Mulches and Herbicides in Ornamental Plantings

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The present high cost of maintenance is a key factor in every sector of landscape industry. Weed control is a particularly expensive aspect of maintenance and land managers constantly are seeking more effective methods of control. Since soil cultivation is laborious and expensive, herbicides and mulches are becoming popular in many countries. In contrast to herbicides, which have become widely used in ornamentals only in the past 20 years, mulching has been used for centuries.

MULCHES

Any material applied to the soil surface primarily to prevent loss of water by evaporation, to suppress weeds, to reduce temperature fluctuations, or to promote productivity may be designated as a mulch (33). Mulching material is usually bulky and costly to transport. Consequently, mulching is unlikely to be economic unless inexpensive material or a local waste product is available (49). This economic factor accounts for the wide range of materials used. These materials include organic substances, such as peat, woodchips, pine needles (44); leaves, sawdust, straw, grass clippings, and corn cobs (24); mineral material, such as sand, gravel, stones, and granite chip (64); and manufactured materials such as plastic, paper, glasswool, metal foil, cellophane, urethane foam (15), and rockwool (44). Proprietary mulches also have been developed, e.g., strawdust consisting of resin impregnated granules of wheat straw. This material is long lasting and sterile and contains slow-release N (54).

Mulches have been used in ornamentals in many parts of the world for a wide variety of purposes, including weed control, regulation of soil temperature, and light reflection, but moisture conservation is considered to be their most outstanding effect (49).

Soil moisture

By providing a protective barrier at the soil surface, a mulch reduces water evaporation (53), and many workers have recorded increased moisture levels (39). Suppression of weed growth also reduces moisture loss through transpiration, enabling the important surface soil layer to remain moist for a longer period than an unmulched soil surface.

Water penetration into the soil may be improved by certain mulches such as straw. This improvement is due to a number of factors, including the protection provided by the mulch against rain impact at the soil surface, reduced soil compaction (31), and increased biotic activity (33). However, not all organic mulches will allow water to penetrate easily. Peat mulches tend to absorb and hold rain and release it to the air again by evaporation (50). Further, if a peat mulch dries out, it will shed water and become difficult to rewet (24). Fresh grass clippings, too, may prevent water penetration and immobilize soil N.

Where moisture conservation is a major consideration, organic mulches, such as bark, straw, or wood chips are preferred to plastic as they tend to maintain higher soil moisture levels (4, 43). However, there are large differences among organic materials in their moisture conservation properties, straw being more effective than manure, with hay grass and wood shavings intermediate (28). The moisture holding properties of any individual material is affected by its physical condition. Finely ground bark with particle sizes ≤ 25 mm retain more moisture than coarsely ground bark (>75mm), with a medium grind (<50mm) intermediate (24).

Plastic and other solid synthetic mulches may prevent water penetration and cannot be laid over large areas without some means of water ingress. In addition, the high temperatures that develop under clear plastic also tend to reduce soil moisture levels (4).

High soil moisture is not always beneficial to plant growth. On low-lying, poorly drained sites or on soils that do not dry quickly, excessive moisture under mulches during wet springs may result in root asphyxiation (1). Impeded drainage and N deficiency were suggested as the likely causes of the better response of the moisture-loving *Alnus cordata* Desf. than *Acer pseudoplatanus* L. and *Tilia cordata* Mill. to mulches of bark, sewage sludge, and Press-board sheets (32).

Weed control

There are many reports of satisfactory weed control with a wide variety of mulching materials. Good results have been obtained with plastic film (17) and organic materials also have given good results (37), with bark more effective than straw. The thickness of a mulch necessary to control weeds depends on the type of material used. A depth of ≈100 mm when settled is required for straw (9) and about 50 to 75 mm for sawdust (50). A deep mulch (100 mm) of hardwood bark chips, sawdust, or crushed corn cobs gave more effective control than a shallow mulch (50 mm) of the same material (24). Provided a 75 mm layer of bark mulch is properly applied, 85% weed control should be achieved during a 3-year period (10). Apart from the smothering effect of mulches, chemicals in the materials also can affect weeds. Phenols and tannins in coniferous bark or sawdust improved the degree of weed control and reduced cultivation costs compared with chopped bark, straw, or a mixture of chopped shrub waste and limestone gravel (40). Similarly, better weed control was obtained in roses with sawdust than with rockwool (44).

