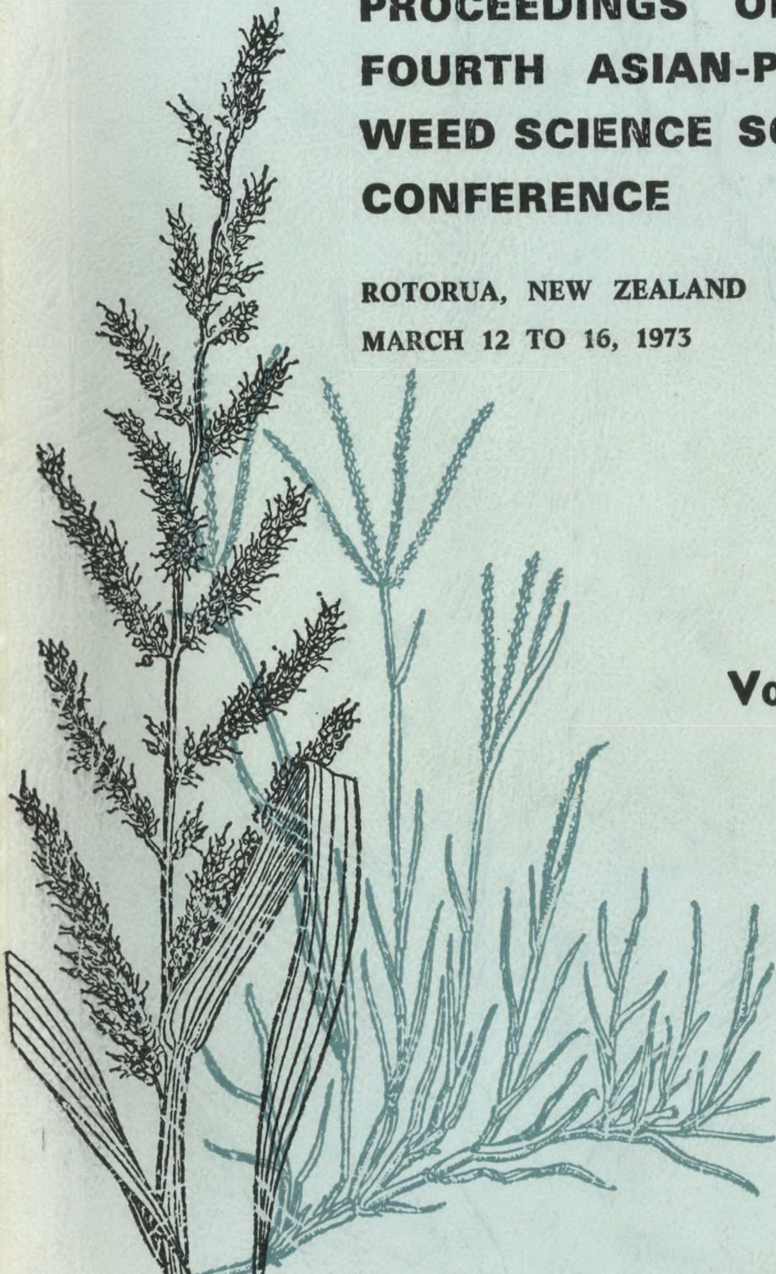
PROCEEDINGS OF THE FOURTH ASIAN-PACIFIC WEED SCIENCE SOCIETY CONFERENCE

ROTORUA, NEW ZEALAND
MARCH 12 TO 16, 1973



Volume 2

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ROTORUA INTERNATIONAL HOTEL

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WEED CONTROL IN FOREST ESTABLISHMENT IN NEW ZEALAND

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Summary

Exotic forests in New Zealand total over 525 000 ha. The planting programme is 24 000 ha annually and is rising. Much planting country is steep and a major problem is removal and control of vegetation. Manpower is required to fell and prepare heavy cover for burning, but most areas are cleared by regimes involving the use of machines, fire and herbicides. Aerial application of herbicides, for site preparation and for releasing trees, has markedly increased recently, and there is much interest in new herbicides and in granular formulations. Research is concentrated on bracken (*Pteridium aquilinum* var. *esculentum*) and gorse (*Ulex europaeus*) control.

INTRODUCTION

New Zealand's total land area is 26.9 million hectares of which half is pasture and arable and 25% is forested. Only 525 000 ha of merchantable native forest remain, while major wood production is from about 525 000 ha of planted exotic forest, 70% of which is radiata pine (*Pinus radiata*). Annual wood production averaged 7.95 million m^3 over the last three years. The value of wood exports was $71.2 million in 1971, being mainly pulp and paper to Australia (45%) and logs to Japan (40%). Forestry and wood-using industries employ some 35 000 persons (4.1% of the labour force). The current planting programme is 24 000 ha annually, and may rise to 32 000 ha, while 7 000 ha of logged exotic forest are replanted each year.

AFFORESTATION AREAS

New Zealand was settled by British immigrants from about 1840. There were then large areas of native forest with high-class timbers. Much forest was burnt to clear land for farming. The native forests supplied the bulk of timber requirements up to the early 1950s. By about 1890 it was recognized that logged forest should be replaced; the principal native species are very slow-growing and early attention was given to exotics. By 1923 it was apparent that severe shortages of wood could be expected within 50 years, and large areas of fast-growing exotics were planted during the great depression. At first many species were planted, but it soon became apparent that radiata pine is capable of high production on a wide range of sites, and is far more versatile silviculturally, and in end uses, than any other species planted. Forests of this species are economically competitive with some traditional forms of farming (Fenton *et al.,* 1968).

Forestry has, however, generally been relegated to land unsuitable for farming, either because of topography, fertility or weed cover. The range of site conditions in afforestation areas are broadly:

(a) *Climates*: Exotic forests have been successfully established from Aupori Forest in the north (above Lat. 35° S) to Owaka in the south (below Lat. 46½° S); on the West Coast of the South Island (3000 mm+ annual rainfall) and in Central Otago (500 mm− rainfall); at sea level with virtually no frosts, to hard sites above 600 m a.s.l. with frosts down to −16° C.

(b) *Soils*: Radiata pine grows on a wide range of soil types, from sand dunes to heavy clays, but development is best on the central North Island pumice country, where the bulk of the exotic forests have been established. It will tolerate dry sites, and fairly low fertility on deeper soils, but fails or shows stunted growth on wet sites and is sensitive to low phosphorus levels.

(c) *Terrain*: Of country scheduled for afforestation between 1970 and 2000, 48% is too steep for crawler tractors (Chavasse, 1969). This varies from place to place, but it poses a major problem in forest management.

(d) *Vegetative cover*: An assessment made in 1968 (Chavasse, 1969) was that, for the period 1970 to 2000 (assuming an annual programme of 18 000 ha) cover types would be broadly as follows:

Open country, fern, light scrub, grass	200 000 ha (38%)
Heavy or difficult scrub (including gorse, *Ulex europaeus*)	160 000 ha (31%)
Residual bush, cutover, etc.	160 000 ha (31%)

As the planting programme increases, so the proportion of difficult scrub, residual bush, etc., will increase. Table 1 shows details of cover types for areas to be planted from 1969 to 1978.

TABLE 1: COVER TYPES ON COUNTRY TO BE PLANTED FROM 1969 TO 1978

Cover Type	*ha*	*%*
Manuka- or kanuka-dominated associations (*Leptospermum scoparium, L. ericoides*); some areas with bracken (*Pteridium aquilinum* var. *esculentum*), and most with other broadleaved species or with gorse (7 000 ha)	54 000	26.6
Cutover podocarp forest, with enclaves of other types	46 000	22.6
Bracken, often with scattered scrub	28 000	13.8
Native grasses and low heathy scrub	23 000	11.3
Gorse-dominated associations; often with bracken and some broadleaved species	15 000	7.4
Broadleaved scrub; includes 600 ha with gorse	12 000	5.9
Cutover beech forest (*Nothofagus* spp.); includes areas of bracken, etc.	11 000	5.4
Introduced grasses and other exotic plants	10 000	5.0
Other difficult species — broom (*Cytisus scoparius, C. monspessulanus)*, Himalaya honeysuckle *(Leycesteria formosa*), tree lupin (*Lupinus arboreus*), barberry (*Berberis* sp.) and tree tutu (*Coriaria arborea*); 600 ha contain gorse	4 000	2.0

With plans for a much increased planting programme (N.Z. Forest Service, 1972) and also for management of large areas of beech forest in the South Island (White Paper, 1971), some of these types are likely to show a marked increase in future.

A survey in 1969 (Chavasse, 1970) showed that in that year the N.Z. Forest Service undertook releasing operations in cover types shown in Table 2.

The greater part of these releasing operations was undertaken with hand tools. The most troublesome weeds are bracken and gorse, followed by grasses, tree lupin and Himalaya honeysuckle.

OBJECTIVES

Because intensive plantation management is now practised in New Zealand, the aim of establishment has been full stocking in the interests of maximum yield and optimum quality. Radiata pine shows a good deal of malformation in the young age classes, and acceptable stockings at time of first pruning are 1250 to 1850 stems/ha. Between planting and first pruning there may be a loss of up to 30% owing to weed smothering, animals, fungi and toppling. It has therefore been the practice to plant 1700 to 2500 trees/ha. With improvement in genetical quality (Shelbourne, 1970) and new ideas on silviculture (Fenton and Sutton,

TABLE 2: COVER TYPES IN WHICH RELEASING WAS NECESSARY IN 1969

Weed Species		*Additional Areas in Mixture with (ha)*						
Name	*Area (ha)*	*Bracken*	*Gorse*	*Grasses*	*Blackberry*	*Hardwoods and fern*	*Himalaya honeysuckle*	*Other*
Bracken	2720	—	1070	100	310	300	360	230
Gorse*	1360	1070	—	110	1030	—	40	—
Grasses*	1940	100	110	—	—	140	20	—
Blackberry (*Rubus fruticosus* agg.)*	—	310	1030	—	—	—	—	80
Hardwoods and fern	330	300	—	140	—	—	—	10
Himalaya honeysuckle*	30	360	40	20	—	—	—	—
Tree tutu	20	190	—	—	—	10	—	—
Muehlenbeckia spp.	179	20	—	—	—	—	—	—
Tree lupin*	1120	—	—	—	—	—	—	—
Thistles*	140	—	—	—	—	—	—	—
Broom*	20	—	—	—	80	—	—	—
Other*	490	—	—	—	—	—	—	—

*Exotic plants.

1968), this is changing. But if fewer trees are planted, then it becomes more necessary to make sure that most, if not all, survive. It has been found that blanking is of dubious value, while releasing is very costly in manpower and often partially ineffective. There are strong incentives for improving: tree stock quality to get increased survival and early growth; tree handling to ensure that trees are in first-class condition when planted; and site preparation so that most of the problem weeds are dealt with before planting. Much of the difficulty in establishment has been due to attempting to reduce direct costs to a minimum. This is unrealistic (Sutton, 1969; Chavasse, 1969, Chapter 9) because poor establishment inevitably leads to serious costs or financial losses later in the rotation. The major objectives of establishment are therefore:

To achieve 100% establishment of trees which grow fast in their first year following planting.

To improve site preparation to a point where releasing is markedly reduced or obviated.

To reduce manpower requirements in all phases of establishment.

METHODS

Because of the types of cover and the vigour of weed growth in the benign climate of most afforestation areas, control or removal of vegetation is of major importance. Methods are discussed in detail in the report on *FRI Symposium No. 11* (Chavasse, 1969). This symposium, primarily designed to examine knowledge of the subject at that time, also had the effect of disseminating information and stimulating changes in attitudes and techniques. Thus, since 1969, there has been a major increase in the use of chemicals for site preparation and releasing; increasing use of, and experimentation with, machinery; and greater expertise in the use of fire, especially in pine cutovers.

Fire is the major land-clearing tool and several cover types can be readily removed by burning alone. However, this is frequently insufficient as regrowth is usually vigorous and releasing becomes essential. In some cases (*e.g.*, for most grasses) this can be achieved with herbicides, but for the most important weed, bracken, hand cutting is required, sometimes up to five times over two or even three years, adding up to $250/ha to the cost of establishment.

Most areas are now cleared under regimes which may include the use of machines, herbicides and fire, sometimes spread over two, three or even four years. These regimes may include a final herbicide treatment after planting, as in gorse, to release trees. However, large amounts of manpower are used to clear some major cover types such as cutover and residual bush and heavy, tall scrub. The essential objective is the preparation of fuel for burning. Owing to the deep and tenacious root systems of many native trees, suitable mechanical methods have not yet been developed.

Herbicides have come to play an important role in both site preparation and releasing, and are mainly applied from aircraft. Fixed-wing machines are best for larger areas and easier country, while helicopters are better in broken country or where distribution of weeds is patchy. Brief details are as follows.

HERBICIDES USED IN SITE PREPARATION

The major use of chemicals is as desiccants to aid burning. For example, standing live broadleaved scrub (including gorse, broom, and Himalaya honeysuckle), or native scrub regrowth following hand-felling or crushing, may be prepared by applying desiccants. On easy country, weeds are frequently chopped by giant (75 cm) discs, and herbicides are used for killing regrowth prior to planting. The major herbicide for these operations is 2,4,5-T ester, often in conjunction with additives such as picloram, paraquat, ammonium sulphamate or sodium chlorate, applied in water at rates of 220 to 550 l/ha, sometimes with 10% diesel oil added.

Herbicides for Releasing Trees

Important weeds are gorse, grasses, lupin, tutu, broom and thistles. These are treated with low rates (less than 1.1 kg/ha) of 2,4,5-T ester, sometimes with picloram, in 110 to 220 l of water/ha, applied by aircraft. Release from grasses may be undertaken using hand sprayers, incorporating tree shields, to apply mixtures containing triazines, amitrole, and sometimes 2,2-DPA. Large areas of grass are aerially sprayed with atrazine and amitrole.

While application before planting is not critical, aerial treatment for releasing needs considerable care and the avoidance of overlap. Neither ground control methods, nor accuracy of placement, are as yet sufficiently developed for optimum application of chemicals, although a marked improvement has taken place over the last four or five years. Pilot skill is of great importance, and is generally of a high standard.

RECENT RESEARCH DEVELOPMENTS

With the interest in forest-farm production, establishment of trees in pasture has attracted attention recently, and it has been found preferable to remove grass where necessary prior to planting. This can be done readily by using paraquat applied to short grass in spots or strips by hand sprayer or by tractor-mounted gear. If more complete clearance is desired, triazines can be added.

In view of restrictions on liquid herbicides in certain circumstances, more attention has been given to granular formulations for grass control, and dichlobenil and chlorthiamid are effective alternatives.

Most attention has been directed to control of bracken and gorse. On easy country both can be markedly reduced by cultivating with 75 cm discs. In some cases control has been effected by "blading" — removing cover and some soil with a bulldozer or V-blade — but this is not desirable where it could lead to soil or water loss. The major problem is on steep country. It has been found that gorse can, in some circumstances, be eradicated by burning, followed by two separate herbicide applications in autumn when regrowth is a few centimetres high. Although several chemicals gave satisfactory results, the best were 2,4,5-T ester with picloram, and 2,4,5-T with paraquat, followed by 2,4,5-T at the second application (Chavasse and Davenhill, 1972).

Bracken regrowth has been eliminated by the application of granular herbicides following a hot burn. These include sodium chlorate/borate, dichlobenil and chlorthiamid. Among liquid formulations, dicamba ester, asulam and karbutilate are promising, provided they are applied at the correct time in relation to bracken growth stages.

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WEED CONTROL IN A LARGE COMMERCIAL FORESTRY COMPANY IN NEW ZEALAND

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Summary

The planning and operational practice of chemical weed control in a large forestry company are discussed, and examples of current weed problems and their control are given. The importance of trial work is mentioned, with some suggestions for future investigation.

INTRODUCTION

N.Z. Forest Products Ltd. is a forestry company producing pulp and paper, cardboard and wallboards. The company holds 134 000 ha of land in the central North Island, mainly at Kinleith, of which 100 000 ha are planted. New plantings total 4000 to 5000 ha per annum. Much of the land available for afforestation is cutover indigenous forest, with some medium scrub and some light scrub and fern. These sites require mechanical and chemical treatment for site preparation (Church and Bowers, 1971), and chemical weed control after planting. Because of the large areas involved, the shortage of labour, and the high cost and relative inefficiency of hand releasing, tree release is achieved, where possible, using aerially applied chemicals (Bowers, 1971).

PLANNING OF OPERATIONS

Areas planted during preceding years are reported on by field staff as a normal procedure, and a final survey is carried out to check chemical and application rates. This final survey is often done by helicopter, as large areas can be checked in a short time, and boundaries of weed infestations can be marked on aerial photographs. Areas for desiccation are checked and water and chemical rates are assessed. A chart is then prepared showing weed species and desiccant areas by hectares and rates of application of water (Table 1). This chart also summarizes the total amount of water to be applied at each application rate, in thousands of litres. Using these figures, and knowing the required time of spraying of the various weed species, an aircraft utilization chart is drawn up showing the volumes to be applied related

TABLE 1: SPRAYING BY AREA AND APPLICATION RATE
Hectares (thousands of litres in parentheses)

Litres per hectare	*Release Spraying by Species (ha)*							
	Scotch Thistle	*Mont-pellier Broom*	*Himal-aya Honey-suckle*	*Wine-berry*	*Grass*	*Other*	*Desiccant Spray-ing*	*Totals*
56	2,000 (113)					60 (5)		2,060 (118)
112		140 (18)		250 (26)				390 (44)
168		235 (41)	90 (14)	1,550 (258)		25 (5)		1,900 (318)
224		90 (18)	830 (186)			150 (36)	1,290 (290)	2,360 (530)
336		40 (14)			640 (208)		3,000 (1,010)	3,680 (1,232)
Totals	2,000 (113)	505 (91)	920 (200)	1,800 (284)	640 (208)	235 (46)	4,290 (1,300)	10,390 (2,242)

to the times and rates of application. Figure 1 shows a condensed version of this chart, which in practice shows all the individual blocks to be sprayed. For example, the area of 2,060 hectares at 56 l/ha in fact may comprise several discrete areas ranging in size from 20 hectares to 800 hectares. Copies of the complete chart, together with appropriate maps, are available to aviation companies when tenders are called. In the allocation of spraying

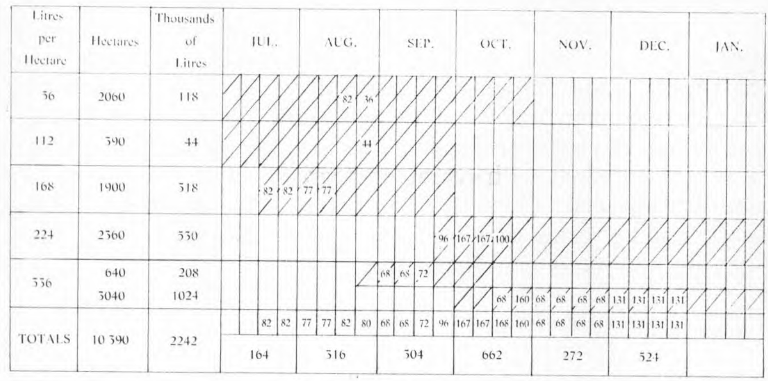

Fig. 1: Aircraft utilization by thousands of litres. Hatching shows limits of operation. The positions of the figures indicate the required time of treatment. Aircraft use drops during November owing to other spraying requirements.

work, areas are often grouped if they are to be sprayed from the same airstrip to allow continuity of operations. The number of aircraft is also specified when calling for tenders.

