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Ecology and Control of Cereal Cyst Nematode (*Heterodera avenae*) in Southern Australia

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Abstract: The ecology and control of cereal cyst nematode in southern Australia is reviewed. The wide distribution of *Heterodera avenae* in Victoria and South Australia is due largely to movement of cysts by wind during dust storms. The fungus *Rhizoctonia solani* frequently is associated with the nematode in a disease complex in wheat, and disease symptoms are most severe on lighter or well structured soils. Crop rotations which include periods of fallow, or of nonhost crop reduce population levels of *H. avenae* and improve yields. Early-sown crops (April–May) are less severely damaged than late-sown crops (June–July). The resowing of damaged wheat crops or the application of nitrogenous fertilizers rarely improve grain yields. 'Katyil,' the world's first wheat cultivar bred specifically with resistance to *H. avenae*, has been released in Victoria. Chemical control of the nematode in cereals is now commercially feasible, and five nematicides are registered for use by growers.
Key words: wheat, crop rotation, resowing, fertilizers, resistance, nematicides.

The cereal cyst nematode (*Heterodera avenae* Woll.) is the most important pathogen of wheat and other cereals in the southern wheatbelt of Australia (28). More than 2 million hectares of Victoria and South Australia are infested, and grain yield losses in wheat alone are estimated to be worth $AUS 72 million annually (10).

The annual rainfall in this region is low, ranging from 240 mm in the north to 600 mm in the south. The heaviest rains occur during the winter months (May–September). Most of the southern wheatbelt was cleared of its native vegetation (predominantly *Eucalyptus* spp.) in the late 1800s. The land was used initially to graze sheep for the production of wool and from the 1870s for growing cereals.

Heterodera avenae was first reported in Australia in 1930 (17), but it is thought to have been introduced from Germany in

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the late 1800s (28). Despite the apparent ease of dissemination of *H. avenae* by wind, not all wheat-growing regions adjacent to diseased areas became infested. Both distribution of the nematode and symptom expression are clearly influenced by soil type (25,27,28). In Victoria and South Australia *H. avenae* can be detected only in sandy soils and clay loams; it is not found on heavy, poorly structured soils in other wheat-growing regions adjacent and climatically similar to infested areas. There is a consistent association of increased disease severity with lighter soils (28,39).

In the last 15 years there has been a realization that disease patches in cereal crops are caused by a combination of nematode and soil-borne fungi such as *Rhizoctonia solani* Kuhn. Experiments have shown that in wheat the effects of these pathogens in combination are greater than with either pathogen alone (30,31).

Much research has been conducted in Australia on the biology, ecology, and control of *H. avenae* (10); it is not surprising that most of the effort has been directed at achieving practical control measures. Various potentially useful methods have been evaluated, and the results of some of this research are presented here.

Crop Rotation

Most farmers in the cereal-producing areas of southern Australia derive their incomes from the production of both wool and cereal grains. The rotations practiced need to be compatible with both enterprises as greater emphasis may be placed on one commodity or the other, depending on their relative net returns.

Until the 1930s rotations included a pasture phase based on native grasses, interspersed with fallows and cereal crops. The results of the first Victorian rotation experiments (33) showed that a period of 3 years under fallow or nonhost crop, such as peas or natural pasture, markedly reduced nematode populations. These rotations were not widely adopted, as long-term fallows were impractical and the size of the average farm limited the area that could be left uncropped. Peas were not popular as an alternative crop, and cropping under fallow–wheat, or fallow–wheat–oats continued to be practiced.

In the early 1950s it was evident that increasing numbers of crops of wheat, oats, and, to a lesser extent, barley were being severely damaged by *H. avenae*. The yield losses were greatest where heavy cropping had resulted in a high level of nematode infestation accompanied by depletion of soil nitrogen. At about the same time, the practicability of growing barrel medic (*Medicago tribuloides* Desr.) was demonstrated, and this made it possible to vary rotational practices by including medic ley pastures. Wheat yield following wheat–fallow was increased after 2 years' natural pasture plus fallow, but almost doubled after 2 years' barrel medic plus fallow (32). In practice, barrel medic can be replaced by any legume pasture species provided it is climatically suited to the district. The value of such rotations in reducing nematode numbers is lost, however, if the legume pasture contains a high proportion of graminaceous weed species (29).

Nonhosts are effective both in producing an economic return to the landholder and in reducing nematode numbers. However, disease symptoms are most severe and yield losses are greatest on farms of limited size (260 ha or less) where a close rotation (usually fallow–wheat) has depleted soil fertility and allowed the build-up of a high nematode population level. Under present conditions, it is impossible for a grower to lengthen his rotation without loss of income. In this situation, some growers have turned to barley as an alternative crop.

