of some CDA application equipment have been referred to earlier; there is a need for improvement in available equipment to reduce plant damage, herbicide waste and operator exposure. Modification of conventional knapsack spraying equipment to eliminate the need for mixing of herbicide concentrates by operators while retaining the even spray distribution given by flat fan jets would be one answer. Such a system has been proposed by Dawson *et al.* (1989) but is not available commercially.

There are other possible routes to progress. Is there a need to re-emphasise to those involved in planning planting schemes, the landscape architects, the vital importance of effective weed control and the need to consider it at the planning stage? Can more use be made of 'hard' landscaping to reduce potentially weedy areas? Can more grouping of species resistant to particular herbicides be done? What scope is there for planting species and cultivars more tolerant of weed competition? Tree species can differ significantly in susceptibility to weed competition (Davies 1987).

Finally, the development of a safe, reliable and environmentally-acceptable grass suppressant must be a continuing target. This is a difficult specification for any chemical to fulfil but a successful product could lead to considerable savings in view of the heavy investment of time, machinery and fossil fuel in the regular mowing of large areas of amenity grass.

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DEVELOPMENTS IN APPLICATION TECHNOLOGY FOR INDUSTRIAL WEED CONTROL

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ABSTRACT

The reasons for weed control in industrial situations, such as railways, industrial sites, local authorities and industry are discussed.

Specialist equipment has been developed to overcome problems of both large and small scale application of herbicides, which differ considerably from application equipment available for agricultural spraying.

Recent developments have included weed control systems which match specific formulations of herbicides to hand-held rotary atomizer sprayers, resulting in significant reductions in both operator contamination and spray drift in comparison to knapsack sprayers.

INTRODUCTION

There is considerable diversity of sites where industrial weed control is practised.The weed control requirements also differ from situation to situation. Total vegetation control is essential around petroleum container tanks in order to remove or reduce potential fire hazard whereas on local authority playing fields selective herbicide treatments are necessary to improve the quality of the turf and hence the playing surface.

The growth of weeds on pavements, roadside verges, railway tracks and embankments, factory sites, power stations and oil refineries can pose serious problems to local authorities, government departments, utilities and industry. The type of weed control needed also differs eg, Total vegetation control is essential around petroleum container tanks whereas selective removal of woody species on railway embankments is required.

Weeds growing on Local Authority and industrial sites cause many problems. Tall weeds can block site lines on roads making driving dangerous; they obscure warning signs and hide the kerb from view; their roots block drains which can result in local flooding of roads which mean cars are at risk through aquaplaning during heavy rainfall; weeds growing on slab paved footpaths or tarmacadam footpaths cause serious disruption of the surface creating a danger to pedestrians.

On railways, weeds impede drainage causing localised flooding, damage to mechanical and electrical equipment, obscure signs and obstacles creating danger for staff operating on the track.

Apart from removing such hazards to safety and efficacy weeds are aesthically unacceptable. Untreated areas become untidy creating traps for detritus and neighbourhood areas become run-down and uncared for with the weeds creating an even more dilapidated appearance.

Table 1. The Industrial and Amenity Weed Control Market

Market Section	Areas of Herbicide Use
Authorities	Footpaths, Verges, Cemeteries, Parks, Motorways Kerbs and Channels.
Utilities	Generating stations, Sub-stations, Holder sites Wayleaves.
Industry	Rail track, Rail Embankments, fence lines, Storage areas, pipelines.
Amenity	Sports Grounds, Gardens.
Forestry	Pre and Post planting, Heather and Bracken central forest roads.

Given the diversity of situations and type of weed control required application technology of herbicides is playing an increasingly important role in achieving not only effective control of weed but also enhanced operator safety and minimal adverse effects in the environment.

This paper provides a historical perspective of the application of herbicides and compares four different kinds of application equipment; the spray train, weed control attachment for road sweepers, pedestrian operated sprayers and rotary atomisers. The comparison illustrates the need for specialised equipment for the various situations of use of herbicides for industrial weed control.

Early Methods of Application

The first herbicides for industrial weed control were based on Sodium Chlorate. The rates of active ingredient applied were much higher than more recently introduced herbicides (Table 2).

Specialised equipment was developed to handle the high water volumes required. Typically water volumes ranged between 1,800 litres to 3,400 litres/ha. Application equipment consisted of powered sprayers comprising large spray tank attached to a pump driven by a petrol engine from which either hand lances or spray booms were fed by delivery hoses. These units needing to be mounted on lorries, tractor drawn trailers or similar vehicles and requiring up to 3 persons to operate efficiently.

TABLE 2 Comparison of application rates of commonly used herbicides for industrial weed control.

Herbicide	Application rate (range)
Sodium Chlorate	220 - 450 kg ai/ha
Imazapyr	0.25 - 1.0 kg ae/ha
Atrazine	2.0 - 9.5 kg ai/ha
Diuron	2.7 - 17.5 kg ai/ha
Triclopyr	0.96 - 3.84 kg ai/ha
Glyphosate	1.08 - 2.16 kg ae/ha

On many sites where weed control is necessary access to water often proves difficult and for these areas granular formulations were developed and applied by various types of spreading equipment. These range from chest mounted applicators comprising a hopper feeding onto a spinning impeller which spread granules over swaths up to 8 foot, to larger units which needed to be mounted onto pedestrian or motor driven trolleys where larger hoppers fed the granules into an air stream created by the motor driven blower thus enabling swaths of up to 30 foot to be treated at any one time.

Smaller sites have historically been treated by using knapsack sprayers with the early versions of this equipment being made up of a pressurised metal canister containing 15-20 litres of spray solution. On the early knapsack sprayers it was difficult to achieve a constant pressure and subsequently accurate application.

Reasons for Change

With the advent of new herbicides namely the triazines and substituted ureas and continually improving product formulation allied to the development of controlled droplet application means that the need for equipment using high water volumes declined markedly.

DEVELOPMENTS (Conventional application methods)

Spray Train for Railways

With the need to spray thousands of miles of rail track and embankments each season, and the need to fit in with the complexity of railway timetables, special trains have been developed in a number of countries.

In the U.K the first train was introduced in the early 1950's. These trains applied a liquid formulation of Sodium Chlorate which was carried in tank waggons and pumped through to the machinery coach. Application was by means of spray nozzles fitted to booms which extended beyond the width of the train and were swung inwards to avoid track side obstacles, platforms and bridges. Spraying was undertaken at a maximum 20mph and up to four trains were required to cover the rail network.

Today there are two trains operating throughout the U.K, of which one of them is operated by Nomix-Chipman Ltd. The train operates from mid April to mid August. On railway tracks, typical weed problems include Poa annua, Carex spp, Convolvulus arvensis, Epilobium ciliatum, Equisetum arvense, Solidago canadensis, Conyza canadensis, Geranium molle, Heracleum spondylium and Potentilla reptans. In Scotland, Pteridium aquilinum is a major problem.

On embankments, major woody species include Rubus fructicosus, Quercus rubra and Fraxinus excelsior. Polygonum japonica is becoming widely spread.

The Nomix-Chipman spray unit is a 468 tonne train 130 metres in length. It comprises of a purpose built spray carriage, mess carriage with cooking and sleeping facilities, two box wagons for chemical storage, and four 31,500 litre water bowsers. The water holding capacity of the train is sufficient for two days of spraying. The requirement to transport large water volumes is necessary as there are now only a limited number of water points along the railway track which were in abundance during the steam age.

A 240 volt generator operates the chemical mixing, pumping and application motors. Three 675 litre tanks in the spray carriage allow chemical to be mixed and applied to a chemical injection circuit. Each nozzle is supplied with one chemical pump/motor. The use of spray booms is confined to application on the track. Application to the 'Cess' (Cinder strip at base of ballast), the 'Wideway' (the area between adjacent tracks) and embankments are by sixteen specially designed large bore nozzles, the angle of which can be manually adjusted on the move to suit the varying width and direction of the cess, wideway and embankments.

