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The use of plant pathogens for biological weed control in South Africa

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ABSTRACT

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The use of pathogens for the biological control of the weeds *Acacia saligna* (Labill.) Wendl., *Hakea sericea* Schrad., *Ageratina adenophora* (Spreng.) K. and R., and *Ageratina riparia* (Regel) K. and R. in South Africa over the last decade is reviewed. An Australian gall-forming rust fungus, *Uromycladium tepperianum* (Sacc.) McAlp., has been introduced and, since 1987, inoculated onto *Ac. saligna* at over 50 localities throughout the distribution of the weed. Two exotic leaf pathogens, *Phaeoramularia* sp. and *Entyloma ageratinae* Barreto and Evans, were introduced during 1988 and 1989, respectively, to control *Ag. adenophora* and *Ag. riparia*. All three pathogens are dispersing naturally, but it is still too early to evaluate their effect on the weed populations. A locally occurring strain of the fungus, *Colletotrichum gloeosporioides* (Penz.) Sacc., which causes a fatal disease of *H. sericea* has been exploited. A formulation of the pathogen for application to young seedlings of the weed is currently being developed commercially.

INTRODUCTION

Several plant pathogens have proved useful as biological control agents of weeds. The introduction of the exotic pathogens, *Puccinia chondrillina* Bubak and Syd., *Entyloma ageratinae* Barreto and Evans, and *Phragmidium violaceum* (Schultz) Wint. has helped control the weeds *Chondrilla juncea* L. in Australia, *Ageratina riparia* (Regel) K. and R. in Hawaii, and *Rubus* spp. in Chile, respectively (Oehrens, 1977; Cullen, 1978; Trujillo, 1985). Following a different approach, the mycoherbicides Collego (*Colletotrichum gloeosporioides* (Penz.) Sacc. f.sp. *aeschynomene*) and Devine (*Phytophthora palmivora* (Butler) Butler) have been developed and registered for inundative application to two crop weeds (Templeton, 1982).

One of the first reports of the potential of a plant pathogen to control a weed in South Africa was made by Wager (1947) who suggested that the rust *Kuhneola uredinis* (Link) Arth. may help control bramble (*Rubus* spp.) in

Natal. More recently, the discovery of a fatal disease on *Hakea sericea* Schrad. in the Southern and Southwestern Cape Province, and the potential of an Australian gall-forming rust fungus to control biologically *Acacia saligna* (Labill.) Wendl., further stimulated interest in this area. As a result, a plant pathologist was appointed in 1979 to the Weeds Research Unit of the Plant Protection Research Institute specifically to study the use of pathogens for the control of weeds in South Africa. Progress in the use of pathogens for the biological control of *Ac. saligna*, *H. sericea*, *Ageratina adenophora* (Spreng.) K. and R. and *Ag. riparia* over the last decade is reviewed.

ACACIA SALIGNA

Acacia saligna (Fig. 1), commonly known in South Africa as the Port Jackson willow, is a shrub or small tree growing up to 10 m tall. It is native to the southwest of Western Australia, occurring to the west of a line from Ajana (28°00'S 114°40'E), north of Geraldton, to Mount Ragged (33°30'S 123°20'E), east of Esperance (Maslin, 1974). Originally described as *Mimosa saligna*, by Labillardiere in 1807, it was placed in the genus *Acacia* by Wendland in 1820 (Maslin, 1974). *Acacia cyanophylla* Lindl. is now regarded as a synonym of *Ac. saligna*, which is a highly polymorphic species (Maslin, 1974). In South Africa, the plant has been referred to as *Ac. cyanophylla*, *Ac. falcata* Willd., *Ac. falciformis* DC. and *Ac. saligna* (Boucher and Stirton, 1978; Shaughnessy, 1980).

The earliest record of Australian acacias being grown in the Cape Colony was made in 1834 when the genus *Mimosa* was included in a list of some of the plants grown in the Cape Town garden of Baron von Ludwig (Shaughnessy, 1980). No species names were mentioned, but *Ac. saligna* may have been one of these. It was one of the species planted after 1848 in an effort to stabilize the sand along the 'hard' road across the Cape Flats (Shaughnessy, 1980).

