Paper 8

WEED CONTROL IN MAIZE IN NEW ZEALAND

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INTRODUCTION

Weeds play a big part in maize production. The importance of controlling weeds to prevent yield losses in maize is universally recognised by agricultural researchers and maize producers alike. It has been reported that losses in yield of maize reach up to 45% in Germany, 30% in Russia, 50% in India and 40% in Indonesia if weeds are not controlled (Nieto, 1970). Very little data are available on this subject in New Zealand but, based on an average of eight trials, Matthews (1974b) estimated that the best weed control treatments gave rise to maize yields up to two and a half times that of unweeded plots. Yield increases of 70% were reported by Patterson (1960), and Cumberland *et al.* (1970b) concluded from a review of trial work that weed control not only increases the grain yield but also the number of plants surviving to harvest, and the number of cobs produced by each plant.

The yield losses discussed above arise from the competition of weeds with the maize crop. Competitive factors, in order of importance in maize-weed competition, are water, nutrients and light. Like many other crops, maize suffers the worst weed competition in the early stages of growth — the critical period is usually the first 30 to 40 days after emergence (Cumberland *et al.*, 1971; Remison, 1979). This is mainly because the young plant grows very slowly during the first 6 to 8 weeks. However, weeds can cause losses throughout the life of the crop, particularly under dry conditions. The common warm-zone grasses, eg. summer grass, paspalum and witchgrasses, are extremely efficient utilisers of water and can become serious competitors within the maize crop. Trial work in New Zealand has shown that broadleaf weeds usually depress maize production more than grass weeds (Cumberland *et al.*, 1971; Patterson, 1960). In general, the cost of controlling weeds in maize is substantial and economic maize production without weed control is a virtual impossibility.

MAJOR WEED SPECIES IN MAIZE

The composition of the weed flora in maize crops has been influenced considerably over the years, by cultivation and the use of selective herbicides. Chemical weed control produces the most rapid change in the composition of weed communities, particularly when selectivity depends on physiological resistance. Thus the major weed spectrum can vary widely, and is usually influenced by the previous site history. During the first and possibly the second year out of pasture, broadleaf weeds are the main problem in maize. However, in subsequent years and when the earlier germinating broadleaf species have been removed, grass weeds become the major problem (Farrell, 1977; Matthews, 1975). The continuous use of atrazine in maize crops has been one major factor in the shift of the weed spectrum to Panicoid grass species and some persistent perennial broadleaf weeds, due to their physiological tolerance to this herbicide (Matthews, 1975; Rowe *et al.*, 1976; Rahman, 1982b). Although McKee (1955) referred to barnyard grass as being a problem in the Gisborne area, it was not until 1962 that Thompson first presented trial data on their control and made reference to the growing importance of warm-zone grasses.

Table 1 summarises the common broadleaf and grass weeds of maize crops in New Zealand. These include both annual and perennial species. It must be emphasised that many of these species are not those most difficult to control but rather those which are most prevalent. Widespread and repeated use of the same herbicides may result in an increase in the relative importance of certain tolerant or semi-tolerant species such as fathen, couch etc.

MECHANICAL WEED CONTROL

Maize farmers in the past have been limited to tillage, cultivation and hand weeding for control of weeds. The official recommendation in the 1950's, by the then Department of Agriculture, included a total of two harrowings and four cultivations (Chamberlain, 1956). The first harrowing was to be done parallel with the rows about 8 days after sowing, and the second light harrowing was recommended as soon as the seedlings were above ground. The first cultivation was to be carried out when maize was 15 cm high, and three further cultivations at intervals of a few weeks were usually necessary.

Timing of cultivation is critical as it is ineffective when the soil is wet. McKee (1955) discussed alternative methods of cultural weed control on different soils in the Gisborne

Table 1: Major weed species of maize crops in New Zealand.