The need to fit in with the complex rail timetable requires the spraytrain to travel at speeds up to 80km/hr. With a conventional hydraulic nozzle, drift would be inevitable, but with the use of the large bore nozzle, the hazard of drift is practically eliminated.

The system employed on the spray train uses a low operating pressure (170 k pa) and a relatively high spray volume (225 Litres/ha) to produce large droplets (in the region of 600 microns).

The spray circuit is charged with water by a 315 litres per minute pump with manually operated by pass valves supplying the nozzles. The water does not return to the tank. This system maintains a constant rate of water to the nozzles regardless of the forward speed of the train and enable several different mixtures at varying application rates to be applied at any one time.

Individually pumps and motors inject chemical into the circuit immediately before each nozzle. The rate of which is monitored by flow meters and is proportional to the forward speed. The flow rates, forward speed and distance travelled are monitored and stored via an on board computer. This system ensures the accuracy of herbicide application which is within 2 per cent of the manufacturers recommended rates. The computer is programmed with rail plans of the rail network and can give a itemised list of the quantity of chemical applied and the distance of the track covered for each section of the British Rail Network.

ROAD SWEEPER SPRAY ATTACHMENT

A development from the spray train has been the Hereford Road Sweeper attachment. This enables the sweeping of the Kerb and channel of roads to be achieved at the same time as an application of herbicide.

The equipment can be fitted to any mechanical sweeper. The unit is operated by the existing sweeper water pump. Water passes through the ON/OFF Control valve and the pressure regulator set at 170 kpa into a fluid operating dosing pump. Chemical concentrate is automatically drawn from the container and metered into the flow of water before being applied through the nozzle. The nozzle can be mounted either ahead or behind the rear wheels and provides a swath of 9 or 12 inches.

SELF PROPELLED SPRAYERS

The use of the high volume sprayers with large spray tanks (referred to previously) necessitated the use of motorised vehicles with driver, adding considerable expenses to the spraying operations. With the advent of newer chemicals requiring lower rates of active ingredient per hectare lower water volumes were required thus enabling smaller spray tanks to be used.

A development in high volume sprayers taking advantages of these lower volumes is the self propelled sprayer. This comprises a 100 litre spray tank attached to a motorised pump all contained within a steel frame.

The motor also drives the ground wheels via a gearbox enabling the unit to be pedestrian operated and yet move at up to 3 mph. This unit is ideal for the application of herbicides in urban areas such as pedestrian precincts and parks where vehicle access is difficult. It can be used for both total and selective herbicide applications having hand lance and hose as well as boom attachments.

KNAPSACK SPRAYERS

Knapsack sprayers overcome many of the problems associated with the self propelled pedestrian machines, which are often awkward to use in areas where access is difficult and obstacles prevent continuous spraying. Being relatively portable makes them an ideal choice for the weed control operator. The BCPC publication 'Hand-operated sprayers handbook' (Anonymous, 1989) provides a valuable guide in the safe and effective use of these sprayers.

This type of sprayer has developed from the heavy metal containers which needed to be continuously pressurised to the more sophisticated plastic units in use today which although still requiring pressurisation are considerably lighter and easier to use.

DEVELOPMENTS (Controlled droplet application with the use of rotary atomizer sprayers).

Knapsack Sprayers, do however have some disadvantages. They require frequent re-filling which is non-productive; operator fatigue is a problem as full containers weigh approximately 20kg. The use of rotary atomizers overcome both of these disadvantages. Their use in agriculture, particularly in the third world, has been established for some time. The widespread use in industrial weed control however, stems from development during the early 1980's and since that time there has been a rapid increase in their use.

Initially the Micron Herbi (manufactured by Micron Ltd) was used. The principle of this type of equipment enables a 2.5 litre bottle of spray solution to cover a substantially larger area compared with a knapsack sprayer (Table 3). Typically 10 to 20 litres/ha is the application rate for a rotary atomiser sprayer compared with 200 to 400 litres for a knapsack sprayer.

TABLE 3 Comparison of area covered by various hand-held applicators.

Sprayer	Container Capacity (litres)	Spray Coverage (m^2)
Micron Herbi	2.5	1250
Knapsack Sprayer (Spraying 200 litres/ha)	20	1000
Nomix-Chipman Accurate spraying (10-20 Litres/ha)	5	5000 - 2500
Nomix SuperPro (Spraying 10-20 Litres/ha)	5	5000 - 2500
Nomix Compact (Spraying 10-20 Litres/ha)	0.75	750 - 375

With the introduction of rotary atomizer applicators, herbicide were specifically formulated and packaged ready for use in undiluted forms.

The undiluted formulation which connects directly onto the spray equipment forms a closed transfer system. This provides cost and safety advantages. The elimination of mixing and measuring gives economies of labour. There is also a significant reduction in the potential risk in operator contamination.

Unlike the early rotary atomizers, with the Accurate (Nomix-Chipman), the swath can be varied from 25cm to 100cm. This is achieved by a shutter which shrouds part of the spray swath with excess chemical being collected in a sump and recirculated to the nozzle.

A further development came with the Nomix system (Nomix-Chipman Ltd). This system matches specifically formulated herbicide packaged ready for use undiluted for direct connection with the applicator.

A 5 litre collapsible bag contained in a box is used to deliver ready to use herbicides through a light weight rotary atomizer sprayer. Control of swath width is achieved by an electronic control and adjustable pacing device, coupled with an in-line Calibration Cup which enables the operator to achieve accurate application rates.

By matching the formulation to the spinning disc, it is now possible to considerably cut the level of both operator contamination and drift in comparison to a knapsack sprayer.

Studies carried out at Cranfield Institute of Technology showed that the Nomix rotary atomiser significantly reduced drift to the order of 3% of the levels recorded with a knapsack sprayer (C.R Merritt, 1989).

Abbot et al, 1987 showed that hazard of operator contamination was greater for hand-held spraying equipment compared with tractor powered sprayers. The study showed that mixing and measuring can lead to high levels of contamination. Merritt (1989) showed that such contamination was significantly reduced with the Nomix rotary atomiser.

ROTARY ATOMISER ROAD SWEEPER SPRAYING ATTACHMENTS

The principle of the Nomix System has been adapted to also produce a Rotary Atomiser unit for attachment to Road Sweeping Vehicles. This unit also applies specifically formulated herbicides to kerbs and channels during the sweeping operations again without the need for any water. The unit is electrically operated from the driver cab with application rates able to be varied whilst the vehicle is in motion.

Conclusions

The diversity of industrial Weed Control sites has lead to specific application equipments being developed to combine operating efficacy with minimal risks to the spray operator and the environment. Recent developments, particularly in respect, of rotary atomisers have been shown to reduce the hazards of drift. Accidental operator contamination during measuring and mixing the herbicide concentrate is also minimised. The use of systems which match application equipment to specifically formulate herbicides reduce risk even further.

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A NOVEL TECHNIQUE FOR THE CONTROL OF DEEP ROOTED WOODY AND HERBACEOUS PERENNIAL WEEDS IN NON-CROP AREAS USING TEBUTHIURON PELLETS

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ABSTRACT

The control of deep rooted woody and herbaceous perennial weeds in non-crop areas can be difficult if desirable undergrowth is to be retained, where site access is limited or water supply is unavailable. On exposed sites spray drift presents a continual hazard and there may be few suitable spray occasions. The use of tebuthiuron pellets provides a practical method of control in these situations. Application of the pellets can be directed to control the target weed species with minimal damage to grasses and desirable herbaceous plants. This is important where vegetation cover is needed for amenity purposes or to prevent erosion. In eight demonstration trials, undertaken in 1990 to 1991 in the U.K. in co-operation with British Rail, British Gas and the National Grid, a high level of weed control was recorded on a range of species including birch, bramble and Japanese knotweed.

