Proceedings of the

WEED SOCIETY

of New South Wales

Volume III
1970

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.

PROCEEDINGS

This third volume of proceedings collated by Mr A. D. Mears and Dr P. W. Michael includes a selection of papers presented at the Thistle Symposium held at Goulburn, N.S.W., on 5th May, 1970. The symposium was jointly sponsored by the New South Wales Department of Agriculture, Weed Society of New South Wales, Southern Tablelands Research Extension Committee and Southern Tablelands and South Coast Regional Noxious Plants Committee. In addition, a paper originally presented at a Symposium organized by the Weed Society of New South Wales at Leeton, N.S.W., on 14th March 1968, and two contributed papers, are included.

Members are entitled to receive one copy of the Proceedings free; non-members may purchase copies for two dollars.

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.

CONTENTS

BIOLOGY AND ECOLOGY OF THISTLES

P. W. MICHAEL*

THE THISTLES THEMSELVES

A list of the thistles which occur in south-eastern New South Wales with their scientific and common names, their life duration and seed size, is given below. A simple key to their identification appears at the end of this paper. The thistles with milky sap (*Sonchus* species—sow thistles) are excluded.

Thistles of South-Eastern New South Wales

Scientific name	*Common name*	*Duration*	*Approx. seed weight (mg.)*
Carduus nutans	nodding thistle	biennial	3·5
Carduus pycnocephalus	slender thistle	annual	5
Carduus tenuiflorus	winged slender thistle	annual	3
Carthamus lanatus	saffron thistle	annual	26
Centaurea calcitrapa	star thistle	annual; biennial	3–4
Centaurea melitensis	Maltese cockspur	annual	2
Centaurea solstitialis	St. Barnaby's thistle	annual	2
Cirsium arvense	perennial thistle	perennial	–
Cirsium vulgare	spear, black thistle*	biennial	4–4·5
Cirsium vulgare subspecies *crinitum*	(tentative identification)	biennial	5–5·5
Onopordum acanthium	cotton thistle } *woolly thistle	biennial	11
Onopordum illyricum	Illyrian thistle } *woolly thistle	biennial	15
Silybum marianum	variegated thistle*	annual	22

* Sometimes called Scotch thistle.

Of the thistles included in the above list, star thistle, Maltese cockspur, St. Barnaby's thistle and perennial thistle will be treated very briefly as they are only of limited importance in the region. Perennial thistle occurs in small but persistent infestations only in the southern parts. In New South Wales seed production does not appear to be important in perennial thistle which propagates by means of roots. Maltese cockspur and St. Barnaby's thistle are of much greater importance in arable areas in central and northern New South Wales, while star thistle is essentially a roadside weed much more common in the south-west slopes region than on the tablelands or the coast.

The remaining annual and biennial thistles are a prominent feature of improved pastures in areas receiving upwards of 20 inches to about 35 inches annual rainfall. Saffron thistle occurs at its worst in the drier parts of the region and although it is often abundant in grazing areas, it is essentially a weed of cultivation, especially in wheat-growing.

Introduction and Spread

The early introduction of thistles to Australia was both intentional and accidental. Variegated, cotton and Illyrian thistles were all introduced

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intentionally as "Scotch thistle", variegated probably also as a medicinal plant. Saffron thistle, a close relative of safflower, was, I suggest, introduced intentionally also. The small seeded spear, slender, winged slender and nodding thistles were introduced accidentally in pasture seed, a recent introduction (probably first in the 1940s) being nodding thistle in perennial rye grass seed from New Zealand. *Cirsium vulgare* ssp. *crinitum* may have had a similar history to nodding thistle.

Thistles, along with Bathurst burr, were among the first weeds to attract attention from landholders in Australia. The first noxious weeds legislation was directed against variegated thistle in South Australia in 1851.

Thistle seeds are spread by water, wind, livestock and in grain or pasture seed. Insects, especially ants, may spread the smaller seeds like those of spear thistle or sticky seeds like those of slender thistle. Spread by wind is not so common as is generally believed, the wind-blown pappus commonly seen most often being devoid of the seed itself. It is, however, important in the spread of spear and nodding thistles. The spread of saffron thistle in the past, as now, can be largely attributed to its presence in wheat grain. And, indeed, perhaps one of the reasons the big-seeded cotton thistle is so abundant in the Crookwell area can be attributed to the early history of wheat-growing there.

Soil Fertility Relationships

Before cultivation and the development of improved pastures, the annual and biennial thistles, excluding saffron, perhaps, were prominent around homesteads, on stock camps and around rabbit warrens, and it is from these that they have spread. Their occurrence on areas of higher fertility than the generally prevailing country has long been recognized. And with the general increase in fertility of pastures, associated with the introduction of clovers and the use of superphosphate, there have been big increases in spear thistle, cotton and Illyrian thistles and nodding thistle. Variegated thistle appears to be confined mainly to soils of high natural fertility, especially alluvial soils or soils of igneous origin, but it is likely that the use of subterranean clover pastures has largely aided its persistence. It appears to have higher nutrient demands than cotton and Illyrian thistles, which, in turn, have higher demands than those of spear thistle. Nodding thistle may have even higher demands than variegated thistle.

It is unwise to ascribe predominance of these thistles just to high nitrogen; other nutrients are important also. The slender thistles appear to be especially favoured by high calcium. Saffron thistle appears to be rather indifferent to soil fertility, but it suffers from competition from useful or other weed species under conditions of high fertility.

Dormancy, Germination and Flowering

Viability of new thistle seed is, in general, very high. It falls off fairly rapidly in variegated, cotton and Illyrian and nodding thistles, but sufficient seed may survive for a number of years (perhaps the traditional seven years) to allow for the appearance of significant infestations. Dormancy seems to be important in spear and saffron thistle, new seed germinating rather poorly. It is likely that these two thistles may survive for longer periods.

Germination of the annual thistles appears to be strictly seasonal, while the biennial thistles may germinate in either autumn or spring and even in winter and summer if moisture and temperature conditions are favourable.

The flowering of the biennial species, especially of cotton, Illyrian and nodding thistles, may be dependent on their rosettes being subjected to a certain length of cold period through the winter months—for example, cotton thistle germinating in early autumn may flower in the same season, thus behaving as an annual, while those germinating in late May may not flower until late spring in the following year. However, it appears in nodding thistle, for example, that flowering may occur in the first summer even if seedlings do not appear until early spring. This may happen only under conditions of high fertility.

Relationship of Occurrence to Seasonal Conditions

Thistles do not invade pastures in areas of long growing season with continual cover of pasture species. But, in areas with dry summers, the absence of pasture cover (or the presence of bare ground) in late summer-early autumn is important in the development of heavy infestations of thistles. The thistles appear to respond to the high nitrate conditions induced. Field experiments have shown that the establishment of cotton thistle can be increased by the addition of nitrogenous fertilizer.

Any factors which tend to open up pasture swards, for example, the self-mulching of soils in the Monaro region, the rolling up of subterranean clover at the end of summer, or long-sustained drought, tend to favour the establishment of thistles when suitable rains come.

The irregular appearance of thistles from season to season is well known. This phenomenon appears to be at least partly related to sustained periods of drought. Thistles may be at their best (or worst) in the year immediately following a drought due to the factors already mentioned, and then, with a new crop of viable seed produced, conditions are good for another high germination in the following year, provided favourable rains occur.

So-called "thistle" years are often associated with good "clover" years, and years in which thistles are not so prominent are often associated with annual "grass" years. These "clover" or "grass" years seem to be largely determined by the distribution of rainfall throughout the year. In south-eastern New South Wales, good rains in January and February are followed by good germination and establishment of subterranean clover and thistles. Later opening rains seem to favour the annual grasses. Providing large numbers of thistles are already well established, heavy spring rains (especially in October) allow for the full development of stands of variegated, cotton and Illyrian thistles.

Previous paddock history is undoubtedly also an important factor in the seasonality of thistles.