		Common name	Botanical name
broadleaf weeds	annuals	redroot	*Amaranthus powellii*
		black nightshade	*Solanum nigrum*
		willow weed	*Polygonum persicaria*
		water pepper*	*Polygonum hydropiper**
		fathen	*Chenopodium album*
		twin cress	*Coronopus didymus*
		shepherd's purse	*Capsella bursa-pastoris*
		thorn apple	*Datura stramonium*
	perennials	Californian thistle	*Cirsium arvense*
		field bindweed	*Convolvulus arvensis*
		greater bindweed	*Calystegia silvatica*
		broad-leaved dock	*Rumex obtusifolius*
grass weeds	annuals	summer grass	*Digitaria sanguinalis*
		smooth witchgrass	*Panicum dichotomiflorum*
		barnyard grass	*Echinochloa crus-galli*
		rough bristle grass	*Setaria verticillata*
		crowfoot grass	*Eleusine indica*
	perennials	couch	*Elytrigia repens*
		paspalum	*Paspalum dilatatum*
		Mercer grass	*Paspalum distichum*
		Indian doab	*Cynodon dactylon*
		onion twitch	*Arrhenatherum elatius* var. *bulbosum*

* Prevalent in peat soils and wet fields.

district and cited several cases where, in a wet season, crops had to be ploughed under because inter-row cultivation could not be carried out at the correct time. If earth and trash build up on the tines, the maize seedlings can easily be injured; soil compaction, loss of soil structure, wider row spacing, higher energy input and more costly equipment are other disadvantages of cultivation. Cumberland *et al.* (1970b) demonstrated clearly the depressive effect which inter-row cultivation could have on maize yields.

Although tillage and cultivation are still valuable practices in maize, in most countries they are now integrated with herbicide application. As a general rule, cultivation is now used in New Zealand mainly in those instances where control of weeds with herbicides has been inadequate.

The standard practice in the past was to use the row spacing which will comfortably accommodate the machinery required to go into the standing crop (Chamberlain, 1956; Graham, 1967). In other words, the row width was dictated by the need for cultivation, and the standard practice even in the early 60's was to sow in 90 cm rows (Graham, 1967). More recent research has shown that closer row spacings and a higher plant population produce higher yields (Douglas *et al.*, 1971). Closer row spacings have been possible, however, only as a result of the availability of suitable herbicides. Currently, maize is sown in 76 cm rows, but McCormick and Douglas (1975) have suggested that with herbicides available for complete weed control, even closer row spacing is possible although it may not be practical with the present machinery.

MINIMUM TILLAGE

The trend in many countries, particularly the United States, is toward minimum tillage, conservation tillage and zero tillage (no-till) practices (Behrens, 1975). In some instances, ploughing has now been eliminated — in no-till maize production, herbicides have replaced tillage implements, both for seedbed preparation and for destroying weeds in the crop. Matthews (1972) has put forward many excellent economic and ecological reasons why, with the advent of selective herbicides in maize, cultivation should be abandoned altogether. Early trials on minimum tillage by McCormick and Mackay (1973) gave disappointing results, mainly because of the lack of suitable machinery. Yortt (1982) obtained similar yields with minimum tillage and conventional systems but Hughes (1982) obtained lower yields with minimum tillage at some sites in the Manawatu. Results with green feed and silage maize have been more consistent and successful (Byford *et al.*, 1979; Williams *et al.*, 1971). It appears that better machinery is required for precision planting into uncultivated ground before the minimum tillage system is adopted by maize growers in New Zealand.

CHEMICAL WEED CONTROL

The primary role of herbicides in maize production is to reduce the requirement for cultivation, both for the establishment of the crop and for subsequent weed control. They also significantly reduce the energy input into maize production.

The use of selective herbicides for weed control in maize was initiated about 35 years ago with the introduction of hormone herbicides. Other chemicals have since been developed and at present about 15 herbicides are available for use in this crop. This array of chemicals enables New Zealand maize growers to effectively control most of the major weeds in maize.