INTRODUCTION

The concept of using large (0.45 cm long) tebuthiuron pellets for the control of unwanted woody species was first developed in the southern states of the U.S.A. where invasive species of brush, scrub and trees had colonised large areas of grazing land. There was a need for a selective system of control that would remove unwanted species without causing an adverse effect on underlying herbaceous plants. In addition residual activity was required to prevent re-establishment of the undesirable vegetation. Following its successful use in this situation the pellets were subsequently introduced into non-crop areas.

In the U.K. tebuthiuron pellets were first marketed in 1991 as the product Perflan 20P for non-crop areas. The ready-to-use pelleted formulation contains 200 g/kg of tebuthiuron and can be applied both pre and post-emergence. Its areas of use include alongside railway tracks, roads and motorway reservations. It may also be used as an overall treatment under transmission cables and pylons. The pellets can be applied by hand, blower, gravity feed applicator or spinner at any time of year. Once applied the pellets disintegrate in rainfall or heavy dew releasing tebuthiuron into the soil where it controls deep rooted weed species causing minimal injury to desirable shallow rooted grasses and herbaceous plants.

In 1990 to 1991 eight trials were undertaken on non-crop sites in U.K. to demonstrate the pelleted formulation of tebuthiuron and its control of important non-crop weed species eg, birch (*Betula* spp.), bramble (*Rubus* spp.), gorse (*Ulex* spp.), Japanese knotweed (*Reynoutria japonica*) and rosebay willowherb (*Chamaenerion angustifolium*).

MATERIALS AND METHODS

Eight trials were undertaken in the U.K. on non-crop sites. British Rail, British Gas and the National Grid provided the sites which were selected as being representative of the typical weed problems encountered. The tebuthiuron pellets were mainly applied in the late winter or early spring. These were either broadcast by hand at 3.0 and 4.0 kg AI/ha as a band or overall treatment or placed at the base of individual trees at 1.4 g AI/5-10 cm stem diameter (Table 1).

The treatments were applied between 15 February and 4 June 1990 and weed control assessment made between 15 and 17 May 1991. Weed control was recorded as percentage control with respect to the untreated plots. Percentage weed cover was recorded in the untreated plots at the time of the assessment. The number of individual weed species treated were also recorded in some trials. The weed species present and their growth stages at application are given in Table 2.

TABLE 1. Details of tebuthiuron pellet trials sites.

Trial No.	Location	Plot size (m)	No. of replicates
1	British Rail, Flowery Field Station, Manchester, Lancashire	30 x 1	1
2	British Rail, Bolton, Lancashire	20 x 1	1
3	British Rail, East Didsbury Station, Didsbury, Lancashire	20 x 1	1
4	British Rail, Newthorpe, Yorkshire	12.5 x 3	3
5	British Rail, Dorridge Station, Dorridge, Warwickshire	Individual Trees	1-6
6	British Gas, Hilsea, Hampshire	25 x 2	2
7	British Rail, Tinwell, Cambridgeshire	25 x 5	1
8	National Grid, Fenindre Sub-Station, Felindre, South Glamorgan	30 x 30	1

TABLE 2. Weed species and growth stage at application.

Weed species	Trial No.	Growth stage
Alder (*Alnus* spp.)	8	2-3 m high
Birch (*Betula* spp.)	5,8	2-4 m high
Bramble (*Rubus* spp.)	1,6,7,8	Mature plant
Broom (*Sarothamnus scoparius*)	5	1-2 m high
Buddleia (*Buddleia* spp.)	8	2-3 m high
Gorse (*Ulex* spp.)	8	1-2 m high
Ivy (*Hedera* spp.)	4,8	Mature plant
Japanese knotweed (*Reynoutria japonica*)	2	1.5-2 m high
Mountain Ash (*Sorbus* spp.)	8	2.5-3 m high
Rosebay willowherb (*Chamaenerion angustifolium*)	4,8	1 m high
Sycamore (*Acer pseudoplaatnus*)	3	3-5 m high
Willow (*Salix* spp.)	5	5-6 m high

RESULTS

Broad-leaved trees

Complete control of birch, mountain ash and sycamore was achieved following application of tebuthiuron pellets applied as a band treatment at 4.0 kg AI/ha and as a spot treatment at 1.4 g AI/5 - 10 cm stem diameter. A high level of control of alder was also achieved. Control of willow appeared slower and complete control was not recorded at the time of the assessment. However, limited regrowth on this species had occurred indicating recovery would not be expected. The 3.0 kg AI/ha rate applied to sycamore, did not achieve complete control at the time of the assessment (Table 3).

Herbaceous perennials

Complete control of rosebay willowherb was achieved following application of tebuthiuron at 4.0 kg AI/ha. A high level of control was also recorded for Japanese knotweed. At the time of the assessment severe damage was recorded on this species. However further trials are necessary to further validate the level of control (Table 4).

Scrub species

Control of bramble was variable following application of tebuthiuron pellets at 4.0 kg AI/ha. This variability may be due to the re-invasion of bramble from outside the treated zone. This would suggest that for improved consistency of control a wider band or an overall application would be needed. A high level of control of broom, *Buddleia*, gorse and ivy was recorded (Table 5).

TABLE 3. Control of broad-leaved tree species following application of tebuthiuron pellets

Treatment	Percentage weed control						
	Alder	Birch		Mountain Ash	Sycamore	Willow	
Tebuthiuron							
3.0 kg AI/ha	-	-		-	75	-	
4.0 kg AI/ha	95	100	100	100	-	100	75
1.4 g AI/ 5-10 cm stem diam.	95	100	100	100	-	100	75
No. of trees assessed	6		6	10	100*	5	
(spot treatment)	(3)	(3)	(3)	(3)		(3)	(3)
Trial No.	8	5	8	8	3	5	5
Application Date	4.6.90	7.3.90	4.6.90	4.6.90	15.2.90	7.3.90	7.3.90
Assessment Date	15.5.91	16.5.91	15.5.91	16.5.91	17.5.91	16.5.91	16.5.91

* Percentage weed cover in untreated plots at assessment

TABLE 4. Control of herbaceous perennials following application of tebuthiuron pellets

Treatment	Percentage weed control		
	Japanese Knotweed		Rosebay Willowherb
Tebuthiuron			
3.0 kg AI/ha	75	75	-
4.0 kg AI/ha	-	-	100
Percentage weed cover in untreated plots at assessment	100	20	15
Trial No.	2	4	8
Application Date	15.2.90	23.2.90	4.6.90
Assessment Date	17.5.91	17.5.91	16.5.91

TABLE 5. Control of scrub species following application of tebuthiuron pellets.

Treatment	Percentage weed control								
	Bramble				Broom	Buddleia	Gorse		Ivy
Tebuthiuron									
3.0 kg AI/ha	-	-	-	-	-	-	-	100	-
4.0 kg AI/ha	90	25	75	100	100	95	100	-	100
1.4 g AI/ 5-10 cm stem diam.	-	-	-	-	100	95	100	-	-
Percentage weed cover in untreated plots at assessment () individual trees [] spot treatment	25	100	20	20	(5) [3]	(3) [3]	(15) [3]	25	100
Trial No.	1	6	7	8	5	8	8	4	8
Application Date	15.2.90	12.3.90	15.3.90	4.6.90	7.3.90	4.6.90	4.6.90	23.2.90	4.6.90
Assessment Date	16.5.91	15.5.91	17.5.91	15.5.91	16.5.91	15.5.91	15.5.91	17.5.91	16.5.91

DISCUSSION

The pellets require rainfall after application to enable tebuthiuron to become available in the root zone of target weed species. In the spring and summer of 1990 conditions were exceptionally dry with rainfall significantly below the average in many regions. These conditions produced two unexpected results. The first was that the pellets produced more damage to the underlying vegetation than was expected. It is possible that tebuthiuron moved only a short distance into the soil where it became available to the shallower rooted vegetation. The second unexpected result was that bramble took longer to develop damage symptoms. This result could have been as a result of the dry conditions and also re-invasion from areas outside the treated area.