Fertilizer beneath sawdust mulch encouraged the growth, emergence, and vigor of weeds, but this problem could be reduced greatly by the use of 6-chloro-*N,N'*-diethyl-1,3,5-triazine-2,4-diamine (simazine) or newspaper beneath the mulch (32). Mulching with conifer sawdust reduced the time required for weed control in plants of *Spiraea japonica* L. (38). Although organic mulches can be effective against annual weeds, they usually have little effect on established perennials. Perennial weeds can emerge through deep layers of organic mulch and, if present when the mulch is applied, are likely to thrive because of the absence of competition from annual weeds. Opaque plastic materials give excellent control of annual weeds and are more effective than organic mulches against perennials. However, some of the more aggressive perennial species, or those with sharply pointed shoots such as *Elymus repens* (L.) Gould can penetrate thin polyethylene (38 μm) film (18).

Despite the general efficacy of mulches against weeds, problems can arise with both opaque synthetic and organic mulches. If plastic mulches are torn, accidentally or to assist water penetration, weed growth through the holes will be vigorous (50). Even with undamaged plastic, vigorous weed growth can occur at the gap around the stem or stake. Transparent plastic film results in higher soil temperatures than opaque film and crop growth may be enhanced initially (1), but the vigorous weed growth that occurs beneath clear plastic is a severe limitation. Consequently, transparent films are seldom used for mulching of perennial plants. Some organic mulches (bark and sewage sludge) can break down rapidly and be reinvaded quickly by weeds (32). Finely, pulverized grades of bark, in particular, tend to be colonized rapidly (10). Moreover, the weed problem may be increased by weed seeds introduced in certain mulches, such as fresh manure or hay cut when seeding.

Soil temperature

Each mulch type creates its own unique soil temperature regime, and large differences have been recorded between organic and plastic mulches. Soil temperatures are lower under organic mulches during the day and slightly higher at night than those on bare soil (44). Temperature fluctuations are therefore reduced (4), but organic mulches have less effect on seasonal temperature variation than on daily variation (8). A deep mulch (100 mm) of hardwood chips, sawdust, jointer curls, or corn cobs had a better insulation value than a shallow 50 mm mulch (24).

Dark-colored mulches, such as black polyethylene, absorb the sun's rays and may increase soil temperature considerably, especially during sunny periods. In a trial in Wisconsin, plastic mulches significantly increased soil temperatures at 100 mm depth compared with organic mulches (4).

Higher soil temperatures also were recorded under black plastic than under bark or hay, and these differences were greatest early in the season (43). Plastic mulches reduced the degree of diurnal variation in France by raising soil minimum temperatures (1), but this effect was less obvious in Wisconsin (4).

Effect of mulches on soil nutrients

Different mulches will affect soil fertility in a variety of ways. In a comparison of nine mulches, including straw and synthetic materials, the soil under bark showed the highest pH, organic matter content, and K levels (4). Bark mulch also gave a greater increase in K, Ca, and Mg than sawdust or corn cobs (24).

The application of mulching materials with a high C:N ratio (> 30:1) will result in a depression of nitrification at least initially. Mulches, such as fresh sawdust (C:N ratio 500:1) and wheat and barley straw (100:1), normally will require additional application of N to compensate for this imbalance, but mulches of young grass clippings (12:1), average grass clippings (19:1), or seaweed (19:1) will not (62). Plants of *Spiraea japonica* L. mulched with conifer sawdust were smaller in size than unmulched plants after 6 years, but growth of both mulched and unmulched plants was greatly improved with applications of ammonium sulphate (35, 38). The growth of rhododendrons was reduced temporarily by a mulch of fermented bark, while their growth was adversely affected by unfermented bark throughout a 3-year study period (27). Better growth of trees and shrubs was recorded with a combination of bark mulch plus N fertilizer than with fertilizer or mulch alone (59). Apart from the effect of mulching material on nitrification, plant growth also may be affected positively or negatively by chemicals in the mulching material. The growth of seedlings of *Picea sitchensis* Carr. and *Pinus contorta* Douglas was improved by the nutrients washed out of the mulch of bracken (*Pteridium aquilinum* Kuhn) applied to nutrient-deficient acid heath soil and removed before the tree seeds were sown (30).