History of chemical weed control in New Zealand maize crops

As early as 1951 Baigent reported the use of 2,4-D and MCPA in maize crops. He mentioned "several thousand acres of contract spraying in maize" and suggested that "the use of selective hormone sprays will be a great step". In 1955, McKee reported that while harrowing and inter-row cultivation were the main methods of weed control in the maize crops of the Gisborne district, more progressive growers were using 2,4-D. The recommendation at that stage was to use "½ to almost 1 lb a.e. of 2,4-D amine per acre as soon as possible after crop emergence", depending on growing conditions, the type of weed and the level of control desired.

The initial excitement wore off, as limited research and considerable grower experience over the next 10 years showed that 2,4-D was limited in its effectiveness to certain broadleaf weeds, and in many cases injured the maize plant. Meanwhile, the development of triazine herbicides was taking place overseas in the 1950's, and their use for weed control in maize was first reported in New Zealand at the end of that decade. Patterson (1960, 1961) showed that atrazine and simazine gave excellent control of broadleaf weeds, although this did not result in significantly higher yields than with the amine salt of 2,4-D. At rates of up to 1.6 kg/ha they did not control grass weeds. Atrazine was commercially released in New Zealand in 1963 and is still the standard herbicide for maize in this country.

Further research led to the recommendation of directed band spraying of atrazine at 4.5 kg/ha, with a non-ionic surfactant, for the control of barnyard grass, which was the main grass weed of Gisborne at that time (McPhail, 1968). However, with the repeated use of atrazine in the Gisborne region and the advent of maize growing in areas other than Poverty Bay, a different association of grass weeds emerged and this led to the search for specific grass weed herbicides.

Early trials with linuron (Sumich, 1963, 1966) showed good control of annual grass weeds, especially with a non-ionic surfactant, with reasonable crop safety when it was used as a post-emergence directed treatment. However, although this chemical has been registered for use in maize for several years, it has not gained wide acceptance owing to the need for special application equipment.

The major breakthrough for the control of grass weeds in maize came in the late 1960's in New Zealand, with evaluations of the thiocarbamate material butylate, and the acetanilide herbicides propachlor and alachlor. Cumberland *et al.* (1970b) and Mitchel (1970) reported that alachlor and propachlor gave satisfactory control of grass weeds, except under dry conditions. Butylate gave good results even under dry conditions.

The 1971 New Zealand Weed and Pest Control Conference received the largest ever number of papers on the control of grass weeds in maize. In addition to the three herbicides mentioned above, trial results with other materials including benthiocarb, prynachlor, chlorpropham, chloramben, chlortoluron, S 6115, cyanazine, cyprozine, terbutryn, prometryn and ametryn were presented by several authors. Matthews (1971) reviewed the activity of many of these herbicides on warm-zone grass weeds. The most common recommendation in the early to mid 70's was pre- or post-emergence atrazine with either propachlor or alachlor applied within 14 days of planting (Upritchard and Naish, 1974).

Although good control of most annual grass weeds was obtained with butylate (Kitchener, 1971), its lack of activity on perennial grasses such as couch, Indian doab and Mercer grass resulted in its replacement with the more versatile herbicide, EPTC + R−25788 in 1974. Around this time another acetanilide herbicide, metolachlor, was also introduced into New Zealand, and was shown to be more active and more persistent than alachlor, particularly where soil moisture was a limiting factor (Rowe *et al.*, 1976). Until 1983 metolachlor was commercially available in New Zealand only in combination with atrazine.

The only dinitroaniline herbicide commercially released for control of grass weeds in New Zealand was pendimethalin in 1981. Due to its effect on root growth, its margin of crop safety in hybrid seed and sweetcorn production is very small. In 1983, the Pesticides Board granted an Experimental Use Permit for Limited Sale to the new grass herbicide tridiphane (Dowco 356), which can be used for pre-emergence, early post-emergence or late post-emergence applications in maize. It has been reported to control grasses up to the one tiller stage. More field evaluations are presently being conducted with this chemical.

