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THE WEED SOCIETY OF NEW SOUTH WALES

FORMATION AND OBJECTS

The Society was formed at an inaugural meeting in Sydney on 17th February 1966, and as part of its constitution established its objects to be :

(*a*) To promote wider interest in weeds and their control.

(*b*) To provide opportunities for those interested in weeds and their control, to exchange information and ideas based on research and practice.

(*c*) To encourage the investigation of all aspects of weeds and weed control.

(*d*) To co-operate and, where appropriate, affiliate with other organizations engaged in related activities in Australia and overseas.

(*e*) To encourage the study of weed science and the dissemination of its findings.

(*f*) To produce and publish such material as may be considered desirable.

(*g*) To foster the development of an Australia-wide weeds organization.

MEMBERSHIP

(*a*) Membership is of three classes, " ordinary ", " honorary " and " corporate body ", and is open to all those individuals and corporate bodies respectively who are interested in weeds.

(*b*) Honorary members are elected from persons who, in the opinion of the Executive Committee, have made major contributions to the objects of the Society and have the same rights as ordinary members.

(*c*) Corporate body members may nominate one representative to the Society who has the same rights as an ordinary member.

Membership fees are : private members $4 annual subscription, corporate body members $10 joining fee and $10 annual subscription. Fees are payable on the first day of March in each year.

The fourth volume of proceedings edited by Dr. P. W. Michael and Mr. A. D. Mears includes two reviews and three contributed papers.

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Applications for membership, payment of subscription and orders for copies of the Proceedings should be sent to the Treasurer, Weed Society of N.S.W., c/- Department of Agriculture, State Office Block, Sydney, N.S.W., 2000.

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Review:

WEED CONTROL IN TOBACCO

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The great majority of papers on weed control in tobacco deal with the use of herbicides. Few discuss other methods or the effect of weeds on quantity and quality of tobacco. According to Doyle (1967), American workers began searching for an adequate herbicide in 1949. Estimates of the economic losses due to weeds under American conditions have been made (Anon., 1968).

Under Australian conditions, it is reported that weeds substantially reduce both yields and quality (Doyle, 1968). Weed-free plots, achieved by either chemical treatment or hand hoeing, yielded 47 to 70% more leaf. Substantial labour saving resulted from the use of chemicals, and leaf value increased by from 12 to 24% (Doyle, 1969).

The greatest purpose of weed control in tobacco should be to prevent competition from weeds and loss in quality and to control pests and diseases, rather than to prevent harvest difficulties. The apparent lack of attention to these factors, however, is an example, in a particular crop, of the too deep involvement of weed workers in herbicide evaluation.

Because inter-row cultivation is often necessary to aid water penetration and allow needed crop care, weed control between rows is thereby achieved. Although filtration of light by tobacco canopies may inhibit the germination of some weeds (Taylorson and Borthwick, 1969), other techniques for weed control are also required.

WEED SPECIES

Most weeds of tobacco are summer-growing annuals. Some are common to most areas, but many others are found in local situations. Perennials are of less importance.

The most troublesome weed appears to be nut grass (*Cyperus rotundus* and *C. esculentus*). Broomrape (*Orobanche* spp.) is reported to be serious in India and Pakistan (Parker, 1968), and in Egypt (Kachan, 1966), where a breeding programme has been developed to select for resistance. Several authors have been concerned with *Cyperus* spp. Shepherd (1968) reports the presence of *C. esculentus* in Australia. Studies on *Cyperus rotundus* as a weed of tobacco have been reported in Australia (Anon., 1969 ; Parker, 1966 ; Doyle, pers. comm.). Nut grass presumed to be *Cyperus rotundus* causes major damage to southern Italian crops (Marcelli *et al.*, 1966). Under New South Wales conditions *Cyperus rotundus* incidence is made more severe, and control more difficult, by the system of sharefarming, whereby a particular area is used only infrequently.

Few authors give detailed lists of weeds, but species causing concern in Canada and U.S.A. (Doyle, pers. comm.) include *Amaranthus* spp., *Chenopodium album*, *Ambrosia artemisiifolia*, *Setaria* spp., *Digitaria* spp., *Mollugo verticillata*, *Eleusine indica*, *Portulaca oleracea*, *Solanum carolinense*, *Campsis radicans* and *Sorghum halepense*. Principal weeds in Australia are *Digitaria sanguinalis*, *Eragrostis cilianensis*, *Portulaca oleracea*, *Brachiaria piligera* and *Echinochloa crus-galli* (Doyle, 1968 ; Shepherd, 1968). In Argentinian crops *Cestrum parqui*, *Solanum argentinium* and *Nicotiana longiflora* occur (Ramallo, 1968).

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Disease Control Aspects

Plants in a number of families other than *Solanaceae* have been indicated as alternate hosts for pathogenic organisms of tobacco. Under glasshouse conditions plants from 19 families acted as hosts for the nematode causing southern root knot (*Meloidogyne incognita*), (Davidson and Townshend, 1967). Plants within *Solanaceae* (*Cestrum parqui*, *Solanum argentinium*, *Nicotiana longiflora*) are alternate hosts of the tobacco mosaic virus (Ramallo, 1968). Black shank of tobacco (*Phytophthora parasitica* var. *nicotianae*) incidence was more effectively reduced by some non-solanaceous crops in a rotation (Dukes, 1969). The tobacco etch virus was tentatively identified on a weed species (Varma, 1968).

Weed Control in Seedbeds

The importance of weed-free conditions for tobacco seedlings has been recognized. Soil fumigants are a satisfactory method of weed control, but some other chemicals have been tested (Chappell *et al.*, 1968 ; Link, 1966). Herbicides considered useful were pebulate, nitralin, diphenamid, EPTC and amiben. Diphenamid was used as an after-sowing treatment at 3·9 and 7·8 kg./ha. without causing injury to seedlings.

The fumigant allyl alcohol, applied a week before sowing, controls weeds, which enhances the vigour of tobacco seedlings (Cibes and Amy, 1956). Similar weed control was obtained with metham sodium at rates which damaged seedlings (Piglionica, 1966).

The replacement of allyl alcohol for this purpose has not been demonstrated in the literature.*

Chemical Weed Control in the Field

Chemical weed control has become widely practised since 1949 (Doyle, 1967), but mechanical methods will continue to have a place. Many herbicides have been investigated throughout the world to establish useful selectivity to avoid the development of " off flavours " in the leaf and to ascertain damage to following crops.

Soil residues of herbicides used in tobacco can be expected to affect following crops. The degree of this effect will depend on the particular herbicide ; rate and placement ; soil factors, including moisture, organic matter, mineral colloids, biological activity, temperature, and cultural treatment.

When linuron or diuron were used in a tobacco crop grown in a sandy loam soil, the yields of wheat, peanuts, tobacco, soybeans, but not cotton, sown in the next season were reduced (Upchurch *et al.*, 1969). Diphenamid reduces yields of following gramineous crops (Smith, 1964).

Studies of the effect of pesticides on tobacco flavour are a feature of research. Herbicides do not present as great a problem as other pesticides.

The content of organic pesticides in leaf can be very high in young plants, but when stable compounds are used residues near harvest of up to 100 p.p.m. have been found (Guthrie, 1968). Dissipation of different pesticides varies. Studies on the dithiocarbamates (Muller and Moldenhauer, 1968), substituted ureas (Artho *et al.*, 1968), diphenamid, pebulate, benefin, vernam, nitralin and amiben (Klingman, 1967) indicate that these herbicides do not lead to the build-up of significant residues, nor to lowering of leaf quality. The curing process has been demonstrated to reduce the concentration of substituted ureas present in the leaf (Artho *et al.*, 1968).

Low rates of 2,4-D applied 24 hours before harvest as a maturing agent increased carbohydrate and reduced nicotine contents (Masuda and Kashihara, 1968).

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* Common names of herbicides as approved by Standards Association of Australia, Weed Science Society of America, or appropriate European authorities.

Herbicides

Herbicides can act as deterrents to other biological entities, and some studies of their effect on fungi have been recorded. Both pathogenic and non-pathogenic fungi were affected by selective rates of herbicides (Valaskova, 1968). Trifluralin in liquid media and low nutrient sandy loam reduced mycelial tissue produced (Rodriguez-Kabana *et al.*, 1969). The southern blight fungi, *Sclerotium rolfsii*, was not shown to be significantly affected by trifluralin or paraquat (Rodriguez-Kabana *et al.*, 1967).