Plant growth

In view of the complex effects of mulches on many different soil functions, it is not surprising that different types of mulch affect different plant species in different ways and that no single mulch type performs best in all situations or for all species (4). Good responses in terms of increased plant vigor has been obtained with a wide variety of different materials, including pine bark (32), hay, black plastic, and calcined clay (43), heavy-duty green plastic (4), bark and sawdust (39), and plastic and gravel mulch (58). Peat mulch was particularly beneficial to rhododendrons, giving stronger growth and more flower buds than eight other materials (27).

Black plastic mulches for woody ornamental and fruit plants have been tested extensively at the Weed Research Organization, U.K. (17). Consistently good results have been obtained with black polyethylene, 38 or 125 μm thick, without adverse effect on any plant species. Average increases in the growth of apples and blackcurrants mulched with black polyethylene was in the order of 30% to 40%, compared with only 10% for a straw mulch. In these trials, polyethylene-mulched crops made more growth than those kept weed-free with herbicides or with hand weeding. The increased vigor of plants mulched with opaque plastic compared with unmulched plants may continue for several years. The weights of shoots on mulched vines were much higher over a 5-year period than those from nonmulched vines (1).

Extensive root systems also have been recorded under mulches (1, 3). The total weight of a vine root system in the 0 to 0.60 m soil layer for a mulched plant was 150% heavier than that of a nonmulched, cultivated plant after 1 year. Initially, plastic films tend to encourage shallow rooting. Ninety two percent of the roots of a mulched vine rootstock occurred in the 0 to 0.30 m layer, and none occurred between 0.45 and 0.60 m, compared with only 69% of the roots of a cultivated vine in the 0 to 0.30 m layer. This absence of exploitation of the deeper soil layers by mulched plants is normally shortlived. Further studies with vines in France showed that after 3 years, depth of the root system was similar for both mulched and cultivated plants but that the superiority of mulched plants was due to their more vigorous root growth in the 0 to 0.15 m layer (1).

Not only do plants respond differently to different mulches, but different plant species may respond differently to the same mulch. Mulching with bark or sawdust significantly increased the growth of *Hypericum calycinum* L., *Potentilla fruticosa* L., and *Cotoneaster dammeri* Schneid., but not that of *Spiraea japonica* L. f., *Arundinaria vagans* Gamble, and *Geranium macrorrhizum* L. (42).

Mulching usually, but not always, results in greater growth than herbicide treatment or cultivation alone (see e.g. refs. 20 and 56). However, Whitham (63) obtained a strong correlation between growth of *Eucalyptus melliodora* Cunn. and weed control with most mulching and herbicide treatments tested. In this work, a mixture of simazine and 1*H*-1,2,4-triazol-3-amine (amitrole) gave greater growth than pine bark, grass hay, sawdust, black plastic, scoria, newspaper, or hoeing.

Plant establishment

The rapid development of an extensive shallow-rooting system on vines mulched with plastics enabled the vines to recover more rapidly after planting (1). This recovery was attributed to the increased development of surface roots and the balanced root system of young plants. Establishment of ornamental perennials and shrubs was also improved by organic mulching materials, especially bark and sawdust (39).

Appearance of mulches

In landscape situations, the appearance of a mulch is very important. Bark, both chips from softwood and coarse ground and screened hardwood, make decorative mulches (24). Of nine different mulches tested in Wisconsin, bark was considered to be the most satisfactory, since it blended with the surrounding soil (4). In this trial, clear polyethylene, which became muddy and trapped weed growth underneath, and other synthetic mulches, which tore, were particularly unsightly.