OPERATIONS

Types of Aircraft

The quality of the result obtained generally depends, not on the type of aircraft, but on the skill of the individual pilot. The spraying of forest areas is a difficult task, as landmarks are few and areas are often in steep or broken country, and a good pilot is essential. Helicopters are generally used for small, awkward areas, or for areas too far from an existing airstrip. Fixed-wing aircraft are cheaper if an airstrip is available and have been used in steep country with success.

Provision of Airstrips

Studies have shown that the optimum spacing for airstrips is 16 to 24 km apart. N.Z. Forest Products Ltd. has three existing airstrips, and more are planned. The use of farm airstrips is not desirable, as some chemicals used in forestry may damage pasture, and the use of the strip may clash with current farm work.

Control of Operations

N.Z. Forest Products Ltd. staff control all spraying operations. Ground controllers with radio-equipped vehicles watch the operation, and report back to the operation controller on the airstrip or landing pad. Spraying is stopped when drift exceeds the allowed maximum, or when the fines are lifted owing to heat. The mixing of chemicals is supervised by the operation controller. Pilots are supplied with aerial photographs, and boundaries are carefully checked. Great care is taken near susceptible crops, reserves and streams, and spraying may not be permitted in some cases if the risk is considered too great.

Records

Full records are kept of all operations, so that accurate costings can be made of all facets of the work, comparisons made between different aircraft types and methods, and to enable better planning of future operations.

TABLE 2: SOME CURRENT WEED CONTROL PRACTICES

Weed Species and Treatment	*Rate per Hectare*
1. Cutover bush and scrub:	
60% sodium chlorate	22 to 33 kg
butyl ester of 2,4,5-T	4 kg
Water + surfactant	170 to 340 l
2. Scotch thistle (*Cirsium vulgare*):	
picloram (potassium salt)	0.07 kg
2,4,5-T (150-octyl ester)	0.28 kg
Water	28 to 55 l
3. Montpellier broom (*Cytisus monspessulanus*):	
picloram (potassium salt)	0.1 to 1.4 kg
2,4,5-T (150-octyl ester)	0.42 to 0.56 kg
Water	110 to 220 l
4. Himalaya honeysuckle (*Leycesteria formosa*):	
As for (3)	As for (3)
Water	170 to 220 l
5. Wineberry (*Aristotelia serrata*):	
As for (3)	As for (3)
Water	170 to 220 l
6. Grass (mainly reverted pasture):	
amitrole	1.1 to 1.7 kg
ammonium thiocyanate	1.0 to 4.0 kg
atrazine	3.5 kg
Water + surfactant	340 l

TREATMENTS

A range of current chemical treatments is given in Table 2. The treatments shown are only a guide, and each problem must be individually assessed.

CURRENT INVESTIGATION WORK

As a necessary adjunct to spraying operations, N.Z. Forest Products Ltd. undertakes investigations into the use of chemicals in forestry. Most of the investigation is done jointly with chemical companies, about 10 of which currently are co-operating in trial programmes. New chemicals showing promise in initial trials are tested in greater detail and in aerial trials, to enable them to be used in practice as soon as possible. Current spraying operations are based on trial work done initially in the company's Kinleith forests. Liaison is maintained with other forestry concerns and with the Forest Research Institute. New techniques in aerial application are tested jointly with aviation firms, and the company is co-operating with the Forest Research Institute and the New Zealand Forest Service in a research project undertaken by the New Zealand Agricultural Engineering Institute, to monitor the application of liquids from aircraft.

CONCLUSION

The use of aircraft and chemicals is an integral part of silviculture, and has made possible increases in the quantity, quality and cost efficiency of site preparation and tree releasing. With regard to chemical releasing, it should be stressed that on both ecological and economic grounds the aim is to control the weed species, not to eradicate it. By using chemicals properly, competition is removed and marked increases in tree growth are possible. Much has been achieved in only a few years; N.Z. Forest Products Ltd. has used chemicals for site preparation for 7 years and for release for 5 years. Much remains to be done. For example, a total of some 6,100 ha was aerially released during the last growing season.

During the same period, 5900 ha were released by hand, at greater cost and with poorer results. Some of the main fields for investigation are listed below:

(1) The control of droplet size, with a resultant decrease in the danger of drift, a reduction of application rates and a more efficient use of the limited spraying weather.

(2) The chemical control of bracken.

(3) The use of granular herbicides, together with the development of suitable spreading equipment.

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THE USE OF HERBICIDES IN FOREST NURSERIES

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Summary

In radiata pine *(Pinus radiata)* crops, broadleaf weeds are effectively controlled with propazine, a safe, cheap, broad-spectrum herbicide, reinforced when necessary with chlorthal for better grass control. For pre- and early post-emergence control in contorta pine *(Pinus contorta)* and Douglas fir *(Pseudotsuga menziesii)*, two conifers that are susceptible to propazine, nitrofen is recommended. Eight weeks after emergence, propazine and chlorthal, which give longer lasting control, may be substituted for nitrofen. Under moist conditions, diphenamid, which gives excellent broad-spectrum control in Douglas fir and radiata pine seedbeds, can be used in place of nitrofen from time of sowing onwards. For eucalypts, linuron is a proven pre-emergence herbicide on heavy soils. Nitrofen, which so far has been tested only on *Eucalyptus delegatensis*, appears a promising alternative to linuron on lighter soils.

INTRODUCTION

In New Zealand forest nurseries, tree seedlings are raised almost entirely in open beds. Seed of most forest species is sown in spring for the production of one-year-old (1/0) or 2-year-old (2/0) planting stock. Seed of radiata pine, by far the most important species, is also sown in summer for lifting as 1½/0 stock.

Forest nurseries are situated in all parts of the country in a wide range of climatic conditions and on a wide variety of soils: peat, pumice, ash, loess, clay and silty alluvium.

These soil/climate combinations affect the rates at which weedicides are safe and effective. At Puha for instance, on a loess (light soil, high temperatures), it is safe to apply up to 1.12 kg/ha of propazine soon after sowing of radiata pine. In practice, only 0.56 kg/ha is needed for good weed control, whereas in Milton (silty loam, low temperature) it is safe to use 3.36 kg/ha and only 1.12 kg/ha is required for good weed control. On light soils, maximum safe rates (and also minimum effective rates) have generally been less than those established on a sandy pumice loam at the Forest Research Institute (FRI).

PRESENT PRACTICES

The regime for raising 1/0 radiata pine is as follows: Seed is sown from late September to mid-October, followed by an application of 0.56 to 1.12 kg of propazine in 450 l water/ha to control a wide range of broadleaf weeds and annual grasses. If it is necessary to control summer grass (*Digitaria sanguinalis*) chlorthal is used at the same time, generally at 9 to 10 kg/ha but in one nursery at as low a rate as 5 kg/ha. The usual time of application for both is within two days of sowing ("post-sowing") or, when seedlings are about to emerge, as a "pre-emergence" treatment. Weeds that have germinated between sowing and emergence are eradicated with paraquat at 0.42 to 0.7 kg/ha in 450 l water/ha. During their emergence tree seedlings are particularly susceptible to the effects of weedkillers and applications are generally avoided during this period.

Depending on soil conditions, complete emergence of radiata pine ranges from 10 days from sowing in some nurseries to 5 weeks in others. As post-emergence applications of propazine at 0.56 to 1.12 kg/ha may be made with safety when the youngest seedlings are 3 weeks old, post-sowing/pre-emergence applications have to afford control of weeds for about 8 weeks. This is usually obtainable, but under dry conditions propazine and chlorthal are sometimes not entirely effective and light mineral oils (18 to 22% aromatics) at rates ranging from 170 to 335 l/ha are used to kill small weeds. As mineral oils are expensive and have no lasting effect, alternatives are being sought.

During the growing season, broadleaf weeds are controlled by applying propazine or simazine when necessary at 1.12 kg/ha. Simazine has greater activity than propazine against annual grasses.

An application of 2.24 kg of atrazine plus 25 l of an emulsifiable oil in 450 l water/ha is being used in the Rotorua area as spring/early summer "clean up" treatment in summer-sown radiata pine, when seedlings are a minimum of 10 cm high. Current weed control practices for other species have been reported on (van Dorsser, 1971).

PROBLEM WEEDS

The most difficult weeds to control in nurseries are prostrate amaranth (*Amaranthus deflexus*), Indian doab (*Cynodon dactylon*), sorrel (*Rumex acetosa*) and oxalis (*Oxalis latifolia*).

These weeds are best dealt with in fallow ground as it is impossible to control them in a tree crop. Established prostrate amaranth, Indian doab and sorrel have been controlled by a mixture of amitrole + thiocyanate and amine salt of 2,4-D + dicamba. Frequent cultivation is also effective in eradicating established sorrel in fallow areas. Seedling amaranth and sorrel are controlled by pre-emergence applications of propazine at a minimum rate of 0.3 kg/ha. For eradication of oxalis, soil fumigation with methyl bromide at 500 kg/ha is entirely effective.

CURRENT RESEARCH AND PROMISING CHEMICALS

Current research is concentrating on finding selective weedkillers for pre- and early post-emergence use on Douglas fir and contorta pine. Radiata pine is usually included as a reference species. Results with three chemicals to which the above species have shown tolerance are summarized in Table 1.

TABLE 1: RATES TOLERATED AND MAXIMUM RATES TESTED (IN PARENTHESES) IN TRIALS AT FRI.
Chemicals were applied in 450 l water/ha

	Treatment (kg/ha)		
	Post-sowing (within 2 days of sowing)	*Pre-emergence (when seedlings are about to emerge)*	*Post-emergence (3 wk after emergence of last seedling)*
Radiata pine	chloramben 11* (14) 17 (17)† diphenamid 33.5 (33.5) nitrofen 14 (14)	chloramben 6 (21) diphenamid 33.5 (33.5) nitrofen 14 (14)	diphenamid 33.5 (33.5) nitrofen 14 (14)
Douglas fir	chloramben 11* (14) 17 (17)† diphenamid 17-22 (33.5) 28 (28)† nitrofen 14 (14)	chloramben 6 (21) diphenamid 14.5 (16.5) nitrofen 14 (14)	diphenamid 33.5 (33.5) nitrofen 14 (14)
Contorta pine	chloramben 11* (14) 17 (17)† diphenamid 11 (11) 28 (28)† nitrofen 14 (14)	chloramben 6 (21) diphenamid 11 (16.5) nitrofen 14 (14)	nitrofen 14 (14)
Eucalyptus delegatensis	nitrofen 6.7 (6.7) nitrofen 14 (4)		

*Some growth depression at these rates.
†In one summer trial.

WEED CONTROL OBTAINED IN TRIALS AT FRI

Chloramben

For control of most annual grasses and broadleaf weeds, a minimum of 9 kg/ha is required. Good control has been achieved by 14 kg/ha. It appears that barnyard grass (*Echinochloa crus-galli*) may be controlled at rates higher than 14 kg/ha.

Diphenamid

Under moist conditions very good control of annual grasses, including barnyard grass and annual broadleaf weeds, has been obtained with diphenamid applied at 11 to 14 kg/ha. Summer grass is controlled by 7 kg/ha. Barnyard grass control is obtained by 9 kg/ha. For control of broadleaf weeds a minimum of 11 kg/ha is necessary.

Nitrofen

At 7 to 9 kg/ha, annual grasses are controlled. For control of most annual broadleaf weeds, rates from 9 to 14 kg/ha are required. Barnyard grass is controlled by 9 to 10 kg/ha of nitrofen. It appears that, when soils are moist, application rates may have to be higher than under dry conditions.

SUGGESTED WEED CONTROL REGIMES

Despite earlier promising results with chloramben, this chemical cannot be recommended because it depresses early height growth and has inadequate activity under dry conditions. The following weed control regimes are suggested on the basis of trial results so far.

Radiata Pine

The post-sowing/pre-emergence use of propazine, chlorthal and paraquat has been outlined under "present practices". If barnyard grass control is required and conditions are moist, applications of diphenamid at 11 to 14 kg/ha immediately after sowing or before emergence are suggested. Under dry conditions, better results are likely to be obtained from nitrofen applied at the same times at a minimum rate of 9 kg/ha.

Should weed control by propazine and chlorthal have been inadequate because of dry soil conditions, mineral oils are the only proven materials that may be used to selectively control weeds in the early post-emergence phase. The mineral oils have no lasting effect and herbicides with knockdown as well as residual action are being tested as possible alternatives.

The use of simazine and of atrazine + emulsifiable oil during the growing season has also been outlined under "present practices".

Douglas Fir and Contorta Pine

Propazine cannot be used with safety on these species until seedlings are 8 weeks old. Currently, repeat applications of mineral oils at rates ranging from 170 to 355 l/ha constitute the only method of selective pre- and early post-emergence weed control in these species. As an alternative to the mineral oils, nitrofen applied post-sowing/pre-emergence or post-emergence at rates of 7 to 9 kg/ha is recommended, particularly under dry conditions.

If the soil is moist, more lasting control may be obtained by diphenamid used post-sowing/pre-emergence on Douglas fir at rates not exceeding 14.5 kg/ha and post-sowing on contorta pine at a maximum of 11 kg/ha.

Eucalypt Species

The present regime of linuron applied post-sowing at up to 1.12 kg/ha on heavy soils, gives good weed control without tree damage. On lighter soils, where 0.56 kg/ha is applied at the same time, the margin between minimum effective and maximum tolerated rates is minimal.

A rate of 6.7 kg/ha of nitrofen applied post-sowing to *Eucalyptus delegatensis* has given adequate weed control without tree damage. Higher rates are being tested and no recommendation can be made at present.

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LEGISLATION RELATING TO AGRICULTURAL CHEMICALS IN NEW ZEALAND

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Summary

The legislation relating to agricultural chemicals in New Zealand is briefly summarized, with major emphasis being placed on the Agricultural Chemicals Act 1959, which sets up the framework for registration of agricultural chemicals, all of which must be registered before they are sold. Regulations governing the sale and use of certain pesticides and the use of hormone weedkillers are discussed, as well as regulations relating to voluntary registration of ground applicators of agricultural chemicals and compulsory chemical rating of pilots. Other legislation relating to protection of bees and fish is discussed, and finally Department of Health requirements as they relate to agricultural chemicals are briefly summarized.

The Agricultural Chemicals Act 1959 repealed the Fungicides and Insecticides Act 1927 and set up the present registration system.

An agricultural chemical is defined in the Act as any substance, whether mixed with any other chemical or not, sold or used for the purpose of protecting any form of plant life from injury caused by organism or virus or for the purpose of curing any such injury or any disorder of plant life of a physiological nature or for the purpose of destroying, preventing, stimulating or in any other way influencing the growth of any form of plant life; and includes any rodenticide and any substance which the Governor-General by Order in Council declares to be an agricultural chemical for the purposes of the Act; but does not include agricultural lime nor any fertilizer not mixed with an agricultural chemical.

The Agricultural Chemicals Board, an independent authority, was set up under the Agricultural Chemicals Act. The Board consists of eleven persons nominated by the following persons or organizations:

The Minister of Agriculture and Fisheries.
The New Zealand Vegetable and Produce Growers' Federation Inc.
Federated Farmers of New Zealand Inc.

The New Zealand Fruitgrowers' Federation Ltd.
The grape growers of New Zealand.
The Minister of Health.
The National Beekeepers' Association of New Zealand Inc.
The Agricultural Chemical and Animal Remedies Manufacturers' Federation of New Zealand Inc.
The Minister of Science.
The New Zealand Grain, Seed and Produce Merchants' Federation Inc.
The Director-General of Agriculture and Fisheries (who shall be Registrar).

The principal functions of the Board shall be generally to promote the welfare of the agricultural and horticultural industries by ensuring that any agricultural chemicals used in those industries are efficient and used safely; and to consider and determine applications for the registration of agricultural chemicals. Other functions include the promotion of any research with a view to testing or improving agricultural chemicals, dissemination of information, encouraging use of certain agricultural chemicals, and making recommendations to the Minister of Agriculture and Fisheries on the use of agricultural chemicals.

No proprietor (manufacturer or importer) is allowed to sell any agricultural chemical unless it is registered or provisionally registered by the Board. Sale includes barter and also includes offering, exposing or attempting to sell, or having in possession for sale or delivering by way of gift or sample or causing or allowing to be "sold" and "to sell" has a corresponding meaning. The provisions of the Act are binding on the Crown.

Every agricultural chemical registered under the Act shall be sold in a package to which is attached a label which has been accepted by the Board. The Act specifies that the minimum requirements which shall appear on the label should include *inter alia,* (a) name and address of the proprietor, (b) the Registration Number, (c) the net contents, (d) the active ingredient, (e) the remedial properties claimed, (f) the precautionary advice as required by the Director-General of Health for the purpose of safeguarding human health, (g) information to safeguard the health of livestock, fish, beneficial insects, or wildlife, (h) advice to avoid damage to beneficial plants, (i) such other matter as the Board may require.

The Board may refuse registration for a number of reasons, including if the chemical is likely in the opinion of the Board to be materially prejudicial to the health or safety of human beings, livestock, beneficial plants, or animals, or if the material is ineffective or not up to standards prescribed. There is no provision for re-registration, but provision is made for renewal of application if the Board feels it is desirable to review the application of any agricultural chemical.

Provision is made for appeals, for the appointment of inspectors, and for control over advertisements (where these are considered to be misleading or inaccurate), and power is given to make Regulations.

There are two types of registration — provisional and full. Provisional registration is further subdivided as follows:

Provisional Research

A chemical is used at a research level and is labelled accordingly.

Provisional A

The product and not the chemical is registered for "Experimental Use Only — Not for Sale". This level of registration enables the proprietor to carry out small-scale trials, but the product must not be sold. As well as efficiency of the product being studied at this stage, side-effects on wildlife, residues in plant tissues, and other factors which may influence the wider use of the product are studied.