More recently, rotations have been examined in which various cultivars of oats, barley, and wheat were followed by fallow–wheat (2). The initial grain yield varied with the cereal cultivar grown, but the highest yields were obtained from barley cultivars followed by wheat, with the lowest yields from the oat cultivars. Wheat produced the greatest number of *H. avenae* cysts, followed by barley, with oats having the lowest numbers. In the first residual wheat crop, the yield following oats (in particular 'Avon') was greater than after wheat or barley. A similar trend was evident in the second residual wheat crop 2 years later. Avon produces few cysts (21,29), but its growth is reduced because the roots are not resistant to larval invasion (27) and its grain yield may be low. Additionally, the

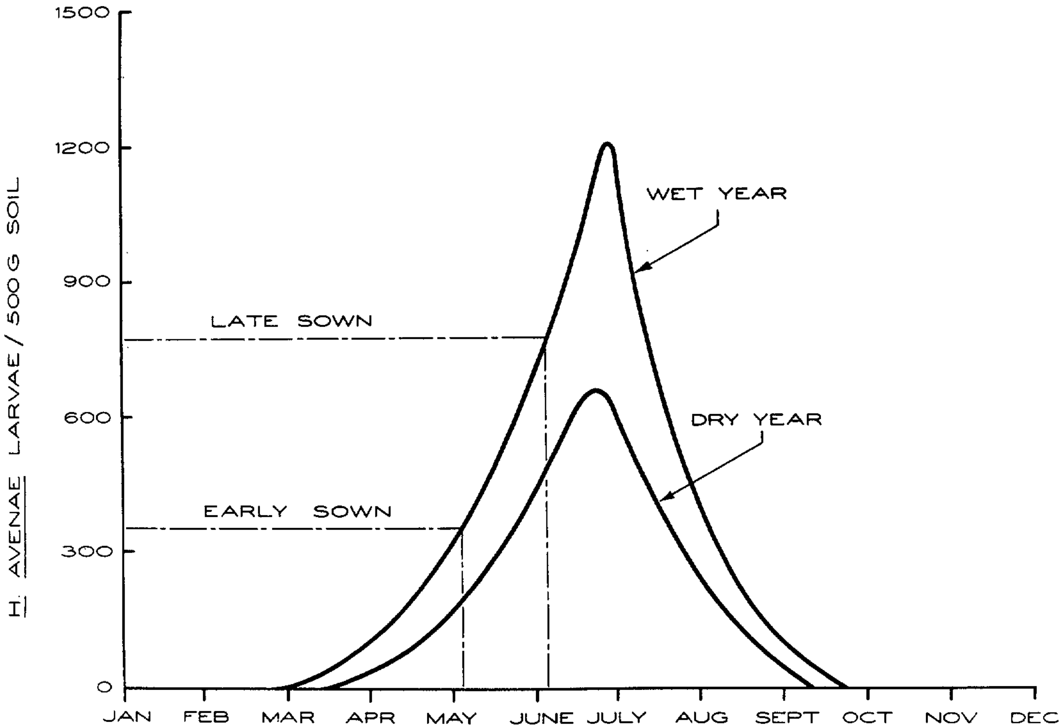

FIG. 1. Relationship between time of sowing and population levels of *Heterodera avenae* in wet years and dry years in southern Australia.

economic returns for barley and oats are generally lower than for wheat, and because their markets are limited, they are not popular with growers. Individual growers may benefit by using Avon in rotation with wheat, but the long-term economics in a substitution of fallow–wheat–oats (Avon), for fallow–wheat, needs investigation.

TIME OF SOWING

Long-term experiments in the Mallee and Wimmera districts of Victoria have shown that maximum wheat yields are obtained when crops are sown in May and June, respectively. No account was taken of the presence or absence of *H. avenae* when considering optimal sowing times. Forty years ago it was shown that on nematode-infested land, early sown crops provided better yields than later sown crops (33), and this has been confirmed during disease surveys of cereal crops (27).

In a recent experiment to examine the effects of time of sowing and nematicide application (14), we have shown that with the exception of aldicarb, nematicide application combined with early sowing did not increase grain yields. However, all nematicide treatments increased grain yields of late-sown crops, but the yields were lower than those obtained from early-sown crops without the application of a nematicide. A delay of 4 weeks in sowing resulted in a yield loss of 1 t/ha.