A Simple Key to the Identification of Thistles

A. Leaf margins spiny.
- B. Perennial plants with creeping root system .... *Cirsium arvense*
- B. Annual or biennial plants with tap root.
  - C. Flowers yellow .... *Carthamus lanatus*
  - C. Flowers pink-red-purple (rarely white in *Carduus nutans*).
    - D. Plants with large more or less globular flowering heads (1″ or more broad).
      - E. Leaves with smooth upper surface, with network of prominent white veins .... *Silybum marianum*
      - E. Leaves with prickly or hairy upper surface, without network of prominent white veins.
        - F. Leaves with prickly hairs on upper surface.
          - G. Flowering heads often surrounded by narrow leaves much longer than the heads .... *Cirsium vulgare* ssp. *crinitum*
          - G. Flowering heads not surrounded by such leaves.. *Cirsium vulgare*
        - F. Leaves with soft woolly hairs on upper surface.
          - H. Leaves with dense hairs on both surfaces, flowering heads erect.
            - I. Outer hard bracts of flowering heads broad (up to $^3/_{16}$″) and strongly bent back .... *Onopordum illyricum*
            - I. Outer hard bracts of flowering heads narrow (about $^1/_{16}$″), not so strongly bent .... *Onopordum acanthium*
          - H. Leaves with only sparse hairs, except on veins of lower surface, flowering heads nodding .... *Carduus nutans*
    - D. Plants with small (less than ½″ broad), more or less oblong flowering heads.
      - J. Plants with heads clustered (up to 10 or so) at the end of flowering stems with leafy spiny wings .... *Carduus tenuiflorus*
      - J. Plants with heads in twos or threes at the ends of flowering stems without leafy spiny wings .... *Carduus pycnocephalus*

A. Leaf margins not spiny.
- K. Flowers pink-purple .... *Centaurea calcitrapa*
- K. Flowers yellow.
  - L. Spines at end of hard bracts of flowering heads stout, yellow, up to ¾″ long. .... *Centaurea solstitialis*
  - L. Spines at end of hard bracts of flowering heads, weak, usually reddish or purple up to ½″ long .... *Centaurea melitensis*

THISTLE CONTROL RECOMMENDATIONS

P. H. Hodge*

The Thistle Problem

The main problems of thistle control on the Southern Tablelands concern the biennial species (cotton thistle, Illyrian thistle, spear thistle and nodding thistle) and the annual variegated thistle. These are all weeds of high fertility situations, e.g., clover pastures and sheep camps. Existing thistles may be killed with herbicides, but thistles are likely to re-appear in the same situation because seed may still remain on or be spread to that area. Even if one species of thistle (e.g., variegated thistle) could be completely eliminated and all seed destroyed, it would in all probability be replaced by

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other thistles (such as woolly and spear) unless the environmental conditions are changed.

Factors in the environment which affect thistle infestations are climate, soil, plants (competition), animals and man (management).

Control by Pasture

Nothing can be done to influence seasonal conditions of rainfall and temperature. On the other hand, the good soil fertility conditions which favour the thistles mentioned, can be used to advantage for establishing and maintaining high-carrying, permanent pastures. Permanent pastures of *Phalaris tuberosa* or well-managed lucerne or a mixture of both provide the best practical means of thistle control.

Establishment of a vigorous perennial grass-clover sward before thistles invade an area is the ideal to aim for.

Phalaris tuberosa

For thistle control Phalaris is best sown in the spring (early September). A seed-bed may be prepared either by mouldboard ploughing or by chemical "ploughing". The mouldboard plough is recommended for seed-bed preparation in preference to the chisel plough, as it buries seed of potentially competitive plants.

There may be just as much or more competition from certain thistles (cotton, Illyrian and nodding) with a spring sowing as with an autumn sowing. However, because of greater competition in autumn sowings from the annual grasses that occur in thistle communities (barley grass, brome grass and rat's tail fescue—and subterranean clover could be added to this list of competitors) a spring sowing of Phalaris is recommended.

For non-arable situations such as sheep-camps on rocky hilltops (a common situation on the Southern Tablelands), chemical "ploughing" followed by broadcasting of Phalaris seed in August is recommended. A mixture of 5 lb. of 2,2-DPA (2,2-dichloropropionic acid) and 1 lb. of amitrole (3-amino-1,2,4-triazole) per acre is effective in killing grasses as well as thistles and other broad-leaved plants. It may be necessary to temporarily fence such areas when the whole paddock is not being seeded. Stock should be kept off areas sown to Phalaris for at least six months after sowing.

Phalaris is more suitable than lucerne for thistle control where paddocks are large and set-stocking is to be practised.

Lucerne

Lucerne sown in spring (early September) is also recommended for thistle control. Lucerne is more exacting than Phalaris in its nutritional and management requirements. In addition to superphosphate, the minor elements molybdenum and boron are recommended. Superfine-lime drilled in contact with inoculated and lime-pelleted lucerne seed is a basic recommendation. The superfine-lime and superphosphate can be mixed together in equal quantities on the day of drilling. If stored, the mixture may set hard.

Lucerne should be spelled for at least 30 days between grazings. Cutting lucerne for hay is one means of preventing the seeding of thistles. Heavy stocking pressure also helps control thistles in lucerne provided the lucerne is allowed to recover between grazings.

Herbicides for Thistle Control

The use of herbicides alone gives only temporary control of thistles. However, herbicides may be used as an adjunct to ecological control.

All the thistles listed on page 3 (except perennial thistle) are susceptible to 2,4-D (2,4-dichlorophenoxyacetic acid) when the plants are in the small rosette stage. *2,4-D* amine at rates of 8 to 12 oz. active ingredient per acre can be used for selective control in grass and clover pastures. The higher rate is recommended for larger rosettes (over six inches in diameter).

Once past the rosette stage, cotton and Illyrian thistles are difficult to kill with 2,4-D. An added problem is that at any one time, these thistles usually occur in all stages of growth. Older thistles can not be killed by 2,4-D.

2,4-D ester has been used successfully for controlling thistles, especially nodding thistle in young Phalaris pasture but will seriously damage or destroy clovers. Greater care must be exercised when using 2,4-D ester, as it can damage a greater range of commercial crops and garden plants through spray drift or drift of vapour after application.

For selective control of thistles in lucerne, 2,4-DB (2,4-dichlorophenoxy-butyric acid) should be used at 8 to 12 oz. active ingredient.

The optimum time for spraying with 2,4-DB as far as lucerne is concerned, is when the seedling lucerne has from one to eight trifoliate leaves, which coincides with emergence of most thistle seedlings (and other broad-leaved weeds).

As for 2,4-D, cotton and Illyrian thistles are difficult to control with 2,4-DB once past the rosette stage.

Dicamba (3,6-dichloro-2-methoxybenzoic acid) at 4 oz. active ingredient per acre is effective in killing cotton thistle and Illyrian thistle but also kills clover and lucerne. For spot spraying, dicamba can be used at 2 fl. oz. of 20% product in 3 gal. of water.

Dicamba is also effective in controlling perennial thistle at a rate equivalent to 2 lb. active ingredient per acre. For spot-spraying perennial thistle, dicamba can be used at 1 pint of 20% product in 3 gal. of water. At these rates of application, dicamba acts as a soil sterilant.

THISTLES AT "LAKE EDWARD"—A CASE HISTORY

J. E. Carter*

Background Information

"Lake Edward", a 2,560-acre property, has been owned by the Carter family for 91 years. It is of basalt soil with an elevation of 2,800 ft. and a 31-in. rainfall.

Superphosphate and subterranean clover have been applied from 1927 and super application on the whole property now aggregates an average of 30 cwt. per acre. Light ryegrass sowings followed potatoes from 1935 onwards.

Heavy stands of variegated thistle developed on the sheep camps and higher country (mostly the better basalt soils) from the 1940s. Cotton thistle superseded the variegated thistle in the fifties. By 1958 an area of 30 acres on one heavy basalt hill carried nothing at all but cotton thistle.

* "Lake Edward", Crookwell, N.S.W. 2625.

In the course of 25 years, this area had changed from natural redgrass, to subterranean clover (up to 2 ft. deep), to variegated thistle (up to 14 ft. high) and finally to cotton thistle.

The Answers Found

By 1958 it was clear that if a way could not be found to overcome the cotton thistle the property would eventually succumb and the stocking capacity would disappear. We therefore selected the worst site, which was ploughed and harrowed, and sown for two years to Chou Moellier (and thistle!). In September 1960 it was sown with *Phalaris tuberosa* at 3 lb. per acre. Phalaris was selected, as in small, long-established stands, it had remained relatively unaffected by thistle spread. In conjunction with C.S.I.R.O., we also tried Brignoles cocksfoot and Demeter fescue.

We applied various herbicides over the first two years, using three applications, to enable the Phalaris to establish itself against the competition.

Since 1962 we have used no herbicide. The 30 acres are now virtually free of thistle, with a dense cover of Phalaris and subterranean clover coming up through the mat each spring, provided the Phalaris is heavily grazed in winter.

We have followed this programme yearly since 1960. Of the 1200 acres in my own care, 660 are now under Phalaris. I have a further 110 acres of arable country to sow and then will have to begin experimenting with chemical farming.

The success of Phalaris can be attributed to the following points:

(1) Its ability to stool vigorously under heavy winter grazing and thus give complete soil coverage.

(2) Its deep rooting system which enables it to withstand the occasional drought without thinning out and giving bare earth for weeds to grow. Nature abhors a vacuum! The 1968 drought was tremendous proof of this. When it rained in May, the Phalaris gave us feed to lamb on in August, whilst everywhere else the weeds and slow-growing grasses were taking a long while to recover from the drought.

Brignoles cocksfoot and, to a lesser extent, Demeter fescue, both failed in the above departments and have been set aside for all pasture (weed control) programmes on our property, as I feel they are not suited to our heavy basalt soils.

Conclusion

Cotton thistle can be completely controlled in this environment with *Phalaris tuberosa* sown at 3 lb. to the acre and given help for the first spring and two autumns with a suitable herbicide. We have had success with 2,4-D 80% ester applied in the rosette stage and have used nothing else for eight years in the course of establishing Phalaris in various paddocks.