While some herbicides can affect soil micro-organisms, they are unlikely to be replacements for more specific pesticides, or other methods of disease control.

Many herbicides have been tested for the control of weeds in tobacco, and in 1967 two were cleared for use, benefin in U.S.A. and Australia, and pebulate in Canada and U.S.A. (Doyle, 1967). Others widely tested included trifluralin, EPTC, norea, vernolate and nitralin ; they demonstrated good weed control but unsatisfactory selectivity. Chlorthal gave some indication of usefulness at high rates ; diphenamid gave good weed control and useful selectivity, but was suspect for leaf residues (Doyle, 1967).

More recently a number of other herbicides have been tested, and include pebulate, amiben (Chappell *et al.*, 1968), pyriclor (Dale, 1968), methan sodium, dazomet (Fetvadziev, 1966), prometryne (Gasymov and Torchulu, 1966), dichlobenil (Smith, 1964), metabromuron (Kampe, 1969 ; Mickovski, 1968), each demonstrating a level of usefulness.

With the apparent clearance of diphenamid (Klingman, 1967) a number of herbicides is now available for use in tobacco. However, those most commonly used for general weed control are benefin, pebulate and diphenamid. There is little to suggest that any of the others tested will provide better, or more economical, control than those already in use.

The ideal herbicide would be one which would give a wide range of crop safety combined with good kill of both broad-leaved weeds and grasses, surface-applied preferably at the time of transplanting, and capable of being activated without mechanical incorporation. The combination of all these features in a single chemical does not exist at present. A mixture of benefin and vernolate proved superior to either diphenamid or pebulate (Clark, 1967).

Herbicides for Specific Problems

The use of pebulate and vernolate to control nut grass was established in U.S.A. and Canada in 1967. In Australia, pebulate was shown to be superior in crop safety to EPTC (Doyle, 1968). Italian work suggests that EPTC is satisfactory (Marcelli *et al.*, 1966) ; this is confirmed for seedling *Cyperus* spp. by work in Trinidad (Seeyave and Rajkumar, 1969). Amitrole, methyl bromide, MCPA and 2,4-D did not, as a result of a single application, prove satisfactory for *Cyperus* spp. control and cannot be used in the growing crop (Parker, 1966). Diphenamid and benefin are also useful (Anon., 1969).

Broomrape (*Orobanche* spp.) has not been reported in Australia in tobacco, but its status overseas justifies consideration. Hand pulling, general hygiene and herbicides are practices used in control, with diphenamid and trifluralin as alternatives to hand pulling in Pakistan and India (Parker, 1968). Good control was achieved in Bulgaria with 2,2-DPA and linuron as a pre-transplant treatment (Fetvadziev, 1966). Fetvadziev also reports control of later developing broomrape by 2,4,5-T, allyl alcohol and DNOC. The report must engender some doubt because of the use of 2,4,5-T.

Incorporation of Herbicides

Herbicides must be incorporated to a depth which provides useful weed control with a minimum of crop injury. In other crops techniques of incorporation have been studied and are widely practised. These give better weed

control at lower rates by prevention of herbicide breakdown by sunlight, closer contact to weed seeds, and readier activation. Implements which turn the soil forward have been shown to be the most effective. Rotary hoes are best, and tined implements worst (Rylands, pers. comm.; Klingman, 1967). Another technique of interest is one described by Shepherd (1968), which involves the use of a sweep moving below the surface at a set depth, applying herbicides as well as destroying weed growth present.

Other Methods of Control

In a previous review it was postulated that herbicides will eliminate the need to use cultivation to control weeds in tobacco, but there was evidence of added value arising from inter-row cultivation (Doyle, 1967). The control of rhizomatous weeds by deep ploughing may have advantages (Andreeva-Fetvadzhieva, 1966). Narrow plant spacing may increase yield, but may also reduce quality (Chaplin *et al.*, 1968).

It is reasonable to expect that combinations of chemical and mechanical methods of weed control will prove the most effective, reliable, and least costly. The precise balance of the two methods will depend on soil type, the weeds present, and watering technique.

Conclusions

More accurate problem definition and the development of weed control systems using combinations of chemical and mechanical methods are needed. Because rotation of other crops with tobacco is a probability, method of reducing soil residues of herbicides is important. Progress in this direction involves the need to define the effect of weeds on tobacco and the time at which this is most critical.

Methods of inducing herbicide breakdown adaptable to farm practice may be necessary. Further work should aim to elucidate the role of weeds as disease hosts, the risk of quality losses from herbicides, and control of individual weeds, particularly nut grass.

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Review:

HERBICIDES FOR TOTAL VEGETATION CONTROL

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Interest in total vegetation control, particularly by governmental authorities in keeping communication lines clear of unwanted plants, has opened a major market for suitable herbicides. In this State the annual spending on total vegetation control is in the vicinity of 4–5 million dollars a year.

In the last 25 years the use of herbicides in agricultural and non-agricultural situations has become widely established. The number of basic herbicides available has increased rapidly. For example, in Canada in 1944 there were only 14 herbicides, but in 1965 users could choose from 125 basic herbicides available in 8,000 registered formulations (von Stryck, 1969). In the United Kingdom in 1966 there were approximately 350 herbicide products approved by the Ministry of Agriculture, based on no fewer than 50 different active chemicals (Fryer, 1966). In U.S.A. in 1959 herbicides with a total value of $128,000,000 were used on 53,000,000 acres (21,000,000 ha.). In the three years to 1962 herbicides to the value of $273,000,000 were used on 71,000,000 acres (28,400,000 ha.) (Anon., 1965). These examples given indicate the trends in herbicide costs and the realization of the importance of weed control.

Total vegetation control has received less research attention than selective weed control. This review is concerned essentially with development in chemical control since 1950.

The triazines, ureas and carbamates, discovered in the 1950s, were first used as selective herbicides. But now, alone and in mixtures, they are the most common herbicides in total vegetation control. This is because of their long-term effects and because few species are resistant. An unsatisfactory knock-down effect led to their use in combination with amitrole,† paraquat, 2,4-D and others.

Length of Vegetation Control

The need for knock-down herbicides in combinations with triazines and ureas was proved in experiments from 1955 to 1963 in New Zealand (Meeklah, 1964). Simazine, diuron, monuron and bromacil were compared. The time to re-treatment was selected as being the time when the control dropped to 70%. Results showed that 10 lb./ac. (11·2 kg./ha.) simazine gave approximately 13 months effective control (i.e., over 70% bare ground), 20 lb./ac. (22·40 kg./ha.) gave 18 months control; 16 lb./ac. (17·94 kg./ha.) monuron, 7–11 months, 32 lb./ac. (35·87 kg./ha.) up to 19 months; 10 lb./ac. (11·20 kg./ha.) bromacil, 14 months control. Diuron appeared to be more efficient than monuron and similar to simazine when compared on an active ingredient basis. Bromacil may be more efficient than simazine and diuron.

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† Common names of herbicides as approved by Standards Association of Australia, Weed Science Society of America or appropriate European authorities.

These herbicides, particularly simazine, need additives to achieve maximum efficiency. These additives in no way adversely affected soil persistence. The most efficient additives examined were paraquat, amitrole and a 2,2-DPA/amitrole mixture.

In general, increasing the rate of herbicides did not give a pro rata increase in length of persistence.

To prolong the effect of herbicides economically, it is important to use specific herbicides intelligently against re-establishing species.

Timing of Re-Treatment

Some authors emphasize the importance of the timing of initial treatment and the maintenance aspects of total vegetation control. The basic economic period of protection between application of herbicides is thought to be 12 months.

The tolerance levels of 53 broad-leaved species and 15 grasses to three residual herbicides and their combination with added translocated herbicides were established. The notably greater phytotoxicity of the uracils over the triazines or urea-type residuals available at that time (i.e. 1963) was seen (Ward, 1964).

Some of these results are supported by results of other authors. In 1966, Hyvar X(R)* (bromacil 80%) at 5 to 12·5 kg./ha. (4·5 to 11 lb./ac.) was applied in 1,000 or 4,000 l. water/ha. (89 or 356 gal./ac.), to cut or uncut vegetation, in early spring and in full growing stage. The results showed that under Central European climatic conditions 5 kg./ha. (4·5 lb./ac.) controlled annual grasses, 5 to 7·5 kg./ha. (4·5 to 6·5 lb./ac.) controlled dicotyledons, and 7·5 to 12·5 kg./ha. (6·5 to 11 lb./ac.) controlled rhizomatous, perennial weeds including *Phragmites communis* (common reed), *Cirsium arvense* (perennial thistle) and *Convolvulus arvensis* (bindweed). *Rubus caesius* (blackberry) recovered from 12·5 kg./ha. (11 lb./ac.). This experiment confirmed that the weeds were more susceptible during early and active growth stages (Javorská, 1968).