Control of broadleaf weeds

Non-Hormone Herbicides

Most broadleaf weeds can be effectively controlled from germination to young seedling stage with a pre-emergence or post-emergence application of 1.0-1.6 kg/ha of atrazine. The addition of crop oil or surfactants in post-emergence treatments increases the effectiveness of atrazine on weeds (Cumberland *et al.*, 1970b; Patterson, 1971; Upritchard and Naish, 1974). Maize is physiologically tolerant to all chloro-*s*-triazine herbicides, including atrazine, because of its effectiveness in detoxifying triazine molecules soon after they enter the plant (Couch and Davis, 1966).

Although many triazine herbicides have been evaluated in New Zealand over the years, cyanazine is the only material other than atrazine which has become commercially available in this country. Cyanazine is used on a substantial area of maize in the United States (Behrens, 1975) due to its shorter soil persistence and better control of certain grass weeds. However, due to its lower activity on broadleaf weeds it is not as useful as atrazine, particularly under continued rainfall with repeated weed germinations as often occurs in New Zealand (Matthews, 1975; Rahman *et al.*, 1980).

A more recent herbicide, registered for maize in 1983, is metribuzin. At rates of 400-600 g/ha it is to be used mainly for the control of broadleaf weeds (although it has some activity on certain grass weeds), and in combination with alachlor it has provided excellent weed control (Rahman *et al.*, 1981; 1983). Its use is limited to pre-emergence applications, and the lower crop tolerance to it and its higher cost compared to that of atrazine are the major disadvantages.

Bromophenoxim, developed for the control of atrazine-resistant fathen, was also granted registration for maize in 1983. Addition of atrazine, or a similar chemical, with bromophenoxim is necessary for control of other annual broadleaf weeds. Although bromophenoxim is selective to maize, some slight temporary scorching can occur occasionally. It has provided very promising control of fathen in field trials (Rahman *et al.*, 1983).

Hormone Herbicides

As mentioned earlier, 2,4-D was the first, and for many years the only, selective herbicide used for weed control in maize. Its usage has declined in recent years, as more effective herbicides have been introduced. Post-emergence applications of 2,4-D are still extensively used in the United States (Behrens, 1975) but in New Zealand its use is now limited to certain difficult-to-kill weeds.

2,4-D amine at 0.5-1.0 kg/ha can be used in emerged maize to control many young broadleaf weeds and to check Californian thistle. To minimise damage, it must be employed early and, if possible, drop nozzles should be used to reduce spray contact with the upper leaves. Serious injury, including onion-leafing, abnormal brace-root formation, lodging, stalk brittleness and poor seed set can occur if maize is more than 30 cm tall and growing rapidly at the time of spraying (Claridge, 1972; Matthews, 1974a; McKee, 1955). MCPA is less damaging to maize than 2,4-D but its effectiveness on weeds is also lower than 2,4-D.

Dicamba, at rates of 200-400 g/ha can be used for more tolerant weeds, such as field and greater bindweeds, volunteer potatoes and Californian thistle, when the crop is 15 to 25 cm high. However, its margin of crop safety is smaller than 2,4-D and both the rate and time of application recommendations must be followed strictly (Matthews, 1974a; Rahman, 1982a).

Table 2: Major herbicides for weed control in maize in New Zealand.