On headlands and rocky outcrops which are unploughable, we still have heavy stands of cotton thistle but it does not encroach on the Phalaris stands. These small areas now present more of an aesthetic than an economic problem. Due to its size, some cotton thistle seed can lie dormant for up to 20 years before germinating. Thus, constant spraying will not eradicate the weed.

Management

It is essential to graze *Phalaris tuberosa* heavily during winter, and this is easy as it is only working along with nature. We have worked on an overall D.S.E. (dry sheep equivalent) of seven to eight for five years, and the

Phalaris country approaches 10. Last year nine wethers cut 108 lb. wool to the acre (set-stocked) and half a heifer per acre was run for three months. This was an exceptional year, but a D.S.E. of ten on this country under Phalaris is quite feasible in many years.

I am opposed to heavy grazing in summer whenever it can be avoided, as it gives weeds their opening for the autumn germination. Usually the spring takes care of this, but in 1967 it didn't, and this gave rise to the nodding thistle problem that we now have.

Phalaris Poisoning

In the past ten years, Phalaris poisoning has occurred once only—during exceptional hand-feeding conditions in the drought where ewes were put into a Phalaris paddock during rain so that they could be hand-fed with their wheat ration. They were left in for an hour and then put out, but by next morning 12 ewes were dead. This was probably because of the new shoot and overcast conditions which are the usual causes of sudden death from Phalaris.

Carduus nutans—*Nodding Thistle*

In 1953, after some varying diagnoses, *Carduus nutans* was identified on "Lake Edward". The plant was then covering an area of about 100 square yards. Had we known what lay in store, we would have covered the area with concrete! As it was, we cut the plants, only to see a slightly stronger germination in 1958. Then followed a slow, leap-frogging spread along the line of the prevailing westerly winds.

New Zealand experiments have shown it is very rare for a seed to be carried more than eight feet by wind, so this method of spread is very slow.

By 1967 we had about ten acres infested in eight different areas. The spring failed, the sheep ate everything—grass, thistle seed and all. By May 1968, when the drought broke, we had a bare dust-bowl with the ideal "vacuum" for weed germination.

In September 1968, 400 of my 1200 acres were infested with nodding thistle. This was a repetition of the New Zealand story where the dry seasons of the 1950s were largely responsible for the species getting out of control. It is still spreading there. I am certain that the spread has been brought about mostly by seed ingested by sheep and distributed through the droppings. As each plant can yield 7,000 seeds, the possibilities are frightening.

Our Phalaris country stood the shock well—some areas were infested but not to the extent of subterranean clover or thin ryegrass stands.

Nodding Thistle Programme, 1969

As it proved impractical to spray in the spring of 1968, we made our first assault by aerial spraying in April 1969. Spraying at this time usually covers all the autumn germination of thistle, which is the larger, due to the depletion of pasture cover in our dry summer. Also, it is safer for stock, due to more roughage being available and less craving for the drying thistles with their associated nitrite poisoning risk. It has the added advantage where trees are present, as they are dormant at that time and don't suffer as they would in the spring.

This spraying cost $1.50 per acre (70 cents for ¾ pint 2,4-D 80% ester and 80 cents application). A very good kill resulted. A small spring germination followed which we attended to on the ground with the same application. Autumn 1970 saw another heavy germination, and a May spraying of 340 acres at $1.40 per acre (chemical through the Shire Council was cheaper and we went up to 1 pint to the acre).

Farming

After ploughing, areas infested by thistle produced fantastic germinations, with the ground completely covered by rosettes. Sowing 6 lb. Phalaris per acre and three sprayings have given a good stand of Phalaris, but there were some very anxious moments en route. This pasture must be taken carefully through to its first winter before being heavily stocked, otherwise the nodding thistle will have room to germinate more freely.

Conclusion

The nodding thistle battle is only just beginning, and in the light of New Zealand results must be viewed with extreme pessimism. Its "Achilles heel" would appear to be its small seed and the possibility of its not lasting long. (Germination drops by 75% in two years.) Such ideas as burning stands to kill seed, the use of even stronger competitive species and incompatible species, biological control by predators, etc., all have possibilities, but at present dense Phalaris swards and periodic spraying appear the only practical controls.

I do not favour grazing control due to our unreliable environment. In reliable rainfall, heavy grazing will definitely strengthen the pasture, but when the rainfall fails, the sward opens up and allows weeds, particularly the nodding thistle, to get right away.

The picture of nodding thistle moving into open subterranean clover country, which comprises most of the Tablelands and includes much non-arable country, is ghastly, but the probability is very real and must be faced.

Leeton Symposium, 1968:

SOME ASPECTS OF WEED CONTROL IN IRRIGATION SYSTEMS OPERATED BY THE WATER CONSERVATION AND IRRIGATION COMMISSION OF NEW SOUTH WALES

G. R. Sainty*

The control of aquatic weeds in water supply and drainage channels in the irrigation areas and districts of south-western New South Wales is a major problem. Most species will restrict water flow, thus preventing channels operating at their designed capacity.

The more obstructive plants have been known to reduce flow of large supply channels to 20% of their design capacity.

The majority of these plants are perennials. However, the annual growth is unpredictable due to various environmental factors such as water flow, turbidity and temperature.

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This paper, originally presented at the Leeton Symposium in 1968, has been updated by the author to September 1970.

Principal Aquatic Weed Species and their Distribution in the Channel Systems of South-Western New South Wales

The species are listed in approximate descending order of importance.

(a) Supply Channels			
	(i) Emergent	cumbungi (broad-leaf)	*Typha orientalis* (syn. *T. muelleri*)
		cumbungi (narrow-leaf)	,, *domingensis* (syn. *T. angustifolia*)
		phragmites	*Phragmites australis* (syn. *P. communis*)
	(ii) Submersed	elodea	**Elodea canadensis*
		common milfoil	*Myriophyllum propinquum*
		coarse milfoil	,, *elatinoides*
		blunt pondweed	*Potamogeton ochreatus*
		floating pondweed	,, *tricarinatus*
		ribbonweed	*Vallisneria gigantea*
(b) Drainage Channels			
	(i) Emergent	water couch	*Paspalum paspaloides* (previously known as *P. distichum*)
		smartweed	*Polygonum* spp.
		paspalum	*Paspalum dilatatum*
		rushes	*Juncus* spp.
		sedges	*Cyperus* spp.
		spike rush	*Eleocharis* spp.
		water primrose	*Ludwigia peploides*
		arrowhead	*Sagittaria montevidensis*
	(ii) Submersed	ribbonweed	*Vallisneria gigantea*
		curly pondweed	*Potamogeton crispus*
		floating pondweed	,, *tricarinatus*
		blunt pondweed	,, *ochreatus*
		common milfoil	*Myriophyllum propinquum*
		coarse milfoil	,, *elatinoides*
(c) Farm Dams and Storages			
	(i) Emergent	cumbungi	*Typha* spp.
	(ii) Submersed	red milfoil	*Myriophyllum verrucosum*
		sago pondweed	*Potamogeton pectinatus*
		najas	*Najas tenuifolia*
		algae	*Chara*, *Nitella*, *Spirogyra*, *Cladophora Rhizoclonium* (these algae also occur in channels)
	(iii) Floating	red azolla	*Azolla* spp.
		duckweed	*Lemna* spp.
		duckweed	*Spirodela* sp.

* Elodea only infests the western Irrigation Districts of this area supplied from Yarrawonga Weir on the Murray River.

Control Methods

The control of weeds in channel systems operated by the Water Conservation and Irrigation Commission is a balanced one. Both mechanical and chemical techniques are necessary, and one is complementary to the other.

(a) *Mechanical*

There are a number of devices used for mechanical control. They include draglines and backacters with weed buckets. There are also "arrow-cutters" made up of lengths of flat steel sharpened on the outer edge and welded into an arrow shape. A tractor is used to pull the cutter along the channel and the sharp edges slice through the weed. The cut submerged weeds pose a big problem. Weed-buckets are required to pull the plant mass from the channels.

Mechanical methods of control possess the faults that they are of a temporary nature, they are expensive, and they may deepen the channel, thus making it impossible to dry the channel bed, which provides a situation ideal for weed growth. Mechanical removal has a tendency to break up and spread plant growth.

Mechanical control has the advantage in situations where chemical treatment is unacceptable. This may be in a place where masses of weed growth require immediate removal, which cannot be done by herbicides. As well, there are many restrictions on the use of herbicides because of the possible damage from residues or spray drift. From time to time, channels which are mainly controlled by chemical means require de-silting.

(b) *Chemical*

Twenty-five different types of herbicide are currently being used by the Irrigation Commission. The following table shows the main use of some of these herbicides and, where applicable, an approximate rate of application.