In trials from 1960 to 1965, monuron, diuron, isocil and simazine were tested. Initial applications of simazine, diuron, or monuron at 40 lb./ac. (44·80 kg./ha.) in early spring gave good control of vegetation for about one year. Thereafter annual re-treatment at 20 lb./ac. (22·40 kg./ha.) was necessary to maintain reasonable control. All three herbicides moved laterally and injured vegetation down the slope. Attempts to reduce lateral movement by using reduced rates in combination with contact herbicides were partially successful.

The combination diuron 5 lb./ac. plus paraquat 2 lb./ac. (5·60 kg./ha. plus 2·24 kg./ha) gave control equal to that obtained with the higher rates of diuron with no lateral movement one month after treatment. There was a gradual reduction in control two and three months after treatment. When used alone, the best total performance of isocil was at 4 to 8 lb./ac. (4·48 to 8·97 kg./ha.) and of diuron at 10 to 20 lb./ac. (11·20 to 22·40 kg./ha.) (Upchurch *et al.*, 1968).

In Brazil, high rates of bromacil, simazine and diuron, alone or in combination, were used in 1964 to eradicate *Panicum purpurascens* (Para grass). Observations one year later showed that bromacil (as Hyvar X(R) 80% a.i.) at 30 kg./ha. (26·80 lb./ac.) gave 100% control); bromacil at 15 kg./ha. (13·25 lb./ac.) plus TCA at 100 kg./ha. (89·25 lb./ac.) gave 97% control and bromacil at 10 kg./ha. (9 lb./ac.) plus simazine (as Gesatop(R) 50% wettable powder) at 20 kg./ha. (17·75 lb./ac.) gave 95% control. Diuron (as Karmex(R) 80% wettable powder) at 30 kg./ha. (26·75 lb./ac.) and diuron 15 kg./ha. (13·25 lb./ac.) plus simazine 15 kg./ha. (13·25 lb./ac.) plus TCA 100 kg./ha. (89·25 lb./ac.) did not give satisfactory control (Leiderman and Gregori, 1966).

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* (R) indicates Registered Trade Name.

Performance of Herbicide Mixtures

Many research workers are still looking for different mixtures of new and established products to achieve long and cheap total vegetation control. Chlorfenac 3 lb./ac. (3·36 kg./ha.) plus dicamba 1 lb./ac. (1·12 kg./ha.) gave a good root kill of *Campsis radicans* (a woody species) and a satisfactory root kill of *Rubus spp.* (blackberries) and *Brunnichia cirrhosa* in U.S.A. These three species became a problem where *Sorghum halepense* (Johnson grass) and *Cynodon dactylon* (couch) had been eradicated. Where vines of *Rubus spp.* and *Brunnichia cirrhosa* grew together with *Sorghum halepense*, chlorfenac 4·5 lb./ac. (5 kg./ha.) plus sodium chlorate 75 lb./ac. (84 kg./ha.) gave 50% to 80% kill of roots and a follow-up application a year later gave 55% root kill of all species (Mitchell *et al.*, 1967).

Some of the other rates and combinations which have been successfully used are Chlorea Granular(R) (sodium chlorate 40% plus sodium metaborate 51% plus monuron 2·4%) at 650 to 1,300 lb./ac. (729 to 1,457 kg./ha.); Hyvar X(R) (bromacil) at 10 lb./ac. (11·20 kg./ha.) and 20 lb./ac. (22·40 kg./ha); monuron 40 lb./ac. (44·80 kg./ha.); atrazine 40 lb./ac. (44·80 kg./ha); ureabor granular (disodium tetraborate pentahydrate 63·2% plus disodium tetraborate decahydrate 30·8% plus monuron 4%) at 870 lb./ac. (975 kg./ha.); Urex(R) (monuron plus TCA) liquid oil concentrate or granular at 40 lb./ac. (44·80 kg./ha.) and 80 lb./ac. (90 kg./ha.); Dybar(R) (fenuron 25%) at 80 lb./ac. (90 kg./ha.) and diuron at 40 lb./ac. (44·80 kg./ha.) (Lewis, 1968).

In the U.S.A. mixtures of bromacil 3 to 10 lb./ac. (3·40 to 11·20 kg./ha.) plus 2,3,6-TBA (4·48 kg./ha.) compared favourably with bromacil alone in giving rapid response, excellent residual control and a generally reduced volatility hazard. However, some re-growth of *Convolvulus arvensis* (bindweed) and *Smilax sp.* occurred after two to three months (Hernandez, 1968).

In the last few years total vegetation control has grown in importance. More and more special total vegetation control herbicides and their mixtures are being tested.

In U.S.A., in 1967 several code-numbered herbicides and mixtures were tested, some with unknown chemistry (Bayer, 1970). The experimental site was an old lucerne stand which had been invaded and was a complex of *Medicago sativa* (lucerne), *Phleum pratense* (common timothy), *Dactylis glomerata* (cocksfoot), *Poa compressa* (Canada bluegrass), *Rumex crispus* (curly dock), *Arctium minus* (small burdock), *Taraxacum officinale* (dandelion), *Lactuca scariola* (prickly lettuce), *Malva neglecta* (common mallow) and *Amaranthus retroflexus* (redroot).

The majority of the treatments tested provided good to excellent control of the predominant species for one season. The mixtures included atrazine plus amitrole plus fenac; bromacil plus amitrole plus fenac and borate-chlorate. Single herbicides which gave good kills included Nia 11092, bromacil and AP920. Some of these were used as granules, but they were generally slower to act than when applied in solution.

New Chemicals

Of the more recent herbicides developed, Nia 11092 (m-(3,3-dimethylureido) phenyl *tert*-butylcarbamate)) appears to be one of the most useful. It was discovered in February, 1964, by the Niagara Chemical Division, F.M.C. Corporation, U.S.A.

This product was intensively tested between 1964 and 1968 and was tried on 48 herbaceous and 17 woody species to determine its pattern of use, rates and combinations (Hagood, 1970).

Rates of 21 herbicides and their combinations were compared for sterilant action, from which the two most effective, Nia 11092 and bromacil, were selected and their comparison was extended over three to five growing seasons.

The five years of field data indicated that Nia 11092 is non-selective and persistent. In later trials different combinations, initial and maintenance rates

were tried. The most economic and effective weed control programme was obtained with an 8 to 10 lb./ac. (8·96 to 11·20 kg./ha.) application in the first year, 3 lb./ac. (3·36 kg./ha.) in the second year, 3 lb./ac. (3·36 kg./ha.) in the third year, and 2 lb./ac. (2·24 kg./ha.) in the fourth year. When similar rates of bromacil were applied it was found that its effectiveness in the first year was basically the same as Nia 11092. In the following years bromacil was not as effective as Nia 11092. The combination 1 : 1 of Nia 11092 and bromacil produced very promising results.

For tree and brush control, 17·6 lb./ac. (19·73 kg./ha.) a.i. to 20 lb./ac. (22·40 kg./ha.) a.i. of Nia 11092 and bromacil is recommended for the first year. The spray can be directed to either the soil or the foliage. After three years, control of the woody species was 99% or higher.

The most recently released total vegetation control herbicide is thiadiazolyleurea (GS 29696). It was selected and is being developed by J. R. Geigy, S.A. Basle, Switzerland. From some experimental field trials in Switzerland, France, U.K., Italy, Holland and U.S.A. the general recommendation is 5 to 10 kg. a.i./ha. (4·5 to 9 lb. a.i./ac.). Higher rates might be needed in heavy soils with low rainfall.

GS 29696 acts mainly through the plant roots, and it appears that the best time of application is prior to or just after the start of vegetative growth. Rainfall after treatment enhances the response (Anon., 1970).

Conclusion

Results in this State and from overseas and the great number of products available make it imperative that detailed evaluation of the most promising herbicides under different environmental conditions be undertaken.

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Contributed Paper:

ATRAZINE ADSORPTION AND CONTROL OF *ECHINOCHLOA* IN AUSTRALIAN SOILS

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SUMMARY

Following unfavourable reports of control by atrazine of *Echinochloa* spp. (barnyard grass) in the Murrumbidgee Irrigation Areas of New South Wales a comparison was made of the resistances of local forms of barnyard grass to atrazine, and of atrazine adsorption by various soils. Results suggested that these factors were not decisive ones. Other possible reasons for erratic control are mentioned.