During the 1870s, the planting of Port Jackson willow by farmers on the Cape Flats was actively encouraged because of its usefulness as a timber for the construction of wagons and fencing posts, as firewood and because of the suitability of its bark as a tanning agent (Shaughnessy, 1980). By 1880, seed was being distributed as far as Port Elizabeth and Durban. By 1893, it was found that the bark from *Ac. saligna* yielded less tannin than that of *Acacia mearnsii* De Wild from Natal and Australia, but planting of the species for other purposes continued on a smaller scale (Shaughnessy, 1980).

Sand dune reclamation schemes along the southern and western coasts played an important role in the dispersal of both *Ac. saligna* and *Acacia cyclops* Cunn. ex Don. in these areas (Shaughnessy, 1980). Hall and Boucher (1977) reported that seed of *Ac. saligna* was still being sold to the public on a large scale as recently as 1973, when 99.6 kg of seed was sold. This evidence

Fig. 1. Port Jackson willow, *Ac. saligna*. (a) Flowering shoot; (b) mature phyllode; (c) mature pod. (Drawn by R. Weber, National Botanical Institute, Pretoria.)

is contradictory to an observation by Roux (1961) that the spread of acacias after 1886 was largely by natural means.

According to Shaughnessy (1980), there were several introductions of *Ac. saligna* seed into South Africa from Australia. She presents evidence that there were two forms of *Ac. saligna* being planted by 1850. In 1885, further stocks of two forms were introduced from Australia under the names of *Ac. saligna* and *Ac. cyanophylla*. The possible existence of different forms of the plant and the fact that several introductions of seed were made may have implications for biological control and influence whether biological control agents will attack the weed populations uniformly.

A detailed survey of the total area currently infested with *Ac. saligna* has not been made. Based on replies to a questionnaire, Van den Berg (1973) estimated that approximately 20 000 ha in the Cape Province were infested with *Ac. saligna*. Taylor (1975) estimated that 300 000 ha of coastal macchia were invaded by *Ac. saligna* and/or *Ac. cyclops*. Roux and Middlemiss (1963), Hall and Boucher (1977) and Macdonald et al. (1985) drew up distribution maps of *Ac. saligna* in the Southwestern and Southern Cape Province, showing progressively larger areas of infestation. It is also established in the lower reaches of the Orange River in the Northern Cape Province and in the southern parts of the Transkei Republic (Boucher and Stirton, 1978), and there are records of collections at Pretoria (25°40'S 28°15'E) in the Transvaal and at Pietermaritzburg (29°35'S 30°25'E), Bothas Hill (29°45'S 30°45'E), Stanger (29°20'S 31°20'E) and Virginia Airport (29°45'S 31°05'E) in Natal (Ross, 1975).

Evidence for the continuing spread of *Ac. saligna* and increasing density in infested areas is also presented by McLachlan et al. (1980), Beeston (1985) and Taylor et al. (1985). Macdonald and Jarman (1984) predict a further increase in the extent of invasions in the strandveld, coastal fynbos, mountain fynbos and river valleys in the Southwestern and Southern Cape.

Milton (1980) ascribes the success of *Ac. saligna* in the Southwestern Cape to pre-adaptation to the sandy soils low in nutrients, the ability to survive summer drought, the prolific production of hard long-lived seed, and the lack of natural predators and pathogens. An annual seed fall of 5443 seeds m^{-2} (Milton and Hall, 1981) and seed banks of between 11 920 seeds m^{-2} (Milton and Hall, 1981) and 45 800 seeds m^{-2} (Holmes et al., 1987) in the top 15 cm of soil under a stand of *Ac. saligna* have been recorded. Although most of the seed is dormant, seed viability is high (94–98%) and declines only slowly (Milton and Hall, 1981; Holmes, 1988). Seed dormancy is readily broken by heat (Jones, 1963; Milton and Hall, 1981) and after fire 70% of the seed bank may germinate (Holmes, 1988).

This plant is ranked as the most problematic plant invader in the Southwestern and Southern Cape Province (Macdonald and Jarman, 1984), totally replacing areas of the natural fynbos (macchia). Although Jones et al.