Herbicide	Approx. Amount Used by the Commission (1969/70)	Usual Application Rate	Use
acrolein	80,000 lb.	½–2 gal./cusec	all submersed plants
amitrole*	3,800 gal.	6–8 gal./acre	water couch cumbungi sedges smartweed
aromatic solvents	1,600 gal.	8–10 gal./cusec	all submersed plants except floating pondweed
2,2–DPA	34,000 lb.	10–45 lb./acre (product)	cumbungi phragmites paspalum Johnson grass (*Sorghum halepense*)
diuron	2,200 lb.	10–35 lb./acre (product)	sterilizing wetted area of drainage channels
bromacil	1,400 lb.	3–7 lb./acre (product)	total weed control around structures, bridge approaches, etc.
invert 2,4,5–T	40 gal.	spot treatment	evergreen woody species
low volatile 2,4–D ester	250 gal.	spot treatment	hard to kill noxious weeds and deciduous trees; e.g. stinkwort (*Inula graveolens*), wire weed (*Polygonum aviculare*) also *Myriophyllum* spp.
2,4–D amine	80 gal.	1–2 lb./acre	susceptible noxious plants, e.g. *Xanthium* spp.
fenuron	400 lb.	spot treatment	boxthorn (*Lycium ferocissimum*)
atrazine	340 lb.	8–10 lb./acre (product)	total weed control around structures
2,4–D butoxy ethanol ester	50 gal.	spot treatment	horehound (*Marrubium vulgare*)
picloram and 2,4–D amine	60 gal.	spot treatment	Eucalypts on channel reserves
copper sulphate	500 lb.	2 lb./cusec (flowing water) 3 lb./acre foot (static water)	filamentous algae *Spirogyra* spp. *Cladophora* spp.
TCA and 2,2–DPA mixture	4,500 lb. TCA	spot treatment	phragmites cumbungi *Bambusa* sp.
DSMA and 2,2–DPA mixture		5 lb. product of each two applications	paspalum

* Chemical names of herbicides are given at the end of the paper.

Spray Equipment

Many different types of spray units are required to apply herbicides to channel systems, due to the variation in channel size (6 ft. to 30 ft. bed), the type and density of weed growth and the access adjacent the channel.

The following units are currently being used by this Commission:

	Pump	Tank	Approx. Cost (Pump and Tank)
(i)	21 g.p.m. three piston pump; engine functioned	Twin 300 gal. fibre glass tanks with mechanical agitation. Mounted on a F.W.D. 5-ton truck and fitted with a Cranvel hydraulic outrigger	$12,000 including truck and ancillary gear
(ii)	21 g.p.m. three piston pump; power-take-off functioned	300 gal. metal tank with mechanical agitation, mounted on trailer, drawn by tractor, and fitted with a manual counterweighted boom	$1,900
(iii)	14 g.p.m. four piston radial flow pump, engine functioned	100 gal. fibre glass tank. Mounted on a F.W.D. utility	$460
(iv)	9 g.p.m. single piston pump, engine functioned	200 gal. fibre glass tank mounted on a trailer	$800
(v)	Pack type misting machine	1 gal.	$120

Costs

About $200,000 was spent in 1969/70 on chemical weed control in the various Irrigation Area Districts operated by the Water Conservation and Irrigation Commission in south-western New South Wales. This amount was used to control weed growth in a channel system exceeding 4,500 miles in length, and includes cost of herbicide, supervision, labour, truck running and equipment depreciation, etc.

It is misleading to quote costs without describing the situation. However, as a guide, the following expenditure and costs are given:

Herbicide	*Target*	*Cost/mile*
acrolein (1969–70 season)	all submersed weeds	$55 per application for 2 gal./cusec treatments or $35 per application for low-rate long-contact injections (costs calculated from treating 900 miles of channel and inclusive of all costs such as labour, mileage, supervision, etc.)
amitrole (1966/67 season)	water couch, continuous dense infestation	$90 for initial spray, $70 for respray (average over 280 miles of drainage channel 8 to 24 ft. in width, inclusive of all costs)
amitrole (1969/70 season)	water couch (light infestation and weed generally under control)	$25 per application (channel width as above)
diuron	water couch, cumbungi, rushes and sedges	$150 per acre, 35 lb. a.i. per acre (average calculated over 36 acres and includes all costs except mechanical cleaning prior to spraying)
diuron	water couch, cumbungi and rushes	$75 per acre, 15 lb. a.i. (maintenance treatment of channels previously treated with diuron)
aromatic solvent, xylol plus emulsifier	*Potamogeton* spp. excluding *P. tricarinatus*	$40 (cost calculated from the treatment of 40 miles supply channel)
mechanical devices (1965) dragline with weed bucket	all weed growth and some silt	$260–$360 (channels with 8–16 ft. bed)

Precautions and Special Conditions for Herbicides Used in Supply and Drainage Channels

Unrestricted use of herbicides in irrigation systems can result in damage to crops, unnecessarily kill fish and wild fowl, and be toxic to humans and stock. Therefore, it is necessary to have certain restrictions on the amount of herbicide used and the situation in which it may be applied.

The chemicals commonly used by the Commission have varying degrees of persistence and toxicity to stock or crop. The following notes on some herbicides are listed in approximate descending order commencing with the most hazardous.

(a) *Acrolein*

This is a very toxic and potentially explosive herbicide. This chemical dissipates within a few days in flowing water. It is more persistent in deep, static water. Its application is governed by many restrictions. As a general rule, it is applied at rates less than 15 p.p.m. and treated water is not used for eight miles downstream of the injection point. Water containing acrolein is not permitted to flow into rivers or creeks.

(b) *2,4-D; 2,4,5-T; 2,4,5-TP; Picloram and 2,4D*

The following are some of the restrictions covering use of the above growth-regulatory type herbicides:

(i) Formulations of 2,4-D purchased are restricted to the amine or low volatile ester, and invert emulsion of 2,4,5-T or 2,4-D ester.

(ii) Spray units that have used these herbicides are rinsed with detergent. An alternative method used is to add 2 lb. of washing soda per 100 gal. of water and agitate.

(iii) These herbicides are not applied through misting machines.

(iv) These herbicides are not used in spray form within two miles of cotton from 1st October to 31st April.

(v) These herbicides are not used in spray form within 10 chains of orchards and vegetables. Particular crops liable to damage include vines and tomatoes.

(vi) Spraying with these chemicals is restricted to calm days.

(vii) The above herbicides are not applied to weeds growing in supply and drainage channels unless it is established that contaminated water will be dissipated on wasteland.

(viii) As a general rule, spraying of this group of herbicides is supervised by a weeds inspector.

(c) *Amitrole + Ammonium Thiocyanate*

Amitrole is at present the only effective foliage-applied chemical for water couch. A close watch is kept on the extent of amitrole residues in drainage and supply channels. It has been calculated that 20–25% of the amitrole applied to typical drainage channels will flow away in the water. Based on this percentage, amitrole usage is restricted in the Murrumbidgee Irrigation Areas so that the concentration of amitrole does not exceed 0·005 p.p.m. in the drainage water.

Water samples are taken monthly at a number of sites and analysed by Unisearch Ltd. of the University of New South Wales for amitrole residues.

(d) *Diuron and Bromacil and Fenuron*

These are residual herbicides which are persistent in the soil. They are non-toxic to humans. At the rates of application used to control weeds in channels and around structures, these products may damage roots of trees which extend into the treated area. Because of this, diuron, fenuron and bromacil must not be applied within 100 ft. of useful trees or shrubs. Use of diuron in drainage channels is based on a maximum residue level of 0·005 p.p.m.

(e) *2,2-DPA*

This is a non-toxic herbicide with a limited residual life in the soil of about eight weeks. Care is taken to ensure that irrigation water is not excessively contaminated, and that there is no spray drift on to horticultural crops.

(f) *TCA*

This product is mainly used as a soil sterilant, although it has some foliage effect. Its use is not permitted within 100 ft. of useful trees, shrubs or vines. The chemical rapidly decomposes in the soil. When substantial areas of a supply channel are treated it is essential that the first flush of water be disposed onto wasteland.

(g) *Copper Sulphate*

This chemical is harmless to humans if concentration does not exceed 1 p.p.m. of copper ion or 4 p.p.m. of the hydrate. Gloves should be worn when handling raw crystals or concentrated solution. Copper sulphate may cause corrosion of aluminium or galvanized pipe and tanks.

Current Weed Control Investigations

The main work being undertaken by the weeds section of the Commission includes:

(*a*) Determination of the effect of acrolein on rice. This work is being carried out in conjunction with the Department of Agriculture. The preliminary work shows that emergent rice is not sensitive to acrolein at the usual rates of application. Work is continuing on young submerged rice.

(*b*) Determination of the most effective rate of application and interval between applications of amitrole on water couch.

(*c*) Effect of diquat on elodea in channel situations.

(*d*) The efficiency and residue problems associated with the use of xylene or similar solvents and various emulsifiers when applied to submersed weeds in drainage channels.

(*e*) Determination of the efficiency and costs of applying acrolein at low concentration (less than 1 p.p.m.) and over extended periods (24 to 72 hours). This technique has proved sucessful and more economical in channels with flows greater than 50 cusecs, when compared with the conventional 2 gal./cusec treatment.