Common name	Trade name	Rate* kg ai/ha	Stage of application crop	Stage of application weed	Major weed spectrum**
butylate + R-25788	Sutan	4.3-5.8	pre-plant	pre-emerg.	grass weeds
EPTC + R-25788	Eradicane super	4.3-5.8	”	”	”
alachlor	various	3.5-4.0	pre-emerg.	”	”
metolachlor	Dual	2.9-3.2	”	”	”
propachlor	Ramrod	5.2-6.5	”	”	”
pendimethalin	Stomp	1.6-2.0	pre-to early post-emerg.	pre- to early post-emerg.	”
tridiphane*** (Dowco 356)		0.5-0.7	pre-to early post-emerg.	pre-to early post-emerg.	”
atrazine	various	1.0-1.7	pre-to post emergence	pre-to post emergence	broadleaf weeds
cyanazine	Bladex	1.0-1.5	”	”	”
metribuzin	Sencor	0.4-0.6	pre-emerg.	”	”
2,4-D amine	various	0.5-1.2	post-emerg.	post-emerg.	”
dicamba	various	0.4	”	”	”
bromophenoxim	Faneron	0.5	”	”	fathen
linuron	various	1.0-1.5	”	”	broadleaf & grass weeds

* use the high rate on soils high in clay or organic matter content, or for control of less susceptible species.
** Most grass herbicides provide limited control of some broadleaf weeds. Similarly some of the broadleaf herbicides will control certain annual grasses, especially at higher rates.
*** Experimental registration only at present.

Control of grass weeds

The list of herbicides available for control of grass weeds in maize has grown steadily since the late 1960's. At present about eight chemicals are registered in New Zealand for this purpose (Table 2).

Acetanilides

Of the two herbicides belonging to this group tested in early years, alachlor and propachlor, alachlor has proved to be the more efficient and is used widely at the present time. It is usually surface applied as a pre-emergence herbicide, and rainfall within 8 to 10 days after application is required for best results. It is not effective under dry conditions but its efficiency may be improved by soil incorporation, a practice which has been followed in recent years by some growers in the Gisborne region. The newest acetanilide is metolachlor, which is very effective in controlling annual warm-zone grasses and where soil moisture is limiting, it is more active than alachlor (Rowe *et al.*, 1976).

Both alachlor and metolachlor are well tolerated by maize. They are active primarily on annual grasses and suppress their germination and coleoptile growth by inhibiting protein synthesis (Deal *et al.*, 1980). Their effectiveness on perennial grass weeds is limited.

Thiocarbamates

Three thiocarbamate herbicides, butylate, vernolate and EPTC, have been used by maize growers in New Zealand. However, currently EPTC is the only material sold commercially, because of its greater effectiveness, particularly on the perennial grass weeds. Maize tolerance to thiocarbamates is only moderate but it has been increased by the addition of the antidote R-25788. All the thiocarbamate compounds affect leaf emergence from the coleoptile and the young shoot growth of germinating grasses.

The thiocarbamate herbicides are volatile and must be incorporated into the soil immediately after application. The incorporation can be done with discs, roller tillers, cultivators or power driven equipment and, if possible, in the same operation as spraying. Seed should not be planted in deep furrows as treated soil may be removed from the row resulting in irregular weed control.

Dinitroanilines

The only chemical belonging to this group registered for the maize crop in New Zealand is pendimethalin. It can be applied pre-emergence or early post-emergence, up to the first true leaf stage of weeds. If incorporated into the soil, it is very damaging to the maize crop. Seeds should be drilled to a minimum depth of 30 mm to avoid crop injury. Due to its lower crop safety margin compared to other grass herbicides, pendimethalin is registered for maize only, and it is not to be used on sweetcorn or on maize crops grown for seed.

Ureas

Linuron is the only member of this group currently registered for weed control in maize. When applied as a directed post-emergence spray, it controls some broadleaf and annual grass weeds. Contact with maize foliage often results in crop injury. As a pre-emergence spray linuron has not provided adequate control of grass weeds. Although results with some other urea herbicides, particularly chlorbromuron have been encouraging (Matthews, 1971; Rahman *et al.*, 1983), none have become commercially available in New Zealand for use in maize.