(1963) did not find evidence for the production of growth inhibitors by *Ac. saligna*, Witkowski and Mitchell (1987) found that the presence of *Ac. saligna* increased soil phosphorus levels and postulated that the enriched soils are less favourable for the indigenous fynbos.

Mechanical and chemical control of Ac. saligna

A variety of mechanical and chemical control measures are being implemented by various land-management bodies and private land owners. The methods in use were evaluated at a management workshop in 1984 (Macdonald et al., 1985). Of the mechanical methods, hand pulling of seedlings, digging out of entire plants and debarking to soil level appeared to be the most successful. The use of fire to kill seedlings or mature plants was only partially successful. Herbicide application to cut stumps or spray applications to coppice or seedlings was moderately successful. The estimated costs of clearing thickets of different densities using different clearing methods ranged from R526 to R2408 per ha of an 'average' infestation, based on 1986 prices (Macdonald and Wissel, 1989). Because of these high costs, control measures are only practised in valuable conservation and intensively farmed areas. No control is being practised over the majority of the infested area.

Biological control of Ac. saligna

Biological control of *Ac. saligna* was recommended as a priority by Taylor (1969), Neser and Annecke (1973) and Ferrar and Kruger (1983). A preliminary survey indicated that a number of seed-attacking insects were present on the plant in Western Australia (Neser and Annecke, 1973). The plant was severely attacked by a gall-forming rust fungus, *Uromycladium tepperianum* (Sacc.) McAlp., in Australia (S. Neser, personal communication, 1979). Van den Berg (1977) observed that this fungus weakened some species of *Acacia* in Australia to such an extent that unfavourable conditions or insects could then cause their death. Based on these observations, a closer study of the biology and host range of the rust was undertaken in Australia from 1982 to 1985 (Morris, 1987).

Biology of U. tepperianum

Originally described as *Uromyces tepperianus* Sacc., the fungus was later moved to the genus *Uromycladium* McAlp. as *U. tepperianum* McAlp. (McAlpine, 1905). *Uromycladium tepperianum* is the most common of the seven *Uromycladium* species and has been recorded on over 100 *Acacia* species and on *Paraserianthes lophantha* ssp. *lophantha* (Willd.) Nielson in Australia and *P. lophantha* ssp. *montana* (Junghuhn) Nielson in Java (Mc-

Alpine, 1905, 1906; Samuel, 1924; Burges, 1934; MacNish, 1963; Talbot, 1964; Simmonds, 1966; Gathe, 1971; Warcup and Talbot, 1981; Sampson and Walker, 1982). The rust is also recorded on introduced *Acacia armata* R. Br. in New Zealand (Gilmour, 1966) and Burges (1934) mentions the occurrence of *U. tepperianum* on introduced *Acacia decurrens* (Wendl.) Wild. in New Zealand and South Africa. The latter author does not, however, state the source of his information for the occurrence in South Africa. No record of the disease is found in the South African literature (Doidge, 1950; Gorter, 1977). Burges (1934) probably misidentified the rust species in New Zealand as Cunningham (1931) and McAlpine (1905) record *Uromycladium notabile*, not *U. tepperianum*, on this *Acacia* species in New Zealand and Australia, respectively. *Uromycladium tepperianum* has also been reported on *Ac. mearnsii* (Browne, 1968; Gibson, 1975; Warcup and Talbot, 1981), an important commercial plantation tree in South Africa. These reports could, however, either not be confirmed or were found to be misidentifications (Morris et al., 1988).

Despite the large recorded host range of *U. tepperianum*, various authors (Samuel, 1924; Burges, 1934; Van den Berg, 1977) suggested that genotypes of the fungus adapted to particular host species do occur. They based their suggestion solely on field observations and had not cross-inoculated rust from different *Acacia* species. Gathe (1971) reportedly obtained infection and the formation of spermagonia within 8–15 days on detached phyllodes of a number of *Acacia* species inoculated with teliospores from two host species. M.J. Morris (unpublished data, 1983) repeated her method of inoculation with teliospores from *Ac. saligna*. Necrotic lesions containing pycnidia of an unidentified coelomycete with small unicellular conidia, which could be mistaken for rust spermatia, developed on some of the inoculated phyllodes. Similar pycnidia were sometimes seen on galls, and it is suggested that infection of phyllodes in Gathe's trials was caused by such conidia, present as contaminants in teliospore preparations, and not by *U. tepperianum*.