Provisional B

This class of registration is granted when the Board is satisfied that under New Zealand conditions the use and knowledge of the product have advanced to the stage where wider-scale field trials are desirable. When application for Provisional B registration is made, the proprietor presents all the information he has obtained from Provisional A trials in support of his new application. Products granted registration under this class must have "For Field Assessment Only" printed conspicuously on the label. It is intended that this wording should make the user aware that the product is only at the advanced field-trial stage. For this class of registration there are not sufficient data available on which to make firm recommendations, but the Board has sufficient evidence to accept wider field-scale trials to obtain the necessary information for full registration. A product's use at this stage should be closely observed by the proprietor to determine performance in the field, as well as to study any undesirable side-effects and to find methods of use and application to ensure that the product can be safely marketed.

The product may be sold at the Provisional B stage but a quantity limit is placed on sales.

Full Registration

A label is accepted for Full Registration when the Board is satisfied that if label directions are followed the material will do what the label claims. By accepting the label, the Board does not assume responsibility for the use of the product, as there are many factors associated with use which are beyond the control of the Board.

All applications for registration are submitted to the Board's office and these are then sent out to the Board's technical advisers. These advisers include research scientists, university personnel, Department of Health officers, and any expert who may be working in the particular field under consideration. All data are sent to the Board's advisers and these are evaluated by them to ensure that the proposed label claims are supported by the data. Comments received from the technical advisers are considered by the Board after evaluation by the Board's secretariat, and any amendments to the proposed label are passed to the proprietor, who must submit a final label before the product is registered. It is up to the proprietor to supply experimental data to support his label claims. No official testing is done by the Board, but in practice samples are usually given to research workers for trial at an early stage of a product's evaluation.

The Agricultural Chemicals Regulations 1968 set out a list of insecticides for which it is necessary to have a permit before they can be bought or used. Notices issued pursuant to these regulations make label directions for certain insecticides mandatory. The regulations also cover the application of defined herbicides near a vineyard. The herbicides involved include 2,4-D, MCPA, 2,4,5-T, dicamba, and other hormone weedkillers which may be applied at specified distances from a vineyard, depending on formulation, time of year, and application method. A vineyard is defined in the Regulations as one acre planted in grapevines. Apart from directed hand application, use of herbicide dusts is not permitted during the main growing season (that is 1 September to 30 April next following).

A voluntary scheme covering the registration of persons engaged in the ground application of agricultural chemicals has just been put into operation, and details are covered in the Agricultural Chemicals (Registration of Applicators) Regulations 1971. These regulations set out the prerequisites for an applicant — namely, that he should:

(1) Have completed a course in agricultural chemicals

(2) Have passed an examination

(3) Have had satisfactory practical experience.

The accepted course is the Technical Correspondence Institute Course in Agricultural Pesticides, the examination is one set by the Agricultural Chemicals Board, and every applicant is interviewed by a panel to determine his practical ability. Provision is made for three classes of registration, namely:

Class I — Total Vegetation and Brush Control
Class II — Crop and Pasture Weed Control
Class III — Insect and Fungous Disease Control,

and certificates which are renewable annually are issued in the appropriate classes to successful applicants.

No person shall apply agricultural chemicals from an aircraft unless he is the holder of a chemical rating issued pursuant to the Civil Aviation Regulations 1953 which authorizes the holder to act as pilot in command of an aircraft used in the application of these materials. The applicant shall be the holder of a commercial pilot's licence and shall pass an examination which may be written or oral or both in the following subjects:

(1) Functional and chemical classifications of agricultural chemicals.
(2) Methods of application and spraying techniques.
(3) Clinical effects of agricultural chemicals.
(4) Legislation pertaining to agricultural chemicals and their application.
(5) Operational methods and practices.
(6) Spraying equipment.

Provision is made in the regulations for a suspension of a chemical rating if it is considered that agricultural chemicals are being applied in a careless, incompetent, or inefficient manner.

The Apiaries Act 1969 prohibits the application of agricultural chemicals which are toxic to bees to orchard trees and berry fruits when they are in flower. Application to leguminous or cruciferous crops at certain times of the year is not allowed unless a permit from the Ministry of Agriculture and Fisheries is obtained. The Fresh Water Fisheries Regulations 1951 state that it is an offence to contaminate any water with any substance poisonous or harmful to fish, and provision is made for a substantial fine on a successful prosecution.

The Department of Health administers legislation relating to poison classification and permitted residue limits for agricultural chemicals. The Poisons Act 1960 and Amendments and the Poisons Regulations 1964 and Amendments set out the Poison Schedules. The scheduled materials used in agriculture are in one of three classifications which are based on both toxicity and availability. Restricted Poisons, for example, are available to commercial users only. For chemicals in this group disposal of empty containers is mandatory and instructions are laid down in this regard. The Noxious Substances Regulations 1954 make provision for the handling and wearing of protective clothing while handling noxious substances. They also cover employers' liability when instructing employees in the handling of these materials and in the provision of washing facilities.

The Deadly Poisons Regulations 1960 restrict the sale, distribution and use of deadly poisons, for example "1080". No person shall apply any of these controlled deadly poisons unless he is an approved operator, having satisfied the Director-General of Health of his competence in the handling of such materials.

The Food and Drug Act 1969 makes provision for the promulgation of residue limits for various pesticides in or on food, and the Food Additives Notice 1972 has been issued setting these limits. If no limit is specified, no residue is permitted in or on the food.

This paper covers the main provisions of the legislation relating to the sale and use of agricultural chemicals in New Zealand, and although this coverage is not exhaustive, it is hoped that the reader will obtain an overall impression of the requirements in this country.

PROBLEMS IN THE SAFE USE OF HERBICIDES

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Summary

As a result of the modernization of agriculture, the amount of agricultural chemicals applied to farms and forests has greatly increased, and it is important to consider their safety to humans and the environment. In this paper, after discussing the toxicity of herbicides and the regulations governing their use, the following safety precautions are proposed: (1) Observe the legal pesticide requirements, (2) apply herbicides in reasonable amount and only when they are required, (3) apply herbicides rotationally, (4) have an integrated weed control system, and (5) inspect all toxicities of the practical herbicides.

INTRODUCTION

When pesticides are selected for their toxicity to target pathogens, pest insects or weeds, it is inevitably necessary to consider also their effects on non-target organisms. In this paper, safety to crop plants, fate in the environment, toxicities of herbicides, regulation of their use by law, and measures to aid in their safe use will be discussed.

SAFETY TO CROP PLANTS

Safe use of herbicides to crop plants means the ability to use them without any damage to the crop. Agricultural herbicides should have at least some degree of selectivity between crop plants and target weeds. Even when both crop and weeds are higher plants, the former should not be injured to any extent and the latter should be killed by the herbicides. Thus care should be taken to ensure that the herbicides can be used safely within the range of their selectivity. The selectivity mechanisms of each herbicide should also be considered.

If the herbicide has long residual properties, its selectivity to the following crop should be considered. Sometimes attention should be paid to the possible synergistic action of a herbicide and a pesticide, for instance, the combination of organophosphorus or carbamate insecticides with propanil or an anilide herbicide (Matsunaka, 1971a). Because all precautions against crop injury by a herbicide is printed on the product label, it should be the first principle of safe use to follow carefully the instructions given.

FATE OF HERBICIDE

The effects of herbicides on human or non-target organisms, or on the environment other than farms or forest should be discussed after the general outline of the fate of herbicides has been determined. The fate of herbicides in the field or in the food chain can be summarized as shown in Fig. 1 (Matsunaka, 1971b).

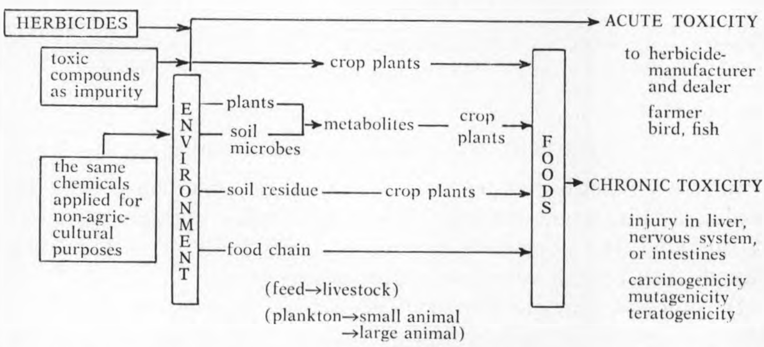

Fig. 1: Fate of herbicides and their effects on human and non-target organisms.

ACUTE TOXICITY OF HERBICIDES

Because herbicides are essentially poisons for higher plants, their mammalian toxicity is usually very low. However, some of them have relatively high toxicities.

Acute toxicity of a herbicide seems to have a high relationship with its mode of action. As shown in Table 1, herbicides which inhibit the formation of energy in weeds have a relatively high toxicity to mammals or fish. On the other hand, photosynthesis-inhibiting or light-requiring herbicides, for instance simazine or nitrofen, have very low acute toxicities.

Herbicides intended for use in rice culture should have low toxicity to fish or shellfish. Fish and mammalian toxicity are not necessarily parallel and in Japan the former is measured using young carp and classified into four grades, A, B, C, and D. Depending upon these grades, application of the herbicide in practice is regulated by law.

TABLE 1: MODE OF ACTION AND ACUTE TOXICITY OF HERBICIDES

Mode of Action	*Herbicides*	*Acute Toxicity** LD_{50} *(mg/kg wt)*
Inhibition of energy formation	PCP	78 (R)
	DNOC	10 (M)
	dinoseb	40 (R)
	fentin	109 (M)
Disturbance of hormonal regulation	2,4-D	375 (R)
	MCPA	700 (R)
Inhibition of photosynthesis	diuron	3,600 (R)
	simazine	5,000 (R)
	prometryn	3,750 (M)
	bromacil	5,200 (R)
Active only with light	nitrofen	3,580 (M)
	chlornitrofen	10,800 (R)

*R, rat; M, mouse.

CHRONIC TOXICITY OF HERBICIDES

Recently, residues of herbicides in food or water have been regarded as important because they may display chronic toxicities in humans after long-term uptake of such food or water, even though they have a very low acute toxicity.

In practice chronic toxicity appears as injuries in the liver, nervous system, or other internal organs. Carcinogenicity, mutagenicity, or teratogenicity may also result.

Carcinogenicity of pesticides was placed in the following four groups by the U.S. Department of Health, Education and Welfare (1969):

"A. Not positive — Data acceptable, testing adequate, results judged negative for tumour induction in at least two species."

"B. Positive — Data acceptable, testing adequate, results judged positive for tumour induction in one or more species and significant at the 0.01 level."

"C. Evidence insufficient to judge." In this group, the herbicides were grouped according to priorities for additional testing. For instance, the C-1 compounds have the first priority for additional testing. In the C-4 group, tumour incidence was not increased in studies conducted with one species, but current guidelines require negative results in two animal species for negative judgements to be recorded.

"D. Information available is insufficient to justify any comment."

The report grouped herbicides as shown in Table 2.

TABLE 2: CARCINOGENICITY OF HERBICIDES

Group	*Herbicides*
A	chlorpropham
B	amitrole, di-allate
C-1	monuron, azobenzene
C-2	propham
C-3	dichlorprop, isopropyl ester of 2,4-D, fenoprop
C-4	atrazine, 2,4-D, butyl ester of 2,4-D, iso-octyl ester of 2,4-D, diuron, maleic hydrazide, propazine, simazine, cacodylic acid, chloranocryl, diphenylacetonitrile, dinoseb, noruron, pentachlorophenol, 2,4,5-T

Mutagenicity, that is, a capacity to produce genetic damage which increases the incidence of hereditary defects in future generations, should also be watched for as a consequence of herbicide use. In the U.S. Department of Health report a programme for mutagenesis testing was proposed.

Teratogenicity of herbicides became notorious after the discovery of the high activity of the dioxine-compound contained in 2,4,5-T.

The U.S. Department of Health report also proposed that the use of currently registered pesticides to which humans are exposed and which are found to be teratogenic by suitable test procedures in one or more mammalian species should be immediately restricted to prevent risk of human exposure. Of the herbicides in current use, it pointed to the butyl, isopropyl, and iso-octyl esters of 2,4-D and 2,4-5-T. The report also proposed that no new pesticides should be registered until tested for teratogenicity by suitable procedures.

TOXICITY OF THE METABOLITES OR DECOMPOSED PRODUCTS OF HERBICIDES

In general, herbicides have a relatively low acute toxicity, but this does not always mean that the metabolites or decomposed products from the herbicides have a low toxicity. As shown in Fig. 1, herbicides will be metabolized by crop plants, weeds, or micro-organisms in the soils, or be decomposed by solar radiation. For instance, propanil, swep or diuron will be hydrolysed to 3,4-dichloroaniline by the action of soil micro-organisms. Then two molecules of the 3,4-dichloroaniline will form tetrachloroazobenzene. Some azobenzene compounds are recognized as being carcinogenic, for instance, butter yellow (*p*-dimethylaminoazobenzene). Fortunately, the azobenzene compounds mentioned were not found to provide problems of carcinogenicity but there are many nitrogen-containing compounds from aniline compounds in the soil (Chisaka and Kearney, 1970), and their carcinogenicity or other toxic effects should be checked.

TOXICITIES OF THE IMPURITIES IN HERBICIDES

The teratogenicity of the 2,3,6,7-tetrachlorodibenzo-*p*-dioxine contained in 2,4,5-T showed the importance of inspecting the toxicities of impurities in pesticides. Usually pesticides need to be very cheap, and therefore cannot be purified to the same extent as medicines, so are likely to contain some impurities. Toxicity tests should therefore be conducted not only on the purified active ingredient but also on the technical sample or the final preparation. If the purified product has a far lower toxicity than the technical one, toxicities of the impurities should be surveyed. In such a case improvement of manufacturing procedure will lower toxicity.

LEGAL REGULATION OF THE SAFE USE OF HERBICIDES IN JAPAN

Legal regulation of the safe use of pesticides is usually applied at two points — at registration and in relation to its use in practice or to residue problems in crops.

When a new herbicide is submitted for registration, or renewal of registration (in Japan the first registration is effective for only three years), the government requires the applicant to furnish documented evidence to support the claims made for the product. In addition to the efficacy data, the following details are also required: Toxicity tests, which include acute mammalian and fish studies, sub-acute studies, and from January 1973 chronic tests using mammalian species, which means two or three years' long-term feeding experiments, other toxicity studies, such as on carcinogenicity, teratogenicity, and metabolism, results of residue analyses of the herbicide itself and of assumed important metabolites in crop plants and soils.

The permissible residue level in food is determined by law and is based upon the acceptable daily intake recommended by FAO and WHO or other authorized organizations and upon the nature of the food which contains the chemicals. Market-basket samples for survey are collected from grocery stores and the residues determined by analysis. If the residue exceeds the permissible limit, the food must be abandoned and both the producer and the seller may be punished. Because farmers have no instruments to determine the amount of residue chemicals, they are provided with directions for the safe use of pesticides. These show application methods, permissible formulations, limitation of the frequency of applications, prohibited period of application before harvesting, and so on.

PRACTICAL MEASURES AND PRECAUTIONS

As indicated above there are many problems in the practical use of herbicides, but their positive advantages to agriculture are also great, so that almost all modern agriculture depends upon using them. Because of this, the following practical measures to solve the safety problems that arise are proposed (Matsunaka, 1971b).

(1) *Obey the legal pesticide requirements*

Herbicides should be used in accordance with the instructions on the product labels and of course in accordance with the pesticide regulation laws. As they form part of a total system, the first step in making safe use of herbicides is to obey these regulations and instructions.

(2) *Apply herbicides in reasonable amount and only when they are required*

For economic reasons, the use of herbicides will usually be limited to the smallest amount. But if the extent of weed damage to crop plants is not known, an overdose may be used, or be used unnecessarily. It is therefore essential to diagnose the amount of weed damage, and to clarify whether herbicide is needed or not. Recommended practice based upon simple observation of weed emergence by farmers should be published to assist them.

(3) *Apply herbicides rotationally*

There is virtually no information on the problems which may arise after long-term successional use of a herbicide, for instance ten years. Now three or four herbicides are available for one weeding purpose. It would, for long-term safety, be better that the successional use of single herbicide be replaced by three or four herbicides used in rotation, that is, by the use of a particular herbicide only once every three or four years. To control particular weeds that are tolerant to a herbicide the rotational use of three or four herbicides would be preferable.

(4) *Have an integrated weed control system*

The combination of cultural, mechanical, and biological measures for weed control with the chemical one should be recommended. Techniques for each method should be developed. In particular, studies on biological control of weeds in crops should be pursued more vigorously. The effects of combined methods should also be studied.

(5) *Inspect all toxicities of practical herbicides*

As described above, not only the acute but also the chronic toxicity of herbicides should be clarified. Further, the toxicities of metabolites or the products of photolysis, and of impurities in the products should be determined. Interactions of herbicides with one another or of herbicides with pesticides will be the next problem. With those herbicides which are used very extensively, these determinations should be done earlier and more minutely.

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VOCATIONAL TRAINING IN THE USE OF HERBICIDES IN NEW ZEALAND

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Summary

A brief indication of the range of interest in a correspondence training course in agricultural pesticides is given. Factors leading to the development and maintenance of a successful course are considered. Included is a suggested test for course content. The important principles needed to attract people to this type of training are outlined.

In August 1966, the N.Z. Technical Correspondence Institute made available a correspondence study course in agricultural pesticides. The course was produced at the request of the Agricultural Chemicals Board and was designed for people applying pesticides and particularly those in the contracting industry. However, the course has proved of interest to a number of occupational groups, as is indicated by the table below.

Occupations	*No. Completed*
Contractors and employees	145
People involved in selling	187
Noxious weeds inspectors	62
Agricultural aviation industry	57
Technicians — Commercial and government	82
Forestry	25
Farming and farm workers	20
Horticulture — greenkeepers, etc.	20
Other	31

As a result of producing the study material and operating the course for the six years of its existence, ideas and principles have been developed that may interest those contemplating the organizing of training of this kind. This subject is covered under the following headings: Course content; method of tuition; industry response; general comments.

COURSE CONTENT

The subject matter and its presentation are influenced by two main factors:

(1) The objectives of the training course.

(2) The kind of people likely to enrol for the course.

Objectives

In the initial stages of preparing the course there were difficulties in determining content and depth of treatment until the objectives of the course were set down. The acquiring of competence in the safe use of pesticides was considered to be the main objective. The relevant legislation would also need to be included. However, it was thought that safety and legislation would not be popular subjects. Accidents usually happen to "other people". These subjects do not appear "on the surface" to contribute to business success. Because of the desire to attract people to the course, aspects affecting efficiency were included. This reasoning led to an objective that aimed to promote *the safe, legal and efficient use of pesticides on farm land.* With this established, the position was reached to test for course content by asking the question: "What does an operator need to know so that he can operate safely, legally and efficiently?"