As a result of these observations it is considered that optimum results will be obtained if the treatment is made during the winter months when rainfall is more reliable. For the control of larger woody species of trees and scrub a suitable regime will be to cut, stump and clear during the spring and early summer; coppicing will then commence during the remainder of the growing season with application of tebuthiuron pellets taking place during the winter. Tebuthiuron will then be moved into the root zone by rainfall and become available for uptake by the roots of woody and deep rooted herbaceous perennial weeds when the spring growth commences. Control would be expected to be more rapid and achieve consistent kill. By applying during the winter period damage to underlying vegetation would also be minimised as this is their dormant period. Movement away from the root zone should then occur and damage to the shallower rooted vegetation when spring growth commences should be avoided. Tebuthiuron has residual action and will therefore prevent the re-colonisation of invasive weed species.

Treated sites should be monitored and a selective, maintenance treatment applied every three to four years. This management programme is aimed at achieving consistent control of dangerous, damaging and unsightly weeds whilst maintaining desirable plant growth. The approach should be of particular interest to public utilities, eg British Rail and power companies as a three metre control swath along one kilometre of truck or fencing requires only 6 kg of formulated product. In addition there is no requirement for water or measuring out liquid or powder concentration formulations which reduces the risk of accidental operator contamination.

WEED CONTROL ON RAILWAYS IN YUGOSLAVIA

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ABSTRACT

Triazine herbicides used for several years in the vegetation control on railway tracks in Yugoslavia resulted in the development of some resistant weed species: *Amaranthus retroflexus, Convolvulus arvensis, Cynodon dactylon, Conyza canadensis,* and *Sorghum halepense.*
During 1987 to 1989 the efficacy of bromacil, dicamba, glyphosate, glufosinate-ammonium, hexazinone, imazapyr, sulfosate and triclopyr herbicides was tested in controlling resistant weeds and woody plants on the railway tracks. Total weed control was provided by a combined application of imazapyr with glufosinate-ammonium, glyphosate or sulfosate by adding triclopyr against woody plants.

INTRODUCTION

In order to obtain normal railway traffic one of the regular measures in Yugoslavia is the weed control.

Along the railtracks various weed species grow and spread gradually if the are not controlled, so they can cause an increased weed stand. The biological flora spectrum of railways is mainly annual species and a considerable amount belongs to grass species (Kovačević, 1977). In recent years the dominant species have been: *Amaranthus retroflexus, Cynodon dactylon, Conyza canadensis,* and *Sorghum halepense.*

The herbicides in weed control have been in use before World War II and sodium chlorate was the first one applied almost all over the world. This non-selective compund controlled a wide range of weeds, but it was not suitable because of its leaching by high rainfall, its corrosiveness, hence it can damage the telecommunication systems.

In Yugoslavia the usage of herbicides for weed control in railways started in the early 1950´s. Later sodium chlorate was replaced by triazine herbicides in combination with herbicides 2,4 - D, 2,4,5-T or dalapon (Kišpatić, 1977; Seiwerth, 1977).

These herbicides and their combinations provided good results for the majority of weed control, however, they had no effect on *C. dactylon, A. retroflexus, Equisetum arvense* and *S. halepense.* Recently, these weeds have been controlled by the herbicides bromacil, diuron, glyphosate, hexazinone, karbutilate and picloram.

Our earlier works were dedicated to the weed control on railway tracks (Arsenović *et al*., 1988, Šovljanski and Arsenović, 1988) where we examined the effectiveness of the single herbicides. To find out the efficacy of the weed control on railways new candidate herbicides were examined during 1987 to 1989. The optimal time, the dosage of herbicides and their combinations were established.

MATERIALS AND METHODS

During the period from 1987 to 1989 seven herbicides (bromacil, dicamba, glyphosate, glufosinate-ammonium, hexazinone, imazapyr, sulfosate and triclopyr) were tested on railway tracks in Yugoslavia.

The experiments were carried out in the localities of Kikinda, Sombor and Novi Sad. Treatments were applied by pressurized knapsack sprayer fitted with red Tee Jet flat fan nozzles delivering 300 l/ha. Plot sizes of 10 x 50 m were used. Treatments were randomised and replicated four times. Four untreated plots were present.

The applications were made post emergence of weed (weeds were 15 to 40 cm high) on June 16, 1987 in Kikinda, on June 26, 1988 in Sombor and on June 28, 1989 in Novi Sad.

Herbicides were used in dosages according to the recommendations of the Yugoslav Federal Ministry for Agriculture (1990).

The total weed numbers were counted in random quadrats for 1 m^2 per plot 30 days after the application.
The coefficient of efficacy (CE) was calculated using the formula

$$CE = \frac{C - T}{C} \cdot 100\%$$

CE = The coefficient of efficacy
C = The average weed number in untreated plots
T = The average weed number in treated plots

RESULTS

During the trials in Kikinda in 1987 the following range of dominant weed species were present: *A. retroflexus*, *C. canadensis*, *C. dactylon*, *E. arvense*, *Papaver rhoeas* and *S. halepense*.

The effects of herbicides applied in 1987 are presented in Table 1.

TABLE 1. Mean weed counts following application of a range of herbicides in 1987 in Kikinda

Herbicides	Dosage (kg AI/ha)	$\bar{X}$	CE(%)
Imazapyr + triclopyr	1.0 + 2.15	1.0	98.0
Imazapyr + triclopyr	1.5 + 2.15	0.0	100.0
Imazapyr	2.0	0.5	99.0
Glufosinate-ammonium	1.5	1.5	97.1
Glyphosate	4.8	10.0	80.7
Bromacil + hexazinone	8.0 + 4.5	6.0	88.4
Control	+	(52.0)	-

Complete weed control in the trial in 1987 was achieved using combined imazapyr at the rate of 1.0 kg AI/ha and triclopyr at the rate of 2.15 kg AI/ha.
Glyphosate, used as a standard at the rate of 4.8 kg AI/ha had excellent efficacy on all weeds present.
Glufosinate-ammonium appeared to be efficient in the control of the resistant weeds mentioned above.
With the combined usage of bromacil and hexazinone at the rate of 12 and 8 kg AI/ha, respectively, as well as of bromacil used alone, at the rate of 12 kg AI/ha a smaller effect on weeds was achieved. The effect on the species *A. retroflexus* and *C. canadensis* was not satisfactory.

The dominant weed species in experimental plots in Sombor in 1988 were: *A. retroflexus, C. canadensis, Convolvulus arvensis, C. dactylon* and *S. halepense.*

The effect of herbicides applied in 1988 are presented in Table 2.

TABLE 2. Mean weed counts following application of a range of herbicides in 1988 in Sombor

Herbicides	Dosage (kg AI/ha)	$\bar{X}$	CE(%)
Imazapyr + triclopyr	1.0 + 2.15	0.5	98.2
Imazapyr + triclopyr	1.5 + 2.15	0.0	100.0
Imazapyr	2.0	0.0	100.0
Glufosinate-ammonium	1.0	4.0	94.3
Glufosinate-ammonium	1.5	3.2	95.7
Glyphosate	4.8	2.0	97.1
Bromacil	12.0	11.0	84.5
Bromacil + hexazinone	8.0 + 4.5	7.0	90.1
Control	-	(71.0)	-

Total weed control in 1988 was achieved using imazapyr alone or combined with triclopyr. On the variants where glufosinat-ammonium was applied the effect on weed was good, but some plants *C. dactylon* were omitted.
The effect of the combined application of bromacil and hexazinone and of bromacil alone was similar to that one acheived in 1987.

During the experiments in Novi Sad in 1989 the following range of dominant weed species were present: *A. retroflexus Artemisia vulgaris, Atriplex tataricum, C. arvensis, Polygonum aviculare, Salsola kali* and *S. halepense.*

The effects of herbicides applied in 1989 in Novi Sad are presented in Table 3.

The best results in the trial in Novi Sad in 1989 were achieved using imazapyr, glufosinate-ammonium and triclopyr,as well as using imazapyr alone at rate of 2.0 kg AI/ha.