(*f*) Investigations of methods of reducing herbicide contamination of irrigation water.

(*g*) The effectiveness of copper sulphate in suppressing the growth of submersed weeds when applied to water flowing in irrigation channels to give a continuous concentration of 0·1 p.p.m.w. copper ion.

(*h*) The evaluation of new residual herbicides in the control of paspalum.

(*i*) The potential of anhydrous ammonia in controlling elodea.

(*j*) Assessment of some aggressive but relatively unobstructive plant species to provide competition for problem aquatic weeds in channel situations.

Appendix — Chemical Names of Herbicides

amitrole	3–amino–1,2,4–triazole
atrazine	2–chloro–4–ethylamino–6–isopropylamino–1,3,5–triazine
bromacil	5–bromo–6–methyl–3–s–butyluracil
2,4–D	2,4–dichlorophenoxyacetic acid
2,2–DPA	2,2–dichloropropionic acid
diuron	N′–(3,4–dichlorophenyl)–NN–dimethylurea
DSMA	disodium methylarsonate
fenuron	NN–dimethyl–N′–phenylurea
picloram	4–amino–3,5,6–trichloropicolinic acid
2,4,5–T	2,4,5–trichlorophenoxyacetic acid
TCA	trichloroacetic acid
2,4,5–TP	2,4,5–trichlorophenoxypropionic acid

Contributed Paper:

THE PREPARATION AND USAGE OF SMALL VOLUMES OF HERBICIDAL SOLUTIONS WITH APPLICATION TO SKELETON WEED (*CHONDRILLA JUNCEA* L.)

C. G. Greenham*

Summary

This paper describes the preparation of 1 ml. or more of solution, accurate for both concentration and pH value; final adjustment of volume is done in terms of weight. It also deals with solubilizing and buffering agents, storage, application of small volumes to plant surfaces, and cleaning of equipment.

Results obtained on skeleton weed with the methods described are included to show that (*a*) for foliar applications "Tween 20" gives a greater 2,4-D content in the roots than three other wetting agents tried, and ammonium thiocyanate up to 4000 p.p.m. has no influence on 2,4-D content, (*b*) roots of plants which have flowered are less susceptible to picloram than those of plants which have not flowered.

Introduction

Frequently in herbicide research it is necessary to prepare small volumes of solutions, either because only small amounts of potential herbicides are available for testing or because the compounds used are in radioactive form and expensive. The following describes a method for preparing 1 ml. or more of aqueous solution or suspension, with an error in concentration not exceeding 2%, and adjusted in pH to within 0·02 unit. Pertinent information relating to the usage of such solutions on skeleton weed is given, also some results obtained. This species, on account of its uniform tap root rich in food reserves, is ideal for studies on the susceptibility of roots to externally applied poisons, and at the rosette stage is excellent for investigations on the translocation of herbicides. An account of the economic importance of the weed and of the influence of pH of foliage-applied solutions on the subsequent 2,4-D (2,4-dichlorophenoxyacetic acid) content in the roots has been given elsewhere (Greenham, 1968).

Preparation of Solutions

The final volume is obtained in terms of weight. A torsion balance† with weight dials and sensitive to 5 mg. is convenient, as the pans have no overhead beam. Micro-beakers or short flat-bottomed tubes make convenient preparation vessels, subsequently referred to as beakers. A miniature glass pH electrode and reference cell are mounted over the centre of the balance pan used for the beaker. The beaker is rested on a parallel-ended support, e.g., cork, which is removed from the pan for removal or replacement of the beaker.

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† The DWL 2 balance (capacity 120 gm.) made by the Torsion Balance Co., Clifton, New Jersey, is suitable.

A blank solution is first used to calibrate the beaker and balance for the volume of the real solution ultimately required. The two solutions should approximate in wetting ability to glass and in specific gravity, or subsequent accuracy will be impaired. The required volume of the *blank* solution is added to the dry beaker, which is placed in position on its support on the pan, and the glass electrode and reference cell are appropriately immersed in the solution (excessive immersion lessens subsequent accuracy). The balance is adjusted to give zero position. The balance, glass electrode and reference cell tip are not subsequently moved. Any rinsing of the latter two is done *in situ*.

The required amount of herbicide is added to the previously calibrated beaker now clean and dry. If the herbicide was received as a solution, any unwanted solvent such as benzene or methyl ethyl ketone is removed by means of a gentle stream of nitrogen or air. Incidentally, the latter solvent is convenient for taking aliquots of picloram (4-amino-3,5,6-trichloropicolinic acid).

To the beaker is now added any required solubilizing or emulsifying agent (see next section). The solubilizing action is often most marked in the absence of water, though triethanolamine and tri*iso*propanolamine used for carboxylic acids may be applied as 1 M solutions. A sealed melting point tube 1 mm. in diameter makes a convenient stirrer. If stirring is inadequate to effect solution, gentle heat may usually be applied. Any required surfactant or other adjuvant, and the appropriate amount of stock buffering agent is now added (see Buffering Agents). About half the additional water required is stirred in, the stirrer is drained against the side of the beaker, which is placed on its support on the balance pan.

Subsequent stirring is conveniently done by a sealed length of 1 mm. diameter melting point tubing, of which the lowest 2 mm. portion is bent at an angle to the main axis; rotation is effected by a miniature motor. Provided that no more than 5 mm. of the 1 mm. diameter stirrer is immersed, it can usually be left in position and even rotated while the volume of solution is being finally adjusted. Dilute acid or alkali is now added as required to adjust the pH of the solution to the required value, also water to bring the solution to the required weight. By experiment it has been shown that if the buffering agent present is to be at a final concentration of 0·1 M, and the pH value selected does not differ from the buffer's pK_a value by more than 0·5, dilution of the solution by as much as one-fifth of its volume during the final weight adjustment will not affect pH by more than 0·01 unit.

No attempt is made to recover the solution wetting the pH electrode and reference cell tip.

Solubilizing Agents and Other Adjuvants

Amines usually make good solubilizing agents for carboxylic acids such as picloram and 2,4-D. Leonard (1958), studying drop applications of 2,4-D without a wetting agent on bean plants, reported that alkylamines tend to be more effective than alkanolamines, ethylamine being the most effective. On the other hand, with spray applications, there is much less difference between the various amines tested, the difference disappearing when "Tween 20" is also included. Leonard also reported an oil-emulsion diluent as considerably more lethal than water for spray applications of 2,4-D to bean plants.

Triethanolamine is hygroscopic and seldom anhydrous. When preparing a standard solution of this compound, it is preferable to prepare a solution of approximately the required concentration and titrate it with standard hydrochloric acid. For titration the use of a few drops of a solution of 0·05 gm.

methyl orange and 0·125 gm. indigo carmine in 100 ml. of water is convenient. This indicator is light grey at pH 4·1, and respectively violet and green when acid and alkaline.

For some compounds polyethylene glycols are useful solubilizing agents (Mitchell and Hamner, 1944), though a few of the higher molecular weight glycols, as commercially supplied, can be toxic unless dialysed (unpublished). Other solubilizing agents are mentioned by Nex and Swezy (1954) and Swezy and Nex (1961). Temple and Hilton (1963) have recorded how the solubility of diuron, atrazine and ametryne in water is increased by the inclusion of certain surfactants. For an account of some of the earlier methods of formulating herbicides, reference should be made to Kelly (1953). Sargent (1966) has outlined how formulation can influence the physiology of entry of herbicides.

Dimethyl sulphoxide is a good solubilizing agent for some herbicides, and when present in quantities up to 8% v/v in the final aqueous solution, has no deleterious action on the uptake and translocation of 2,4-D and 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) by skeleton weed (unpublished). Moreover, dimethyl sulphoxide at a final concentration of 5–10% v/v, or "Tween 20" at 0·5–2% v/v, can be used for emulsifying some esters.

Information relating to concentrations of wetting agents and their interaction with herbicides is given by Jansen *et alii* (1961), and Parr and Norman (1965).

For brush applications of herbicides (see Application), increased wetting ability may be required. Concentrations of "Tween 20" up to 2·1% v/v have no deleterious influence on the absorption and translocation of 2,4-D by skeleton weed (Greenham, 1968). Leaves of this species grown in the glasshouse during winter may not be adequately wetted by 2·1% "Tween 20", so that some additional wetting agent may be needed. Cetyltrimethylammonium bromide ("CTAB") is an excellent wetting agent under such conditions, but its use is liable to result in a smaller 2,4-D content in the roots (*ibid.*). On the other hand, at temperatures of 20–25° C., 0·25% w/v CTAB with 0·7% v/v "Tween 20" does not prevent the 2,4-D content in roots of winter-grown skeleton weed from increasing as concentration applied to the leaves increases, when concentrations of 1·13, 3·4 and 10·2 mM are used (unpublished).

Buffering Agents

The compounds listed in Table 1 have been selected as those least likely to be toxic in their own right, the selection being based on investigations cited at the base of the Table. The pH ranges listed are based on equilibrium constants published by the Chemical Society (1964). The values shown are approximately 1·0 pH unit each side of the most likely pK_a value to be encountered in herbicidal investigations, i.e., with a single buffer agent being used at 0·025 to 0·1 M concentration in an aqueous solution. The pK_a value depends both on the concentration of the buffering agent and on other ions present. For more detailed information, reference should be made to the above publication.