Course Participants

Consideration must be given to the kind of people it is expected will take the course. Experience has shown that an average contractor studying this course is 40 years of age and married, has a formal education to about 15 years, about 15 years' experience in this work, and is a working manager, working in the field by day and organizing his business at night. Often he works many hours a day in certain seasons; for one or two months of the year there may be not so much going on. Provision has to be made for busy people, interested in their work, and with considerable field experience and often little formal training.

Under these conditions a study course must not be a drain on time or money; it must be readily accessible, flexible to fit in with business commitments, simply and clearly presented. In addition, it must have a practical approach that indicates an understanding of the problems confronting the industry.

The course is concerned with the use of herbicides and insecticides on farm land. Some people use only herbicides; others may use both. The course is arranged so that either one can be taken as separate subjects. For example, a person could cover the herbicide section in, say, two months of the winter period when there may be little field activity, then in the following winter the insecticide section could be taken. Further subdivision of the herbicide section is now in progress so that specific fields can be studied. This is an advance because it will mean that a person can study information that has a closer relevance to his work. The closer the course content is to a specific occupation, the greater is the interest and the greater the depth of coverage can be.

METHOD OF TUITION

Correspondence as a method of tuition seems to have suited most of the needs of the industry. It is readily accessible to all, can be done privately, is adaptable to fit in with work and other commitments, can be studied at a speed to suit, and is not expensive. However, industry has from time to time requested that short residential courses be held to supplement the correspondence study. These have proved most useful as a means of consolidating the correspondence work.

INDUSTRY RESPONSE

Throughout the production of the study material and during the running of the course, there has been full support from industry organizations and from individuals. Largely the whole project has been a co-operative effort between industry and the N.Z. Technical Correspondence Institute. As a result, the course has been well accepted by industry. It is surprising the number of people who have stated that they have enjoyed the course. People with many years' experience have advised that they have gained considerable information from the course.

GENERAL COMMENTS

In a study course of this kind, topics can be dealt with to a reasonable depth, provided the course is closely allied to the industry. An academic or formal approach is not so acceptable. As it is, the course has proved of interest to both those with little formal education and to university graduates. Experience indicates that separate courses are neither necessary nor desirable for the different educational backgrounds. Separate courses or sections should be provided, however, for the different occupational groups. People should not spend time studying irrelevant information. Separate sections should be prepared for the aviation industry and noxious weed inspectors, to give examples. As mentioned earlier, it is very important that the study material be relevant and closely related to the activities of the occupation concerned.

One aspect that has been revealed is the speed with which the training can be applied in the field. Those taking the course are all involved in the industry. Information gained may therefore be applied immediately. To cite one example, a person studying the course wrote, "I was interested about the toxicity of this chemical. I shall be using it for the first time tomorrow so will take extra care with it."

The Agricultural Chemicals Board is responsible for overseeing the safe use of pesticides and consequently is vitally interested in the training course. The Board checks all study material and advises on course content. This is an essential part of this training scheme. The close co-operation that has developed between the Board and the Technical Correspondence Institute has been of benefit to both, and to the industry.

TEACHING THE BEGINNING WEED SCIENCE STUDENT

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Weed science has profited immensely from breakthroughs in research; this is a dynamic and exciting field because of the new chemicals and methods becoming available. But for weed science to remain strong, these new methods must be used and understood by well-trained persons. Also, a greater segment of society must be well informed on the damage done by weeds and the benefits from good weed control. For these reasons, teaching weed science is of critical importance.

In this paper it is proposed to discuss three concepts that might be classified under general philosophy of teaching, using examples from weed science; then delve into some other specific techniques that have been used in the course at Oregon.

The first concept is *"You are not a teacher unless someone learns something"*. A lecture has been defined as "a process in which information is transferred from the notes of the instructor to the notes of the students without passing through the minds of either". Too often, teaching is organized to "cover the subject" rather than to change a student's thought processes. A good teacher constantly asks himself, "what do I want these students to know?", and "how do I want them to think about the subject?". *Then* comes the question of how the teaching process should be organized to best accomplish those objectives. In general, a lecture should not be organized in the same format as an encyclopaedia. An encyclopaedia is designed as a storehouse of knowledge organized in a way that persons can find the information they seek. A lecture, on the other hand, is not designed merely to transmit knowledge into the air with the often futile hope that some part of it may be picked up and used by someone. Rather, a lecture needs to be presented in a format and in a manner so that interest is aroused, information is conveyed, but, most importantly, that thought processes are stirred and curiosity is stimulated.

The second concept is *"All students are not the same"*. When students arrive at the first class period they differ in experience, background knowledge, rate at which they can learn, topics they are interested in, and in general motivation. Yet, there is a tendency to treat them all alike. They all get the same lecture, the same exams at the same time, the course starts and ends on the same date for everyone. The ones who fail must repeat everything, including those parts they have already mastered. How many of those failures could have been avoided if the student had been given a bit more time? Why is it necessary to say that "you must master this subject matter in 110 days or you fail"?

I believe that the need for greater flexibility and individual attention is one of the most important problems in teaching. Some significant advances are being made, but more thought must be given to this area. Some real difficulties are encountered when an attempt is made to solve this problem. But time and money are being wasted with present procedures and I believe that alternative methods must be sought.

What can be done? Here are a few ideas; others can no doubt be added. Individual term projects can be designed to let a student decide which area of weed science he wants to dig into. Help him with references and sources of information, and let him go! We have had considerable success with this. Some students still laboriously crank out another library paper because it is required by the professor. But others have taken the opportunity to really learn something of special interest to them. We have had small research projects on everything from influence of wetting agents to the effect of formulation on nozzle output. We have had grower surveys on a variety of subjects, design of equipment plans, classroom demonstrations, preparation of cropping plans for actual farms, etc.

Another idea to inject some individuality is the preparation of study units. We have prepared a slide series on weed identification. Those students who have had little previous experience or are less capable of learning new weeds can spend extra time at their own convenience in working on weed identification using these slide sets. Other topics can be handled in much the same way. If we were really ambitious, we could prepare a slide-tape set on each topic covered in class. These would be helpful for review, for clarification of confusing information from the lecture, or simply for more leisurely study of the materials by the slower students. Of course, slides are not necessary; one could use flip charts, mimeographed sheets, photographs, etc.

We have included discussion sections in the course. The class is divided into sections so that groups are small. This gives more opportunity to discuss informally some of the topics the students *want* to talk about but it also gives more review time for slower students. It is in the discussion period that we may talk about control measures for specific problems. We bring in supplementary materials such as films and slides. We try hard not to examine the students on any information covered solely in the discussion period so that they will not feel they need to take extensive notes.

Perhaps another idea would be to avoid limiting the time in which a student is required to obtain a minimum level of skill and knowledge as has been done in the past. If a person cannot reach that minimum level, give him an incomplete until he does. Certainly there are many difficulties involved in this approach. It interferes with the student's schedule, the teacher's schedule, procedures in the registrar's office, etc. But if the objectives are reviewed, perhaps this would be a better approach for everyone. It would be better for the student because he does not fail and because he is allowed to reach at least a minimum level. It is better for the professor because he did not *fail to teach* and he did not waste time on a person who leaves his class with insufficient information to use it properly. It is better for the school and for society in general because the objective is to *teach,* not to classify people into "passers and failers".

The third concept is *"Subject matter should be related to real life"*. In the United States, the word "relevant" has been used so often that it has almost lost its power. But course content must be applicable to the students' needs. I am reminded of the story of two small boys who were on the school playground when a jet plane flew over. One boy said "Was that a TX 29?". The other boy said "No, that was an LX 552. You can tell by the size of the engines and the shape of the wings". They then continued on into a discussion of fuel efficiency, relative speeds of various planes, lift, thrust, etc. Then the bell rang for continuation of classes. One boy turned to the other and said, "Well, we just as well go finish stringing those damn beads." Unquestionably, course content must be relevant to the needs of the student. However, I believe that the most common failing in weed science courses is teaching for today only and not for tomorrow. The most *practical* subject matter involves emphasis on *principles,* rather than memorization of specific recommendations; rates, timings, volumes of carrier, etc. We hope that concepts our students learn in weed science will be as helpful 10 to 20 years from now as they are today, even if all the present herbicides are replaced by new ones. Of course, to teach important principles properly we must illustrate them with common present-day examples, but the long-term objective remains the understanding of principles. For example, we point out in lectures and demonstrate in the lab that EPTC and other volatile materials are lost more readily from wet soil surfaces than from dry ones. This can be important information which may be useful immediately. There is nothing wrong with that. But the concept is incomplete unless the student understands why this happens. So we discuss principles of adsorption and competition of water for adsorption sites. This concept will live on even if EPTC disappears from the market. I consider this approach to be highly relevant.

A few other techniques used in the weed control course at Oregon State University might now be mentioned. I do not want to give the impression that we think we have a monopoly on good teaching techniques; we do not. However, here are a couple of other examples besides the ones already mentioned which may be helpful.

We try to take several field trips during the term, usually during the laboratory period. Near the end of the course, we charter a bus on a Saturday and visit several good farmers in the area. We ask them to talk to us about their own weed control problems and practices. Included in their discussion, of course, is emphasis on the economics of weeds and their control. This unquestionably adds to the value of the course. It tends to make the students realize really how much they have learned during the term and how much more information is left for them to obtain. It also helps to tie some of the individual aspects studied into more of a package.

I have some rather definite feelings about examinations. We do not give true-false questions because I find it quite difficult to come up with absolutely true statements in this day and age. There are undoubtedly good true-false questions in any subject, but success of a student taking a true-false test may be attributed to good luck and failure may be attributed to an excessively suspicious evaluation of the questions. We do not give essay questions either, because we find it too difficult to decide whether the student really knows the answer or whether he is merely good at regurgitating several pages of notes. We primarily use short answer questions in which directions are given to "answer the following questions in four sentences or less". We try to make the questions realistic. For example, we may have the student assume that he is a county extension agent and is answering a question on the telephone. A question represents a true-life situation and requires weed control knowledge to answer. In other words, we are trying to get the students' minds out of the notebook and into real life. These questions have generally been successful in my opinion and have several advantages: (a) The teacher can read the answers at a glance and know immediately whether the student understands the situation, (b) the questions require thought rather than just memorization, (c) the questions show the student how facts learned in class can actually be used in practical situations, and (d) opportunity is provided for alternative answers that the teacher may not have thought of.

Other techniques could be discussed and I hope to have the opportunity to do so with many of you, either personally or by correspondence.

The purpose of this paper was not to give instruction in how to teach weed science; I am not qualified to do so. But I hope that it served to shake loose some ideas, start some thinking about weed science teaching that will eventually pay off in high quality, well-trained graduates.

NEW TECHNIQUES IN WEED CONTROL

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To introduce the subject, "New Techniques in Weed Control", it is almost necessary to define the geographical area. There are places in the world where weed control itself would be considered a "new technique" in crop production. There are other places where the phrase, "weed control", brings to mind the use of sophisticated chemicals that are able to bring about the death of undesirable plants while having little or no effect on the crop. Now the stage has been reached where as many as four different chemicals are used just to control weeds during the life of one crop. For this discussion, the subjects will be limited to herbicides or herbicide applications.

Of course not all advancements in weed control have been with herbicides. Much has been accomplished with improved machinery, better crop varieties, and clean seed. Biological control has proven to be useful, and continued research offers the promise of more progress in that area. However, by far the greatest forward strides in the control of weeds during the past 25 years has been through the use of herbicides, and there are good reasons for this trend. Machinery or removal of weeds by hand is often harmful to the crop. This fact could not be demonstrated until the use of herbicides enabled weeds to be controlled without disturbing the crop. Research has shown that weeds in cropland exert much of their harmful effect during the early life of the crop. Weeds are often difficult to remove soon enough by any method other than herbicides. Labour is becoming increasingly expensive and, even in areas where it is reported to be inexpensive and readily available, growers are having difficulty in finding sufficient hand labour during the critical weeding periods.

With these thoughts in mind, some of the most promising new techniques in weed control might be discussed.

FOAM

The first attempt to introduce foam as a herbicide application tool was met with a shrug of the shoulders and a "wait-and-see" attitude. The idea has not gone away; in fact, many growers and custom applicators have already accepted the concept of using foam as a carrier for pesticides.

The simplicity of foam application equipment is one of the reasons for its quick acceptance. Five products are currently being marketed in the U.S. for the addition of foam to any pesticide. Their mechanical function is to produce large numbers of small bubbles by mixing the spraying formulation with air and a foaming agent.

One system is a compact, low-cost pump that generates and distributes the foam. Four others are nozzle systems that can be used in place of existing nozzles on conventional ground and aerial equipment. All systems require the addition of a foaming agent to the spray mixture.

The problem of spray drift led to the development of the foam systems and foam appears to be a useful tool in high-drift situations. Foam does not eliminate drift but it does extend application time where drift conditions are marginal. Other benefits have been observed, such as better coverage because the applicator can see where he has sprayed, cleaner equipment since foam is a cleaning agent, and fewer reloading trips because less water is used with foam applications. Better leaf coverage and penetration due to the foaming agent added to the spray mixture has been observed.

The foam being used for herbicide applications is a wet, short-lived material which quickly releases the chemical to the plant or soil surface. Thick, longer-lasting foams are being tested for such uses as frost protection, and for protecting plants during flame weeding.

The list of uses for foam will certainly grow and apparently it will be used for some time as a herbicide application tool.

ACTIVATED CARBON

The adsorptive properties of charcoal have long been known and used to purify water and air. More recently, researchers have discovered that the adsorptive properties of charcoal can be greatly increased by treating at high temperatures with an oxidizing agent. Four of the most common oxidizing agents are air, steam, sulphuric acid, and phosphoric acid. The end product is called activated carbon. The adsorption efficiency of activated carbon is also influenced by particle size, with the smaller particles being most efficient.

The first reported use of activated carbon in conjunction with herbicides was reported in 1947 and since then considerable research has been conducted on various aspects. Until recently, most effort has been directed toward finding a method to use activated carbon to protect plants from soil herbicide residues already present. One technique has been to incorporate activated carbon into the soil at from 225 to 900 kg/ha on a broadcast basis. This approach has been effective but has resulted in loss of weed control from subsequent herbicide applications. With certain crops this can be overcome by using a layer of carbon that completely surrounds the roots. Another technique has been to dip the roots in carbon. Both methods have been effective but require considerable hand labour so they are restricted to high-value crops, such as ornamentals.

A logical follow-up was to use the adsorptive properties of carbon to protect crop plants from a pre-emergence herbicide. A technique has been developed in which the carbon is mixed with water and sprayed in a 2.5 cm band directly over the seeded row. Blanket herbicide applications are then made. The carbon intercepts and adsorbs the herbicide at the soil surface and protects crops planted beneath the band. This method has been most effective where a herbicide is not quite safe enough to be used on a particular crop. As would be expected, some weeds beneath the charcoal band are not killed. The amount of control here depends on the herbicide used, rate of application, and carbon rate. This practice is registered and commercially used in establishing grass seed crops in the State of Oregon. About 170 to 340 kg of carbon per treated hectare are used depending on the type and amount of herbicide. On a broadcast basis, the cost of such treatment would be very high but where only a narrow band is treated the cost becomes more reasonable.

SUBSURFACE LAYERING OF HERBICIDES

As more is learnt about the growth habits of certain weeds and the mode of action of herbicides, herbicides can be used more efficiently. Herbicides such as EPTC and trifluralin must be placed under the soil surface to prevent loss in vapour form. The normal method is to incorporate these herbicides into the top 3 to 8 cm of soil. This has proven to be effective in controlling many annual weeds which germinate within this zone, but has been less effective in controlling perennial weeds which come from greater depths.

The same amount of herbicide applied in a subsurface layer can often effectively control certain perennial weeds. The layer, which is more concentrated than the incorporated treatment, acts as a barrier to the shoot growth of newly-developing shoots. California workers have demonstrated excellent control of field bindweed (*Convolvulus arvensis*) with triffuralin applied in a subsurface layer. They have had best results using a spray blade with nozzles mounted under the blade in such a way that a uniform layer of herbicide is deposited as the blade is pulled through the soil. The most immediate use of the technique will probably be for perennial weed control in orchards and vineyards. However, later results from California indicate that layering of trifluralin in field bindweed-infested areas in annual crops may offer even greater potential use. The layering operation offers adjustment in depth of placement which may allow more crops to develop sufficient root systems for commercially-acceptable yields.

Of course there will be a difference in response among weed species but these can usually be overcome with higher rates and repeat applications. It can also be expected that annual weeds will be a continuing problem that will need to be solved in the usual manner.

HERBICIDE ANTIDOTES

Very few herbicides have as wide a safety margin on crops as is desirable. The need is often felt for a method of increasing the safety of a certain herbicide on a given crop.

EPTC has proven to be effective in the control of certain weeds in field corn and sweet corn. Some of these weeds, such as nutsedge (*Cyperus* spp.), shattercane (*Sorghum bicolor*), and quackgrass (*Agropyron repens*), are not usually controlled satisfactorily with other commercial corn herbicides. However, corn is sometimes injured by EPTC, reducing its usefulness in certain varieties and in certain areas.

Two so-called "antidotes" are being developed which act to reduce or prevent EPTC injury to corn. One chemical (1,8-naphthalic anhydride) is now being marketed by Gulf Chemical Co. under the trade name "Protect". This is a seed treatment which is applied at the rate of 110 g per 25 kg of corn seed. It can be mixed with the seed any time before planting into the EPTC-treated soil.

Another chemical will soon be marketed by Stauffer Chemical Co. It has been tested under the code number, R-25788, (*N,N*-diallyl-2,2-dichloroacetamide). This compound is effective as a seed treatment or when mixed with the EPTC. Since Stauffer

Chemical Co. also markets EPTC, they will offer a special mix of EPTC and R-25788. The effectiveness of this material has been dependent upon the rates of EPTC and R-25788, and the corn variety.

From this short discussion it is clear that the science of weed control is not stagnant. To an unsolved problem one need only apply a little imagination, a lot of work, and perhaps a little luck. The solutions are often surprising and usually very interesting.

METHODS FOR EVALUATION AND SELECTION OF HERBICIDES

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Summary

As part of the programme to evaluate herbicides for use in lowland rice fields, the Research Institute of the Japan Association for the Advancement of Phyto-regulators is responsible for two important tests aimed at clarifying the basic properties of herbicides. The first, "Mode of Action Properties Test", is concerned with establishing weed spectrum, toxicity to rice, persistence in the soil and other properties. The "First Applicability Test" aims at evaluating the adaptable features to wide regional conditions, and at giving a basis for further practical investigations. These precise examinations assist in providing efficient evaluation and selection of herbicides.