High efficacy on weeds was achieved also on the variant where imazapyr and sulfosate were applied at the rates of 1.0+4.8 kg AI/ha, respectively.

TABLE 3. Mean weed counts following application of a range of herbicides in 1989 in Novi Sad

Herbicides	Dosage (kg AI/ha)	$\bar{X}$	CE(%)
Imazapyr + triclopyr	1.0 + 2.15	0.3	99.3
Imazapyr	2.0	0.0	100.0
Imazapyr + triclopyr + glufosinate-ammonium	1.0 + 2.15 + 1.0	0.0	100.0
Glufosinate-ammonium	2.0	1.0	97.0
Imazapyr + sulfosate	1.0 + 4.8	0.3	99.3
Glyphosate	4.8	1.0	97.8
Bromacil + hexazinone + dicamba	4.8 + 1.8 + 1.0	0.7	98.5
Control	-	(47.0)	-

The combined application of bromacil, hexazinone and dicamba at rates of 4.8 + 1.8 + 1.0 kg AI/ha respectively achieved a high level of weed control. The application of bromacil alone at the rate of 8.0 kg AI/ha provided a lower level of control.

During the investigation period 1987 to 1989 the following range of woody weeds were dominant: *Amorpha fruticosa, Prunus spinosa, Sambucus nigra* and *Rubus caesius.*

The herbicide triclopyr applied at rate of 2.15 kg AI/ha controlled all woody weeds in trials in Kikinda, Sombor and Novi Sad.

DISCUSSION

Complete weed control on experimental plots on railway tracks in Yugoslavia during 1987 to 1989 was provided by combined application of imazapyr with glufosinate-ammonium, glyphosate or sulfosate by adding triclopyr against woody weeds. The herbicide glyphosate, used as a standard, demonstrated a high effect on dominant weeds. Glufosinate-ammonium applied at 1.0 kg AI/ha and at 1.5 kg AI/ha gave a good control. Regrowth of some *C. dactylon* occured four weeks after treatments with glufosinate-ammonium and eith weeks after treatments with glyphosate.

On the experimental plots with bromacil, dicamba and hexazinone during the autumn regrowth of *P. convolvulus* and *P. aviculare* was evident. On the railway sections treated by bromacil alone complete control of *A. retroflexus* was not achieved.

The herbicide triclopyr aplied at the rate 2.15 kg AI/ha controlled all woody weeds *(A. fruticosa, P. spinosa, R. caesius* and *S. nigra)* during the three years of trials.

Good control of weed flora on railways tracks was achieved with the late post emergence application of the herbicide imazapyr with glufosinate-ammonium, gluphosate, sulfosate with addition of triclopyr for woody weeds. The application of these herbicides provided total weed control on railway tracks during the growing season.

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READY TO USE GLYPHOSATE FORMULATIONS FOR INDUSTRIAL AND AMENITY WEED CONTROL

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ABSTRACT

Glyphosate is widely used for weed control in industrial and amenity areas. A new ready to use formulation has been developed specifically for application through a rotary atomizer spraying system. Field trials have shown this product to have similar activity to conventional formulations of glyphosate. Further work has evaluated the effect on the activity of glyphosate of changing the swath width produced from the lance by changing the type of rotary atomizer and varying its rotational speed. The development of a new ready to use formulation containing glyphosate and diuron is described. This product combines foliar and residual activity, and allows choice of an application rate for particular vegetation management objectives.

INTRODUCTION

Glyphosate has become a basic tool for the management of vegetation in industrial and amenity areas. The main use has been for clearing well established weed growth, particularly on landscaping sites prior to planting and amongst ornamentals. The use of glyphosate for weed control on hard surfaces is increasing as a replacement for triazine based products.

Until recently, glyphosate products have been diluted in water for application using hydraulic or rotary atomizer sprayers. A ready to use formulation, MON 8723 (marketed as Stirrup® herbicide), 144 g a.e./l glyphosate, has now been designed specifically to have the characteristics for optimum application through the Nomix™ system. In this system, specally formulated herbicides are applied using a rotary atomizer spray lance (Ali & Garnett, 1991). By altering the speed of rotation of the rotary atomizers, the width of the spray band can be varied. In the remainder of the paper, this application system is referred to as the "spray lance".

Glyphosate is a foliar acting, translocated herbicide which is not active in the soil, so users have often tank mixed glyphosate with residual herbicides for application through conventional sprayers. These mixtures may show antagonism of the activity of glyphosate by the residual component (Turner, 1985), but in some situations for maintaining bareground, the practical advantages can outweigh the disadvantages, because subsequent germination is prevented.

Tank mixtures cannot be used with a ready to use spraying system. Not only does preparing a mixture negate the safety advantages of the system, but the resulting mixture is unlikely to have the correct characteristics for optimum use. Consequently, a range of ready mixed products is under development.

The use of glyphosate through the system, and the development of MON 18779, a mixture of glyphosate and diuron (100 g a.e./l + 200 g AI/l), are described in this paper.

MATERIALS AND METHODS

Trials were undertaken between 1989 and 1991 at locations across central and southern England, in a range of industrial/amenity situations varying from pavements to dense established vegetation. Each trial was of randomised, complete block design, with 2 x 10m plots, replicated 3-4 times depending on the type of site.

The products were applied undiluted, as ready to use formulations, using the "spray lance" at application rates from 7.5 to 25 litres per hectare. Two alternative rotary atomisers or "spinners" are available depending on the type of usage. The circular, toothed spinner was used to apply the materials to wide swaths, 0.6-1.0m, *e.g.* for the control of established vegetation or for overall treatments on pavements. The square spinner was used to apply the material to swaths up to 0.5m on fence lines and joints in paved areas. Width adjustments were made by altering the rotational speed of the spinner. The spray lance was calibrated for each treatment by adjusting a simple vernier to change the rate of flow of product on to the spinner.

In most trials, the standard treatments were products formulated for the spray lance: amitrole + atrazine + dicamba (98.8 + 197.5 + 20.0 g AI/l), amitrole + atrazine + diuron (62 + 139 + 177 g AI/l), and imazapyr + atrazine (12.5 + 300 g AI/l). Conventional treatments were applied by a Van der Weij plot sprayer, fitted with 8002 nozzles on a 2 or 3m boom, and set at around 2 bars pressure to apply a spray volume of 200 litres per hectare.

Assessments were made visually using percentage foliar kill up to 4 weeks after treatment. At later assessments, the percentage ground cover of weeds was estimated visually, and percentage weed control was calculated from these figures.

RESULTS

MON 8723 (glyphosate, 144 g a.e./l)

Trials results and wide commercial use of this product has shown excellent weed control, similar to that expected from conventional hydraulic applications of glyphosate.

The current recommendation is to apply 1440 g a.e./ha. glyphosate for general weed control. Four trials undertaken in 1990 showed a shallow dose response from 1080 to 2160 g a.e./ha. in terms of foliar kill (Table 1). Longer term control showed a greater dose response, due to the greater regrowth of perennials in the lower dose treatments. Results were poorer than average since glyphosate is known to be poorly translocated when the weeds are under stress (Chase & Appleby, 1979; Caseley & Coupland, 1985).

Label recommendations are to use the circular toothed spinner for the control of established vegetation, whereas the square spinner should be used where narrow swaths are appropriate on lighter vegetation in maintained areas such as amongst ornamentals and along kerbs or fencelines. The efficacy of MON 8723 at different swath widths was evaluated in dense vegetation. The relatively fine spray at the wide swaths gave similar weed control to conventionally applied glyphosate (Table 2). The level of effect fell off sharply when the width was reduced to 0.3m, since the larger droplets of the spray gave visibly poorer coverage and penetration of the dense vegetation. User trials have fully evaluated the use of narrow swaths under normal usage, with excellent results on light vegetation.