In prestige situations, where cost is not a limiting factor, the moisture-conserving and weed-suppressing advantage of plastic may be combined with the pleasant appearance of natural mulches by covering the plastic mulch with a thin layer of bark or granite chip (62).

Economics

Mulching, with or without the use of herbicides, can reduce substantially labor required for maintaining ornamental plantings. In the United Kingdom, a hand hoeing/forking bare soil regime between shrubs or trees required about 33 man-hours per 100 m^2 per year compared with 5 man-hours for a mulch layer (62). In the Federal Republic of Germany, cultivation costs were reduced on average by 23% to 40% with bark and sawdust mulches, by 10% to 22% with straw, and by 5% to 8% with chopped shrub waste and limestone gravel compared with unmulched controls (40). Decreasing cultivation costs were clearly associated with increasing thickness (19 to 30 mm) of the mulch, although, obviously, also with increasing cost of mulch material.

Despite the reduction in labor requirements, expense is considered to be a major limitation to the more widespread use of organic mulches in the United Kingdom (63), where costs per m^2 for a 50 mm mulch in 1982 were: peat $1.73–2.07 (£1.0–£1.20), bark $1.04–1.21 (£0.6–£0.7), coarse gravel $1.56–1.73 (£0.9–£1.0). The price of black plastic (150 gauge) for a 1 m^2 mulch around trees was $0.35–0.52 (£0.2–£0.3) per tree.

The cost of mulching is highly dependent on the thickness, and the economics of mulching on the longevity, of the materials used. In a trial in New Zealand, newspaper and a thin mulch of straw (20 mm) had virtually disappeared after 6 months, but chopped bark, sawdust, and black polyethylene lasted very well and were not substantially different after 6 months (31). A properly applied bark mulch, 75 mm thick, should last 3 years (10).

The expense of transporting bulky, organic mulches adds considerably to their cost (32). As they need to be applied at a minimum depth of 50 mm, 500 $m^3 \cdot ha^{-1}$ is required. Heavy duty plastic can be handled more easily, but light synthetic mulches are often difficult to lay even in a light wind (4).

Despite the high cost of organic materials, the cost of mulching was recouped in 1 year in Germany due to reduced maintenance cost and improved plant establishment (39). However, a comparison of weed control methods in Sweden showed that chemical weed control was least expensive, followed by combining mulching and chemical treatments and by mulching alone (12).

HERBICIDES

Herbicides, like mulches, can reduce substantially the labor required for maintenance. Much information is now available on their use on trees and shrubs (19, 48), and they can be used with greater safety in woody ornamentals than herbaceous plants or annual flowers.

Woody ornamentals

Many of the herbicide programs used in fruit crops in nursery stocks are directly applicable to urban landscapes where woody perennials are grown. For example, the good tolerance of a range of newly planted liners to high doses of 4-(dipropylamino)-3,5-dinitrobenzenesulfonamide (oryzalin) and 2,6-dinitro-*N*[1], *N*[1]-dipropyl-6-(trifhiromethyl)-1,3-benzenediamine (prodiamine), and the high degree of tolerance of *Thuja* and *Taxus* to 2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluromethyl)benzene (oxyfluorfen) as compared to *Rhododendron, Cotoneaster, Pyracantha*, and *Pieris* (41), is useful information for the land manager and contractor as well as for the nurseryman.

Growers of woody ornamentals are now fortunate in having a range of effective herbicides to draw on when planning a weed control program. In addition to similarities in types of program used in fruit plantations, nurseries, and in plantings or ornamental trees and shrubs, there are also parallels in the programs used for woody plants in North America and in northwestern Europe. A program developed for landscape plantings in medium-loam soil in Ireland is based on applications of simazine in March and July (46) followed later by a spot treatment with N-(phosphonomethyl)glycine (glyphosate), oxyfluorfen, or other appropriate herbicide. This program is very similar to one giving year-round weed control in nursery stock on sandy loam soils on Long Island (52).