Citric acid could in most instances be used as a buffering agent between pH 5·4 and 5·7, though this range is not shown for this acid in Table 1. Each of the two upper dissociation constants contributes slightly to buffering in this range, so that the summed action of the two ions formed here would generally be adequate. Moreover, on account of the overlapping of the two lower ranges of citric acid shown in the Table, this acid can usually be used as a buffering agent from pH 2·0 to 7·7.

When an acid is optically active, the racemic mixture is usually safer to use than one of the isomers. The use of *dl*-malic acid and of citric acid has occasionally been criticized on the grounds that these acids participate in the respiratory cycle. However, the viewpoint is taken here that it is preferable to use a comparatively non-toxic acid of known action rather than one of unknown action which is somewhat toxic, e.g., *o*-phthalic acid (unpublished). The innocuous nature of the *dl*-malic acid is shown by the length of life of carrot root slices in an M/800 solution of this acid adjusted to pH 5·0 with sodium or potassium hydroxide. Slices aerated in this medium will live for six weeks or more (unpublished).

TABLE 1

Approximate pH ranges of selected buffers

Buffer	pH range
Phosphoric acid (ortho)	1·1– 3·1[a]
Glycine	1·2– 3·2[a]
Ethylenediaminetetra-acetic acid	1·7– 3·7[b]
Citric acid	2·0– 4·0[a, c]
dl-Malic acid	2·4– 4·4[c]
dl-Lactic acid	2·8– 4·8[a]
Citric acid	3·4– 5·4[a, c]
dl-Malic acid	3·9– 5·9[c]
Ethylenediaminetetra-acetic acid	5·2– 7·2[b]
Citric acid	5·7– 7·7[a, c]
Phosphoric acid (ortho)	6·1– 8·1[a, b]
Triethanolamine	6·8– 8·8[a]
Boric acid	8·2–10·2[a]

[a] Suitability based on herbicide investigations (Greenham, 1962, 1968).

[b, c] Suitability or low toxicity based on [b] laboratory cultures of *Spirodela* sp. (" duckweed "), [c] sliced tissue culture (unpublished).

Some of the buffering agents have a special action in their own right. Crafts (1956*a*) reported that boric acid enhances epinasty resulting from 2,4-D applications. On the other hand, Leonard (1958) and Greenham (1962) concluded that it does not affect growth inhibition by, or translocation of, 2,4-D. Probably the response caused by boric acid depends on whether the amount of boron in the tissues is limiting or not. Phosphoric acid is reported to enhance translocation (Greenham, 1962). Amines in excess of the amount required to form the salt of 2,4-D enhance the penetration of or response to that compound (Orgell and Weintraub, 1957; Greenham, 1968).

According to Orgell and Weintraub (1957), the concentration of buffer within the range 0·025 to 0·10 M is not an influential factor in epinastic and growth inhibition responses of bean plants to 2,4-D. Nevertheless, the buffering ability of a substance decreases as the pH value departs from its pK_a value, so that concentration *per se* is not the only factor affecting the influence of a buffer.

APPLICATION

Crafts (1956*b*) has shown that the size of drops of a 2,4-D solution affects plant response, even though the total volume applied to a leaf remains constant. Leonard (1958) has demonstrated that the location of a drop of 2,4-D solution on a leaf also affects plant response. Accordingly, the response of a plant to a few drops of a herbicide solution on a leaf is not necessarily an adequate measure of the response to an overall spray application. As usually there is too much hazard associated with the spray application of a radioactive substance, brush applications have been used, particularly on the rosette leaves of skeleton weed (Greenham, 1962, 1968). The volume to be applied, usually in excess of 0·15 ml. per plant and determined by trial beforehand, is measured into a small container. This volume is then applied to the leaves (or other organs) with a small brush wetted beforehand to the same extent as that remaining after the application is complete.

Quantities of liquid less than 0·1 ml. can be applied to a surface (e.g., of a root segment) by means of an "Agla" micrometer syringe,* and the resulting drops then smeared or brushed over the surface by a hydrophobic material such as a piece of "Parafilm M"† held between forceps. If the drops contain no surfactant they can be spread by a small brush, the bristles of which have been soaked in molten petroleum jelly and then wiped free of excess. Resoaking of the bristles is usually necessary after 10 to 20 sq. cm. have been brushed.

An "Agla" syringe can be improved in two ways for the rapid application of solutions. A piece of paper is stuck over the numbers adjacent to the graduations on the rotating thimble, and fresh numbers are then printed on the paper in the reverse direction to that used by the manufacturer. This facilitates mental calculation of a quantity applied by the syringe, the numbers now *increasing* as the volume applied is increased (one revolution of the thimble expels 0·01 ml.). The other modification is an automatic rotation indicator. A brass tube about 1¼ in. long, with an external groove parallel to the central axis of the tube, is fitted over the rotating barrel of the micrometer. A spring-loaded pin, mounted on a stationary arm attached to the body of the micrometer, presses against the brass tube and clicks into the groove at each rotation, thereby notifying the operator.

Storage and Cleaning

Crafts and Yamaguchi (1964) favour the use of 50% ethanol as a bactericide for the storage of radioactive solutions. However, this solvent is a contact herbicide in its own right. The author has found the conventional procedure of storing aqueous solutions in parallel-walled pyrex glass containers in a deep-freeze unit adequate for periods of three to four months. The stoppers are sealed over with silicone grease. With 2,4-D, 2,4,5-T and picloram in 0·05 M triethanolamine there has been no difficulty in effecting re-solution when the contents are thawed.

Brushes and glassware used with 2,4-D or picloram are conveniently cleaned in a mixture of one volume of 0·880 ammonia solution, two volumes of water and 12 volumes of ethanol. Four washings in this mixture are usually adequate. Brushes treated with petroleum jelly are first washed in chloroform.

Some Results Obtained with Skeleton Weed

(a) *Influence of Wetting Agents and Ammonium Thiocyanate on 2,4-D Content in the Roots*

The plants used in this investigation were grown during summer in potting soil in tubes 22½ cm. long by 4½ cm. diameter, subsequently opened for harvesting the roots. The bases of the tubes were covered with a piece of cloth, to prevent roots extruding. To protect and support the leaves it was found desirable (1) to cover the upper sharp edge of the tube with a rubber band 1 cm. wide and (2) to provide a platform for the leaves by

* Burroughs Wellcome and Co., London.
† Marathon Division of American Can Co., Nennah, Wisconsin.

attaching near the top of the tube a water-proofed cardboard dinner plate. To keep the leaves dry after treatment, watering was done by partial immersion of the tubes. The plants were grown and treated in a glasshouse with daytime temperature approximately 20° C.

Before treatment at the age of six weeks the plants were ranked for size, all plants in the one replication being as uniform as possible. There were ten treatments each with seven replications. At 13 days after treatment, when the leaves appeared incapable of further translocation, the roots were harvested. The dried roots were ground and assayed for 20 minutes under a thin-window GM tube. Corrections were made for self-absorption and background. The counts per root are taken as an overall measure of penetration of 2,4-D through the leaf cuticle and cell walls, uptake by the underlying tissue, and downward translocation.

Each treatment required a total volume of 1·9 ml. of solution for seven plants. All solutions contained 3·4 mM methylene-labelled 2,4-D (0·35 mc./mM) and 0·05 M triethanolamine, adjusted finally to pH 7·8. The control solution, also the ammonium thiocyanate solutions, contained 0·7% "Tween 20"; the other solutions contained only the wetting agents specified below (SDBS represents sodium dodecyl benzene sulphonate).

Mean log values per treatment are

(1) Control 4·44	(6) + 0·05% SDBS *4·16*
(2) + 1000 p.p.m. NH_4CNS 4·37	(7) + 0·1% Triton X–100 *4·31*
(3) + 2000 p.p.m. NH_4CNS 4·42	(8) + 0·05% Triton X–100 4·33
(4) + 4000 p.p.m. NH_4CNS 4·37	(9) + 0·1% Vatsol OT *4·26*
(5) + 0·1% SDBS *4·10*	(10) + 0·05% Vatsol OT *4·29*

A difference of 0·09 is significant at $P = 0{\cdot}05$, and of 0·12 at $P = 0{\cdot}01$. Hence only the above values in italics differ significantly from the value for the control.

This shows that "Tween 20" is to be preferred to the other wetting agents, and that ammonium thiocyanate at the concentrations used did not increase the 2,4-D content in the roots of skeleton weed. The influence of ammonium thiocyanate on translocation is somewhat controversial (Michael, 1967), though Basler *et alii* (1967) claim that it enhances the translocation of 2,4,5-T without affecting penetration.