INTRODUCTION

The majority of the experiments for which the Japan Association for the Advancement of Phyto-regulators (JAPR) is responsible are concerned with the use of herbicides in lowland rice fields. In this connection, the Research Institute of JAPR is in charge of the "Mode of Action Properties Test" and the "First Applicability Test", which form an important part of the testing programme. The results of these two tests are correlated with trials testing "Factors influencing Herbicidal Effect" in which the national research institutes contribute, and play an important role in determining the basic properties of herbicides, preparatory to submitting them to the "Second Applicability Tests", which are conducted by prefectural experimental stations. By clarifying the basic properties, these tests therefore aid considerably the efficient evaluation and selection of herbicides. An outline of the two tests is given below.

MODE OF ACTION PROPERTIES TEST

With newly developed herbicides, the following four experiments are conducted.

TABLE 1: OUTLINE OF FIRST MODE OF ACTION PROPERTIES TEST (1972)

Rice Culture	*Water Management*	*Herbicide Treatment and Barnyard Grass Stage*
Early season — planting 28 Apr.:	Planting — rooting water depth:	Soil Surface:
Young seedling — 11.4 cm	Young seedling — 5 cm	26 Apr. (—2)* — pre-emergence
2.2 leaf	Ordinary seedling — 4 cm	1 May (+3) — incipient
Ordinary seedling — 17.0 cm	At time of leaching — 4 cm	Foliage and soil surface:
4.4 leaf	After chemical treatment, leaching at 3 cm/day for 2 days	8 May (+10) — 1.5 leaf
		15 May (+17) — 2.8 leaf
	After leaching — 3 to 4 cm water depth	19 May (+21) — 3.2 leaf
Normal season — planting 6 Jul.:	as above	Soil Surface:
Young seedling — 12.3 cm		4 Jul. (—2) — pre-emergence
2.3 leaf		9 Jul. (+3) — incipient
Ordinary seedling — 48.5 cm		10 Jul. (+4) — incipient
6.5 leaf		Foliage and soil surface:
		14 Jul. (+8) — 1.5 leaf
		18 Jul. (+12) — 2.5 leaf
		22 Jul. (+16) — 3.1 leaf

*(—)pre-, (+)post-days from planting date

(1) Herbicidal Activity and Toxicity to Rice

This is conducted at two periods of rice culture, early season (low air temperature — 15° C average) and normal season (20° C average) and two growth stages of rice seedlings, young (2- to 3-leaf) and ordinary (4- to 7-leaf) are used in each period. The herbicides being examined are applied at two rates to barnyard grass (*Echinochloa* spp.) at 4 to 5 growth stages from pre-emergence to the 3-leaf stage, and to other weeds at 3 growth stages. Toxicity to rice is observed. The experiment is carried out in duplicate.

For this examination, concrete pots 50 × 50 × 30 cm in size, fitted with bottom outlets are recommended. About 12 cm depth of paddy-field soil (alluvium clayish loam, pH 6.2) is added to a sand and gravel bed, and this is then covered with a layer of the same fertilized soil in which has been incorporated seeds of weeds such as barnyard grass, monocholia and slender spike-rush.

Prior to planting of rice, the soil is flooded with water to a depth of 3 to 4 cm. After treatment with chemicals, at the various weed growth stages, water leaching at the rate of 3 cm/day is conducted for two days. The leaching water is drawn from the pots by a rubber tube connected to the bottom outlet which is fitted with a screw regulator to provide an accurate measure of water flow.

In 1972, 35 chemicals were submitted to this test, an outline of which is given in Table 1.

(2) Duration of Herbicidal Effect in the Soil

Two rates of herbicide are applied to Wagner pots (0.05 m^2) filled with puddled paddy-field soil and a 3 cm depth of irrigation water. One day after treatment, 3 cm/day leaching is carried out for 2 days, the water depth then being left at 0.5 to 0.8 cm.

A bottomless vinyl tube, 7 cm in diameter, is inserted into the soil and the seeds of rice, barnyard grass and a vegetable variety are sown on the soil in the tube, the resulting germination of the test seeds giving a measure of the residual effect of the chemicals.

The test is practised 7 times at 7-day intervals.

(3) Movement of Chemical in the Soil

A check-box for tracing translocation is filled with a 3 cm sand layer covered with 10 cm of paddy-field soil. The box is soaked for 24 hours in a basin of water so that absorption is from the bottom and after the water level is above the soil surface, the upper 5 cm of soil is puddled. Chemical treatment is applied with a water depth of 3 cm. To avoid the possibility of decomposition of the chemical by ultraviolet light, it is advisable to cover the top of the box.

About 16 to 20 hours after application of the chemical, a water leaching procedure is conducted until the soil is drained. The box is then removed from the basin and the soil separated into 1 cm layers with a cutting plate. On each soil layer, test plants (rice, barnyard grass and Japanese turnip) are sown, and the degree of chemical translocation is determined from the subsequent plant growth on each layer.

(4) Determination of Absorbing Part of Rice Plant

Wagner pots (0.02 m^2) are filled with fertilized paddy-field soil and flooded with water.

To observe stem absorption, seedlings are planted to 2 cm depth in the soil.

To observe root absorption, seedlings are fixed with cotton fibre through holes in a vinyl plate so that only their roots are in the water.

About 5 days after planting, that is, at the 4- to 5-leaf stage, two rates of chemical are applied, and the site of absorption determined from the symptoms displayed by the seedlings.

FIRST APPLICABILITY TEST

Once the properties of a newly developed chemical are roughly clarified by the preliminary tests and it has passed the inspection committee, it is submitted to the First Applicability Test. This examination aims at determining broad regional adaptability and deciding whether the chemical should be allocated to the Second Adaptability Test conducted by the prefectural experimental stations. It also aims to obtain basic results for adaptability evaluation. It consists of two tests of herbicidal effect and toxicity to rice at two rice-growing stages — *i.e.*, young seedlings and ordinary seedlings.

To establish herbicidal effectiveness, a pure stand of a prevalent weed is treated with two rates of the chemical at 2 to 3 growth stages of the weed from incipient emergence to the 3-leaf stage.

Toxicity to the rice plant is determined from two treatments, one at about planting time, and the other 10 to 14 days after planting, each at two rates of herbicide.

In 1972, this examination was initiated at 7 regions all over the country as a co-operative venture by the Research Institute of JAPR and selected prefectural experimental stations at Hokkaido, Iwate, Niigata, Tochigi, Shizuoka, Hiroshima and Saga. Ten chemicals for young seedlings were submitted and 33 for ordinary seedlings.

HERBICIDAL CONTROL OF WATER HYACINTH (*EICHHORNIA CRASSIPES*) 1. EFFECT OF 2,4-D AND AMITROLE ALONE AND IN COMBINATION

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Summary

Vegetative propagation studies indicated that, within 42 days, the number of plants increased by 7.15 times and fresh weight by 3.34 times that recorded at 15 days after establishment. Mortality was higher with a lower dry matter production from 2,4-D/amitrole mixtures than from either chemical applied alone. 2,4-D at 2 kg and amitrole at 6 kg/ha gave better results than lower doses. Optical density units, reflecting the chlorophyll content, were reduced by both herbicides, applied alone or in combination. However, the reduction was slower with amitrole than with 2,4-D; reduction was greatest with mixed applications of the herbicides. None of the plants regenerated after any of the treatments.

Water hyacinth (*Eichhornia crassipes*) is a free-floating weed reported to reduce the flow of water in canals by 40% resulting in insufficient delivery of irrigation to farms or inadequate drainage from farms, breaks in canal banks, flooding, increased seepage losses and evaporation (Stephens *et al.*, 1957). Water losses through evapotranspiration from this weed in Florida were estimated to be 3.7 times that from open water (Timer and Weldon, 1967), whereas in dry areas of India it is 7.8 times (Holm *et al.*, 1969). In India, the area infested with this weed has been roughly estimated to be 200,000 hectares (Anon., 1966), the major area being located in West Bengal where it interferes with paddy cultivation also. In Haryana State, it is found in abundance in low-lying areas, natural ponds, lakes, canals and irrigation ditches. Present studies were undertaken to evaluate the effective herbicide to control this weed.

MATERIALS AND METHODS

A preliminary trial was conducted at the Aquatic Research Farm of Haryana Agricultural University, Hissar, during September, 1971 to find out the effect of 2,4-D and amitrole alone and in combination on the water hyacinth plants. These plants were established in cemented trenches 6 m long, 1.5 m wide on the surface and 1.0 m at the bottom, and 1.0 m deep. A 0.25 m layer of farm soil was enriched with farmyard manure at the rate of 50 kg per trench. In each trench, 428 plants were established before the start of the experiment. The amine salt of 2,4-D and amitrole were applied to the surface of the plants at the initiation of the flowering stage in 600 l/ha of water in the following nine treatments (all expressed as kg/ha a.i.):

2,4-D	*amitrole*	*2,4-D + amitrole*
1	2	2 + 2
2	4	2 + 4
3	6	2 + 6

One plot (untreated) was maintained as a control.

Prior to conducting this trial, propagation of water hyacinth plants by vegetative means was studied in the trenches. Sixty plants were established during July 1971 in each trench, and their numbers were noted at weekly intervals and fresh weight 15 and 45 days after establishment. Other observations recorded in the main trial were mortality, dry weight of plants, and chlorophyll content of the leaves and floats measured in optical density units by a Spectronic 20 calorimeter with infra-red filter at 665 mμ. Regeneration of plants was also noted at weekly intervals after treated plants had been placed in fresh water.

RESULTS AND DISCUSSION

Vegetative Propagation Studies

Within 42 days of establishment, the average number of plants in 12 trenches had increased vegetatively by 7.15 times (Table 1). Rate of increase was slow in the early stages (15.8 to 23.8 plants/week) but later the rate was as high as 153.2 plants/week. Fresh weight of the whole plant also increased from 12.4 kg per trench recorded 15 days after establishment to 41.4 kg per trench after 45 days, an increase of 3.34 times. Even under controlled conditions, the plants were capable of multiplying by seven to nine times; under natural conditions the propagation rate may be much greater. Matthews (1967) reported that, in two months, 15 seedlings multiplied to 140 plants by vegetative propagation and covered approximately 4 m^2.

TABLE 1: PROPAGATION OF WATER HYACINTH PLANTS BY VEGETATIVE MEANS
($9\ m^2$ area)

Trench No.	*Initial No. Plants*	*Mortality % — Days after Estabishment* 7	14	21	28	35	42	*Fresh wt (kg)* 15	45
1	60	74	90	149	238	386	582	14.0	65.0
2	60	69	76	89	151	341	439	10.0	45.0
3	60	72	77	80	109	225	391	8.0	33.5
4	60	70	79	100	180	275	548	10.5	51.5
5	60	71	82	94	123	228	327	11.0	32.5
6	60	96	120	150	245	377	508	16.5	32.5
7	60	93	107	138	169	210	389	12.5	43.0
8	60	74	100	142	217	367	518	12.0	40.0
9	60	78	82	97	110	228	353	11.0	51.0
10	60	83	110	121	152	187	248	16.0	32.0
11	60	88	106	143	173	260	401	16.5	28.0
12	60	83	112	124	156	224	443	11.0	42.5
Mean	60	79.3	95.1	118.9	168.6	275.7	428.9	12.4	41.4
Rate of multiplication/week		19.3	15.8	23.8	49.7	107.1	153.2	—	—

Mortality of Weeds

Periodic observations clearly showed that the 2,4-D/amitrole mixtures at all rates were superior to either chemical alone in killing the weeds (Table 2). 2,4-D was more effective than amitrole in the early stages, but subsequent mortality was almost the same. Of the various rates used, 2,4-D at 2 kg/ha and amitrole at 6 kg/ha gave promising results. 2,4-D at 2 kg/ha mixed with different rates of amitrole gave similar results. Other workers have also reported results with 2,4-D (Appala Naidu *et al.*, 1965; Lawrence, 1962) and amitrole (Kapoor and Joshi, 1965; Green, 1969).

Symptoms observed during the course of study were curling of leaves 2 days after application of 2,4-D, yellowing after 4 to 5 days, browning of leaves after 7 to 10 days and finally death of the plants. With amitrole chlorosis of the leaves started 5 to 7 days after treatment, mortality occurring within 30 to 45 days. With all the treatments the leaves were affected earlier than the floats. It is apparent that translocation of amitrole was slower than 2,4-D and thus the symptoms of mortality appeared later (Conner *et al.*, 1964).

TABLE 2: MORTALITY AND DRY WEIGHT OF WEEDS AS AFFECTED BY DIFFERENT TREATMENTS
(Mortality — 0 = no control, 10 = complete control)

Treatment (kg/ha)	Mortality — Days after Spraying						Dry wt (%)		
	7	14	21	28	35	42	10	20	30
2,4-D 1	5.0	6.0	7.0	8.0	9.5	10.0	8.59	7.21	6.64
2,4-D 2	6.0	7.0	8.5	9.0	10.0	10.0	7.99	6.23	5.66
2,4-D 3	6.5	7.5	8.5	9.5	10.0	10.0	6.23	5.76	4.99
amitrole 2	1.5	3.5	4.5	6.0	7.5	8.5	10.31	9.55	7.94
amitrole 4	2.5	4.0	5.0	7.0	8.5	10.0	10.18	7.21	6.57
amitrole 6	3.0	6.0	7.0	8.0	9.5	10.0	7.70	6.73	5.87
2,4-D 2/amitrole 2	6.5	8.0	9.0	9.5	10.0	10.0	7.09	6.82	6.19
2,4-D 2/amitrole 4	7.0	8.0	9.0	10.0	10.0	10.0	6.88	6.10	5.01
2,4-D 2/amitrole 6	7.5	8.5	9.0	9.5	10.0	10.0	6.60	5.33	4.66
Control	0.0	0.0	0.0	0.0	0.0	0.0	10.75	11.79	14.11

Dry Weight of Weeds

Mixtures of 2,4-D and amitrole helped to reduce the percentage dry weight to a greater extent than either chemical alone (Table 2). 2,4-D was more effective than amitrole. Lower rates of herbicides resulted in higher dry weights than higher doses. It was not possible to record the weight after 30 days as the plants were by then almost completely killed and had settled to the bottom. In the control plots, the dry weight increased from 10.75 to 14.11% 30 days after the start of the experiment.

Effect on Optical Density Measurement

2,4-D markedly reduced optical density units (which indicate the chlorophyll content) from 1.400-1.600 to 0.078-0.120 in leaves, and from 0.280-0.320 to 0.040-0.070 in floats by 24 days after treatment (Tables 3 and 4). Higher doses of 2,4-D were more efficient than lower doses. It is claimed that 2,4-D in lethal doses reduces the photosynthetic efficiency of chloroplasts thus reducing the chlorophyll content and also the dry matter production of the plant. Lower doses of amitrole did not reduce the optical density units in leaves and floats as much as compared with higher doses. Even a medium rate of 2,4-D proved better than a higher rate of amitrole. Amitrole appears to hinder or inhibit the formation of chlorophyll. This inhibition may result from failure of the plastids to develop. When this happens, the plant may lack chloroplasts and therefore lack chlorophyll

TABLE 3: EFFECT OF DIFFERENT TREATMENTS ON THE OPTICAL DENSITY UNITS (O.D.U.) OF SURFACE LEAVES OF WATER HYACINTH

Treatment (kg/ha)	*Initial O.D.U.*	*O.D.U. — Days after Spraying* 4	8	12	17	24
2,4-D 1	1.400	0.850	0.680	0.520	0.160	0.120
2,4-D 2	1.600	0.900	0.565	0.375	0.100	0.089
2,4-D 3	1.560	0.680	0.385	0.300	0.090	0.078
amitrole 2	1.500	1.200	0.700	0.645	0.500	0.280
amitrole 4	1.500	0.850	0.650	0.525	0.350	0.110
amitrole 6	1.580	0.760	0.460	0.295	0.220	0.090
2,4-D 2/amitrole 2	1.400	0.830	0.500	0.320	0.110	0.095
2,4-D 2/amitrole 4	1.500	0.800	0.330	0.200	0.085	0.065
2,4-D 2/amitrole 6	1.400	0.650	0.270	0.150	0.070	0.050
Control	1.500	1.500	1.410	1.330	1.200	1.160

TABLE 4: EFFECT OF DIFFERENT TREATMENTS ON THE OPTICAL DENSITY UNITS (O.D.U.) OF FLOATS

Treatment (kg/ha)	*Initial O.D.U.*	*O.D.U. — Days after Spraying* 4	8	12	17	24
2,4-D 1	0.280	0.260	0.170	0.100	0.075	0.070
2,4-D 2	0.320	0.220	0.145	0.130	0.085	0.045
2,4-D 3	0.285	0.190	0.135	0.090	0.060	0.040
amitrole 2	0.410	0.560	0.315	0.185	0.165	0.080
amitrole 4	0.225	0.200	0.155	0.130	0.100	0.060
amitrole 6	0.220	0.145	0.110	0.080	0.070	0.050
2,4-D 2/amitrole 2	0.195	0.150	0.105	0.185	0.065	0.055
2,4-D 2/amitrole 4	0.450	0.250	0.160	0.065	0.055	0.035
2,4-D 2/amitrole 6	0.235	0.205	0.160	0.060	0.040	0.030
Control	0.260	0.380	0.450	0.530	0.420	0.360

(Rogers, 1957; Hilton *et al.*, 1963). Combination of the herbicides gave a greater reduction in optical density units of leaves and floats than 2,4-D or amitrole alone. The higher rates of amitrole with 2 kg 2,4-D, resulted in comparatively fewer optical density units than lower doses.

Regeneration Studies

Herbicide-treated plants were established in fresh water at weekly intervals up to 4 weeks. None of the plants was able to survive even with the contact time of one week. Plants treated with amitrole at 2 kg/ha were still slightly green when transferred to fresh water one week after treatment but were also unable to survive. Sixty days after treatment not a single new plant had regenerated.

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THE USE OF PARAQUAT AND 2,4-D FOR THE CONTROL OF WATER HYACINTH (*EICHHORNIA CRASSIPES*)

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Summary

The main aquatic weed in irrigation canals in the Muda Project area of North Malaya is water hyacinth (*Eichhornia crassipes*). Small amounts of other weeds, *Pistia stratiotes, Jussiaea repens, Altermenthesa sessiles, Ipomoea repens* and *Scirpus grossus* are also present. The presently employed method of manual removal of these weeds is time-consuming and expensive. Studies on the chemical control of water hyacinth established that paraquat, although initially more effective than 2,4-D up to 4.48 kg/ha, gave only short-lived control. 2,4-D at 4.48 kg/ha provided good control, but its effects were slow to develop, 6 weeks being required to achieve maximum kill and 8 weeks for complete sinking of the dead vegetation. A low rate combination of paraquat at 0.28 kg/ha and 2,4-D (sodium salt or amine) at 1.12 kg/ha applied in 450 l/ha gave faster kill and better control of water hyacinth than the high rates of either 2,4-D or paraquat applied alone.