Perennial weeds are a serious problem in nurseries and ornamental landscapes both in North America and northwestern Europe. At present, the main preplanting herbicide used to control such weeds is glyphosate (25). After stock is planted, a soil-acting pre-emergence herbicide or mixture of herbicides is usually applied. In New York State, granular formulations are normal (13), but sprays are more common in Britain (11). A second application of soil-acting herbicide often is applied 2 or 3 months after the first one.

There is abundant evidence in the literature of the need to supplement overall application of soil-acting herbicide with a subsequent localized application or spot treatment with a contact or translocated herbicide (16, 55). When only annual weeds are present, 1,1-dimethyl-4,4-bipyridinium ion (paraquat) is generally satisfactory for this purpose, but glyphosate is more effective where perennial weeds also occur (22, 23).

Bulbs, annual flowers, and herbaceous plants

Bulbs can be used in mixed plantings to enhance the appearance of woody ornamentals and are tolerant of a number of herbicides. *N,N,*diethyl-2-(1-naphthalenyloxy)-propionamide (napropamide), dimethyltetrachloroterephthalate (DCPA), and α,α,α-trifluro-2,6-dinitro-*N,N,*-dipropyl-p-toluidine (trifluralin) proved very safe, oryzalin was fairly safe, but oxyfluorfen and 3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2-(3*H*)-one (oxadiazon) were very harmful (5). Damage to bulbs by oxyfluorfen also was recorded in trials in Ireland (36).

In general, herbaceous plants and annual flowers were more susceptible than woody plants to damage by herbicides. This difference is due partly to their small size and more limited root system. None of eight herbicides tested was safe on *Salvia*, and considerable variation in tolerance of other annuals also was recorded (6). Many container-grown annual flower genera were tolerant to post-emergence applications of grass herbicides but their tolerance to napropamide, 3-amino-2,5-dichlorobenzoic acid (chloramben), and prodiamine varied with the plant genus (42). Excellent broad-spectrum weed control has been obtained with oryzalin in 80 herbaceous ornamental genera/cultivars, although slight phytotoxicity was seen on six cultivars (61).

Weed control strategies

Where herbicides are used in perennial crops over a period of years, it is inevitable that the weed flora will change and that no one herbicide can be used exclusively for any length of time. The longer the period of herbicide usage and the higher the desired standard of weed control, the more important is the choice of herbicide rotation. A long-term herbicide program cannot be drawn up in advance since it is difficult to predict with any degree of certainty how the weed flora will change. A minor weed species can become dominant after a few years of a mono-herbicide program and improved control can be obtained with rotations of different herbicides (57).

In Britain, simazine is still the principal pre-emergence herbicide (25) and may be applied in mixtures with other herbicides to increase the spectrum of weeds controlled (11). In New York State, simazine usually is applied in combinations with one of the following: oxadiazon, oryzaln, *N*, N-dimethyl-α-phenylbenzeneacetamide (diphenamid), trifluralin, DCPA, 2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)acetamide (alachlor), or napropamide (13). In California, acceptable results have been obtained on ground cover plants with alachlor, 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide (metolachlor), napropamide, 2,4-dichlorophenyl-p-nitrophenyl ether (nitrofen), oryzalin, oxadiazon, oxyfluorfen, and prodiamine (21). Oryzalin, napropamide, nitrofen, and prodiamine were tolerated by a broader spectrum of ground cover species than the other herbicides tested. In Ireland, acceptable results have been obtained in shrubs with simazine, 6-chloro-N-ethyl-*N'*-(1-methylethyl)1,3,5-triazine-2,4-diamine (atrazine) (47), napropamide, oryzalin, oxadiazon, oxyfluorfen, 2-chloro-N-(1-methylethyl)-N-phenylacetamide (propachlor) and N-[3-(1-ethyl)-1-methylpropyl)-5-isoxazolyl]-2,6-dimethoxybenzamide (isoxaben) (D.W.R., unpublished data).