MON 18779 (glyphosate + diuron, 100 g a.e./l+200 g AI/l)

Three alternative formulations of glyphosate + diuron (MON 18767, MON 18768, MON 18769) were screened in dense, established vegetation. The objective was primarily to evaluate the efficacy of the glyphosate component. MON 18768 was consistently superior to MON 18767 applied at an equal rate of glyphosate, but there was little difference between MON 18768 and MON 18769 (Table 3). Unfortunately, the drought conditions after spraying reduced the overall effectiveness of these treatments, and may have increased the antagonistic effect of the diuron on glyphosate activity. Based on these results and other factors, MON 18768 was chosen for further development and minor formulations changes resulted in the final formulation, MON 18779.

From the results of these trials and four trials undertaken in autumn 1989, proposals were developed for a range of application rates in various situations. These were tested in trials in 1990 and 1991.

In 1990, in established vegetation, a rate of 1500 + 3000 g AI/ha., glyphosate + diuron was required for acceptable control of most weeds over a period of 12-16 weeks, but 2500 + 5000 g AI/ha. was needed to control established perennial broad-leaved weeds (Table 4). This rate was also necessary to give a high level of control over 25 weeks. Long term weed control was superior to the standard which had allowed considerable regrowth of perennial weeds.

Further trials were established in 1991 on a range of typical usage sites, using dose ranges appropriate to the type of site. Short term results, up to four weeks after treatment show a slight dose response for MON 18779, which was faster acting than the standards (Table 5). Imazapyr + atrazine was extremely slow to produce symptoms on the weeds. Only one trial has so far been assessed at three months after treatment. At this site the slightly poorer effect from MON 18770 compared to the standards is due to the germination of two weed species against which diuron is known to be only moderately susceptible.

TABLE 1. Glyphosate dose response using 0.9m swath : % weed control (mean of 4 sites).

Application Rate product l/ha	glyphosate g AI/ha	Grasses Weeks after treatment 1	2	4	12	Broad-leaves 1	2	4	12*
7.5	1080	75	84	79	52	61	82	79	0
10	1440	76	89	79	64	65	83	77	0
15	2160	83	95	93	79	67	88	80	0

* many broad-leaved weeds were "released" by the removal of the grasses.

TABLE 2. Glyphosate : weed control using different swath widths (mean of 4 sites)

Swath width (m)	Walking speed (m/s)	Grasses Weeks after treatment 2	4	10-20	Broad-leaves 2	4	10-20
		% foliar kill		% control	% foliar kill		% control*
MON 8723 (1440 g a.e./ha. glyphosate)							
0.15	0.9	65	64	54	53	56	0
	1.3	66	64	75	52	55	0
0.30	0.9	64	61	61	55	53	0
	1.3	65	68	53	50	52	0
0.60	0.9	75	74	61	58	60	0
	1.3	79	78	84	59	64	0
0.90	0.9	80	82	82	64	66	0
	1.3	80	84	88	63	63	0
glyphosate° (1440 g a.e./ha.)	-	79	85	78	67	73	0

* many broad-leaved weeds were "released" by the removal of the grasses.
° formulated as Roundup® Pro.

TABLE 3. Glyphosate + diuron formulation screen : % weed control (mean of 6 sites)

		Grasses				Broad-leaves			
	glyphosate + diuron	perennial		annual		perennial		annual	
		Weeks after treatment							
Formulation	g AI/ha.	4	12	4	12	4	12	4	12
MON 18767	1500 + 3000	70	53	100	90	54	33	51	20
MON 18768	1500 + 3000	79	68	100	94	61	43	55	36
	2000 + 4000	86	82	100	95	65	57	91	34
MON 18769	2000 + 3200	89	80	100	93	68	57	56	31

TABLE 4 : Glyphosate + diuron dose response : % weed control (mean 6 sites)

		Grasses				Broad-leaves				All
	glyphosate	perennial		annual		perennial		annual		Weeds
	+ diuron	Weeks after treatment								
Treatment*	g AI/ha	4	12	4	12	4	12	4	12	25
MON 18779	750+1500	69	78	100	97	52	53	87	77	57
	1000+2000	91	81	100	100	39	55	89	87	54
	1500+3000	98	91	100	100	81	72	98	96	66
	2000+4000	96	91	100	100	61	61	100	100	71
	2500+5000	96	97	100	100	84	85	99	99	88
MON 8723 (glyphosate)	1440	86	88	100	50	45	55	98	50	58
amitrole + atrazine + dicamba[(1)]		100	90	100	100	71	66	98	100	38
amitrole + atrazine + diuron[(2)]		-	-	-	-	-	-	-	-	-
imazapyr + atrazine[(3)]		83	100	100	100	-	-	56	93	-

* All ready to use formulations

(1) Sarapron 1976 + 3950 + 400 g AI/ha
(2) Rassapron 1220 + 2780 + 3540 g AI/ha
(3) Moderator 250 + 6000 g AI/ha

TABLE 5. Glyphosate + diuron performance in different situations: % weed control.

		Type of Site								
		footpaths etc. (3 sites)			medium vegetation 2 (sites)			heavy vegetation (2 sites)		
Treatment*	g AI/ha.	2	4	12	2	4	12	2	4	12°
MON 18779	750+1500	81	57	-	-	-	-	-	-	-
(glyphosate	1000+2000	72	53	-	64	67	-	-	-	-
+ diuron)	1500+3000	75	80	-	73	77	-	50	83	65
	2000+4000	97	77	-	82	87	-	60	95	70
	2500+5000	-	-	-	-	-	-	62	96	82
MON 8723 (glyphosate)	1440	32	60	-	76	88	-	67	77	40
amitrole + atrazine +	915+2085 +2655	70	47	-	51	51	-	-	-	-
diuron	1220+2780 +3540	-	-	-	-	-	-	30	90	90
amitrole + atrazine +	1482+2962 +300	73	53	-	59	59	-	-	-	-
dicamba	1976+3950 +400	-	-	-	-	-	-	50	78	85
imazapyr +	187.5+4500	53	53	-	39	25	-	-	-	-
atrazine	250+6000	-	-	-	-	-	-	10	51	97

* ready to use formulations.
° one site only

DISCUSSION

Glyphosate has been recommended for use through rotary atomisers for many years. Results in most situations are similar to those from conventional applications. Improved activity has been noted at low spray volumes (10-20 litres per hectare) in laboratory experiments (Turner & Loader, 1978) which may be related to the increased concentration of product in the spray solution (Merritt, 1980). In contrast, application through rotary atomisers is sometimes less effective in very dense vegetation where some plants may be sheltered from the spray and are "released" when the other plants have been controlled.

Against this background, it is unsurprising that the formulations of glyphosate and glyphosate + diuron performed well in the trials reported in this paper. The results were comparable with those expected from conventional hydraulic applications, but the great benefit of these products is in their formulation. The spray lance and the ready to use formulation combine to give an enclosed system, which obviates the need for pouring, measuring and mixing concentrate herbicide, a major source of operator contamination. The risk of operator contamination during spraying and off-site movement of the spray are also minimised because of the controllable swath and droplet size (Merritt, 1989).

The development of ready to use formulations of glyphosate provides the opportunity for safer use of a product with benign toxicological and environmental characteristics.

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THE POSSIBILITIES FOR CLASSICAL BIOLOGICAL CONTROL OF WEEDS OF INDUSTRIAL AND AMENITY LAND IN THE U.K. USING INTRODUCED INSECT HERBIVORES OR PLANT PATHOGENS

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ABSTRACT

Classical biological control of weeds uses introduced specialist herbivores, such as insects or plant pathogens, to reduce the vigour of an undesirable plant species. It is a well established and successful technique in many areas of the world, but to date there have been no serious attempts to control biologically any invasive weeds in the U.K. We briefly review the history, rationale and economics of classical weed biological control, emphasizing the advantages and disadvantages of the technique. We stress that biocontrol should be considered for appropriate target weeds as part of an integrated strategy for weed control rather than as a last resort when other methods are failing. We outline the typical procedure used in a classical biocontrol programme using examples from the U.K. bracken biological control programme. Invasive weeds such as bracken (*Pteridium aquilinum*), Japanese knotweeds (mainly *Reynoutria japonica*), giant hogweed (*Heracleum mantegazzianum*), Himalayan balsam (*Impatiens glandulifera*) and *Rhododendron ponticum* are particular problems in amenity or conservation land in the U.K. where herbicide use or mechanical control is physically difficult, prohibitively expensive or environmentally undesirable. Similar problems are encountered in disused industrial sites, railway and roadside verges, water margins and other land with low economic returns. Finally, we review the current information on the potential for classical biological control of exotic weeds in the U.K. concentrating on Japanese knotweeds, giant hogweed and Himalayan balsam.