INTRODUCTION

The acreage of double-cropped rice has increased significantly in Malaysia over the last few years through the establishment of irrigation facilities in the Muda and Kemubu areas of northern West Malaysia. However, to maintain an efficient and adequate supply of water to the rice fields, the vast network of water channels must be kept free of aquatic weeds and other impediments. In the Muda area, the main weed problem is water hyacinth (*Eichhornia crassipes*) which can "choke" up the smaller distributary canals within a short time. Other species present are *Pistia stratiotes, Jussiaea repens, Ipomoea repens,* and *Scirpus grossus. Eleocharis dulcis* is common in areas with acidic soils.

2,4-D at rates of 2.5 to 5.0 kg/ha applied in high volumes of 1000 to 2000 l/ha have been shown to give good control of water hyacinth (Young, 1967; Green, 1969; Leiderman and Grassi, 1970) but its effects are slow to develop, taking 4 to 6 weeks to achieve complete kill. Further, sinking of the dead mass of vegetation can take an additional 2 to 3 weeks. The bipyridilium herbicides, diquat and paraquat, are faster acting, but require uneconomic rates of 1 to 2 kg/ha for good results (Blackburn, 1963).

Because of 2,4-D's slow action and the risk of damage to crops (either by drift or from residues in irrigation water) where it is applied at high rates, the chemical has not been considered suitable for practical use in the Muda irrigation project area. Manual removal of floating and submerged weeds continues to be the common practice, in spite of its slowness and high cost. A safe, cheap and effective chemical weed control system could provide an attractive alternative. This paper describes the results from trials in which paraquat, 2,4-D and combination of these two herbicides were evaluated against *E. crassipes*.

MATERIALS AND METHODS

Plots measuring 12 × 6 m were demarcated by tying strings across large ditches or canals heavily infested with water hyacinth. These strings also prevented lateral movement of weeds from one plot to the next. The chemicals included 2,4-D ("Fernoxone") and amine ("DMA" 6) salts and paraquat ("Gramoxone"). Spraying was done using a hand-pumped knapsack sprayer fitted with a cone jet on a long lance. Except in trials comparing different volumes, the rate used was 450 l/ha. Visual assessments based on an arbitrary scale* were taken at weekly intervals following treatment. The rate of sinking of the dead/dying weed mass was similarly assessed at regular intervals. Expected values for the combined effect of a mixture of 2,4-D and paraquat were calculated using the following formula suggested by Gowing (1960):

$$E = X + \frac{Y\,(100-X)}{100}$$

where E = expected kill

X = actual kill with more toxic chemical alone.

Y = actual kill with less toxic chemical.

A higher actual percentage control than expected, assuming an additive effect, suggests synergism, and a lower than expected value suggests antagonism between the two chemicals being evaluated in mixture.

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*0 = no scorch/kill. 100 = complete scorch/kill.

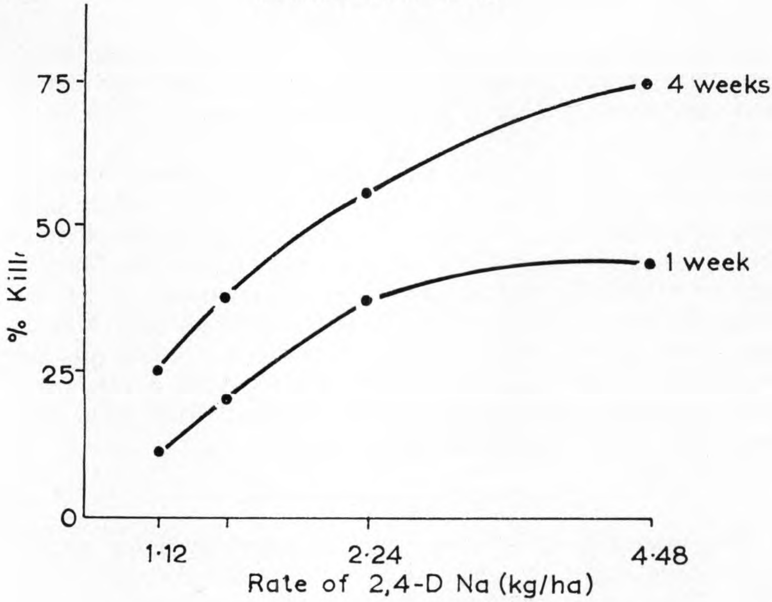

Fig. 1: Effect of rate of 2,4-D on water hyacinth.

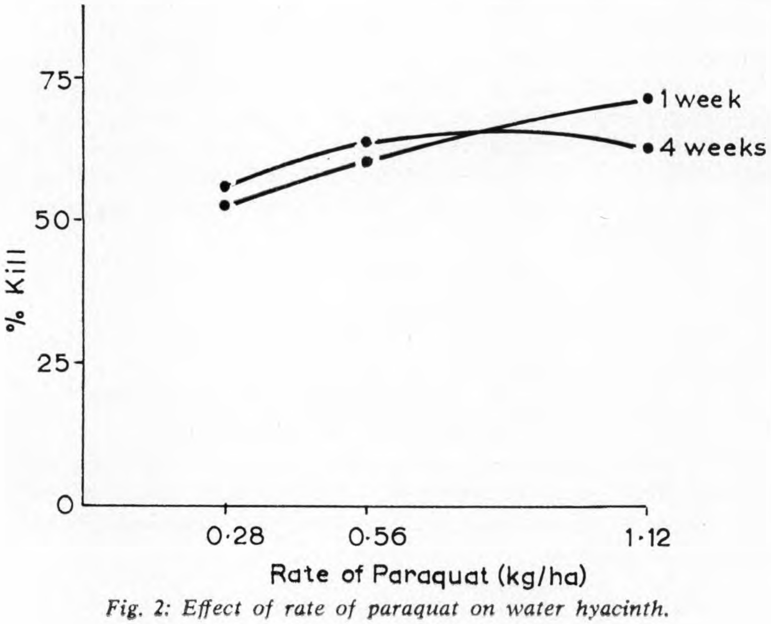

Fig. 2: Effect of rate of paraquat on water hyacinth.

RESULTS

EFFECT OF RATE OF PARAQUAT AND 2,4-D

In an initial trial, 2,4-D (sodium salt) and paraquat were compared at a range of doses. The results are presented in Figs. 1 and 2. Control with both chemicals improved as the dosage rate was increased. 2,4-D gave good control only at 4.48 kg/ha and the effects were slow to appear, reaching a maximum value 5 to 6 weeks after spraying; the treated weed mass did not sink until 7 to 8 weeks after herbicide application. Paraquat acted much more rapidly but even at 1.12 kg/ha, the highest rate tested, control was less persistent than with 2,4-D at 4.48 kg/ha.

EFFECT OF PARAQUAT AND 2,4-D TANK MIXTURES

In the next series of trials, mixtures of 2,4-D and paraquat were examined.

Treatments and results in the first two trials of the series are presented in Table 1. As observed earlier, where either chemical was used alone the degree of control improved as rate was increased, but 2,4-D was inadequate at 1.12 and 2.24 kg/ha, whilst

TABLE 1: EFFECT OF RATE OF PARAQUAT AND 2,4-D ALONE AND IN MIXTURE ON THE CONTROL OF WATER HYACINTH

() = Expected value, assuming additive effect

	% Control — Weeks after Spraying							
	Trial I				*Trial II*			
Treatment (kg/ha)	*1*	2	3	4	*1*	2	3	4
2,4-D 1.12	15	15	20	20	10	10	20	25
2,4-D 2.24	20	25	35	35	25	25	30	35
2,4-D 4.48	35	45	55	65	25	35	45	60
paraquat 0.28	40	60	62	55	55	60	55	55
paraquat 0.56	75	70	70	60	63	70	66	65
paraquat 1.12	77	75	70	58	70	70	65	60
paraquat 0.28/2,4-D 1.12	75	85	90	90	60	70	73	75
	(49)	(66)	(70)	(64)	(60)	(64)	(64)	(66)
paraquat 0.28/ 2,4-D 2.24	70	82	80	88	58	65	65	70
	(52)	(70)	(75)	(71)	(60)	(64)	(64)	(71)
paraquat 0.28/2,4-D 4.48	80	85	88	90	60	75	80	82
	(61)	(78)	(83)	(84)	(66)	(74)	(75)	(82)
paraquat 0.56/2,4-D 1.12	90	90	94	95	70	80	78	80
	(79)	(75)	(76)	(68)	(67)	(73)	(73)	(74)
paraquat 0.56/2,4-D 2.24	90	93	93	97	75	85	90	95
	(80)	(78)	(81)	(74)	(72)	(78)	(76)	(77)
paraquat 0.56/2,4-D 4.48	88	90	95	93	77	88	88	90
	(84)	(84)	(87)	(86)	(72)	(81)	(81)	(86)

paraquat was insufficiently active at all 3 rates. The paraquat/2,4-D mixtures generally gave excellent control, invariably better than that with either component used alone and usually better than would be expected from a simple additive effect. This apparent synergism was particularly marked with the lowest rate mixtures where control was far superior to that with the highest rate of either component used singly.

In subsequent trials, the influence of other factors on the activity of mixture treatments was evaluated. The results obtained are presented below.

Effect of Formulation of 2,4-D

Two formulations of 2,4-D, namely sodium salt and amine (esters were not included because of the dangers to crops, inherent from their higher volatility), were applied at 2.24 kg/ha alone or in mixture with 0.28 kg/ha paraquat. Results in Table 2 show the amine formulation to be marginally better than the sodium salt, applied alone or in mixture with paraquat. These differences, however, were not of practical significance.

TABLE 2: COMPARISON OF Na-SALT AND AMINE SALT FORMULATIONS OF 2,4-D ALONE AND IN MIXTURE WITH PARAQUAT FOR THE CONTROL OF WATER HYACINTH

Treatment (kg/ha)	*% Control — Weeks after Spraying* 1	2	3	4
2,4-D amine 2.24	20	34	38	40
2,4-D Na-salt 2.24	25	30	30	33
paraquat 0.28/2,4-D amine 2.24	65	80	85	88
paraquat 0.28/2,4-D Na-salt 2.24	60	75	80	85

Effect of Volume Rate

Paraquat 0.56 kg/ha in mixture with either 1.12 or 2.24 kg/ha 2,4-D was applied in 450 and 900 l/ha. Results presented in Table 3 show very little difference between treatments.

TABLE 3: THE EFFECT OF VOLUME RATE ON THE PERCENTAGE CONTROL OF WATER HYACINTH

Treatment (kg/ha)	*Volume (l/ha)*	*% Kill — Weeks after Spraying* 1	2	3	4
paraquat 0.56/2,4-D 1.12	450	63	76	90	95
paraquat 0.56/2,4-D 2.24	450	65	85	95	96
paraquat 0.56/2,4-D 1.12	900	65	82	94	96
paraquat 0.56/2,4-D 2.24	900	65	85	95	95

However, in subsequent work, a high volume rate has been observed to be better with very dense stands.

DISCUSSION

When applied alone, 2,4-D at a high rate was found to produce longer lasting effects than paraquat against water hyacinth. However, when paraquat and 2,4-D were applied in mixture, more rapid and lasting control was achieved at very much lower rates than the two chemicals applied individually. The control obtained by these mixtures was considerably better than could be expected from a purely additive effect, suggesting synergism between the two herbicides. This apparent synergism between a fast-acting desiccant and a foliage-absorbed translocated herbicide is in contrast to the results obtained from trials on *Mikania cordata* (Seth, 1971) where the control given by a paraquat/2,4-D mixture was actually less than could have been expected from an addition of activity. In the case of *Mikania cordata,* it was argued that the rapid desiccation of tissue even by low rates of paraquat (0.28 kg/ha) was limiting uptake or movement of 2,4-D, thus producing poorer results than expected.

In contrast to *Mikania,* desiccation of *E. crassipes* by paraquat is slower and less complete and consequently is less likely to limit uptake and translocation of 2,4-D. Furthermore, the continued increase in the level of control with paraquat as well as paraquat/2,4-D mixtures for the first two weeks after application seems to suggest that, in this aquatic environment, the presence of water "bridges" is facilitating prolonged uptake of 2,4-D and paraquat through partially desiccated but water-saturated tissue.

To conclude, it has been shown that the use of 0.28 kg/ha paraquat in mixture with 1.12 kg/ha 2,4-D provides an effective and safe method of control of water hyacinth growing vigorously in irrigation canals and ponds in North Malaya. The use of such a technique, aimed at breaking all barriers to chemical uptake, might merit further evaluation against broadleaved weed species which are partially resistant to paraquat and susceptible only to high rates of translocation herbicides.

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CONTROL OF CATTAIL (*TYPHA ANGUSTATA*) IN RELATION TO PERIOD OF STUBBLE SUBMERGENCE

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Cattail (*Typha angustata*), locally known as "patera" in North India, is a common weed of hydrophytic habitat. The plant is a robust, rush-like herb, growing up to 4 m high and is found throughout India, particularly in the plains of northern and eastern regions. Cattail flourishes well in ponds, lakes, slow-running rivers and streams, and marshy places from sea level to 700 m altitude (Subramanyam, 1962). Its roots and stems are embedded below water or in water-saturated soil (Trivedi and Sharma, 1968).

Unchecked growth of cattail produces several harmful effects. When growing in irrigation and drainage systems, cattail interferes with the normal flow of water and promotes the deposition of silt. It transpires large quantities of water (Young and Blaney, 1942) which could be utilized otherwise. It has also been reported to reduce the yield of reeds (*Phragmites* spp.), used in the paper industry (Podlipenskii, 1966), and of rice (Smith and Shaw, 1966).

An extensive survey by the writers has revealed that thousands of hectares of low-lying fields in Haryana State are heavily infested with this weed, especially the fields of paddy. In addition, most of the ditches, ponds, lakes and drains along the irrigation canals are badly choked with cattail.

Gates (1941) suggested that *Typha latifolia* may be easily eradicated by digging or by keeping the tops cut close. Since mechanical control by digging is difficult, and cutting the shoots is ineffective owing to the network of rhizomes, which give rise to new shoots, it is essential to find some effective method of control. The present study has investigated the possibility of controlling this emergent weed by cutting the shoots close to the ground and keeping the stubbles submerged under water for different periods, thereby changing the usual habitat.

MATERIALS AND METHODS

Unlined pits of 3 × 2 × 1 m dimensions were prepared at the Research Farm of Haryana Agricultural University, Hissar. To create optimum soil conditions for growing cattail, each pit was enriched with 30 kg F.Y.M. and 150 g of urea (46% nitrogen), and the pits were kept flooded continuously for 20 days before planting. In each pit, two cattail plants of uniform size were planted on 10 August, 1970 spaced 1 m apart and 1 m from the sides of the pit. A liberal supply of water kept the soil well saturated for the whole of the growing period. The depth of the standing water in the pits ranged from 20 to 80 cm.

Cutting of shoots began on 19 March, 1971, about 7 months after planting, when the plants were well established and pits almost covered with cattail. The plants were cut only once under water, about 5 to 10 cm above ground level, and subsequently stumps were kept submerged for six different periods — *i.e.,* 0, 1, 2, 4, 8 and 16 weeks. Each of the six treatments was replicated four times. The cuttings were taken on 19 March, 14 May, 11 and 25 June, and on 2 and 9 July, 1971 so as to complete the required period of submergence for all the treatments on 9 July, 1971. The foliage was completely removed from the pits at the time of cutting. The increase in the height of stubbles during submergence was recorded from 20 stubbles for comparison with those which were exposed just after cutting.

All the pits were drained on 9 July, 1971. Meanwhile, two stubbles were collected from each pit for biochemical analysis. The stubbles were analysed for moisture, reducing sugars (Walter, 1924), total sugars (Dubois *et al.,* 1956), fat (A.O.A.C., 1960) and protein (Lindner, 1944). Protein content was calculated by multiplying the percentage nitrogen content by the factor 6.25.

Subsequently, after draining, the pits were kept only saturated with moisture; flooding was not allowed. When the shoots started coming up after the exposure of the stubbles, the number of shoots per pit and their heights were recorded on alternate days. For height measurement, five shoots, if available, were selected in each pit. All the regenerated shoots were harvested 22 days after exposing the stubbles, and their fresh and dry weights recorded. Total fresh or dry weight of shoots per pit was divided by total number of shoots harvested to give average fresh or dry weight per plant.

The meteorological data recorded during the course of investigation in an observatory located only about 500 m away from the experimental site are shown in Fig. 1.

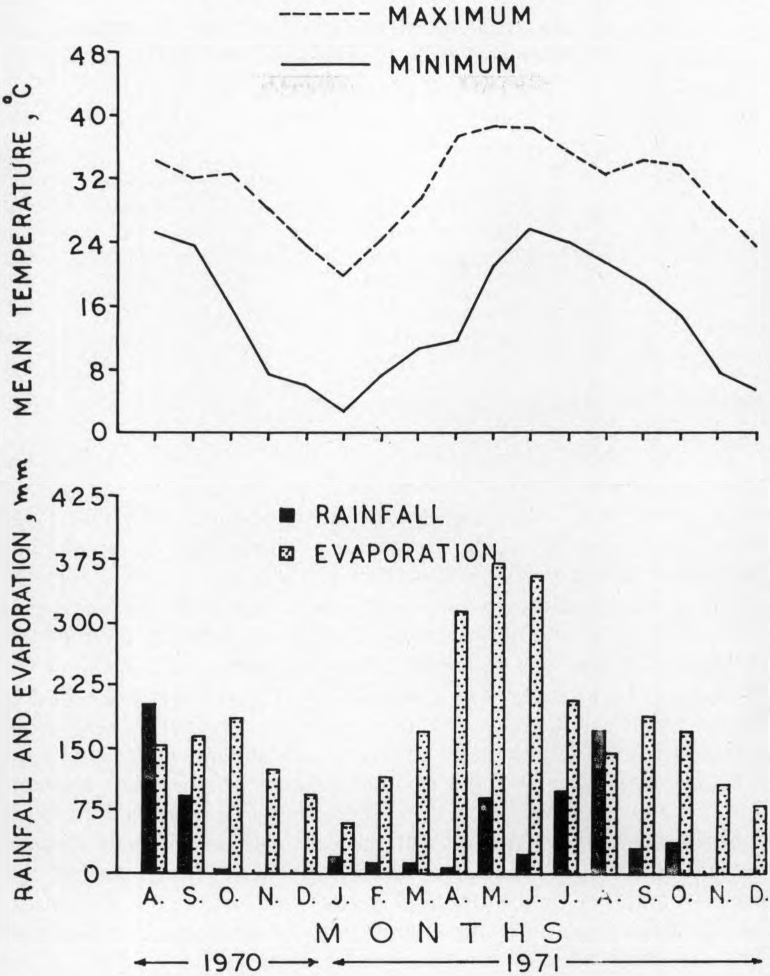

Fig. 1: Temperature, rainfall and evaporation during the period of investigation.