INTRODUCTION

Atrazine is recommended as a pre-sowing or pre-emergent herbicide for weed control in maize and sorghum in the Murrumbidgee Irrigation Areas (M.I.A.) of New South Wales and is the prime candidate for weed control in these crops in other parts of the world (Gast, 1970).

Advantages of atrazine are that it is remarkably safe for maize and sorghum and controls a wide spectrum of weed species. In Australia the cost compares very favourably with alternative herbicides.

Against this there are reports (Irrigation Research and Extension Committee, personal communication) that in the M.I.A. control of *Echinochloa* spp. with atrazine in irrigated crops is sometimes inadequate. Discussion with the growers concerned suggested that occasionally the herbicide may have been used incorrectly, but there were instances of poor weed control which were not easily explained. The aim of this study was to investigate two of many factors which could contribute to erratic weed control, namely the susceptibility of different forms of *Echinochloa* and the influence of soil type on atrazine adsorption and effectiveness.

Forms of *Echinochloa* have been reported to differ in susceptibility to other herbicides—to diuron (Michael and van Rijn, 1970) and dalapon (Roché and Muzik, 1964). Since several forms of *Echinochloa* have been identified in the M.I.A. (Michael, personal communication) it seemed relevant to test those occurring locally in maize- and sorghum-growing soils for differences in susceptibility to atrazine.

It has long been recognized that the soil composition is a major factor influencing the quantity of triazines required to control weeds (Gast, 1970).

Bailey and White (1970), Weber (1970), Hayes (1970) and Osgerby (1970) have reviewed many studies showing that triazine herbicides can be extensively adsorbed by some organic materials and clays. Although few authors report a good direct relationship between adsorption and phytotoxicity, in general it has been shown that in soils rich in herbicide-adsorbing components higher concentrations are necessary to control weeds.

Consequently, seven local soils (Table 2) were chosen to represent at the extreme the lighter and heavier soils of the area, and atrazine adsorption was measured.

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Since a large proportion of local soils are relatively high in clay, a further study was made of atrazine adsorption by a wider range of soils (from the Riverina and Namoi area—Table 3) in which the clay types had been identified. Four contrasting soils (Table 4) from other parts of Australia were included to investigate the influence of clay type and organic matter content on adsorption.

Three of the local soils were chosen for testing the susceptibility to atrazine of forms of *Echinochloa*.

Although important in understanding the availability of herbicide to plant roots, the desorption of herbicides from soils has been studied much less than adsorption. In general, desorption of triazines from soils is much the slower process (Hance, 1967 ; Walker, 1968) and studies of infra-red spectra (Russell *et al.*, 1968 ; Brown and White, 1969) suggest that hydrolysis of triazines occurs at clay surfaces. This raises the question of whether atrazine is degraded during sorption and whether it can desorb from the surface in a form which is phytotoxic.

Therefore, in two soils the reversibility of the sorption process was examined.

Methods

(1) *Susceptibility of Forms of Echinochloa to Atrazine in Three Soils*

The three forms of *Echinochloa* studied were a form of *E. colonum* and contrasting early-flowering and late-flowering forms of *E. crusgalli*. Three soils (C, D and F ; Table 2) were selected as relatively light, medium and heavy soils of the area.

Samples of air-dry soil (300 g.) in pots (10 cm. diameter, 10 cm. high) were treated with solutions of atrazine in methanol (10 ml.) to give 0, 0·375, 0·75 p.p.m. in the soil. (Equivalent to approximately 0, $\frac{1}{4}$, $\frac{1}{2}$ lb./ac. to 2 in. depth.) The methanol was allowed to dry overnight then the soils tipped out, thoroughly mixed and replaced. Pots were watered with nutrient solution (Cary, 1970) and allowed to drain. Seeds of *Echinochloa* were rubbed gently between sandpaper to promote germination, and incubated at 30° C. in the dark for three to four days. About 20 germinated seeds per pot were planted on top of moist soil and covered with $\frac{1}{4}$ in. of sand. The experiment was conducted in growth cabinets at 27° C. and light intensity of about 10·5 mW./cm.^{2} (400–700 nm.) for 16 hr./day. There were six replicates. Pots were placed in individual foil trays and watered daily with nutrient solution diluted 1 : 3 with water.

Seedlings were counted at two-day intervals. Eight to 10 days after sowing emergence was complete and plants were thinned to 15 per pot. Symptoms of herbicide damage were just beginning to appear in plants exposed to atrazine.

Three weeks after sowing surviving plants were counted. Seedlings killed were calculated as a percentage ; fresh weights of surviving plants were recorded and reduction in fresh weight as a percentage of control was calculated (Table 1).

(2.1) *Atrazine Adsorption by Soils*

(*a*) *Spectrophotometric Method*—" local soils ". This method was used for an initial study of seven local soils of contrasting texture described in Table 2.

Organic carbon was determined by the method of Tinsley (1950) clay (<2 μm.) by pipette separation and pH at a ratio of 1 : 2·5 soil : 0·02M calcium chloride.

Samples of soil (5 or 10 g.) were shaken end-over-end in centrifuge tubes with atrazine solutions prepared in 0·02M calcium chloride to maintain flocculation. Five initial atrazine concentrations in the range 4 to 240 μmol./l. were used. Blanks were shaken with 0·02M calcium chloride solution.

A trial using soil F showed that adsorption was complete within two hours. Subsequently, samples and controls were shaken for 16 hours then centrifuged, an aliquot of the supernatant liquid was diluted with water and atrazine concentration determined by ultraviolet spectrophotometry at 224 nm. The concentrations of standard solutions were also determined and adsorption calculated from differences between initial and final concentrations.

(*b*) *Method Using Carbon-14-labelled Atrazine* (modified from Walker, 1968). For all other soils measurement of adsorption was facilitated by the use of solutions containing carbon-14 ring labelled atrazine (0·0025 μCi/ml.). Samples of 5 g. of soil were shaken with 15 ml. solution for 16 hours.

After centrifuging, 1 ml. of the supernatant liquid was transferred to a vial, 10 ml. of a water-miscible scintillation fluid (Bray, 1960) added, and samples counted for five minutes, giving a minimum of 10,000 counts. Controls were also counted. Quenching, checked by the pulse height shift method (Baillie, 1960), was found to be negligible, and so adsorption was calculated from differences in activity between samples and controls.

The soils described in Table 3 were collected from the Riverina and Namoi areas. Organic carbon was determined by the method of Walkley and Black (1934). Surface areas were determined by nitrogen adsorption (Clarke, personal communication, 1970). Clay minerals were described by Little (1970).

Soils in Table 4 were analysed by the same methods as "local soils". Information on clay minerals determined by X-ray crystallography was supplied by Clarke (personal communication, 1970).

(2.2) *Atrazine Desorption from Two "Local Soils"*

Atrazine solution (15 ml., 138·9 μmol./l.) was shaken with samples of 5 g. soil C or F for 16 hours, then centrifuged.

Samples of the supernatant liquid were withdrawn from two replicates for counting and atrazine adsorption determined as described in section (2.1 (*b*)) above.

In eight other samples 10 ml. of the supernatant liquid was replaced with 10 ml. 0·02M calcium chloride. The samples were re-shaken for ¾, 1, 2, 4, 16, 24 or 48 hours and centrifuged again. Separate samples were used to avoid complications due to changes in the soil : solution ratio.

Scintillation counting. The extent of desorption of carbon-14 activity (Table 5) was measured by counting sub-samples of the supernatant liquid as described in section (2.1 (*b*)).

Since hydroxyatrazine, which is not phytotoxic, could contribute to carbon-14 activity, the nature of the activity desorbed was investigated.

Gas-liquid chromatography (GC) was used to estimate the proportion of the recovered activity attributable to atrazine; hydroxyatrazine would not be detected using this method.

An internal standard, propazine, was used to compensate for slightly variable injection volumes and changes in sensitivity of the GC detector.

Sub-samples (8 ml.) of the supernatant liquid after desorption, with 2 ml. 50 p.p.m. propazine added, were extracted into methylene chloride, evaporated to dryness and taken up in 1 ml. acetone for injection into the gas chromatograph.

Standard mixtures of solutions of atrazine and propazine were also prepared.