At any given herbicide dose, some weeds will be more susceptible than others (7). There are six different commercial recommendations for propachlor, depending on the species and size of weed and crop (34). For certain weed species, e.g., *Polygonum aviculare* L., it is sometimes possible to select a herbicide such as propachlor that will give good control at a very low dose. Where herbicides are used repeatedly in a long-term "crop", the number of weed species present is likely to decline. Consequently, there is considerable scope for selecting a herbicide or mixture of herbicides to deal specifically with the main weeds present or those expected to be troublesome later in the year.

Long-term use of herbicides

Preliminary results have been published of a long-term trial on the effect of repeated applications of herbicides on ornamental trees and shrubs (45, 47, 62). The trial, started in 1969, is still in progress in an amenity area containing representatives of more than 200 genera of ornamental plants, mainly shrubs. The soil, a medium loam, derived from Cambrian shale and quartzite, contains ≈25% clay and 4.5% organic matter in the top 75 mm.

The objective of the trial is to study the implications of maintaining an amenity area largely with the use of herbicides, supplemented by a small amount of hand weeding and at minimal cost. For this reason, the weed control program has been based largely on the inexpensive triazine herbicides, simazine and atrazine, without the use of soil tillage or mulches. Most of the area was treated with two applications of simazine at 1.7 kg a.i./ha each year between 1969 and 1976 and between 1981 and 1986 and with two applications of atrazine at 1.7 kg a.i./ha each year between 1976 and 1981, except in 1970 (three applications) and 1979 (one application). Several other herbicides were used as spot sprays against specific weeds (47). To reduce the risk of a build-up of triazine-resistant biotypes, a determined effort was made to kill any weeds that survived the routine application of triazine herbicide before seeds were shed. This goal was largely achieved, although some weeds escaped, usually as a result of being partially hidden by plant foliage.

Following the repeated use of herbicides on the same area for 17 years the main conclusions are:

(i) Under the prevailing soil and climate conditions, herbicides provide a practical, highly successful, and inexpensive means of maintaining an area of woody ornamentals. Neither simazine nor atrazine caused any obvious damage to the foliage or vigor of the large number of genera treated. Scorching of leaves of *Ligustrum ovalifolium* Hassk 'Aureum' in Mar. 1980 shortly after treatment with atrazine was erroneously considered to be herbicide injury (47). This damage subsequently was correctly diagnosed as being caused by salt spray. Although the soil type with its high clay and organic matter content would help to minimize simazine injury, similar soils occur in many other parts of Ireland.

(ii) There is no evidence of any build-up of triazine-resistant weed biotypes, although triazine herbicides have been applied usually twice a year for 17 years. In some parts of the world, the control of *Senecio vulgaris* L. (52) and *Poa annua* L. (29) has been short-lived as resistant populations have developed after several years of continued herbicide use. These species were two of the most common weeds when the present trial began (47). Both species still occur occasionally but are well controlled by simazine or atrazine. The absence of resistant biotypes can be attributed to the policy of killing weeds before seed shedding. This strategy has also enabled inexpensive triazine herbicides to be used as the main soil-acting herbicides throughout the period.

(iii) After 17 years, weed populations have been reduced, fewer weeds require to be spot-treated, and the problem of weed control has decreased. Continuing treatment with soil-acting herbicides applied overall and with contact or translocated herbicides applied as spot treatments is still required, however, as weed germination is evident each year on any area inadvertently left unsprayed with soil-acting herbicide.

The weed flora have changed significantly since 1969. Species, previously common, but sensitive to triazine herbicides, have almost disappeared. These include *Stellaria media* (L.) Vill. *Capsella bursa-pastoris* (L.) Medicus, and *Senecio vulgaris* L. In 1986, the major weeds were *Galium aparine* L. and woody species. *Galium aparine* L. is still mildly troublesome because of its capacity to germinate during the autumn and early winter and overwinter as a seedling beneath ornamental plants when many are leafless. Subsequently, it may escape detection because it has inconspicuous flowers and scrambles through plant foliage during the growing season. Moreover, it has an efficient method of fruit dispersal.