RESULTS

PHYSICAL AND CHEMICAL CHANGES IN STUBBLES

Submergence had a profound effect on the condition of stubbles. Visual inspection revealed that they began to decompose from the beginning of submergence. Roots and rhizomes attached to the cut shoots decomposed earlier, and took about 8 weeks to disappear, the stubbles as a whole being almost completely decomposed within 16 weeks.

TABLE 1: CHEMICAL COMPOSITION (%) OF STUBBLES SUBMERGED FOR DIFFERENT PERIODS

Period of Submergence (wk)	*Moisture**	*Total Sugars*	*Reducing Sugars*	*Protein*	*Fat*
0	79.4	9.61	3.20	4.60	0.45
1	79.5	7.26	2.16	4.45	0.50
2	83.0	4.32	2.00	4.12	0.48
4	87.2	2.66	1.71	3.61	0.50
8	88.7	2.61	1.41	4.00	0.52
16	91.0	2.13	1.00	4.72	0.50
S.E. (±)	1.23	0.75	0.25	0.58	0.04
C.D. (5%)	3.70	2.26	0.75	n.s.	n.s.

*Moisture calculated on fresh-weight basis and others on oven-dry basis.

Data for chemical composition of stubbles (Table 1) indicate that moisture content increased with an increase in the period of submergence. The highest moisture content (91.0%) was found with the 16 weeks' treatment. There was no significant difference between the values noted under 0, 1 and 2 weeks' submergence, but they were significantly less than that obtained with 4 weeks' submergence. A further significant increase in moisture content was observed when submergence continued for 16 weeks. Total sugar was drastically reduced during the first 2 weeks of submergence, and thereafter the reduction was slow and negligible. There also occurred an abrupt and significant reduction in reducing sugar content when stubbles were retained under water even for one week. There was a further decline with any prolonged submergence, but the rate was progessively slower. Percentage of protein decreased slowly with an increase in the period of submergence up to 4 weeks and increased thereafter, but the differences were non-significant. Fat percentage in stubbles was not much affected by different treatments.

Regeneration of Shoots

Shoots began emerging from the first day of exposure in the 0- and 1-week submergence treatments (Fig. 2). The number of shoots recorded up to 2 days after exposure under these two treatments was no more than the growing cut shoots (Table 2). It took 4 days for new shoots to appear under 0- and 1-week treatments, whereas in pits where submergence was continued for 2 weeks, the shoot emergence was delayed by another 4 days. No regeneration was observed in pits receiving submergence treatments longer than 2 weeks.

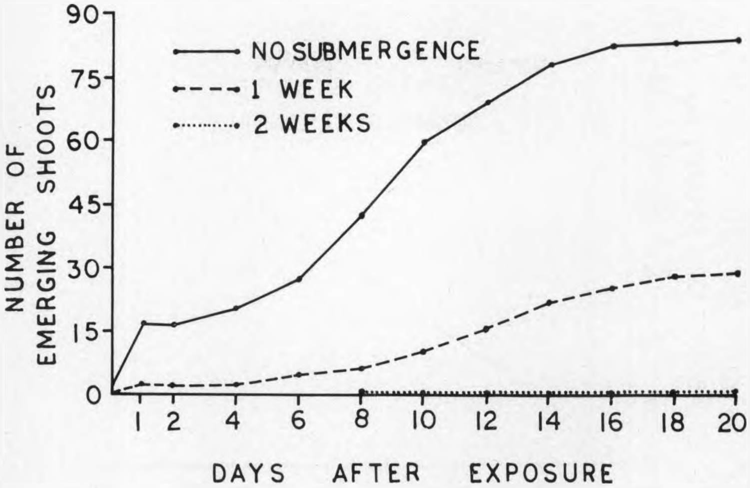

Fig. 2: Number of emerging shoots as affected by different periods of submergence.

TABLE 2: REGENERATION IN CATTAIL AS AFFECTED BY SUBMERGENCE OF STUBBLES FOR DIFFERENT PERIODS

		Growing Stubbles		*Total Shoots*	
Period of Submergence (wk)	*Av. No. of Shoots Cut/Pit**	*Av. No. per Pit**	*% Regrowth†*	*Av. No. per Pit**	*% Regeneration†*
0	157.2	16.0	10.3	84.0	54.1
	(11.9)	(4.0)	(18.5)	(9.0)	(47.7)
1	137.7	1.2	0.8	29.7	21.9
	(11.7)	(1.4)	(4.4)	(5.2)	(25.9)
2	163.5	0	0	0.5	0.3
	(12.7)	(1.0)	(0)	(1.1)	(1.4)
4	132.2	0	0	0	0
	(11.5)	(1.0)	(0)	(1.0)	(0)
8	94.5	0	0	0	0
	(9.7)	(1.0)	(0)	(1.0)	(0)
16	114.7	0	0	0	0
	(10.7)	(1.0)	(0)	(1.0)	(0)
S.E. (±)	(0.70)	(0.17)	(0.94)	(0.57)	(3.20)
C.D. (5%)	n.s.	(0.5)	(2.8)	(1.7)	(9.6)

*Population figures shown in parentheses are transformed to $\sqrt{(N+1)}$
†Percentage figures shown in parentheses are transformed to arc sin $\sqrt{}$ percentage.

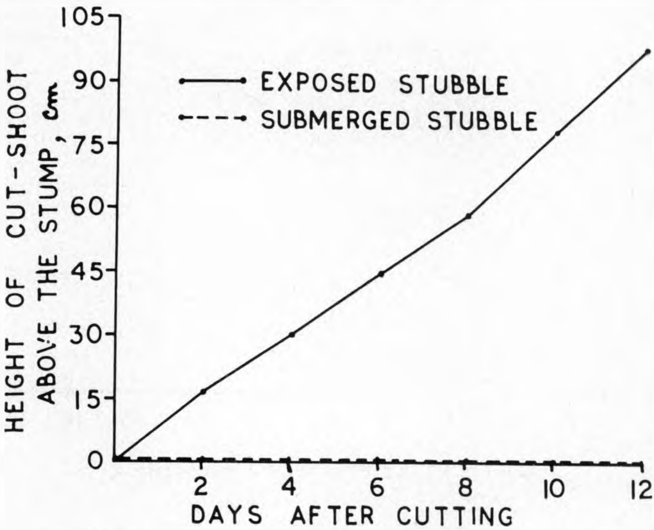

Fig. 3: Effect of submergence on the elongation of cut shoots.

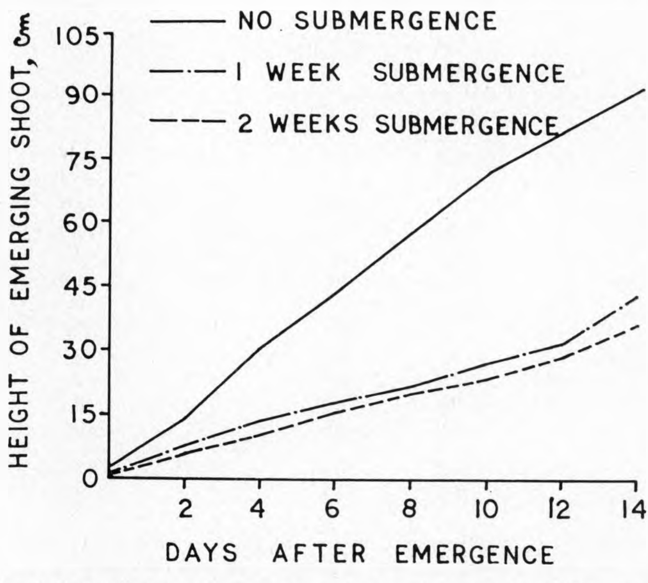

Fig. 4: Growth rate of emerging shoots as affected by different treatments.

The rate of shoot emergence showed a steady increase until a peak was reached. The highest rate was observed on the 10th and 14th days of exposure of stubbles under 0- and 1-week submergence treatments, respectively. Later, the rate of regeneration declined gradually. Most of the shoots emerged within 20 days after exposing the stubbles.

The final shoot count (Table 2), made 22 days after exposure, revealed that retaining of stubbles under water was very effective in controlling regeneration. One-week and 2-weeks' submergence reduced regeneration by 59.5% and 99.4%, respectively, over unsubmerged control. Complete control of regeneration was obtained by submerging the stubbles for more than two weeks.

Growth Rate of Stubbles and New Shoots

It was interesting to note that cut shoots (stubbles) of nonbearing shoots could grow normally in length when exposed just after cutting, but in submerged stubbles, growth was completely inhibited, at least during the period of submergence (Fig. 3).

The growth rate of new shoots was also very much affected by different treatments (Fig. 4). Shoots grew at much slower rates under 1- and 2-weeks' submergence as compared with unsubmerged control.

Fresh and Dry Weights of Shoots

Data presented in Fig. 5 clearly indicate that both fresh and dry weights of shoots both per pit and per shoot were sharply reduced by submergence of stubbles. Per pit, fresh weight of shoots was reduced by 85.34% and 99.96% and dry weight by 90.77% and 99.96% over control by retaining the stubbles under water for 1 and 2 weeks, respectively. Likewise, fresh weight per shoot was reduced to 40.9% and 7.6% and dry weight to 34.2% and 8.1% under 1- and 2-weeks' submergence, respectively, as compared with no submergence. Since regeneration was completely checked by submergence of stubbles for more than 2 weeks, the production of fresh and dry matter also ceased.

DISCUSSION

By submerging cattail, which is an emergent plant, the respiratory and photosynthetic processes are retarded. These two processes are vital for the survival and growth of plants. The emerged organs are mainly responsible for respiration and photosynthesis.

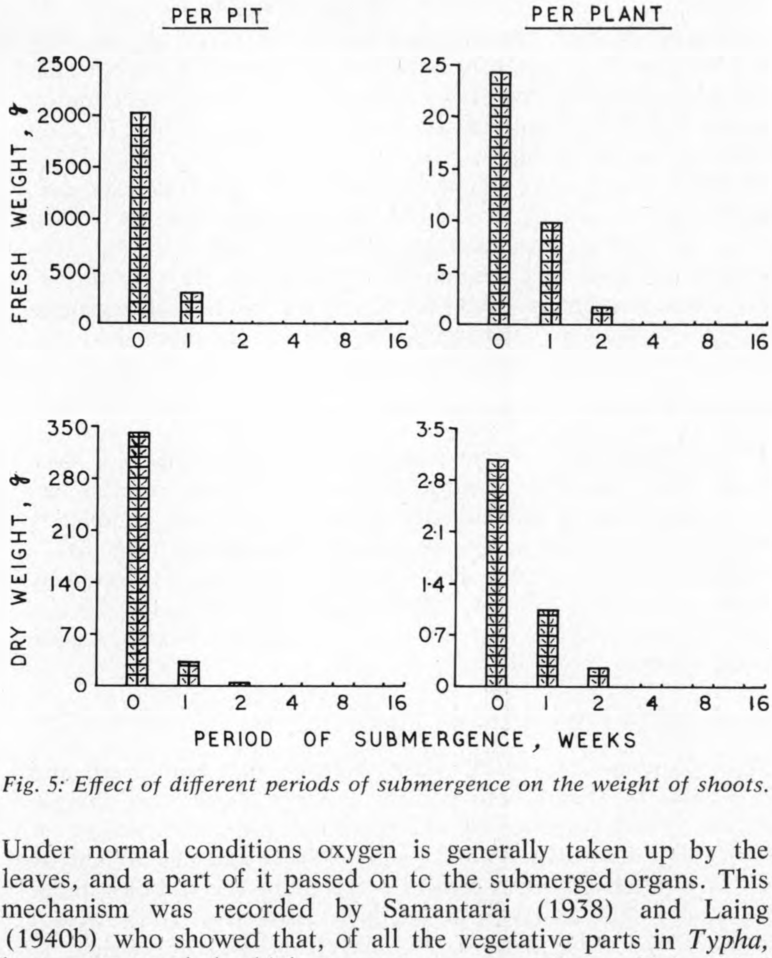

Fig. 5: Effect of different periods of submergence on the weight of shoots.

Under normal conditions oxygen is generally taken up by the leaves, and a part of it passed on to the submerged organs. This mechanism was recorded by Samantarai (1938) and Laing (1940b) who showed that, of all the vegetative parts in *Typha,* leaves possessed the highest oxygen concentration, which varied from 19.6 to 10.0%. They also inferred that the aerial foliage is probably the main source of oxygen for the organs buried in the substrate. Even if the stubbles are assumed capable of absorbing dissolved oxygen, the amount of air dissolved in water is so small that it could not meet the oxygen requirement of stubbles. Under normal conditions, the amount of oxygen dissolved in a unit volume of fresh or salt water does not exceed 5% of that present in an equivalent volume of the atmosphere. Moreover, the rate of diffusion of oxygen in water is several thousand times less than its rate of diffusion in air (Sculthorpe, 1971). Under dry conditions, where respiration is not impeded, rhizomes and other underground parts remain dormant for a long time. It has been estimated that under such conditions rhizomes of *Typha latifolia* may persist for about two years (Sculthorpe, 1971).

Generally, the submerged parts of emergent plants such as cattail are unable to photosynthesize much owing to the limited penetration of light into the water; unlike submerged plants, their chloroplast is not adapted to such light conditions.

The effects of submergence on the changes that take place in stubbles and consequently on their regrowth can be explained in the light of the above facts. It appears that water entered slowly into the stubbles, filling the air spaces and choking the tissues, which resulted in suffocation. An increase in the moisture content of stubbles with prolonged submergence also supports this view. Increased penetration of water, however, occurred as a result of degradation of the hydrophobic waxy coating into simpler hydrophilic substances. The inhibition of stubble elongation during submergence was mainly due to inhibited respiratory activity. A depletion in the soluble sugar content of stubbles is probably due to the degradation of carbohydrates into ethanol under anaerobiosis (Laing, 1940a).

The marked effect of submergence on regeneration was due to the fact that submergence considerably reduced the food reserves and caused sufficient decay of stubbles. The differences in the growth rates of shoots can also be attributed to the depletion of food material and reduced activity of partially decomposed plant parts. The reasons behind the reduction in the fresh and dry weights of shoots per pit were the reductions in the number and weight of developing shoots. Shoots that emerged under prolonged submergence treatments were more tender and succulent, and accordingly contributed less dry matter.

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A REVIEW OF CHEMICAL CONTROL OF BRUSHWEEDS ON AGRICULTURAL LAND IN NEW ZEALAND

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Summary

The widespread use of herbicides as part of brushweed control programmes on agricultural land in New Zealand is outlined. The development of herbicide additives to 2,4,5-T in the last decade is described to show how the improved degree of brushweed control has been achieved, including a wider range of species and over a longer season of application. Although gorse (*Ulex europaeus*), broom (*Cytisus* spp.), blackberry (*Rubus* spp.) and sweet brier (*Rosa rubiginosa*) are the main introduced brushweeds on agricultural land, attention is drawn to the increasing importance of determining economically effective methods of control of manuka (*Leptospermum scoparium*) and indigenous regrowth brushweeds.

INTRODUCTION

Extensive felling and burning of native forest and tussock grassland in New Zealand followed by ineffective management has caused large areas of hill country to revert to scrub weeds. Not only did indigenous, second-growth, woody plants such as manuka (*Leptospermum scoparium*) return, but ingress was allowed for introduced brushweeds such as gorse (*Ulex europaeus*), blackberry (*Rubus fruticosus* agg.), broom (*Cytisus* spp.), sweet brier (*Rosa rubiginosa*) and barberry (*Berberis vulgaris*). With the unwitting aid of man, his grazing animals and New Zealand's temperate climate, these introduced species have flourished often in almost pure stands rather than the mixed stands known in Europe. So serious was the problem with one of these brushweeds, blackberry, that the New Zealand Government in 1925 offered a $20,000 reward for any proven economic method for its control. However, it was withdrawn in 1948 just before 2,4,5-T was identified from local trials as an outstanding brushweed control chemical. Before this stage, sodium chlorate and ammonium sulphamate were used as less toxic alternatives to sodium arsenite sprays, the latter being commonly applied to blackberry.

Although 2,4-D has some activity on lighter woody weeds such as lupins (*Lupinus* spp.), the 2,4-D/2,4,5-T herbicide mixtures commonly used in the northern hemisphere have not been widely applied in New Zealand for the monoculture of introduced brushweeds. Only on mixed, second-growth, native, woody weeds being cleared for forest planting sites have 2,4-D/2,4,5-T mixtures been considered efficient.

In the seven years to 1955, over 100 000 ha of brushweeds had been treated with 2,4,5-T, but considering the millions of hectares of brushweed-infested land the surface had hardly been touched. Till 1964, 2,4,5-T alone remained the pre-eminent brushweed herbicide in New Zealand. 2,4,5-T is very cost-efficient with a surprisingly broad spectrum of control which includes the two important legume woody weeds, gorse and broom. Although these both occur commonly as economic problems in high production pastures containing perennial clovers, most of the 2,4,5-T has been essentially applied as a localized ground spray treatment. Widespread and lasting damage to the clovers is thus avoided, broadcast treatments being mainly used on near-complete ground cover infestations before sowing to pasture.

In contrast to herbicides introduced for selective pasture and cropping weed control, few new alternative brushweed herbicides became available before 1963. 2,3,6-TBA (formulated as liquid or granules) was quite widely evaluated in New Zealand, the prime target brushweed being sweet brier. A benzoic analogue in the form of dicamba quickly followed in the search for new compounds to overcome the well-recognized deficiencies of the workhorse herbicide 2,4,5-T, namely:

(1) 2,4,5-T has limited translocation within the problem brushweeds — gorse, blackberry and sweet brier. The complete spray coverage demanded of 2,4,5-T limits the use of aerial application to give only partial control, unless repeat seasonal treatments are made.

(2) 2,4,5-T has limited residual activity such that massive basal resprouting can occur, although adequate stem kill apparently has been achieved in the season of application — *e.g.,* in the case of blackberry, sweet brier, barberry, boxthorn (*Lycium ferocissimum*) and hawthorn (*Crataegus* spp.).