(*b*) *Relative Sensitivity to Picloram of Roots of Plants which have Flowered and Which Have not Flowered*

The following procedure has several advantages over the more common method of shaking root sections or segments in a herbicide solution. It eliminates the respiration increase caused by slicing tissue (MacDonald, 1967). It also permits studies to be made without osmotic agents such as mannitol, which can influence metabolism. In the absence of such agents, skeleton weed roots soon burst in an aqueous medium, on account of their high osmotic pressure. On the other hand, with the following technique untreated segments of skeleton weed roots more than a year old are capable of remaining viable for five to six months.

The tap roots used were 4 to 5 mm. in diameter and taken from plants 14 months old (sown in June 1966). The plants had been grown in potting soil in tubes 33 cm. long by 5 cm. diameter, the bases of the tubes being immersed in buckets of sand. In the absence of any vernalizing treatment, only some plants had flowered. One 2-cm. long root segment was taken per plant, within the topmost 4-cm. portion of the root. The segments were trimmed free of side roots, washed, and blotted dry. They were stored in a saturated atmosphere for five days to allow cut surfaces to heal; any segments producing shoots were discarded. The cylindrical surface of the segments was then painted with a volume of liquid proportional to the weight of each segment, viz., 0·005 ml. per 100 mg. weight. The picloram series were treated with the potassium salt of that compound at 1·0 mM, the control series with water. The segments were kept horizontal with one end held in forceps, until the liquid had dried, and then stored horizontally on plastic gauze in a saturated atmosphere. After 25 days the segments were measured near their centre for resistance ratio, by means of a probe and A.C. bridge (de Plater and Greenham, 1959). In instances such as the following, where the mean of the control series is the larger, the smaller the mean resistance ratio in the corresponding treated series the greater is the injury (Greenham, 1957).

Comparisons of the ratio were made in segments paired visually for equality of diameter. The mean log values of the ratios for 14 control segments were: non-flowered series 1·02, flowered series 0·97 ($P < 0{\cdot}01$). This difference is interpreted as showing that in segments not treated with a herbicide, the resistance ratio is naturally greater for plants which have not flowered. On the other hand, for the picloram-treated series the mean values for 21 segments were: non-flowered series 0·34, flowered series 0·95 ($P < 0{\cdot}001$). The large difference between these two means is *increased* if one corrects for the difference between the control means, so that any correction is unnecessary.

Accordingly, the conclusion from the above data is that roots of skeleton weed plants which have flowered are not as susceptible to picloram as roots from plants which have not flowered, the physiology of flowering having altered the susceptibility of the roots.

Acknowledgement

Mr. G. J. Johnston proposed the use of waterproof cardboard plates as supports.

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Contributed Paper:

CONTROL BY DIURON OF *ECHINOCHLOA COLONUM* IN AUSTRALIAN COTTON–GROWING SOILS

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SUMMARY

Unfavourable reports on the effect of diuron in control of *Echinochloa colonum* in cotton in the Namoi River Valley, New South Wales, contrasted with favourable reports in the Ord River Valley, Western Australia, are ascribed in this paper to differences in soil characteristics in the two areas. Physical properties related to wetting, known to be relevant to the activation of diuron, are less favourable, at least in certain soils of the Namoi River Valley. On the other hand, a form of *E. colonum* from the Namoi River Valley was shown to be more susceptible to diuron than the common form of *E. colonum* from the Ord River Valley.

INTRODUCTION

Van Rijn (1967) has shown that diuron [3-(3,4-dichlorophenyl)-1,1-dimethylurea] is a suitable pre-emergence or pre-sowing herbicide for control of *Echinochloa colonum* (L.) Link in cotton in the Ord River Valley, Western Australia. Diuron is often recommended for weed control in cotton in other parts of the world (Gutstein, 1967; Kasasian, 1969). On the other hand, it has been reported (Anon., 1967) that diuron failed to control barnyard grass (*E.* spp.) in the Murrumbidgee Irrigation Areas, N.S.W., and that it should not be used where this weed is expected. Similar reports have been received from the Wee Waa area, Namoi River Valley, N.S.W. (Green, personal communication).

In investigations on the taxonomy of Australian *Echinochloa,* Michael (unpublished data) has shown that the common form of *E. colonum* in the Ord River Valley (Kimberley form) differs substantially from a form of *E. colonum* collected at Wee Waa (Narrabri form). The Kimberley form, when grown in pots, is a stout, prostrate, late-flowering form, while the Narrabri form is a more delicate, erect, early-flowering form. The two forms can also be distinguished by spikelet characters.

Because of the apparent contradiction in the effect of diuron it was considered necessary to test both forms of *E. colonum* for their susceptibility to diuron and to measure any influence the soil from each area might have on their susceptibility.

In the first two experiments reported here, the soils used were Cununurra clay from the Ord River Valley and an unnamed silty clay collected from near Wee Waa. In the third experiment Gundemain clay and Helebah clay from near Wee Waa were included also. Physical and chemical data for each soil are given in Table 1.

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At the time of application of diuron in cotton the soil is moist and a large proportion of the seed of *E. colonum* can be expected to have germinated. Accordingly, one experiment was conducted starting from germinated seed. In the other experiments ungerminated seeds were used.

TABLE 1

Physical and Chemical Soils Data

Locality	ORD RIVER (Kununurra)	NAMOI RIVER (Narrabri-Wee Waa)		
Name of soil	CUNUNURRA clay	GUNDEMAIN clay	HELEBAH clay	Unnamed silty clay
Colour	grey	brown	grey	brown
Clay mineral	montmorillonite	not determined	not determined	kaolinite-illite
Mechanical analysis (%)				
Clay	51	53	53	40
Silt	10	15	11	20
Fine sand	28	16	13	30
Coarse sand	5	6	13	4
Loss on ignition (%)	5·3	7·3	7·0	5·3
Organic carbon (%)	0·5	0·8	1·0	1·3
pH	7·9	7·5	7·7	7·1
Exchangeable cations (m.e./100 gm.)				
Ca	24·6	20·2	22·2	11·4
Mg	18·8	13·2	13·2	10·2
K	1·0	2·0	2·9	2·0
Na	0·6	0·9	0·8	1·0
Total	45·0	36·3	39·1	24·6
Moisture content (%)				
0·33 bars	34	33	42	37
2 ,,	25	24	31	22
8 ,,	21	20	27	18
15 ,,	19	19	25	16
Hours taken for moisture to rise 15 cm. in air-dry column of soil (16 cm. × 3·8 cm.)	9·6	13·1	19·4	21·6
Percentage volume increase on complete wetting of air-dry column of soil (16cm. × 3·8cm.)	14	9	14	4

METHODS

Experiment 1.—Effect of diuron using germinated seed and two soils

The experiment was conducted in a glasshouse at fluctuating temperatures never less than 14° C. (mean min. 18° C.) nor higher than 35° C. (mean max. 32° C.). Plastic pots 5 in. in diameter and 4½ in. high were used. A hole, ½ in. in diameter, was cut in the bottom of each pot and covered with nylon mesh. Half of the pots were filled to 1 in. from the top with Cununurra clay, and the other half with the unnamed silty clay.

Seeds of both forms of *E. colonum* were germinated in the dark in an incubator at 30° C. for 42 hours. Twenty of the germinated seeds of each form were planted per pot on the top of dry soil. The seeds were covered with ½ in. of dry soil, and all pots were watered with 100 ml. of a nutrient solution, equivalent to 60 lb. nitrogen, 45 lb. phosphorus and 90 lb. potassium per acre. The pots were then immediately treated with 0, ⅛, ¼, ½ and 1 lb./ac. active ingredient (a.i.) diuron. In the application of diuron to the soil surface a spray table was used, each pot receiving in all 20 ml. of diuron suspension. Unsprayed pots, used as controls, were given 20 ml. water. There were four replicates. The pots were then placed in a metal tray, which was kept filled with water to ½ in. depth.

Counts of emerged seedlings were made one, two, three, four, five and nine days after planting and spraying. Counts of killed plants were made nine, ten, eleven, twelve, fourteen, sixteen and twenty-two days after planting and spraying. The experiment was then concluded.

Experiment 2.—Effect of diuron using ungerminated seed and two soils

The same procedure as in Experiment 1 was used, except for the following: 1. Twenty ungerminated seeds were planted in each pot. 2. Diuron was used only at 0, $\frac{1}{2}$ and 1 lb./ac. a.i. 3. The pots were placed in a metal tray, kept filled with water to $\frac{1}{2}$ in. depth for five days. The tray was then drained and thereafter the pots were watered from the top every second day. This allowed satisfactory germination and emergence in all pots.

Counts of emerged seedlings were made five, six, seven, eight, eleven and fourteen days after planting and spraying. Counts of killed or surviving plants were made ten, eleven, twelve, thirteen, fourteen, eighteen, twenty-one and thirty-two days after planting and spraying. The experiment was then concluded.

Experiment 3.—Effect of diuron using ungerminated seed and four soils

This experiment was run under similar conditions to Experiment 2, but only the Narrabri form of *E. colonum* was used. Rates of diuron were 0, $\frac{1}{4}$ and $\frac{1}{2}$ lb./ac. a.i. The four soils were Cununurra clay, the unnamed silty clay, Gundemain clay and Helebah clay. The experiment was let run for 30 days when the remaining live plants in each soil were harvested and oven-dry weights obtained.