Most of the woody weeds now occurring are seedlings of ornamental species already present in the treated area: these include *Myrtus apiculata* (DC.) Niedenzu, *Pittosporum tenuifolium* Gaertn., *Olearia paniculata*, (J.R. & G. Forst.) Druce, *Berberis darwinii* Hook., *Echium pininana* Webb & Berth., *Cordyline australis* Hook., *Cupressus macrocarpa* Hartro., and *Cotoneaster* spp. In addition, *Rubus fruticosus* sens. lat. also occurs. Although no *R. fruticosus* plant sheds seeds in the herbicide-treated area, seeds are widely dispersed by birds from nearby wasteland.

(iv) There has been no obvious deterioration of soil structure in the absence of tillage apart from the formation of a thin crust ($\approx$10 mm thick) at the surface. This crust cracks slightly under dry conditions and may become covered with moss during wet weather. Below this crust, soil structure is good. There is ample evidence of vigorous growth of plant roots near the soil surface and no sign of any adverse effects on root growth as a result of soil compaction.

(v) There is also no evidence of any build-up of phytotoxic residues of triazine herbicides after 17 years. Young replacement plants can be planted readily into triazine-treated ground. This planting is done by removing the top 75 mm of soil before digging the planting hole and by retaining this layer, containing most of the triazine residues, at the soil surface after planting.

Some herbaceous perennials, such as *Phlox* and *Fragaria*, present when the trial began were killed by simazine after treatment for several years. Although herbaceous plants are usually less tolerant of simazine than woody ornamentals or bulbs, established plants of some genera such as *Paeonia, Hosta, Eryngium, Bergenia, Kniphofia, Polygonatum,* and *Hemerocallis* appear to have adequate tolerance to withstand routine sprays of simazine.

DISCUSSION

Both mulches and herbicides can be used effectively to control weeds in ornamentals and have a place in the management of amenity landscapes. Both can give excellent results when used in the right circumstances, but the outcome will be disappointing if conditions are unsuitable. Despite their common action in weed control, there are large differences between these two approaches to land management. The physical action of mulches in achieving weed control by excluding light from the photosynthetic portions of a plant is very different from the chemical action of herbicides. Moreover, the benefits of a mulch are usually greater than weed control alone. The improved plant growth and vigor often recorded may be due to the conservation of soil moisture by reduced evaporation and run-off, the provision of a more favorable soil temperature regime, reduction of nutrient loss by leaching, reduced soil compaction and improved water infiltration, increased availability of mineral nutrients, enhanced nitrification, additional nutrients and organic matter derived from a decomposing mulch, or the preservation or improvement of soil structure. In addition, mulches may increase the density and spread of roots by changing the soil hydrothermal regime.

Where mulches result in decreased plant performance, this effect too, may be due to a variety of factors, including reduced nitrification, retention of excessive soil moisture, or the reduction of soil temperatures below optimum for heat-loving plants. Mulches are used in so many different situations and can affect so many different interacting soil factors that it is not usually possible to identify only one factor as being the main reason for good or bad results.

The effect of mulches in reducing weed competition is undoubtedly an important beneficial effect in some situations, but any increase in plant vigor also may be due to some of the other attributes of mulching. Mulching materials have certain limitations in ornamental plantings if weed control is the main objective. Most mulching materials are expensive to obtain and apply and, where weed control is the major consideration, herbicides have an important advantage in their convenience and relative ease of application. Nevertheless, there are situations where mulches are preferable because of their additional advantages, e.g., in prestige plantings where esthetics is highly important and where the application of herbicides may be difficult or undesirable. Moreover, in some European countries it is no longer permissible to apply herbicides in ornamental plantings (A. Håbjørg, personal communication) and here the role or mulches is likely to increase.

As mulches and herbicides have certain limitations, there are situations where both can be used effectively to complement the action of the other. Frequently, these will be used in sequence but they may also be combined together to minimize the direct applications of chemicals to the soil (15).