A Hewlett Packard series 7620A GC with a model 1516A nitrogen detector was used. The column was a 2 ft. × ⅛ in. i.d. glass coil, packed with 3% cyclohexane dimenthanol succinate on an AW–DMCS treated Chromasorb W, 80/100 mesh. Temperatures were: column, 200° C.; injector port, 220° C.; and detector, 400° C. The flow rates were: carrier gas, nitrogen 50 ml./min.; detector gas, hydrogen, 12 ml./min.; and air, 180 ml./min. The position of the crystal was adjusted to give a maximum ionization current of about 0·6 mV. Injection volume was about 2·5 μl. Retention times were: propazine, 3–6 min.; atrazine, 4·8 min.

Atrazine concentrations in supernatant solutions after desorption (Table 5) were calculated from comparisons of atrazine : propazine peak height ratios of samples and standards.

Results

(1) *Susceptibility of Forms of Echinochloa to Atrazine*

Table 1 shows the response of forms of *Echinochloa* to atrazine in terms of reduction of fresh weight and as percentage of seedlings killed. Since the vigour of surviving plants was severely reduced, especially at the higher atrazine rate, fresh weight at harvest is perhaps the more useful comparison.

Note that in the untreated soil the soil type affected the vigour of the plants, and that in the clay loam (D) the late flowering form of *E. crusgalli* was larger and more robust than the other forms.

In soils treated with atrazine at the lower level (0·375 p.p.m.) there was a significant difference in fresh weight between *EF* and *LF Echinochloa* forms in soil D, and between *EC* and *EF* forms in soil F.

TABLE 1

Effect of atrazine on Echinochloa assessed three weeks after planting
E. colonum (*EC*); *E. crusgalli*, early flowering (*EF*) and *E. crusgalli*, late flowering (*LF*)
For each atrazine concentration figures followed by the same letter do not differ significantly at the 5% level

Atrazine p.p.m.		0			0·375			0·75		
Echinochloa form		*EC*	*EF*	*LF*	*EC*	*EF*	*LF*	*EC*	*EF*	*LF*
					Fresh weight per pot (g.)					
Soil C		—	5·13^{a}	—	—	0·89^{c}	—	—	0·10	—
D		3·14^{b}	3·92^{ab}	5·50	—	2·21	0·92	0·45^{d}	0·56de	0·79^{d}
F		3·97	2·42	—	2·73	1·65^{c}	—	1·14	0·71^{e}	—
					Fresh weight reduction (per cent. of control)					
Soil C					—	83	—	—	98	—
D					—	43	83	86	86	86
F					26	32	—	69	71	—
					Seedlings killed (per cent.)					
Soil C					—	21^{f}	—	—	73	—
D					—	21^{fg}	29^{g}	44^{h}	39^{h}	37^{h}
F					0	4	—	24	19	—

At the higher atrazine level (0·75 p.p.m.) there was no significant difference in fresh weight between the response of the three forms of *Echinochloa* in soil D. In soil F responses of *E. colonum* (*EC*) and the early flowering form of *E. crusgalli* (EF) differed significantly. A slightly higher number (24%) of *EC* plants were killed than *EF* plants (19%), although fresh weight at harvest of *EC* plants was larger (1·14 g. compared with 0·71 g.). This could be explained by the difference in vigour of the plants in this soil. In addition it could reflect the greater variability of *E. colonum* response—the *EF* plants tended to be uniformly yellow and scorched, whereas some plants of *EC* survived and the rest were killed.

Differences in soils, estimated by the response of *E. crusgalli EF*, were more marked. The relative effect of the higher level of atrazine was in order soil C>D>F. Effectiveness in soils D and F measured by response of *E. colonum* showed a similar trend.

(2.1) *Adsorption Isotherms*

Adsorption isotherms obtained by measuring adsorption at five different concentrations were described by the Freundlich relationship :

$$y = Kc^{n}$$

or

$$\log y = \log K + n \log c$$

where y is the amount of adsorbed atrazine per gramme of soil at equilibrium concentration c. The constant K represents the concentration of atrazine

adsorbed on soil (μmol./g.) when in equilibrium with a herbicide solution of unit concentration, and can be used to compare adsorption by different soils.

The value of n obtained from the slope of the plot of $\log y$ against $\log c$ reflects the degree of linearity of the isotherm.

When $n=1 \cdot 0$, the relationship between adsorption and equilibrium concentration is linear. Then K is independent of concentration and it could be measured at any equilibrium concentration.

Adsorption isotherms for " local soils " described in Table 2 are plotted in Figure 1. The values of n obtained by linear regression are shown in Tables 2–4.

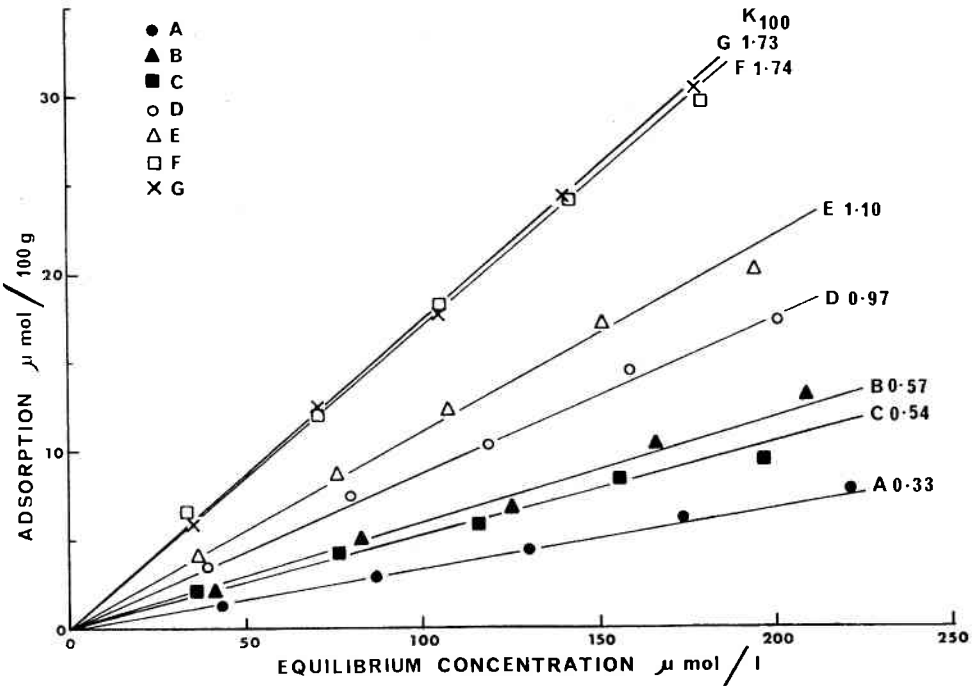

Figure 1.—Adsorption isotherms. " Local soils."

TABLES 2–4

A description of soils and constants from Freundlich isotherms for atrazine adsorption. (For explanation of n, K_{10} and K_{100}, see text)

TABLE 2

" Local soils "

Soil	Colour	Field Texture	Origin	Organic Carbon Per-centage	Clay Per-centage	pH	n+	K_{10}	K_{100}
A	Red-brown	Sandy clay loam	Subsoil	0·3	24	6·3	1·14[a]	0·24	0·33
B	Red-brown	Fine sandy clay loam	Darlington Point	0·5	28	5·5	1·12	0·43	0·57
C	Red-brown	Fine sandy loam	Hanwood	0·6	17	5·4	0·87[a]	0·73	0·54
D	Brown	Clay loam	Hanwood	1·1	31	6·8	0·97	0·95	0·97
E	Grey	Medium clay loam	Darlington Point	1·3	37	7·4	0·97	1·18	1·10
F	Grey	Medium clay	Carrathool	1·6	61	7·0	0·89[a]	2·24	1·74
G	Grey	Medium-heavy clay	Jondaryan	1·8	70	6·3	1·00	1·73	1·73