The existence of distinct genotypes of the fungus was confirmed by Morris (1987) who found significant differences in the diameters and lengths of teliospores collected from three host species, including *Ac. saligna*. When teliospores from the different host species were inoculated onto a range of *Acacia* spp., they only formed typical galls on the host species from which they were collected. Reactions on non-host species varied from a hypersensitive response to abnormal, partially necrotic galls. A representative range of 20 African *Acacia* species and four *Albizia* species were unaffected following inoculation with teliospores from *Ac. saligna* (Morris, 1987).

The fungus is autoecious and has a microcyclic life cycle, producing only two spore states, spermatia and teliospores. The infection process, gall development and the cytology of the fungus have been studied in detail by Burges (1934, 1935) and Morris (1987). Young expanding leaflets, phyllodes, stems and reproductive tissue are susceptible to infection by the fungus. Infection

may sometimes become systemic in the growth tip of a shoot, resulting in the formation of a witches' broom.

On *Ac. saligna*, galls may be annual or perennial. Heavily infected plants may bear several hundred galls and witches' brooms, and produce few phyllodes, flowers and pods. Branches often break when weakened by galls and severely affected plants appear to be more susceptible to drought stress. In confirmation of the latter observation, inoculated seedlings, bearing several galls, were found to have significantly smaller root systems than uninoculated seedlings (M.J. Morris, unpublished data, 1988).

Introduction of U. tepperianum *into South Africa*

The first three releases of this fungus in South Africa were made during June and July 1987, on stands of *Ac. saligna* near Fisantekraal (33°45'S 18°45'E), Fishhoek (34°07'S 18°26'E) and Worcester (33°42'S 19°28'E). Trees at more than 30 further locations throughout the Southwestern and Southern Cape Province were inoculated during 1988 and 1989. Inoculum was collected from galls on seedlings grown in a glasshouse and inoculated with an isolate of the fungus from Busselton (33°40'S 115°20'E), Western Australia. At the first three sites, young tip growth of 30 branches was inoculated with a teliospore suspension (1×10^5 spores ml^{-1}) containing 0.05% Tween 80, and covered with foil-lined plastic bags for 24 h, while at the other sites 50 branches were inoculated.

Between 12 and 296 galls developed at each site following inoculation while a 4–58 (average 21) fold increase in the number of galls was recorded after the first year of natural dispersal at 13 sites where galls were counted. Approximately 5000 was the highest number of galls recorded at a site, with dispersal recorded up to 200 m from the inoculated trees. All the flowers on several young trees became infected and were replaced by galls at some of the sites. These trees died within a few months of the appearance of galls.

It is still too early to assess the effectiveness of this fungus for the biological control of *Ac. saligna* in South Africa. Establishment of the fungus and the initiation of natural spread at most of the sites is, however, encouraging. As the pathogen completes only one life cycle per year, initial spread is expected to be slow, and it may be 5–10 years before the fungus reaches an exponential rate of spread and any influence on populations of the weed can be observed.

HAKEA SERICEA

For details of the history of its introduction into South Africa, current distribution and introductions of insects for biological control of *Hakea sericea*, refer to Kluge and Neser (1991, this volume).

One of the first records of a disease attacking *H. sericea* was made by Taylor

(1969) who observed that: "During the last two years, for instance, a 'disease', presumably caused by a local fungus, has killed off two large patches of *Hakea* in the Southwestern Cape". Interest in this disease increased following the death of many *H. sericea* plants on several farms in the Langkloof valley, in the Southern Cape Province, during the 1970s. Several fungi, including *Pestalotia* spp., *Rhinotrichum* sp., *Cephalosporium* sp. and a *Haplosporella* sp., were isolated from infected stem material (G.C.A. van der Westhuisen, unpublished data, 1975). In inoculation trials, none of these fungi produced typical symptoms, although the *Cephalosporium* sp. resulted in some mortality of inoculated seedlings. Kruger and Haynes (1978) later reported extensive mortality of plants in the Stettynskloof area, near Worcester in the Southwestern Cape Province. A fungus, *Phytophthora cinnamomi* Rands, was isolated from a dead plant and implicated as a possible cause of the mortality.