Prevention or erosion

An amenity landscape where weeds are kept totally suppressed is likely to facilitate the task of controlling weeds in the long-term. However, if this is achieved with herbicides alone, severe wind and water erosion will result during the winter in some situations. Nurserymen can overcome the erosion problem by a combination of carefully applied herbicide applications, the use of short-lasting residual herbicides, and the establishment of oats between the plant rows in autumn (14). In landscape plantings, light mulching with organic material in conjunction with herbicide use would have the same effect.

Appearance of soil surface

The appearance of a herbicide-treated soil surface contrasts markedly with a freshly tilled soil. Recognition that plant growth is good in judiciously herbicide-treated soil and an awareness that, in a 'no-till' program, the shallow root system of ornamental plants is not damaged by soil tillage makes the different appearance of a herbicide-treated soil surface acceptable to some people. Mosses are pleasing on a forest floor and a growing number of land managers welcome their occurrence also beneath herbicide-treated shrubs as a means of protecting the soil surface from rain impact or preventing erosion on sloping sites. Nevertheless, the majority of the general public considers that slight cracking of the soil surface is harmful and erroneously believes that the presence of moss is always indicative of soil conditions unfavorable for the growth of ornamental plants. In these circumstances, the use of a combination of herbicides for weed control and a shallow mulch of bark or other decorative organic material could be useful. In most situations, herbicide programs would provide a more effective means of controlling perennial weeds and a less expensive method of controlling annual weeds than an organic mulch. The mulch would improve the visual appearance of the area to most people, conserve moisture, prevent soil surface cracking and the growth of moss, assist in the control of weeds, and facilitate hand pulling of annual weeds.

In some circumstances, mulching can reduce the effect of herbicides applied subsequently, depending on the type of mulch and herbicide used. An organic mulch will not usually affect the efficacy of contact or translocated herbicides unless the mulch covers part of the weed foliage. However, an organic mulch may severely reduce the effect of a soil-acting herbicide as a result of adsorption by the mulching material. Organic mulches are likely to vary greatly in their effect on soil-acting herbicides. Straw will have a smaller effect than peat in view of the former's lower cation exchange capacity and the ease with which water penetrates. Not only would peat adsorb and inactivate part of the applied soil-acting herbicide when spraying occurs after the mulch has been applied, but in some situations a peat mulch will prevent water from reaching the soil surface and will further reduce the efficacy of the herbicide treatment.

Where organic mulches are used in combination with herbicides, the latter are best applied, where possible, before the mulch. In a comparison between simazine applied immediately before or after an application of 50 mm bark mulch, control of annual weeds improved where the herbicide was applied before the mulch (J.C. Kelly, personal communication). Nevertheless, useful control was also obtained where the herbicide was applied on top of the mulch. Where perennial weeds emerge through an organic mulch, these are best controlled by the application of a suitable herbicide. Digging or hoeing out perennial weeds is likely to expose soil, which will encourage the growth of annual weeds (10).

Herbicides vs. plastic

Despite the better performance sometimes recorded with plastic mulches, the use of herbicides to control weeds in ornamentals and fruit crops in Britain and Ireland is generally more popular than plastic mulches. This preference contrasts with the situation in many other countries. The greater popularity of herbicides in Britain and Ireland is due not only to their cheapness and convenience but also to soil and climatic factors. Simazine, the most widely used herbicide in fruit and ornamentals in these countries, is generally safer and more effective than in many others. Soil organic matter is usually higher, resulting in a greater retention of simazine close to the soil surface, and the risk of damage to ornamental plants through the downward movement of simazine is reduced. In addition, the soil surface remains moist for longer periods and conditions are therefore more generally suitable for simazine application.

New herbicides suitable for landscape plantings are still being developed. Significant opportunities exist for further improvements in chemical control methods through greater knowledge of their mode of action and advances in application technology. Even though mulching is an age-old practice, new materials and better understanding of the complex action of mulches on soil and plant properties will result in more effective usage. As labor costs continue to increase, both practices are likely to be more extensively used as a means of moving some of the work load involved in land management from the busy spring and early summer period to a time where labor is more readily available (64).

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