Non-selective herbicides

Two non-selective herbicides, viz. paraquat and glyphosate, have been used to control the weeds present before sowing or emergence of the crop. Neither of these materials should be allowed to come into contact with the maize plants. Glyphosate is sometimes used for control of perennial grasses before planting the crop. However, at recommended rates EPTC + R-25788 can provide reasonable control of these weeds in addition to the annual grasses. As a shielded post-emergence treatment, paraquat did not provide good control of annual grass weeds and glyphosate was still damaging to the crop (Rahman *et al.*, 1980).

Wide spectrum weed control

The weed spectrum in New Zealand is usually so varied that no single herbicide will provide adequate control. For this reason, a mixture of two herbicides applied either as a tank mix or sequentially has to be employed. The most common recommendation at present includes pre- or post-emergence application of atrazine (for broadleaf control) with one of the grass weed herbicides. Where weeds like couch, Indian doab and onion twitch are a problem, EPTC + R-25788 will provide a better control than the other grass herbicides. The specific selection of the herbicide will, however, depend on cost as well as the environmental factors as discussed below.

Influence of environmental factors

The effectiveness of herbicides is influenced by several environmental factors, including soil temperature and moisture, rainfall, soil texture and organic matter content.

Climatic factors

Rainfall is the main factor which determines the choice as well as the activity of the grass herbicide. All the pre-emergence herbicides are dependent on adequate soil moisture for their activity. Thus best results are obtained when they are applied to fine moist soil, and 10 mm or more of rain falls within a week of application. Under dry conditions, which often exist in the Gisborne region, pre-emergence materials such as alachlor, metolachlor and pendimethalin have proved inadequate. For this reason some Gisborne growers have incorporated alachlor for a more reliable weed control. However, this option cannot be used with pendimethalin.

The pre-plant soil incorporated herbicides are more effective under dry conditions, because incorporation distributes the herbicides through the soil and thereby reduces the need for rainfall. Heavy rain after incorporation and before the crop is established may dissipate these materials, resulting in short term weed control.

Soil factors

Generally, the effectiveness of herbicides is reduced in soils high in clay or organic matter content due to greater adsorption and thus reduced availability to plants (Rahman, 1976; Rahman *et al.*, 1978b; Rahman and Matthews, 1979). Soil factors are important for both pre-emergence and pre-plant soil incorporated herbicides, and the recommended rates for all of them are higher for soils high in clay or organic matter content. Soil acidity is also a very important factor in the case of triazine herbicides where activity is greatly increased in soils with a high pH value (Kells *et al.*, 1980). However, very few maize growing soils in New Zealand have a pH of 7 or higher (D.C. Edmeades, pers. comm.).

The highest recommended rates of alachlor, metolachlor, pendimethalin and EPTC + R-25788 have all provided effective weed control in soils with high organic matter levels (Rahman *et al.*, 1980). Fellowes and Scherp (1971) found adequate weed control from alachlor on high organic matter soils and suggested that on moist soils organic matter may not be a significant limiting factor. Observations suggest that sometimes the effect of high organic matter levels may not be apparent on the initial activity of these herbicides, but instead their persistence may be influenced, ie. the length of effective weed control may be reduced. Soils with high organic matter levels, including peaty soils, must therefore be treated with the highest recommended rate of the herbicide for best results.

Pre-emergence treatments of atrazine have not given sufficient control of broadleaf weeds in high organic matter and peat soils (Matthews, 1975; Rahman *et al.*, 1976b; 1980). It is best, therefore, to use post-emergence applications of atrazine or cyanazine on such soils for adequate weed control. Soil factors are of secondary importance when post-emergence foliar treatments are employed.

MAJOR PROBLEMS OF THE LAST DECADE

Specific weed problems

A limited number of weed species have shown an increase in both distribution and abundance in recent years and these have been largely restricted to maize fields. All of these were more prevalent in the 1970's — their distribution is now restricted due to greater awareness by personnel involved in the maize industry.