Under Australian conditions, the peak emergence of *H. avenae* larvae occurs toward the middle of July (8,26). In years with average rainfall there may be as many as 800 larvae/500 g soil by mid-July, but in years with above-average rainfall (e.g., 1968, 1972, 1973) this number can exceed 1,200 (Fig. 1). In wet years sowing as early as possible allows vigorous seedling establishment before the peak emergence of larvae in July. Early sowing is dependent on adequate rainfall in March and April to permit the cultivations required for weed control and seedbed preparation. Without adequate rainfall, soil cultivation is restricted, particularly in districts with sandy soils that are subject to wind erosion. In years with above average rainfall, soil cultivation may commence early thereby permitting early sowing.

Resowing

According to a South Australian recommendation (1), growers should resow severely infested wheat crops with barley, but there is no published evidence to support a claim for better economic returns from this practice. Barley cultivars are, however, more tolerant than wheat or oats to attack by *H. avenae* (12,27).

We have examined weed control, resowing of the crop, and application of additional amounts of fertilizer in an attempt to improve the growth and yield of crops infested with *H. avenae* (2). Only a combination of chemical weed control and nitrogen fertilizer increased grain yields compared with the untreated control; neither treatment alone improved yield. Increasing the application rate of phosphorus fertilizer at seeding also failed to increase yields. Resown wheat and barley yielded less than the non-resown wheat crop. Resown barley outyielded resown wheat, but neither crop responded to additional phosphorus fertilizer applied with resown seed. Resowing with barley or wheat reduced cyst numbers compared with the non-resown wheat crop. There were fewer cysts on barley than on wheat, and this reduction in numbers was independent of phosphorus application. Infested wheat crops are rarely resown in Victoria. Grain yields from resown barley or wheat are consistently lower than those from non-resown, infested crops. However, when seedling growth is so severely reduced that resowing is considered essential, barley must be preferred to wheat to maximize grain yield and minimize the build-up of nematode population levels (18).

Application of Nitrogenous Fertilizers

Nitrogenous fertilizers are not widely used on cereals in southern Australia. On nematode-free land in the Mallee district of Victoria, the use of nitrogen fertilizer is recommended only in wet years and on light sandy soils (22), but it is sometimes used on the heavier soils of the Wimmera. The most severe nematode damage occurs in years with above average rainfall (30), when available nitrate nitrogen is leached down the soil profile beyond the reach of roots stunted by *H. avenae.*

We have examined the effectiveness of applied nitrogen in alleviating yield losses from *H. avenae* in the Mallee (2). Two sources of nitrogen (urea and ammonium sulphate) were applied at several rates, either at seeding, or at 6 weeks after seeding. Nitrogen did not have a major influence on grain yields, although small increases were recorded with increasing rates of nitrogen. These increases were independent of the nitrogen source and were greater when nitrogen was applied at seeding than when applied 6 weeks after seeding.

Compared with the nil nitrogen treatment, cyst numbers were not affected by low (25 kg N/ha) rates of fertilizer, but the numbers were increased by high (100 kg N/ha) rates of ammonium sulphate, especially when applied at seeding. Cyst numbers were not affected by urea at either time of application. The reason for the lower numbers of cysts with urea compared with equivalent rates of ammonium sulphate is unclear, but if nitrogen is to be applied, urea should be the preferred source of nitrogen. The results of our experiments show that the recommendation not to use nitrogen fertilizers on land free of *H. avenae* is equally applicable to infested areas. Our results also support the conclusion that in years of nitrogen response, application at seeding is more effective than application at some later time (23).

Resistant Cultivars

The possibility of using resistant cultivars to control *H. avenae* was first considered in Australia in the mid-1930s (33). Sources of resistance were reported in oats but not in wheat or barley. Thirty years later additional sources of resistance were confirmed in oats and resistance was discovered in barley, but all the wheats tested were susceptible (12). Concomitantly, Australian studies on the occurrence and distribution of pathotypes of *H. avenae* were commenced (5,9). A pathotype first recorded in Victoria and subsequently detected elsewhere in Australia (11) was found to be different from the many other pathotypes of *H. avenae* recognized internationally (35). Regrettably, most of the oat and barley cultivars used in European resistance breeding programs are susceptible to the Australian pathotype of *H. avenae.*

The first source of resistance in wheat, the cultivar Loros, was reported in Denmark in 1966 (34). Since then Australian researchers have confirmed the resistance of Loros and identified five additional resistant wheats (3,4,24,36–38). Three of them are cultivars of *Triticum durum* Desf., a species of little value in Australian wheat breeding programs. Spring wheat (*T. aestivum* L., AUS 10894—from the Australian Wheat Collection), used as a parent in a backcross program, has resulted in Katyil, the world's first wheat cultivar specifically bred with resistance to *H. avenae* (16). In South Australia a resistant barley cultivar, Galleon, was released in 1981 (11), and other resistant cultivars of wheat, oats, and barley are being evaluated.