TABLE 3

Soils from the Riverina and Namoi Areas

Ref. No.*	District Origin	Organic Carbon Percentage	Clay Percentage	Quartz	Kaolin	Illite	Random Interstratified Material	Surface area m^2g^{-1}	pH	n+	K_{10}	K_{100}
1	Benerembah	1·03	37	5–10	20–30	50–65	10–20	37	6·5	0·83	1·4	1·0
2	Benerembah	1·14	46	1– 5	20–30	50–65	10–20	67	7·8	0·78	1·4	0·8
4	Wilbriggie	0·85	34	5–10	30–40	65–80	—	42	7·1	0·73[c]	1·4	0·7
5	Wilbriggie	0·86	54	1– 5	20–30	40–50	30–40	92	8·1	0·85	0·6	0·5
8	Warrawidgee	1·08	50	1– 5	20–30	50–65	20–30	56	6·3	0·86	1·6	1·2
9	Whitton	0·73	24	5–10	20–30	50–65	—	25	6·3	0·64[a]	1·6	0·7
10	Hay	0·79	49	1– 5	10–20	50–65	10–20	60	7·3	0·94	0·9	0·8
16	Hay	0·78	59	5–10	20–30	50–65	20–30	75	7·2	1·01	0·7	0·7
17	Carrathool	0·86	48	1– 5	10–20	30–40	30–40	52	7·1	0·91	0·9	0·7
20	Coleambally	0·64	63	1– 5	20–30	30–40	40–50	87	7·6	0·82[a]	0·8	0·5
23	Jerilderie	0·65	73	1– 5	20–30	40–50	30–40	115	7·5	0·91	0·8	0·7
25	Deniliquin	1·06	52	1– 5	10–20	50–65	20–30	56	6·9	0·88[b]	1·0	0·8
29	Narrabri	1·28	60	5–10	20–30	20–30	50–65	82	6·5	0·91	1·0	0·8
40	Narrabri	0·93	29	5–10	30–40	—	50–65	17	6·8	0·83[a]	1·5	1·0
51	Leeton	1·33	19	5–10	20–30	50–65	—	12	5·6	0·74[a]	1·6	0·9

* Little, I., 1970.—Tech. Memo. 34/70. Div. Soils, C.S.I.R.O.

TABLE 4

Soils from other parts of Australia

Soil	Organic Carbon Percentage	Clay	Predominant Clay Mineral	pH	n+	K_{10}	K_{100}
Kent sand	0·23	61	Fine-grained kaolinite	4·3	0·82	0·3	0·2
Willalooka sand	1·06	59	Fine-grained illite	6·7	0·98	0·7	0·7
Wollongbar clay loam	1·87	45	Kaolin and iron oxides	6·2	0·79[a]	2·4	1·5
Pelican clay	6·00	54	Montmorillonite	5·4	0·82[b]	8·4	5·6

\+ Values of n significantly different from 1·0 are indicated.

[a] = significance at probability 0·01 to 0·05.

[b] At 0·001 to 0·01.

[c] At less than 0·001.

For several soils values of n differed significantly from 1·0, indicating non-linear isotherms. Therefore, two concentrations, 10 and 100 μmol./l. were chosen to represent the concentration range studied and corresponding values of K (K_{10}, K_{100}) estimated by linear regression are shown.

TABLE 5

Rate and extent of desorption of carbon-14 activity (C-14) from soils C and F Atrazine desorbed was measured by gas chromatography (GC)

Soil	Method	Concentration in Solution (μmol./l.)								Percentage of Theoretical Concentration at Equilibrium	Percentage of Theoretical Equilibrium Concentration after 48-hour desorption
		0 hr.	¾ hr.	1 hr.	2 hr.	4 hr.	6 hr.	24 hr.	48 hr.		
C	C-14	39·4[a]	45·9	46·7	46·5	47·2	47·4	46·3	48·5[b]	50·9	95
	GC		45·8	51·5	—	—	—	—	48·5[b]		
F	C-14	30·3[a]	—	47·3	46·2	48·3	45·8	48·0	47·3[b]	50·9	93
	GC		—	45·0	48·7	—	—	—	—		

[a] Calculated.
[b] Mean of duplicates.

(2.2) *Desorption Experiments*

The results of desorption experiments are shown in Table 5. Assuming complete reversibility, the theoretical distribution at equilibrium of the quantity of herbicide left in the system was calculated from the Freundlich isotherm data. The concentration found in solution after 48 hours desorption was expressed as a percentage of the theoretical equilibrium solution concentration.

DISCUSSION

The effectiveness of atrazine was influenced by soil type. The response of *E. crusgalli* (*EF*) tested in three soils (Table 1) was inversely related to extent of atrazine adsorption (Table 2) as summarized below.

TABLE 6

Effect of atrazine (0·75 p.p.m.) on E. crusgalli *(EF form) related to extent of adsorption (estimated by K_{10} K_{100}) in three soils*

Soil	Fresh Weight Reduction Percentage	Kill Percentage	K_{10}	K_{100}
C	98	73	0·73	0·54
D	86	39	0·95	0·97
F	71	19	1·73	1·73

The difference between the three local soils, although significant in terms of percentage of seedlings killed, was not so marked when fresh weights were compared. Even in the heaviest local soil tested (F) the vigour of the plants, measured by reduction in fresh weight, was considerably reduced (*EC* 69%, *EF* 71%—Table 1) by 0·75 p.p.m. atrazine.

In the other clay soils (Table 3) differences in adsorption were small; in all these soils adsorption was relatively low.

Kent Sand, Willalooka Sand and Wollongbar clay loam also adsorbed only small quantities of atrazine (Table 4); adsorption by Pelican Clay alone was relatively high.

These results are consistent with the organic carbon contents of the soils and reports in the literature that in studies of correlation of chloro-triazine

sorption with soil properties the best relationship is usually with soil organic matter (Day and Jordan, 1964 ; Talbert and Fletchall, 1965 ; Furmidge and Osgerby, 1967 ; Walker and Crawford, 1968). All the soils tested here were low in organic carbon (less than 1·9%) with the exception of Pelican Clay (6·0%).

Although the quantity and nature of clay minerals has been reported to have a significant influence on adsorption, especially in soils which are low in organic matter (Talbert and Fletchall, 1965 ; Harris and Sheets, 1965 ; Walker and Crawford, 1968) it seems that the variation in quantity and nature of clay minerals present in clay soils from the Riverina and Namoi areas (Table 3) did not affect atrazine adsorption appreciably.

Measurements of rate of carbon-14 desorption from soils C and F (Table 5) showed that more than 90% of the theoretical equilibrium solution concentration, assuming complete reversibility, was attained within one hour. There was reasonable agreement between desorption of carbon-14 activity and atrazine measured by gas-liquid chromatography. It seems that in these soils atrazine is not degraded during sorption and can be fairly readily desorbed in a phytotoxic form.

From these results it appears that the two factors studied here—difference in susceptibility of forms of *Echinochloa* and extent of atrazine adsorption by soil—cannot explain poor weed control.

It seems more probable that erratic control may be attributed to other factors relating to effective distribution of atrazine in the root zone of germinating seedlings, e.g. the efficiency of application, tilth, watering regimes, rainfall, etc.

Where evaporation is high, as in the M.I.A., water movement after furrow irrigation will be mainly towards the surface of the soil, and the amount of rain occurring soon after spraying could be a critical factor in the distribution of atrazine into the root zone.

Where similar difficulties have been experienced elsewhere, more reliable weed control has been obtained by preplant incorporation (Knake *et al.*, 1970) or post-emergent spraying with oil additives (Bandeen and Verstraete, 1967 ; McPhail, 1968). Because of the high tolerance of maize (and sorghum to a lesser extent) it might also be feasible to increase the rate of herbicide applied, but the possible hazard of residues to subsequent crops may then require consideration.

Acknowledgements

Seed of forms of *Echinochloa* was supplied by Dr. P. W. Michael, University of Sydney.

Carbon-14 labelled atrazine was donated by Ciba-Geigy Ltd., Basle, Switzerland.

Soils described in Table 3 were collected and supplied by Dr. J. Loveday ; H. J. Beatty determined organic carbon and A. R. P. Clarke determined surface areas. Soils described in Table 4 were supplied by Dr. R. J. Swaby. Clay minerals were analysed by A. R. P. Clarke, C.S.I.R.O. Division of Soils.

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Contributed Paper:

PHYTOTOXICITY OF DIURON IN SOME AUSTRALIAN SOILS

A. R. Pillay and Y. T. Tchan*

Summary

The toxicity of diuron to oats was determined in ten soils of widely differing textures. Initial diuron phytotoxicity varied with soil types. There was a highly significant correlation between phytotoxicity and soil organic carbon content. It is concluded that a knowledge of organic carbon content could be useful in predicting diuron dosage requirements in Australian soils.

Introduction

The s-phenylurea herbicides are widely used for selective control of weeds in crops, for general vegetation control and, to a less extent, for woody plant control in Australia. As these are soil-applied herbicides, adsorption by soil colloids is one of the factors which influence their effectiveness. The extent to which these herbicides are adsorbed in soil determines the herbicide concentration in soil solution. This affects the initial phytotoxicity of herbicides in the soil and can be investigated by using higher plants or algae (Pillay and Tchan, 1972).