INTRODUCTION

Classical weed biocontrol aims to introduce specialized herbivores to reduce and stabilize target plant density at sub-economic levels. Its ecological basis is that the abundance of many plants in the natural environment is controlled by natural enemies, and that most insect herbivores and many plant pathogens are extremely host specific (Strong *et al.*, 1984). The first major success in weed biocontrol was the introduction of the moth *Cactoblastis cactorum* into Australia, which resulted in a massive reduction in infestation of prickly pear cacti, (*Opuntia* spp.) over 24 million ha during the 1920's.

Most biological control programmes to date have involved the introduction of highly specific insect natural enemies of the weed. Recently, host-specific pathogens have been used to control weeds successfully (e.g. releases of the rust *Puccinia chondrillina* against *Chondrilla juncea* (Cullen and Hasan, 1988). Most programmes involve 'classical biocontrol', where initial introductions and establishment of agents lead to long-term weed suppression. However, it is also possible to augment the action of a natural enemy with repeated releases, particularly where it does not disperse effectively. With weed pathogens, for instance, this can involve the mass production and application of fungi as 'biological herbicides'. Fungal bioherbicides have been developed and marketed in the USA using *Phytophthora palmivora* and *Colletotrichum gloeosporiodes* f.sp. *aeschynomene* (Templeton & Greaves, 1984). These large-scale programmes involved relatively high costs of development and registration (US $1.5-2m)(Charudattan, 1988). However, the potential profit generated by the need for recurrent application enables private industry to consider investment.

As with any weed control tactic, classical biological control has its advantages and disadvantages. On the negative side, it is relatively slow acting and normally involves a reduction in spread or vigour of weeds rather than eradication. Eradication may occur on a local scale, but it is difficult to predict in advance. Hence, it tends to be inappropriate for annual crops or other weed problems where immediate, total control is essential. The high degree of specificity that makes the releases of agents safe to non-target plants means that the control is specific to one or a few weed species. Hence it is unsuitable for species rich complexes of weeds where rapid total control is needed. On the positive side, once classical biological control agents are successfully established, the control is permanent, requiring little or no further expenditure and can lead to benefit to cost ratios in excess of 100:1 (Cullen and Hasan, 1988). It is usually totally self perpetuating, requiring no repeated applications - in contrast to mechanical or herbicidal control. The dispersal abilities of agents are usually adequate to locate most patches of the target weed, and if necessary this process can be augmented, consequently the control can reach areas and types of terrain that are difficult to control using other methods. Perhaps most importantly biological control is environmentally very safe with no human or animal health risks, no harmful residues and no direct harmful effects on the local flora. To summarize, successful biological control of weeds is permanent, extremely cost effective and environmentally acceptable.

Targets for classical weed biocontrol typically have been perennial plants infesting large areas of land or water of low economic value (Crawley, 1989). However, the scope of classical biological control may be increased if it is considered as part of an integrated strategy for weed control instead of in isolation. For example, herbivores or pathogens that reduce the vigour of weeds, but fail to control them completely over all or part of their range, may make the weeds more susceptible to mechanical or herbicidal control. Alternatively, fungal efficacy may be enhanced by the addition of a sub-lethal dose of a chemical herbicide to weaken the weeds, enabling the pathogen to invade more easily.

To date, no classical weed biocontrol programmes have been completed in the U.K. but the Agriculture and Food Research Council have funded a 5 year research programme on the potential biocontrol of bracken (*Pteridium aquilinum*) (Fowler *et al.*, 1989).

In this paper, we have concentrated on the classical approach to biocontrol because it is appropriate to many of the invasive plant species causing problems in industrial and amenity land. In the following section we outline the procedures followed in a classical weed biocontrol programme using examples from the U.K. bracken biocontrol programme. Finally, we report on the current status and prospects for weed biocontrol programmes of invasive plants in the U.K. concentrating on the three species, Japanese knotweed (*Reynoutria japonica*), Himalayan balsam (*Impatiens glandulifera*), and giant hogweed (*Heracleum mantegazzianum*), for which preliminary investigations have been conducted.

STAGES IN A BIOCONTROL PROGRAMME

Typically the research phase of a biological control programme can be divided into: a) Background work to establish whether the weed is an appropriate target for biocontrol. b) Field surveys of the natural enemies attacking the weed in its area of origin. c) Host specificity testing. Assuming that appropriate potential agents are found, and that permission to release is forthcoming, then the programme can proceed to the practical aspects of release and monitoring.

Background work

Initial work should ensure that sufficient is known about the taxonomy and biology of the weed, and that the plant represents a suitable target for classical biocontrol from economic and environmental/ecological viewpoints.

Weed taxonomy and biology

It is essential to establish the exact taxonomic status of the target weed and, for an introduced weed, to determine its probable area of origin. The natural enemies attacking the target weed in the U.K. should be studied to ensure that potential agents have not been inadvertently introduced already, and to allow the selection of agents that are ecologically distinct from existing native herbivores.

Benefits and costs of biocontrol

Knowledge of the economic impact of the weed (negative and positive) in the U.K. is required to justify the initiation of a biocontrol programme on a purely cost/benefit basis. Often, quantifying the diverse losses from a wide variety of sources can be difficult. The first approach is to discover the direct costs of current control measures. For example, giant hogweed control by Scottish district councils cost at least £23000 in 1989 (Sampson, 1990). These are only the direct costs of current control. For the bracken programme the economic losses to upland agriculture in England and Wales have been estimated as £3-9 m per year (Lawton & Varvarigos 1989). Even this figure fails to consider much of the amenity and environmental impact of bracken and no attempt has been made to quantify any influence that bracken may have on human health.

The projected cost of a biocontrol programme then needs to be estimated. The bracken programme to date has cost (at 1991 rates) approximately £30000 for field surveys, £150000 for host range screening and an estimated £70000 for background ecological studies at British universities. To this total of £0.25 million must be added a further £0.35m estimated to be the amount required to complete the programme. Thus the total cost of the biocontrol programme for bracken (£0.6m) will represent only 6-20% of the annual losses caused by bracken to farmers in England and Wales alone.

Environmental/ecological issues

An attempt should be made to assess the impact of the weed on natural or semi-natural environments, particularly land valued for conservation or recreation. Conflicts of interest may be revealed by any of these studies and need to be resolved. Examples include possible risk to closely related plants of value, positive economic uses for the target weed and the environmental consequences of the reduction of weed infestation.

Field surveys

Once a suitable area for obtaining potential biocontrol agents has been identified (normally the area of origin for an introduced weed), then faunal and pathogen surveys in these areas can commence, following recommended guidelines (Schroeder & Goeden, 1986). These field surveys can be facilitated by judicious use of herbarium records to assess those areas in the native range where the weed is common, and where a wide range of natural enemies have been recorded. Ecological studies on potential agents and the weed in its area of origin increase the likelihood of finding successful agents, as well as providing early information on their field host specificity. Interest would centre on potential agents that have an impact on the population dynamics of the target weed (attacking critical stages in the life history of the plant and/or causing large scale damage to the plant). The chances of successful control may also be improved by selecting agents that are ecologically and taxonomically distinct from any existing natural enemies attacking the target weed in the U.K. Introduced agents are then less likely to compete with the existing fauna and, more importantly, native U.K. predators and parasites will be less likely to include the novel agent in their prey range.