Results

Experiment 1

The rate of emergence in the pots treated with herbicides was the same as in the controls. Quickest emergence occurred in the case of seedlings of the Narrabri form from Cununurra clay, while the slowest emergence occurred in seedlings of the Narrabri form from the unnamed silty clay. Final emergence of seedlings of the Narrabri form was good from Cununurra clay but very poor from the unnamed silty clay. Seedlings of the Kimberley form emerged well from both soils. (See Table 2.)

Table 2

Mean total numbers of E. colonum *emerged, with time, in all seedling-soil combinations, from the four replicates of all diuron treatments (Experiment 1)*

Days after planting	Narrabri form of *E. colonum*		Kimberley form of *E. colonum*	
	Cununurra clay	Unnamed silty clay	Cununurra clay	Unnamed silty clay
1	11	2	0	0
2	56	16	21	26
3	62	20	46	49
4	65	24	66	69
5	66	26	70	72
9	68	26	72	73

Maximum emergence in all seedling-soil combinations was attained in about five days, but killing of seedlings did not begin until about four days after the time of maximum emergence. Seedlings of the Narrabri form grown in Cununurra clay were killed most rapidly. At all rates seedlings of the Narrabri form were killed more quickly than the seedlings of the Kimberley form. At the rates of $\frac{1}{2}$ and 1 lb./ac. a.i. these differences disappeared with time, but at the rates of $\frac{1}{8}$ and $\frac{1}{4}$ lb./ac. a.i. they continued until the end of the experiment. Seedlings grown in the unnamed silty clay were killed less quickly than in Cununurra clay. Again, differences disappeared with time at the two higher rates, but at the lower rates the differences continued until the end of the experiment. The differences in percentage kill between each soil were much greater than those between the two forms of seedlings. (See Table 3, where the results of two representative diuron treatments, $\frac{1}{2}$ and $\frac{1}{8}$ lb./ac., are presented.)

TABLE 3

Percentage kill of emerged seedlings, with time, in each soil and for each form of E. colonum *for $\frac{1}{2}$ lb. and $\frac{1}{8}$ lb./ac. diuron treatments (Experiment 1)*

Days after planting	Cununurra clay	Unnamed silty clay	*E. colonum*	
			Narrabri form	Kimberley form
		$\frac{1}{2}$ lb. diuron/ac.		
9	23	9	42	4
10	37	15	64	10
11	79	50	86	59
12	94	71	95	80
14	100	93	99	96
16	100	95	99	98
22	100	99	100	99
		$\frac{1}{8}$ lb. diuron/ac.		
9	4	0	4	1
10	6	0	7	1
11	25	0	25	7
12	33	0	29	12
14	45	0	35	20
16	61	2	43	31
22	85	12	57	51

Experiment 2

No differences were noted between rate of emergence in the herbicidal treated pots and the controls.

TABLE 4

Mean total numbers of E. colonum *emerged, with time, in all seed-soil combinations from the four replicates of all diuron treatments (Experiment 2)*

Days after planting	Narrabri form of *E. colonum*		Kimberley form of *E. colonum*	
	Cununurra clay	Unnamed silty clay	Cununurra clay	Unnamed silty clay
5	0	1	5	4
6	8	15	28	25
7	24	39	42	39
8	31	51	48	50
11	72	73	74	70

Emergence, beginning about five days after planting, was slowest in the case of the Kimberley form from the Cununurra clay. The other three seed-soil combinations gave similar emergence patterns, and all four combinations showed the same final emergence. In contrast to Experiment 1, the seedlings of the Narrabri form emerged very well from the unnamed silty clay. (See Table 4.)

Killing began at about the time of maximum emergence, i.e., about ten days after planting the seeds. The slowest kill occurred in the case of seedlings of the Kimberley form grown in Cununurra clay. Seedlings of the Narrabri form were killed more rapidly than seedlings of the Kimberley form, but this difference disappeared with time, as in the first experiment. Differences between soils did not appear in the early killing stages (from about the tenth to thirteenth days after planting). But between the thirteenth and eighteenth day a greater percentage of plants was killed on the unnamed silty clay. (See Table 5.) This apparently conflicts with the results of

TABLE 5

Percentage kill of emerged seedlings, with time, in each soil and for each form of E. colonum *(means of ½ lb. and 1 lb./ac. diuron treatments) (Experiment 2)*

Days after planting	Cununurra clay	Unnamed silty clay	*E. colonum*	
			Narrabri form	Kimberley form
10	6	8	9	4
11	8	10	13	5
12	35	36	46	25
13	56	67	66	57
14	60	73	69	64
18	91	93	90	93
21	99	94	96	97

Experiment 1 but can be explained by the later emergence of the seedlings of the Kimberley form on Cununurra clay, slower emerging plants being more slowly killed (see Discussion). However, on the twenty-first day there was a 99% kill of seedlings on the Cununurra clay, but only 94% kill on the unnamed silty clay. This is taken as a real difference. Of a total of 19 surviving seedlings twenty-one days after planting, 16 (or 84%) were in the unnamed silty clay, and at the end of the experiment, the only survivors (7 healthy plants) were in the unnamed silty clay.

Experiment 3

Diuron (means of ¼ and ½ lb./ac. treatments) reduced the yields of *E. colonum* obtained for the same soil in pots which received no diuron by 96% in Cununurra clay, 85% in Helebah clay, 64% in Gundemain clay, and by 3% in the unnamed silty clay.

DISCUSSION

The delay between application of diuron and killing of seedlings observed in Experiments 1 and 2 can be related to the uptake of diuron by adventitious roots and coronal roots which do not appear until the first foliar leaves expand. It could be expected, therefore, that seedlings which emerge more quickly would be more quickly killed or vice versa, that seedlings which emerge more slowly would be more slowly killed. In Experiment 1 seedlings of the Narrabri form in Cununurra clay, which emerged more quickly than the other seedling-soil combinations, were killed more quickly, and in Experiment 2 seedlings of the Kimberley form in Cununurra clay, which emerged more slowly than the other seedling-soil combinations, were killed more slowly.

The difference in emergence patterns in Experiments 1 and 2 can be explained in terms of the different wetting properties of the two soils and by the apparent differences in sensitivity to waterlogging (or lack of aeration) of the two forms of *E. colonum*. In Experiment 1, the unnamed silty clay, of lower clay content than the Cununurra clay, did not take up water so quickly as the Cununurra clay and we assume that many of the germinated seeds of the Narrabri form died under the dry conditions in the first day or so of the experiment. Germinated seeds of the Kimberley form are assumed to be less sensitive to the same dry conditions. In Experiment 2, where emergence did not occur until about five days after planting, both soils can be assumed to have been thoroughly wet at the time of germination. However, in the Cununurra clay, of higher clay content than the unnamed silty clay, lack of aeration in the first five days may well have been responsible for the slower germination and/or emergence of seeds and/or seedlings of the Kimberley form. After the draining of the metal tray conditions were more favourable for germination and/or emergence. The seeds of the Narrabri form are assumed to be less sensitive to lack of aeration.

In Experiments 1 and 2 the Narrabri form of *E. colonum* proved to be more susceptible to diuron than the Kimberley form, though, at rates of ½ and 1 lb./ac. a.i. effective control of both forms was achieved. More striking, however, were the differences in effectiveness of diuron caused by soil differences. In Experiment 3 it was clearly shown that the effectiveness of diuron in controlling the Narrabri form of *E. colonum* varied considerably in the soils of the Wee Waa area. In none of the three soils was diuron as effective as in Cununurra clay. We conclude, therefore, that the difficulties associated with the use of diuron in the Wee Waa area cf. the Ord River Valley can be ascribed to the nature of particular soils.

The reasons for the poor behaviour of the Wee Waa soils are undoubtedly complex, but we believe that physical properties related to wetting are of considerable importance. Other soil properties, shown in Table 1, which may be relevant are organic carbon, exchangeable cations and pH (Upchurch, 1958; Upchurch and Mason, 1962; Upchurch *et alii,* 1966; Nash, 1968).

Diuron is known to act best under thoroughly moist conditions (Upchurch, 1957; Rizk *et alii,* 1966). It would seem that activation of diuron is more difficult, at least in some of the soils of the Wee Waa area, than in Cununurra clay, and that this is brought about by greater difficulties in wetting. Furrow irrigation, as practised in the Wee Waa area, at least in the poorer soils, may not wet the topmost soil of the ridges sufficiently to activate diuron.

Acknowledgements

Nearly all of the work reported here was done while we were employed by C.S.I.R.O. in Canberra. We thank Mr. R. Paull, Dr. J. Loveday and Dr. D. McIntyre for assistance in the collection of the soils, Mr. W. Reyenga and Mr. M. Perry for technical assistance, and Mr. J. R. Twine for chemical analyses, and Dr. J. Freney for X-ray analyses of the soils.

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