Common symptoms on affected plants include stem and branch lesions, from which copious amounts of gum exude, and a progressive die-back of shoot tips. On stems and branches, the bark around a lesion may be killed, but the wood does not appear to be affected. Plants may be killed if lesions occur on the lower regions of the main stem and the fungus girdles the stem. During a more intensive study, initiated in 1980, a fungus, *Colletotrichum gloeosporioides* (Penz.) Sacc., was consistently isolated from young gummosis lesions on affected plants from the Eastern, Southern and Southwestern Cape Province (Morris, 1982). This fungus caused typical symptoms on inoculated *H. sericea* plants, but did not affect wound-inoculated plants representing 11 indigenous genera in the Proteaceae (Morris, 1982). More recently, it was found that a wider range of crop and indigenous fynbos plants were unaffected when seedlings of these were sprayed with a spore suspension of the fungus (M.J. Morris, unpublished data, 1990). Strains of *C. gloeosporioides* cause shoot-tip die-back of two other invasive *Hakea* spp., *Hakea gibbosa* (Sm.) Cav. and *Hakea suaveolens* R. Br. (M.J. Morris, unpublished data, 1981). These strains are, however, culturally distinct from the strain occurring on *H. sericea* and do not form gummosis lesions on stems and branches of their hosts.

Hakea sericea from the Southwestern and Southern Cape Province appears to be uniformly susceptible to isolates of the fungus from *H. sericea*, but less disease occurs on plants around Grahamstown (33°18'S 26°32'E) in the Eastern Cape Province (S. Neser, personal communication, 1980). When plants grown from seed collected near Grahamstown were planted in an area with a high level of natural infection near Stellenbosch (33°56'S 18°51'E) in the Southwestern Cape Province, these plants appeared to be more resistant to the pathogen (M.J. Morris, unpublished data, 1981). This indicates that populations of the weed around Grahamstown may be distinct from those found elsewhere, and may be the progeny of a separate introduction of *H. sericea*.

Methods of culturing the fungus and for the production of a dried spore

preparation have been developed. Various methods of inoculating plants, including wound inoculation, the use of spore-coated lead pellets fired from a shotgun, and spraying a spore suspension from a helicopter-mounted spray apparatus or a knapsack-sprayer, have been attempted (Morris, 1982, 1983). All inoculation methods were successful, but not all were feasible or cost effective on a large scale. Wound inoculations are currently being employed on a limited scale in certain of the infested areas under the jurisdiction of the Cape Provincial Nature Conservation Department (G. Ruddock, personal communication, 1988). Game guards who routinely patrol these areas inoculate a zig-zag pathway of plants through infested areas. The fungus is then allowed to spread naturally. Spraying mature plants with a helicopter-mounted spray apparatus only resulted in 32% of the plants becoming infected, compared with 19% natural infection of uninoculated plants (Morris, 1983). A possible reason for this low level of infection is that conidia of the fungus rapidly lose viability on exposure to direct sunlight (Morris, 1983). Knapsack-sprayer application of spore suspension was more successful, presumably because the greater degree of run-off carried spores into protected sites on the plant. Spore suspensions would, therefore, be best applied during overcast, rainy weather. However, this is seldom practical on the mountainous terrain infested by *H. sericea*. This research invoked the interest of the Upjohn Company, Kalamazo, USA, who air-freighted 5 kg of dried spore preparation to South Africa, some of which was used in the above trials.