One of the notable species which caused considerable concern in the last decade was Johnson grass (*Sorghum halepense*). It was first recorded in maize in the Gisborne region in 1972. The first sighting in maize in the Waikato region was in December 1978, and by 1980 a total of 39 infestations were known in the region. As Johnson grass is a class A noxious plant in New Zealand there are definite guidelines for its complete eradication (MAF, 1983). Most of the known infestations are now largely under control and every effort is being made to eradicate this weed from New Zealand.

Another grass weed with a potential of being a serious problem, noted on about six maize farms in the last decade, is yellow nut sedge (*Cyperus esculentus*). The growers concerned are making every effort to control these infestations and to prevent it spreading to other properties.

Three broadleaf weeds of maize fields of recent significance, all belonging to different genera but often confused with each other due to many similarities, are Bathurst bur (*Xanthium spinosum*), apple of Peru (*Nicandra physalodes*) and thorn apple (*Datura stramonium*). These are all very competitivie with the maize crop if allowed to develop. They are all annuals and germinate in spring or early summer. As seedlings they are all susceptible to the hormone herbicides 2,4-D and dicamba, but infested fields may require a concentrated spraying effort for several years as their seed is usually persistent.

Another species related to Bathurst bur, Noogoora bur (*Xanthium pungens*), which is a difficult problem in Australia, has been present in the Matamata district for the past four years. Concentrated efforts are being made with the help of MAF and the Noxious Plants Officers to restrict and control this weed.

Californian thistle, field bindweed and greater bindweed have continued to cause problems for some maize growers, requiring an additional spraying with hormone herbicides and thus adding to the cost of growing the crop. In some areas of the Waikato, atrazine-resistant fathen has also become a problem in recent years.

Problem of resistance to herbicides

There is ample evidence to suggest that the strong selective pressure of repeated treatments with atrazine in continuous maize production has proliferated weed biotypes with remarkable tolerance to triazine herbicides. To date, similar mechanisms of resistance to atrazine have been developed overseas by several unrelated weed species, and this subject has recently been reviewed by LeBaron and Gressel (1982) and Rahman (1982c).

The only case of weed resistance to triazine herbicides noted in New Zealand so far has been that of fathen where atrazine has been applied for several years in succession to maize crops. The first instance was noted in the 1979-80 season, and limited work suggested that the fathen plants could tolerate from 35 to 60 kg/ha of atrazine. This problem has been of increasing concern since then, in many maize fields. The only trial work on the subject has been reported by Rahman *et al.* (1983), which confirmed the presence of atrazine-resistant fathen and showed some differences in the effectiveness of various herbicides on this weed. Replacing atrazine in the mixture by chlorbromuron or metribuzin improved the control of fathen. As post-emergence treatments, dicamba and bromophenoxim gave promising control of this weed.

Problem with the herbicide EPTC + R-25788

A problem of decreasing weed control with EPTC + R-25788 (hereinafter referred to as EPTC$^+$) was first observed in the 1977-78 growing season (Rahman *et al.*, 1979; 1981). This was the first reported occurrence of decreased weed control by EPTC$^+$ anywhere in the world.

Weed control efficiency appeared to decrease with continuous use of EPTC$^+$ in many fields. Resting the field from EPTC$^+$ for one season (using other herbicides) improved its performance in the next season but not to consistently adequate levels.

Laboratory and glasshouse research indicated that the reason for loss of activity of EPTC$^+$ was its faster rate of degradation in soils exposed to it in previous years. The original effectiveness was regained by eliminating or reducing the microbial activity, eg. by sterilising through steaming or chemical treatments (Rahman and James, 1983). It was also noted that mixing with an organophosphate insecticide, such as fensulfothion improved the effectiveness of EPTC$^+$ in the "problem" soils. Using this principle, the manufacturers of this herbicide screened a large number of compounds and later released a new formulation to which an inert carbamate material viz., R-33865 (*O,O*-diethyl-*O*-phenyl phosphorothioate) has been added to extend its activity. This new formulation appears to have overcome the problem (Obrigawitch *et al.*, 1982; Rahman and James, 1983) and it was registered for sale in New Zealand in 1981.