Although adsorption of s-phenylurea herbicides by soils has been extensively investigated in other countries (Sheets and Crafts, 1957 ; Sheets, 1958 ; Upchurch, 1958 ; Yuen and Hilton, 1962 ; Hance, 1965), there is insufficient data concerning adsorption of these herbicides in Australian soils. The aims of the experiment reported here are :

(1) To study the effect of different Australian soils on the initial toxicity of diuron (N^1-(3,4-dichlorophenyl)-NN dimethylurea) to oats.
(2) To relate various soil properties to the initial phytotoxicity of this herbicide.

Methods and Materials

Ten soils collected from various localities in New South Wales and South Australia were used. The soils were chosen to represent a wide range of clay and organic matter contents. Some of the physical properties of the ten soils are recorded in Table 1. Algerian oats were used as indicator plants and stock solution of diuron was prepared from an 80% wettable powder formulation.

One hundred and eighty-gramme portions of the air-dried soils were weighed in unperforated plastic cups. The stock solution of the herbicide was diluted with nutrient solution (Tchan, 1959), and applied directly to the soil-culture surface to give the required herbicide concentrations at field capacity. Three hours after addition of the herbicide, 10 oat seeds, pre-germinated on moist filter paper in Petri dishes at room temperature, were transferred to the cups. The plants were grown under fluorescent light, which provided an illumination of 365 ft.-candles. The photo period was 16 hours at 26° C. in the light and eight hours at 16° C. in the dark. The test containers were randomized on the growth room bench. Due to lack of space in the growth room bioassay work included two or three soils at a time. The plants were watered daily with a diluted (1/20) nutrient solution. After germination the plants were thinned

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to six plants per cup. After three weeks the plants were cut at the soil surface and their fresh weights were recorded.

To compare the effect of different soil types and diuron on shoot growth of oats, ED_{50} (equivalent dose for 50% response) values were calculated for each replication of each soil. This was done by plotting the fresh shoot weight as a percentage of the control against the logarithm of the herbicide concentration and a curve was drawn to fit the points. The value on the chemical concentration axis, which corresponded with the point of intersection on the curve and the 50% shoot growth represented the ED_{50} value as a logarithm. The antilogarithm of this value gave the ED_{50} value in μg. of diuron per gramme of soil.

Analyses of variance and Duncan's multiple range test (Duncan, 1955) were done using the ED_{50} values. Significance was determined at 1% level. Correlation and regression analyses were done using the data for the ED_{50} values and the different soil properties, and were considered to be meaningful at the 1% level. Independent variables (soil properties) which were not significant at the 1% level were not used in the regression analysis.

Results and Discussion

The influence of soil type on the phytotoxicity of diuron, expressed as ED_{50} values, is shown in Table 2. The different ED_{50} values for diuron in the various soils are assumed to be due to the differences in soil properties (Table 1).

Table 1

Physical Properties of Soils

Soils	Organic Carbon Percentage (Tinsley)	Sand Percentage (2·0–0·5 mm.)	Silt Percentage (0·05–0·002 mm.)	Clay Percentage (<0·002 mm.)	pH
Wolverton A (N.S.W.) ..	2·64	37·1	30·8	33·0	5·0
,, B (N.S.W.) ..	1·35	31·7	24·3	41·7	5·0
,, C (N.S.W.) ..	0·98	43·3	24·8	38·4	5·0
Cobbity A (N.S.W.) ..	0·69	42·15	12·63	47·7	5·2
Mt. Tomah (N.S.W.) ..	4·8	48·65	28·08	30·48	4·8
Cobbity B (N.S.W.) ..	2·95	54·93	13·25	34·7	6·0
Prospect (N.S.W.)	3·39	33·4	17·8	61·3	5·5
Moon Hills (S.A.) ..	1·15	91·3	1·67	1·33	5·2
Blewitt Springs (S.A.) ..	1·73	93·0	0·83	3·83	5·8
Mount Compass (S.A.) ..	1·12	95·33	2·5	0·5	5·3

Table 2

Effect of Soil Type on the Phytotoxicity of Diuron

Soils	ED_{50} Values (μg./g.)*
Wolverton A	2·62 bc
,, B	2·83 bc
,, C	1·55 bc
Cobbity A..	1·42 bc
Mt. Tomah	6·17 a
Cobbity B..	4·67 ab
Prospect	3·43 bc
Moon Hills	2·23 bc
Blewitt Springs	0·81 c
Mt. Compass	1·47 bc

* Mean values for diuron followed by the same letter or letters do not differ significantly at 5% level of probability.

A high positive correlation ($r=0\cdot876$, significant at $0\cdot1\%$ level) was obtained between diuron ED_{50} value and organic carbon content. This is in agreement with the findings of other workers (Sheets and Crafts, 1957 ; Upchurch, 1958 ; Upchurch and Mason, 1962). But other soil properties such as pH ($r=-0\cdot181$), sand ($r=-0\cdot386$), silt ($r=0\cdot499$) and clay ($r=0\cdot329$) are not significantly correlated with the ED_{50} value of diuron. The lack of correlation with clay content, although clay content ranges from $0\cdot5\%$ to 61%, was unexpected in view of the results of Sheets (1958). It also shows that adsorption on to clay colloids in the soils used, if it occurs at all, does not seem to affect the phytotoxicity of diuron.

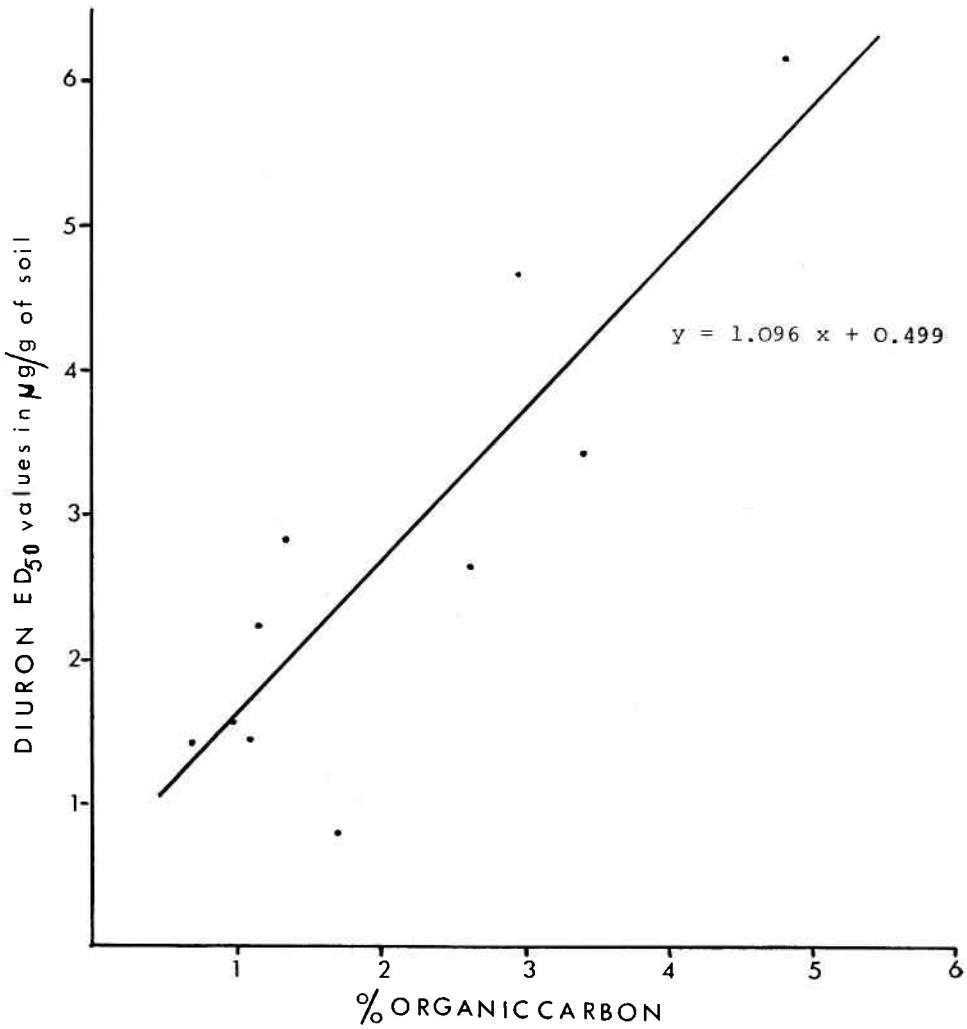

Figure 1.—Correlation of diuron ED_{50} values and percentage organic carbon content with regression line.