More recently, a method of controlling young seedlings of *H. sericea* emerging after wild or controlled fires has been developed (Morris, 1989a). In a series of trials carried out over two seasons in the Southwestern Cape Province, a dried preparation of fungal-colonized wheat bran pieces, which were spread over plots in seedling-infested areas at a rate of 10 kg ha^{-1}, resulted in 30–98% mortality after 4 months (Fig. 2). Mortality following inoculation in May or June, when seedlings were less than 10 cm high, was higher (93–98%) than inoculations made later when seedlings were older and the remaining wet season shorter (30–36%). The fungus sporulates profusely on the dispersed bran following a period of rain and the spores are dispersed by rain splash to the tips of the seedlings which then become infected. The results of these trials suggest that this method of controlling young seedlings can be successfully applied in the Southwestern Cape Province where frequent periods of rain correspond with the germination and early development of seedlings. Mass production and registration of a suitable inoculum formulation is currently being investigated by private industry.

In areas where climatic conditions favour disease development, a high level of mortality may occur naturally. In several instances, mountain slopes have been cleared of *H. sericea* by the disease. As a guide to management programmes, Richardson and Manders (1985) developed a transition matrix model, utilizing the current infection state of a stand of *H. sericea* to deter-

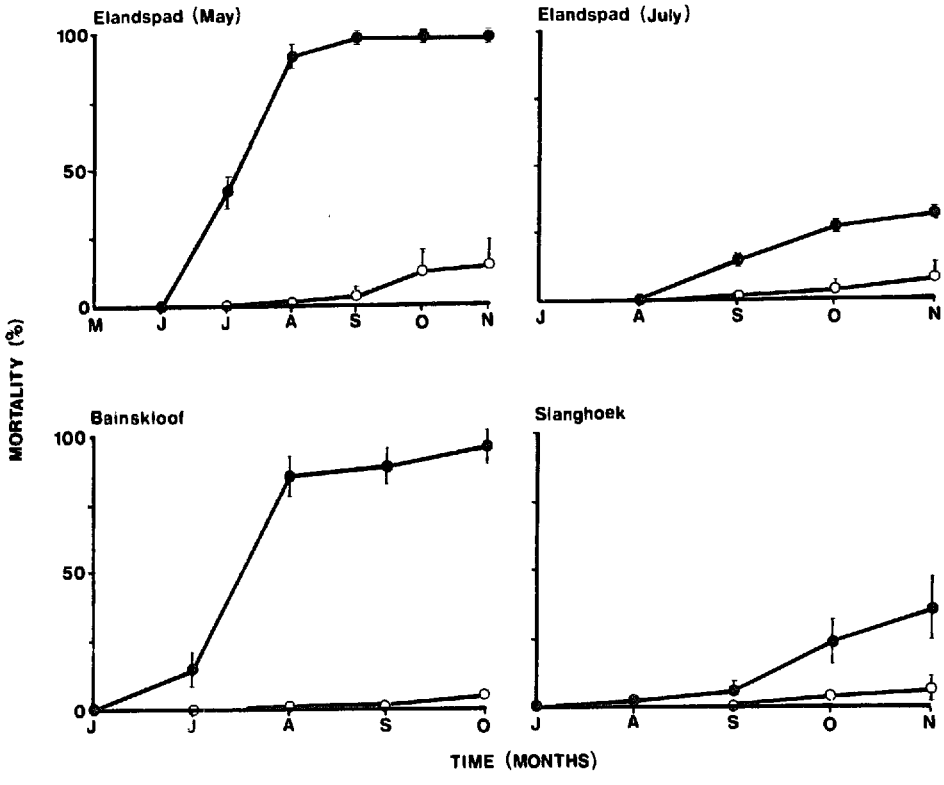

Fig. 2. Mortality of *H. sericea* seedlings following inoculation with a wheat bran formulation of *C. gloeosporioides* at three sites on mountains in the Southwestern Cape Province. (●——●) mean percentage mortality in inoculated plots; (o——o) mean percentage mortality in uninoculated control plots; bar = 1 × standard error (from Morris, 1989a).

mine its fate. The model determines whether the seed crop is below a critical level and whether or not it is necessary to fell a stand prior to burning. Unfortunately, the model was based on data from one locality only. Incorporation of data from other areas, under different climatic conditions, may increase the applicability of the model.