Problem of herbicide residues

All herbicides used principally for grass weed control in maize have a relatively short residual life. Alachlor, for example, persisted in amounts toxic to susceptible bioassay species for only 10 to 12 weeks at a rate of 4 kg/ha, depending on the soil organic matter level (Rahman *et al.*, 1976a). Metolachlor has a slightly longer residual activity in the soil than alachlor (Rahman *et al.*, 1978a; Rowe *et al.*, 1976). Most of the work with EPTC and butylate suggests that they persist in phytotoxic amounts for 8 to 16 weeks, depending on soil type (Rahman *et al.*, 1981; Rahman and James, 1983). Therefore, phytotoxic residues of all the grass weed herbicides will disappear before the end of the maize growing season.

Among the chemicals used for broadleaf weed control in maize, atrazine is the only one which has been toxic to susceptible crops, such as ryegrass, lettuce, beans and brassicas, following maize in the rotation. In the past, atrazine was used at rates of up to 4.5 kg/ha for control of barnyard grass. Due to residue problems from such high rates and the availability of several more effective grass herbicides, the then Agricultural Chemicals Board (now Pesticides Board) revised atrazine labels in 1976, limiting its maximum rate to 1.6 kg/ha for weed control in maize.

Residual activity of atrazine depends on the soil type and is likely to be high in light soils with low organic matter levels (Rahman *et al.*, 1975; Rahman, 1979). Persistence is usually higher in dry, cold seasons than in warm, wet seasons. Trial work by Rahman and Brown (1977) showed that residues of atrazine last longer in the Gisborne area than in the Waikato region, and care is needed in selecting a follow up crop for autumn in the Gisborne region (Naish and Forgie, 1976; Rahman and Brown, 1977). However, all the work has demonstrated clearly that rates up to 1.6 kg/ha of atrazine in maize should pose no problems to susceptible crops in rotation the following spring in any area. Thorough cultivation has been shown to help in dispersing the residues in the soil. Long term studies, in progress for the past five years, show that consecutive annual applications of the recommended rate do not lead to an increase of atrazine residues in the soil (Rahman, unpublished).

Cyanazine has a much shorter residual life in the soil than atrazine (Rahman *et al.*, 1978a). At the recommended rate of 1.5 kg/ha, cyanazine's activity fell below phytotoxic levels in about 3 months, and this should not pose any problems in the crop rotation.

FUTURE TRENDS

The development of effective herbicides for use in maize has reduced the need for tillage and cultivation for weed control. Reduced or minimum tillage in the future may place greater reliance on herbicides for weed control. Therefore, herbicides must be chosen carefully to assure selection of the most appropriate treatment for the specific weed problem, particularly for perennial weeds.

As mentioned earlier, cultivation is now practiced in New Zealand mostly in those instances where control of weeds with herbicides has failed. Improved consistency of herbicide performance and the development of reliable back-up weed control practices are necessary before cultivation can be abandoned completely. Post-emergence herbicide treatments appear to be the best possibility. The search for new herbicides is likely to concentrate on post-emergence materials for control of grass weeds, which appears to be the deficient area at present.

Row width in maize has undergone a steady decline in recent years. Without the need for cultivation, and provided the machinery is available, maize row-width could be replaced by closer or even bidirectionally-spaced plantings. Spacing, or plant density per hectare, would depend on the ultimate maize plant design developed by plant breeders working without the present restrictions imposed by row width.

Although the total area in maize production is very small in New Zealand, its importance on the world scale cannot be underestimated (Sprague and Paliwal, 1984). There is little doubt, therefore, that research effort will continue, not only with weed control measures, but also with various agronomic studies to provide the highest yield at the lowest cost.

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