Figure 1 represents the experimental data points (organic carbon content of the ten soils against the diuron ED_{50} values). These lie close to the regression line obtained by statistical estimation. This suggests that the linear regression equation could be used to indicate the variation in diuron ED_{50} value with increase in the soil organic carbon content.

In view of the above observations, it can be concluded that the organic carbon content should be considered in schemes to predict the diuron dosage requirements in Australian soils.

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Contributed Paper:

LEACHING PROPERTIES OF SIMAZINE AND DIURON IN A MURRAY VALLEY SAND IN RELATION TO WEED CONTROL IN CITRUS

P. W. Weiss*

Summary

Unfavourable control of *Digitaria sanguinalis* by simazine in citrus in the Murray Valley area of South Australia in contrast to good control with diuron is attributed in this paper mainly to excessive leaching of simazine compared with diuron and, to a lesser extent, poorer control of *D. sanguinalis* by simazine *per se* than diuron.

Introduction

The use of substituted triazines and ureas in the form of simazine and diuron respectively is well established for weed control in vines and citrus in the Murray Valley of Australia. However, problems have arisen with the use of simazine in citrus, mainly in South Australia, with regard to satisfactory pre-emergence control of summer-growing grasses, particularly *Digitaria sanguinalis*, and to a lesser extent, *Cenchrus* sp. In some cases there was virtually no control of these grasses with simazine, but satisfactory results were achieved with diuron. Weed control was, however, satisfactory with both herbicides in vines.

It was suspected that leaching could be an important factor, since 12–14 overhead irrigations are commonly applied from late spring to autumn in the case of citrus, whereas vines normally receive side-furrow irrigation (usually four times during spring and summer and twice in winter).

However, it is generally accepted (Weldon and Timmons, 1961 ; Roadhouse and Birk, 1961) that both simazine and diuron leach comparatively little in soil, most being found in the surface inch. Their low water solubilities (5 and 42 p.p.m. respectively) may partly account for this. Leonard and Lider (1961) also found no detectable residues of simazine or diuron below a soil depth of six inches after four successive years use in vineyards. Under glasshouse conditions Burnside *et al.* (1961) found no detectable residues at a soil depth of three to six inches after an application of 2 lb. a.i./ac. simazine, followed by one inch of water. Most simazine was found in the surface half-inch of soil.

In an attempt to explain the observed results in the Murray Valley, it was decided to compare the two herbicides in a similar soil type in the glasshouse, using two rates of herbicide application and various rates of simulated overhead irrigation, ranging from nil to 15 inches. Nil irrigation was included to investigate the herbicidal effect ***per se*** on *D. sanguinalis*.

Methods

A 0–6 in. well-mixed sample of a Murray Sand (sand 85·8%, silt 2·6% clay 10·6%, organic matter 0·9%, pH 8·0) was used in all experiments.

Experiment 1.—The leaching effect of 1·0 in. of water on simazine and diuron

Plastic bags, open at the top and with the bottom end perforated, were filled with soil. Each was placed inside a 12 in. long galvanized iron cylinder

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3·5 in. in diameter. The cylinders were open at each end and capable of being split longitudinally into two equal hinged halves.

Herbicides used were simazine (50% wettable powder) and diuron (80% wettable powder), each at 1·0 and 2·0 lb. a.i./ac. They were applied in 50 ml. of water to the dry soil surface at the top of the upright tubes. There were four replicates.

One day after the herbicide application 1·0 in. of water was applied with a pipette over a period of one hour to the soil surface at the top of the tubes. Controls received the 50 ml. of water and 1·0 in. of water.

One day later the tubes were opened along the hinged side, the soil column sliced down the middle, and the two halves of soil laid horizontally in the cylinder on benches in the glasshouse. Germinated seeds of *D. sanguinalis* were then sown down each half soil column in four rows.

Eight weeks after sowing, the above-soil parts of the plants were harvested in each 1·0 in. section of the column and their green weights recorded. The percentage reduction in yield was calculated from the control weights in each corresponding inch section.

Experiment 2.—The leaching effect of 2·0 in. of water on simazine and diuron

The same procedure as in Experiment 1 was used, except than 2·0 in. of water was applied the day after the herbicide application.

Experiment 3.—The leaching effect of 15·0 in. of water on simazine and diuron

The same procedure as in Experiment 1 was used, except that 15·0 in. of water was applied, in amounts of 1·5 in. ten times over a period of 20 days, before dividing the cylinders.

Experiment 4.—The herbicidal effect of simazine and diuron under non-leaching conditions

Leaching was eliminated by dry-mixing the herbicides at concentrations of 0·25 and 0·50 p.p.m. a.i. with the soil, which was then placed in plastic pots, seeded with germinated *D. sanguinalis*, and watered daily by sub-irrigation.

Counts of the numbers of dead and alive plants were made twice weekly until six weeks after sowing. The total numbers of dead plants were then expressed as percentages of the total numbers of plants that had emerged.

Results

Experiment 1

The results are shown in Table 1.

Table 1

Mean percentage reductions in green weight of D. sanguinalis *compared with controls, by simazine and diuron after 1·0 in. of water*

Depth in soil column (inches)	1·0 lb./ac.		2·0 lb./ac.	
	Simazine	Diuron	Simazine	Diuron
0–1	100	100	100	100
1–2	60	0	92	94
2–3	62	0	58	25
3–4	0	0	20	0
4–5 and below ..	0	0	0	0

Experiment 2

The results are shown in Table 2.

TABLE 2

Mean percentage reduction in green weight of D. sanguinalis *compared with controls, by simazine and diuron after 2·0 in. of water*

Depth in soil column (inches)	1·0 lb./ac.		2·0 lb./ac.	
	Simazine	Diuron	Simazine	Diuron
0–1	100	98	100	100
1–2	96	70	90	100
2–3	75	0	93	73
3–4	76	0	88	15
4–5	0	0	76	15
5–6	0	0	0	9
6–7 and below ..	0	0	0	0

Experiment 3

The results are shown in Table 3.

TABLE 3

Mean percentage reduction in green weight of D. sanguinalis *compared with controls, by simazine and diuron after 15·0 in. of water*

Depth in soil column (inches)	1·0 lb./ac.		2·0 lb./ac.	
	Simazine	Diuron	Simazine	Diuron
0– 1	0	50	50	100
1– 2	0	73	52	100
2– 3	0	68	60	100
3– 4	0	33	80	100
4– 5	0	0	88	97
5– 6	48	0	92	97
6– 7	50	0	98	78
7 –8	58	0	100	48
8– 9	87	0	98	0
9–10	76	0	96	0
10–11	35	0	91	0

Experiment 4

At concentrations of 0·25 and 0·50 p.p.m. of simazine, there was a mean percentage kill of *D. sanguinalis* of 87% and 89% respectively. The corresponding kill with diuron was 98% and 100% respectively.

DISCUSSION

The results confirmed the observations made in the field and point to excessive leaching as an important factor where poor weed control resulted with simazine. Thus Experiments 1 and 2, and especially Experiment 3, show greater leaching with simazine than diuron.

In grass control, this difference is accentuated by the poorer herbicidal effect of simazine *per se* on *D. sanguinalis*, as shown in Experiment 4. However, the differences in Experiment 4 were insufficient to account for the observed field differences, whereas those in Experiment 3 were.

According to the writer's own observations, most of the germinations of *D. sanguinalis* occur between depths of ½ and 2 in. in this soil type. Thus it is essential for the herbicide to be concentrated at these depths to obtain maximum effect.

In each case the higher rate of herbicide application enabled more of the herbicide to be retained near the soil surface than the lower rate. However, even at the higher rate there was a poor degree of control near the soil surface by simazine in Experiment 3.

Although high amounts of irrigation appear most detrimental to the performance of simazine, with both simazine and diuron too light an application of water, at least with a low rate of herbicide, may not mobilize the chemical sufficiently to control grasses germinating from a depth of 1 to 2 in., as shown in Experiment 1.

Since the water solubility of the herbicides used would suggest opposite leaching results to those found, there must be other inherent chemical properties, such as particle size, to explain these results. These would appear to be worthy of further investigation, so that it may be possible to regulate soil movement of the herbicide according to the situation.

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