This apparently host-specific strain of *C. gloeosporioides* can thus be a useful tool in the control of *H. sericea*. The value of introducing the fungus into strips of maturing hakea plants, as is currently being done by the Cape Provincial Nature Conservation Department, needs to be assessed. Results of trials on the use of the fungus for the control of young seedlings emerging following a fire are very encouraging, but the method has not yet been applied on a large scale.

AGERATINA SPP.

Ageratina adenophora (syn. *Eupatorium adenophorum* Spreng. and *E. glandulosum* H.B. and K.) and *Ag. riparia* (syn. *Eupatorium riparium* Regel)

are perennial shrubs, 1–2 m high and less than 1 m high, respectively. Both are natives of Central America. Little is known about the early introduction of these plants into South Africa, but according to Hilliard (1977), *Ag. adenophora* was recorded in the Eastern Transvaal in 1958 and in Natal in 1964, while *Ag. riparia* was recorded as naturalized in Chase Valley near Pietermaritzburg, Natal, in 1955. Both are probably escapees from cultivation. *Ageratina adenophora* is now also known to occur in the Magaliesberg area of the Northern Transvaal (S. Neser, personal communication, 1988) and along streams and in moist areas in the Southwestern Cape Province. *Ageratina riparia* has spread into the Hilton and Sweetwaters areas around Pietermaritzburg.

Both species seed prolifically and trailing branches root when they come into contact with the soil, resulting in the formation of dense stands. It is for this reason that *Ag. adenophora* is regarded as a threat to the Natal midlands forestry industry (Bredenkamp, 1980). Both plants, when eaten by horses, result in the formation of fatal lung lesions (Fuller, 1981; O'Sullivan et al., 1985). Although their distribution is still relatively limited in South Africa, both plants are important weeds in several other countries, including Australia, Hawaii and India (Auld, 1970; Trujillo, 1985; Tripathi and Yadav, 1987). Their naturalization in South Africa is, therefore, of concern and biological control programmes were initiated in an effort to control the weeds before they become more widespread (see Kluge, 1991, this volume).

Biological control of Ag. adenophora

A gall-forming tephritia fly, *Procecidochares utilis* Stone, previously released in Australia, India, Hawaii and New Zealand (Julien, 1982), was released and established in Natal and the Southwestern Cape in 1984 (Bennett, 1986). Another organism, a leaf spot pathogen, accidentally introduced into Australia, probably along with a shipment of *P. utilis* from Hawaii, also contributes to the partial control of the weed in Australia (Dodd, 1961; Haseler, 1966; Auld, 1969). Dodd (1961) records the pathogen as *Cercospora eupatorii* Peck. However J. Walker (Biological and Chemical Research Institute, Rydalmere, N.S.W., Australia, personal communication, 1985) examined the fungus on infected leaf material from Queensland and from Maui, Hawaii, and found that although the fungus from the two localities was similar, it differed from the type material of *C. eupatorii* and should more correctly be placed in the genus *Phaeoramularia*, probably as a new species.

A single spore isolate of the pathogen, obtained from infected leaf material collected in 1984 at Upper Pimpama River, Queensland, Australia, by G.P. Donnelly, Alan Fletcher Research Station, Queensland, was used in host range studies and in the eventual release. A number of closely related plants and more distantly related species in the family Asteraceae were tested for suscep-

tibility to the fungus (Morris, 1989b). All plant species tested, apart from *Ag. adenophora*, were immune to the fungus.

The necessary approval for release of the pathogen in South Africa was obtained and it was inoculated onto infestations of the weed in the Jonkershoek valley (33°58'S 18°57'E) near Stellenbosch in December 1987, and in Queen Elizabeth Park (29°34'S 30°20'E) on the outskirts of Pietermaritzburg, as well as in the weed garden on Cedara Agricultural Experimental Station (29°32'S 30°15'E), in January 1988. A further three releases were made during February 1989 in the Hilton, Sweetwaters and Blackridge areas in the vicinity of Pietermaritzburg. At this time, the pathogen was well established at Cedara and at Queen Elizabeth Park, where it was partially defoliating plants and had spread at least 30 m from the inoculated plants. Although primary lesions developed on inoculated leaves at Jonkershoek, little secondary spread occurred and the disease does not appear to have established there. This is not unexpected as the disease probably originates from tropical Central America (Julien, 1982) and is not adapted to the Mediterranean climate of the Southwestern Cape.