Chemical Control

Chemical control of *H. avenae* in cereals has been enthusiastically adopted by Australian growers. The possibility of using nematicides was first considered in Victoria in the mid-1960s (13). Initial experiments with fumigants (ethylene dibromide and dibromochloropropane) and nonvolatile (aldicarb and methomyl) nematicides resulted in grain yield increases of 200% or more in some situations. Despite these results, suggestions that chemical control of *H. avenae* over large areas was economically feasible were greeted with skepticism.

In other experiments the effectiveness of a range of nonvolatile nematicides and their possible methods of application were evaluated (6,7,20). The results showed that placement of small amounts of nematicide in granule form with the seed in the drill row controlled *H. avenae.* It was important, however, that the nematicide be applied at seeding to provide the early protection necessary for the successful establishment of young wheat seedlings (6). It was impractical to apply the nematicide as a preplant treatment. Further experiments using soil sterilants (mixtures of methyl bromide and chloropicrin) demonstrated for the first time in Australia the yield potential of wheat in the absence of soil-borne pathogens (30). Grain yield increases of 2–3 t/ha were obtained.

By the mid-1970s little commercial interest had been shown in chemical control of *H. avenae,* and it was evident that nonvolatile nematicides were unlikely to be registered for use on cereals in Australia in the near future. Our efforts were redirected toward fumigant nematicides and their possible application at low rates in the drill row at seeding (15). The results obtained from applying dibromochloropropane (DBCP) were good, and equipment was developed to apply it through tubes attached behind the tines on the seeder. In 1977 when we were ready to recommend its use to growers, it was withdrawn from the market because of its adverse effects in humans.

In early experiments ethylene dibromide (EDB) was applied as a preplant treatment, but its use in the drill row at seeding was not attempted because of its possible phytotoxicity to wheat. However, when EDB was eventually applied in the drill row at seeding there were no signs of phytotoxicity, excellent control of *H. avenae* was obtained, and grain yields were improved (14,15). A precision applicator to dispense EDB was developed and is now marketed (19). In 1979 EDB (at the rate of 3.7 liters/ha) became the first nematicide registered for use on cereals in Australia. Following the registration of EDB there was intense activity culminating in the registration of four nonvolatile nematicides (terbufos, oxamyl, aldicarb, and carbofuran) for use on wheat. A variety of formulations permits growers a wide selection of application methods, including seed treatment (oxamyl, carbofuran), application through a granule applicator or small seeds box (aldicarb, terbufos, carbofuran), application as a mixture with fertilizer (terbufos), and application as a liquid in the drill row (EDB, carbofuran flowable). In the 5 years since chemical control became commercially available, the area treated with nematicides has grown to 100,000 hectares, and it is likely that in 1984 this area will increase to 250,000 hectares or more. The development in 1980 of a simple bioassay (40) has assisted growers in their decision as to whether chemical control of *H. avenae* is warranted on their properties.

Conclusions

The economic losses caused by *H. avenae* are clearly recognized, and methods of control are being developed.

Crop rotation is a useful means of reducing nematode numbers, but it has limited application, particularly on farms of limited size. In any case, growers want to intensify production of cereals, and rotations which include periods of pasture have lost popularity. Early sowing has distinct advantages, but it can be adopted only in those years when seasonal conditions allow early preparation of the seedbed. In general, current agronomic practices cannot be manipulated easily to provide the desired level of control of *H. avenae*. There is a move by some growers toward practices such as minimal tillage and direct seeding, but little is known of their effects on nematode population levels and wheat yields.

The resistant wheat cultivars produced so far in our breeding programs have not matched the performance levels predicted for them. The wheat cultivar Katyil, while resistant to *H. avenae*, has the disadvantage of low yield potential. In the absence of *H. avenae* its recurrent parent cultivar, Olympic, has a yield advantage of 6%. Unless our future resistant cultivars have the potential to outyield current cultivars, there will be no incentive for growers to plant them. It may be more profitable to grow a susceptible cultivar and sustain the cost of a nematicide application than to plant a low yielding resistant cultivar.

The most convenient method to control *H. avenae* at present is to use a nematicide. In addition to the five already registered for use on cereals in Australia, several others are showing promise in field trials. With the various formulations available, growers now have a wide selection of application methods from which to choose. The prospects for control of *H. avenae* are by no means grim, and it seems likely that the future method of control will be one in which crop rotation, resistant cultivars, and nematicides will be integrated. Such an approach will allow use of the best features of each method.

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