Host specificty testing

Establishing the host specificity of potential agents is the most important and time-consuming part of any weed biocontrol programme. Typically over 50 plant species would be tested. These species are selected using internationally accepted criteria (Wapshere, 1989) and would include plants closely related to the target weed occurring in the U.K. as natives, crops or ornamentals. Further plant species may be included on the basis of morphological/biochemical similarity to the target weed or occurrence in similar habitats. Plants which normally act as hosts to organisms closely related to the potential biocontrol agent are also included. The range of plant species tested in the bracken biocontrol programme is shown in Table 1.

TABLE 1. Numbers of plant species used in tests with the potential biocontrol agent of bracken.

Native U.K. ferns and clubmosses	17
Other ferns and clubmosses	17
Other U.K. natives	21
Crops	12
Other	4
Total plant species tested	71

The exact design of the host specificity tests has to vary depending on the nature of the potential agent. Normal procedure for insect agents would be to start with simple no-choice tests where the major plant-feeding stage of a herbivorous insect is exposed to each of the plant species. Although these simple tests are a good way to shortlist possible host plants from a long list of plant species to be tested, further more realistic tests are required. With insect herbivores, the next stage may involve laboratory trials where agents are given a choice of plants, including their normal host plant. For all potential agents, the final stage of testing may include field trials in the country of origin or attempts to rear the potential agent through its entire life cycle on test plants. The results of all these tests are carefully scrutinized before any application for a release is prepared. In screening pathogens IIBC employs whole leaf clearing and staining to enable microscopic examination of pathogen development, and assessment of plant / pathogen defence responses within the leaf to complement macroscopic observations of plant health.

Agents showing sufficient host specificity may be harder to find in cases where the target weed is closely related and morphologically similar to plant species valued as natives, ornamentals or crops. Some potential biocontrol targets in the U.K. may suffer from these constraints, e.g. *Rhododendron ponticum* with the many similar, related, species and hybrids used as ornamentals, and *Acer pseudoplatanus* with native field maple (*Acer campestre*) and ornamental *Acer* species. Nevertheless, both insect herbivores and plant pathogens can often be found that are completely restricted to individual plant species or even to sub-specific genotypes of plants.

CURRENT STATUS AND PROSPECTS FOR CLASSICAL BIOLOGICAL CONTROL OF WEEDS IN THE U.K.

The current research programme on classical biocontrol of bracken has produced two potential agents from South Africa that are specific to the weed. Licences have been granted by the Department of the Environment and the Ministry of Agriculture, Fisheries and Food for the release of one species, the noctuid moth *Conservula cinisigna*, into secure field cages. A further application is planned for the second species, the pyralid moth *Panotima* nr. *angularis*.

There is considerable interest in biocontrol of other weeds, particularly Japanese knotweeds, giant hogweed and Himalayan balsam. Available information on the potential for biocontrol of these weeds is presented below. The list of pathogens referred to here was compiled from examination of original herbarium material (IMI herbarium, Kew) and represents a selection of those species that may have potential as biological control agents. It became obvious from the paucity of some collections that field surveys, particularly in the centre of origin of the plants, are essential to fully assess the potential of fungal pathogens as biological control agents. Other invasive weeds in the U.K. may present suitable targets for biological control, but much of the basic information needed to make these assessments is lacking.

Japanese knotweeds

The spread of Japanese knotweeds (mainly *Reynoutria japonica*, but some *R. sachalinensis*) in the U.K. since their importation for ornamental use in the last century, has been documented by Conolly (1977) and is illustrated in Fig 1. The few natural enemies that have colonized *R. japonica* in the U.K. were studied by Emery (1983) and the environmental impact and current problems with control measures have been the subject of an environmental consultancy (Palmer, 1990). In Japan neither of the species are invasive weeds and both are regarded as ordinary components of the native vegetation (M. Miyazaki, personal communication).

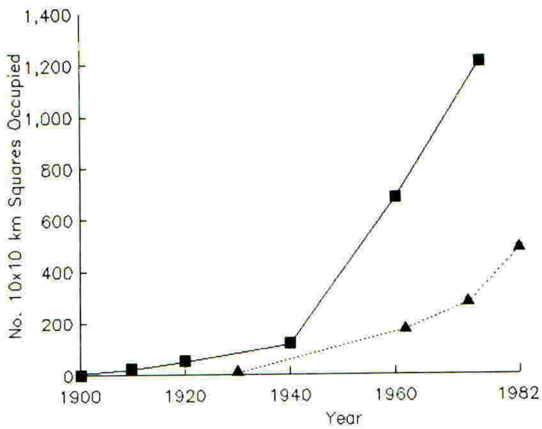

FIGURE 1. Increasing incidence of Japanese knotweed (■) and giant hogweed (▲) in Britain (from Conolly 1977 and Sampson, 1990)

The most promising fungal candidate for classical biological control agent is a rust, tentatively identified as *Puccinia polygoni-weyrichii* from *R.japonica* in Japan. A second rust species, *Puccinia polygonia-amphibii*, is also recorded on *R. japonica* in Japan, however this species occurs within the U.K. where it has been recorded on *Polygonum amphibium* but not on *R. japonica*. Other pathogens have been reported on *R. japonica*, but at present too little is known to allow an assessment of their potential as biological control agents. These include a leaf spot disease (*Phoma* spp.) and *Phyllosticta rayoutina*, both found in the weed's native range. *Colletotrichum gloeosporoides* has also been recorded on *R. japonica* and could have potential as a mycoherbicide if a *forma specialis* could be identified.

Giant hogweed

Heracleum mantegazzianum is an umbellifer which grows up to 4m high it was introduced into the U.K. for ornamental purposes in the 19th century and has since become a troublesome weed (Williamson and Forbes, 1982). Its spread is illustrated in Fig. 1. Preliminary searches of available literature have yielded no information about its insect herbivore fauna in its native range in the Caucasus. Several species of native herbivores have colonised this alien weed in the U.K. most of which also attack native hogweed, *Heracleum sphondylium* (Sampson, 1990). Similarly, only two pathogens have been recorded on *H. mantegazzianum*, both also occurring on *H. sphondylium*. *Melanochaeta asteorae* occurs in the U.K. and appeared to cause little damage to *H. mantegazzianum*. *Ascochyta heraclei* was recorded on *H. mantegazzianum* from Latvia. A number of other pathogens have host ranges restricted to *Heracleum* spp. with most collections having been made from *H. sphondylium*. Other plants in the Umbelliferae are attacked by a wide range of specialised insect herbivores and pathogens in the U.K., so field surveys of giant hogweed in the Caucasus can be expected to be rewarding. Surveys for pathogens of *H. mantegazzianum* could identify similar diseases to those found on *H. sphondylium*, such as the rust disease *Puccinia heraclei* that occurs in the U.K. and a leaf spot, *Ramularia heraclei*, collected on *H. sphondylium* from across Europe. Of other recorded diseases on *H. sphondylium*, *Phomopsis asteriscis*s and *Phyllachora heraclei* would appear to be common in their native ranges, the latter not occurring in the U.K., but may be of little value as biological control agents even if equivalent diseases were found on *H. mantegazzianum*. It is probable that the paucity of information on the natural enemies of *H. mantegazzianum* in part reflects the very restricted centre from which giant hogweed is believed to have originated, consequently there may be a very specialized fauna and flora associated with the plant that has yet to be discovered.

Himalayan balsam

Impatiens glandulifera is an invasive annual that is becoming increasingly common in the U.K. typically as a weed of water margins (Perrins *et al.*, 1990). Its native range includes northern Pakistan, but literature and herbarium searches have revealed little knowledge of the plant or of any natural enemies attacking it. It is not a weed in its native environment which explains this paucity of information on its range and biology.

To summarize, biocontrol of weeds is a novel and promising method for weed suppression in the U.K. We suggest that this environmentally satisfactory control strategy should be considered for many of the invasive weeds in the U.K. - not just for those that cannot be controlled with conventional herbicides. Much of the potential for development of biological control of weeds in the U.K., either alone or as part of an integrated strategy in weed control, remains unfulfilled.

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