This project has been largely opportunistic from the outset and the effect of the pathogen on the weed is not being monitored at this stage. This is unfortunate as it appears that the pathogen can severely defoliate the weed and valuable information on the effects of a leaf pathogen on a weed population could be determined from this project.

Biological control of Ag. riparia

Leaves of *Ag. riparia* infected with a leaf pathogen, originally described as *Cercosporella* sp. (Trujillo, 1985), were obtained from Dr. A.P. Martinez, University of Hawaii, in November 1986. This pathogen, originally introduced into Hawaii from Jamaica in 1975, reduced weed populations on the islands of Oahu and Maui by 80% within 9 months in areas favourable to the disease, and by more than 50% after 8 years in unfavourable localities (Trujillo, 1985). The fungus causes spreading white lesions on the leaves which later become necrotic and may result in necrosis of the entire leaf. The white appearance of the lesions is caused by the presence of fascicles of conidiophores and masses of sporidia.

Recently, two publications appeared describing the fungus as two different species of *Entyloma* de Bary, namely *Entyloma ageratinae* Barreto and Evans (Barreto and Evans, 1988) and *Entyloma compositarum* Farlow (Trujillo et al., 1988). Before the introduction of this fungus into Hawaii, Trujillo (1985) tested 40 plant species in 29 families for susceptibility to the fungus. Morris (1989c) further tested a number of closely related plants in the subtribe Eupatoreae, including some South African native species, and a number of recorded hosts of *E. compositarum*. Contrary to Trujillo's (1985) results, small,

typical sporulating lesions did develop on *Ag. adenophora*. All other species were immune to infection. Approval for release of this pathogen in South Africa was obtained and, during November 1989, ten infected plants were planted out at five weed infestations around Hilton (29°33'S 30°19'E) in Natal. By April 1990, the pathogen had spread throughout the weed infestations surrounding the inoculated plants and the plants were severely defoliated.

CONCLUSIONS

It is still too early to evaluate the success of the above projects. However, initial indications are that *U. tepperianum* will establish and spread throughout the distribution of *Ac. saligna* in South Africa. It, therefore, appears that the multiple introductions of different forms of the plant from Australia may not influence the efficacy of the pathogen. At the current rate of spread of the pathogen it may, however, be at least 10 years before any significant effects on weed populations can be detected and measured. Artificial inoculation of plants at many more localities may help to accelerate the initial spread of this pathogen.

The introduction of pathogens against *Ag. adenophora* and *Ag. riparia* was largely opportunistic, but should the spread of these weeds be curtailed at this early invasive stage, much time, effort and expense in the future may be saved. It would be beneficial if this approach of introducing control measures at an early stage of a weed's establishment could be applied more often. The above three projects have established a precedent for the introduction of selected exotic pathogens into South Africa and surveys for suitable pathogens attacking *Ac. cyclops*, *Chromolaena odorata* (L.) K. and R., *Rubus cuneifolius* Pursh. and *Solanum mauritianum* Scop. have been initiated.

Research into the control of *H. sericea* with a locally occurring strain of the fungus, *C. gloeosporioides*, has emphasized the need for the development of imaginative methods for applying fungi, particularly those with relatively fragile propagules, to weed populations. The use of a solid substrate, from which freshly produced conidia can be dispersed to host plants during conditions favourable for disease development, was effective for the control of *H. sericea* seedlings. Through this research, the interest and involvement of private industry in biological control and the development of mycoherbicides in South Africa has been stimulated. Earlier involvement of industry in the hakea project may, however, have facilitated the more rapid development of a registered mycoherbicide.

These early results are encouraging and indicate that the search for suitable pathogens, local and exotic, for other invasive weeds should be stepped up. The development of mycoherbicides for the control of crop weeds, difficult to control by conventional methods, should also receive attention.

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