However, not until the release of picloram in 1963 did the prospects of obtaining a really high potency, well translocated brushweed herbicide look so promising. Although granular formulations of fenuron and later 2,3,6-TBA had been introduced for brush control by soil surface application, renewed interest was shown in this technique with the introduction of picloram. Granular treatments have real preference over spray applications in New

Zealand for difficult-of-access hill country sites or areas where there is a shortage of water. Localized patches of brushweeds or single plants scattered over a wide area can therefore be most suitably controlled by a persistent herbicide such as granular picloram, which is highly water-soluble and readily translocated throughout the plant system.

Concurrently with the introduction of new compounds and the evaluation of their formulations for brushweed control came the need for the development of more efficient application equipment. The main methods currently used for spray application of brushweed chemicals can be classified as follows:

(1) High volume, high-pressure directed gun sprayers applying at least 2,000 l/ha of brushweeds per metre high.

(2) Aerial broadcast boom treatment applying a total of 200 to 400 l/ha preferably in two sprays runs releasing half the spray volume with each overlapping parallel pass.

(3) Motorized backpack mist blowers applying directed sprays of chemicals at up to twenty times concentration of (1).

The field studies with more recently introduced herbicide products such as dicamba/2,4,5-T, amitrole and diquat will be briefly mentioned in the text where the major problem brushweeds in New Zealand are discussed separately.

GORSE

Gorse undoubtedly remains New Zealand's most widespread and aggressive introduced brushweed problem, since it occurs as infestations on more than half a million hectares of hill country, much of it potentially high-production pasture or conifer forest land. Burning of gorse, followed by cultivation, crushing or cutting with tractor-drawn rotary slashers, is only practical on flat or easy hill country.

The major chemical method for gorse control in New Zealand is high-volume gun spray application with 2,4,5-T alone or in combination with other herbicides. The most commonly used formulations of 2,4,5-T have been the emulsified low volatile esters (butoxyethanol or iso-octyl) or the mixed butyl esters applied at a rate of 8 kg in not less than 4,000 l (0.2%) per hectare of infested gorse up to 2 m high, as a complete cover spray. (The amine salts of 2,4,5-T have been proven considerably less effective.) Stem "brown-off" is normally complete within six months if applications are made in the active growth period between spring and early autumn.

Ideally, as with all brushweed control programmes following chemical treatment, the land is then oversown with a ryegrass (*Lolium* spp.)/white clover (*Trifolium repens*) pasture plus superphosphate fertilizer mixtures after mechanical crushing aided by stock trampling. Adequate land subdivision by fencing to permit stock management for controlled grazing is a necessary part of the pasture establishment and to obtain suppression of emerging seedling brushweeds. Burning of the dead gorse tissue normally leads to heavy re-infestation from seed germination, which, if broadcast resprayed with 2,4,5-T, results in clover removal.

Winter applications of 2,4,5-T alone to the hardened gorse result in slower stem killing activity and quite variable final control, no doubt because of the lower state of plant growth activity and hence reduced translocation of the 2,4,5-T. Likewise, the success of aerial application to heavy gorse stands is dependent on achievement of a high level of translocation of the 2,4,5-T from the limited stem spray coverage achieved. Repeat applications to the following season's regrowth are necessary for adequate basal kill.

The combination of picloram with 2,4,5-T ester has proved particularly effective in reducing the gorse regrowth when applied as a directed high-volume treatment at the rate of 1 + 4 kg/ha, respectively, in 2,000 l. At these rates of either compound separately, the final kill of gorse is inadequate. The additive effect of the combination probably results from the initial foliage and stem kill by the 2,4,5-T. This is followed by lower stem and root kill from the retranslocated picloram, leading to prevention of resprouting from lateral and basal buds.

A more recent development in gorse control has been the extension of treatment time into the autumn and winter periods. Diquat as an additive to 2,4,5-T ester has increased the speed of upper stem brownoff of gorse. This is useful to later identify plants missed during initial spraying, particularly when applied under the hardened growth conditions of winter. Likewise picloram/2,4,5-T is now being accepted as a winter treatment of gorse. Its slowness in stem kill reaction may be hastened by the addition of diquat, but there is no clear evidence to indicate an improvement in final kill from such high-volume desiccant mixtures.

A recently introduced brushkilling mixture of 2,4,5-T and dicamba esters (4 : 1) has been claimed to have increased selectivity to pasture legumes, no doubt because of the reduced soil persistence of dicamba compared with picloram. The basis for the claims of regrowth control from the dicamba ester additive compared with 2,4,5-T ester alone has still to be published. Effective control of gorse from aerial application of herbicides has yet to be reliably demonstrated, especially on hill country not readily accessible to mechanical equipment for follow-up crushing, etc.

BROOM

As in North America and Europe, various species of broom (*e.g., Cytisus monspessulanus* in the North Island) have been most economically controlled with 2,4-D as high-volume treatments using the ester in the late spring. By comparison, in the South Island, broom — almost entirely *C. scoparius* — has proved much more difficult to kill with 2,4,5-T. However, all growth forms of this species have been remarkably susceptible to picloram, even to the 2,4-D amine salt mixture. Aerial application in the late spring of picloram/2,4,5-T ester at the rate of 0.75/3 kg/ha has been successfully used to control broom when in the green fruit pod stage. At this time, root growth is still active in moist soil, leading to sufficient translocation of the herbicide. This is soon followed by soil moisture stress and concentration of the residual picloram within the plant system. Some soil residual action of the picloram is evident from the marked reduction in regeneration of broom seedlings compared with 2,4,5-T treatments. The release of nutrients from the nitrogen-fixing legume system, with the opening up of the broom stand after spraying, can often be graphically seen in the growth response of high-fertility grasses like cocksfoot (*Dactylis glomerata*).

In amongst both seedling gorse and broom there has appeared in the last decade a new problem brushweed in the form of Himalaya honeysuckle (*Leycesteria formosa*) in first-year plantings of radiata pine (*Pinus radiata*). The gorse and broom can be suppressed by aerial spraying with 2,4,5-T or more effectively with a picloram/2,4,5-T ester combination at the rate of up to 0.25/1 kg/ha. This picloram/2,4,5-T mixture is necessary for Himalaya honeysuckle control. In contrast to *Pinus* spp. in North America, radiata pine, widely grown in New Zealand, is remarkably tolerant to this picloram/2,4,5-T mixture when applied prior to active terminal growth in first-year plantings.

BLACKBERRY

Blackberry occurs most widely in the warm, temperate, moist districts of New Zealand, especially on the western sides of both islands. Certain forms of blackberry are very poorly controlled by 2,4,5-T ester applied as a high-volume spray even with complete foliage and stem coverage. Apparently in these variants, where the 2,4,5-T can give almost complete cane die-back, insufficient chemical is translocated to, or remains in, the basal collar zone to prevent massive resprouting in the following season. High dosages of amitrole (not less than 8 kg/ha) have been used for spot treatment of these so-called 2,4,5-T resistant races.

By contrast to straight 2,4,5-T, the picloram/2,4,5-T ester mixture appears to be equally efficient on all forms of blackberry treated so far. For effective control, sufficient picloram must be present in the plant to control the cane buds resprouting from the basal crown. For single treatment kill of mature blackberry, up to 2 kg/ha picloram combined with the 2,4,5-T ester (8 kg) applied as a high-volume spray down to the lower canes may be required. A limited seasonal time of application study has been completed on blackberry. As with 2,4,5-T, interim results suggest that summer to late-autumn treatments, from petal fall till after ripe fruit, achieve maximum basal translocation. Aerial treatment has not been normally attempted, mainly because of (a) the more scattered nature of blackberry infestations compared with gorse and broom, and (b) the difficulty of obtaining adequate spray coverage to the lower canes. For heavy stands of blackberry, as found in stream valley bottoms or old stands along fencelines, it may be more economical to obtain a top cane kill initially with 2,4,5-T followed by burning the dead canes. The following season, regrowth control can then be obtained with a lower dosage of the picloram/2,4,5-T ester mixture applied as a directed spray to the basal cane resprouts. At least two seasons may be required to fully evaluate the final degree of root kill achieved.

SWEET BRIER

Sweet brier has been established in New Zealand since last century. With the reduction in rabbit populations it has become the most aggressive introduced brushweed of the tussock grasslands, situated primarily on the dry inland areas of the South Island. The standard chemical treatment has been 1% 2,4,5-T as the ester applied in diesel oil as a complete basal spray in the early spring. Regrowth from some bushes normally occurred necessitating retreatment. Considering the effort required by this treatment method in such difficult access country, the results were too marginal for widespread farmer acceptance.

Picloram/2,4,5-T mixtures have now replaced straight 2,4,5-T ester as the standard spray treatment for sweet brier control in accessible sites. The same dosage as used for gorse is effective for sweet brier, but the ideal treatment stage is from early spring to early summer. This coincides with early bud burst to first full leaf and petal fall when soil moisture is still high and root growth is active. Occasionally distorted shoot regrowth occurs in the succeeding spring, but with the onset of dry summer conditions leaf wilting results, followed by final cane die-back.

On sites less accessible for spray equipment or for water, granule treatments of picloram have been a simple and reliable treatment to control sweet brier. Ideally application is made in late winter to early spring (August to October) when soil moisture is highest, further precipitation can be expected and root uptake is active. Early trials measured the dosage by application from the drip-line to the base of the bushes. This practice is now commonly used for treatment of scattered infestations.

Subsequent field studies indicated that the underground stems and roots extend well beyond the drip-line, and these also need exposure to picloram spread over a wider area to obtain final kill of the bush. In uniform stands, then, broadcast spring treatment of 2 kg/ha of picloram granules (2% active) has become increasingly used. Aerial distribution has been practised in heavy infestations where containment of the spread of the sweet brier, such as on Molesworth Station, warrants the high cost. The subsequent volunteer grass response on these high country skeletal soils indicates a release of nutrients and soil moisture, previously denied the grasses by the heavy thickets of sweet brier. This grass establishment and animal foraging in turn greatly aid in the suppression of brier seedlings which are quite susceptible to competition and grazing.

MANUKA

Manuka (*Leptospermum scoparium*) is undoubtedly New Zealand's most important indigenous brushweed of the unploughable and less fertile hill country. More than two million hectares of such poor pasture land has reverted to second-growth scrub and fern, much of it dominated by unpalatable manuka.

As with attempts at burning extensive standing manuka thickets, so have chemical spraying trials proved generally unsuccessful. 2,4,5-T is the most active herbicide for manuka but only aerial application can be considered feasible. Recent chemical control studies have been aimed at the use of 2,4,5-T at up to 8 kg/ha as the ester in 200 l of oil. Alternatively, in place of the expensive oil, 2,4,5-T is combined with desiccant additives emulsified in the water. The desiccant additive showing most promise is methylarsinic acid applied at not less than 4 kg/ha. Sodium chlorate, though effective on bracken, appears to have a too rapid scorching effect on manuka. Ammonium sulphamate has also been used to a limited extent. Spring and early summer appears to be the most effective treatment season for manuka when soil moisture is still high. Desiccation follows rapidly in the late summer and autumn heat. The defoliation leading to opening up of the canopy allows volunteer grasses to develop, which stock then forage, and in so doing, break open the manuka stand.

FUTURE DEVELOPMENTS

The programme for clearance of manuka and also for cutover indigenous scrub hardwoods using chemicals as part of the land conversion is still in its infancy in New Zealand. Because of the great mass of dry matter present in such plant communities, herein lies the greatest challenge to the brushweed scientist in this country. Also New Zealand offers a unique situation to him since two of the major introduced weeds, gorse and broom, are legumes like the clover which is part of the dominant cover of the converted pasture. It is highly unlikely that a herbicide will be discovered in the near future suitable for the control of these woody weeds and which is also selective to clover present at the time of treatment. A compound which is highly systemic like picloram, without its soil persistence, would be very desirable. Application techniques can then be directed towards more effective foliage and stem coverage using broadcast low-volume spray treatments. Such a highly translocated herbicide with a spectrum of activity complementary to present products would be most acceptable. But, in fact, the major deficiencies remain in the ability to utilize fully the properties of present herbicide tools, especially in relation to the most susceptible growth conditions of problem brushweeds.

ECOLOGICAL STUDIES OF SCRUB WEEDS IN NEW ZEALAND: A REVIEW

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Recent investigations concerning the ecology of several important scrub weeds in New Zealand are reviewed. Reference is made also to surveys of scrub weed distribution and to current research. Recommendations for limiting specific weeds based on the results reported are included. Generally, these emphasize the importance of plant competition and preventing seedling weeds from establishing by adopting good managerial practices in areas predisposed to weed invasion, *e.g.* subdivision, oversowing and topdressing followed by mob-stocking to facilitate growth control and damage emergent weeds. Some suggestions for the control of mature scrub weeds are given.

INTRODUCTION

Considering that investigations of the biology of weeds tend to be slow and unspectacular by comparison with herbicidal field trials, it is not surprising that few of the important weeds have been studied intensively from an autecological standpoint.

Nevertheless, a growing appreciation of the contributions that can be made to weed science by systematic studies of plant growth and dispersal, associated usually with field surveys of species distribution, is apparent from an examination of the national scientific literature over the past decade.

The object of this review is to consider the progress made by such research in the more limited field of scrub weed control.

SPECIES

Although not the first paper appearing chronologically in this series, that which set the stage for more comprehensive programmes than formerly was by Leonard (1962) who reviewed the regional distribution, the importance and the control of scrub weeds in South Island. Leonard listed about ten species of widespread occurrence as serious or potentially serious pests and several of more localized concern. Among the first group were gorse (*Ulex europaeus*), sweet brier (*Rosa rubiginosa*), manuka and kanuka (*Leptospermum* spp.), broom (*Cytisus scoparius*), bracken (*Pteridium aquilinum* var. *esculentum*), matagouri (*Discaria toumatou*), blackberry (*Rubus* spp.), and tutu (*Coriaria* spp.), while heaths (*Erica* spp.), tauhinu (*Cassinia leptophylla*), barberry (*Berberis* sp.), hawthorn (*Crataegus monogyna*), elder (*Sambucus nigra*) and *Ribes* spp., were included in the second set, all arranged approximately in his order of importance.

Nothing comparable seems to have been published for the North Island, but the proceedings of various scientific societies record few papers which discuss woody plants considered to be less desirable there, than those listed. However, some of the research to be reviewed now was conducted in the North Island and in respect to species common to both islands would be generally applicable.

Gorse

Though preceding the period under review, numerous writers, Duncan (1953), Currie (1959), Allo (1959), Bell (1961) and more recently Batten and McDonnell (1969) have discussed methods of managerial control of this spiny, aggressive legume which thrives in medium to high rainfall districts. Practices incorporating cutting, burning, bulldozing and stocking coupled with oversowing and topdressing have been recommended, depending upon the nature and steepness of the topography and the age and vigour of the infestation.

Moss (1959) summarized the results of investigations on gorse seed dispersal and seed populations in the soil on unploughable hill country. He considered men and animals the most important agents of dispersal and found that hard seed populations could be large and remain dormant a long time. Pre-heating such seed to 88° C for half an hour gave a high germinating capacity, but the temperatures reached during burning standing gorse were sufficient to reduce seed viability by 57%. As populations of 23 to 28/m^2 were recorded where spraying but no burning was practised, it was clear that other means of inhibiting germination would have to be sought.

Again high hopes of limiting the spread of gorse using the seed weevil *Apion ulicis* had not been realized owing to the failure by the insect to produce larvulae regularly enough in winters after the minor flowerings of gorse (Miller, 1970), thus allowing second crops of seed to be shed annually.

Moss (1959) found also that 96% gorse seed lay in the top 5 cm soil and that pasture competition with establishing seedlings followed by mob-stocking was the best method of limiting regrowth on unploughable hill country. This is an idealistic situation involving high fencing costs and possibly herbicidal treatments.

Thus his recommendations supported the practices adopted by farmers generally, but emphasized the desirability of leaving the top soil undisturbed following gorse clearing by whatever means on unploughable areas.

MANUKA AND KANUKA

Manuka (*Leptospermum scoparium*) and kanuka (*L. ericoides*) are generally considered to be the most troublesome representatives of the indigenous flora because of their plasticity. They occur in both main islands, fulfil important seral roles in forest regeneration, and are not amenable to herbicides beyond the seedling stages of growth.

The ecology of *Leptospermum* in Otago was described by Burrell (1965) who mapped the distribution of both species there and found a sharply defined aspect preference at altitudes of 450 to 520 m where *Leptospermum* was restricted to northerly faces up which it continued for 400 m.

The two species have different patterns of seed dispersal (Burrell, 1965) and because managerial control over the years has involved the use of the slasher followed by fire and more recently by oversowing and topdressing, Burrell contended that repeated fires would increase the ascendancy of *L. scoparium* over *L. ericoides*. She tested the effects of subjecting *L. scoparium* seed under laboratory conditions to air temperatures of 100° C for five minutes and found that all seed decayed, indicating that a hot fire would be needed under field conditions to prevent germination.

A major factor limiting the spread of *L. scoparium* naturally, however, is "manuka blight" a combination of a mealy bug *Eriococcus oriariensis* and an associated sooty mould *Capnodium walteri,* the advent and dispersal of which were reviewed by Hoy (1953).

According to Burrell, both species are susceptible in Otago to attacks by the scale but *L. ericoides* usually survives whereas *L. scoparium* is usually killed except where it is growing near its altitudinal limit — *i.e.,* above 600 m.

Experiments and observations in the Manawatu district by Grant (1967) indicated that establishment of *L. scoparium* was favoured by the production of large numbers of readily dispersed seed which are shed throughout the year but mainly in spring. Shed seed was found to be of low viability (15 to 20%) but able to germinate over a wide range of temperature (4.5 to 32° C). More important from the control aspect was that establishment of *L. scoparium* was limited by the requirement for light for germination, and by the action of increasing plant cover reducing seedling survival.

The most significant reduction in seedling numbers under field conditions coincided with heavy mob stocking (first by sheep followed by cattle), whereas little damage to seedlings occurred under set-stocked grazing by ewes and lambs.

The practical implications of these studies, Grant concluded, "are that on newly sown unploughable land previously supporting manuka, swards are very open and ideal for re-establishment by *Leptospermum* so that it is important to maintain a vigorous sward over the biggest area possible to prevent light from reaching the ground".

Sweet Brier

Sweet brier occurs only sporadically in the North Island where it is not generally considered a serious pest, but in the South Island it is concentrated east of the main divide with severe infestations in Marlborough, Canterbury and Otago. It is found from sea level to the uppermost limits of short tussock grassland which varies from 730 to 940 m depending upon latitude and local aspect (Molloy, 1964b).

The plant is a deciduous, thorny, colonizing shrub which forms dense thickets and impedes stock movements.

Dingwall *et al.* (1960) reviewed the state of knowledge and progress achieved by then in the control of sweet brier by cutting, burning, grubbing and mechanical as well as chemical methods and concluded that "although plants could be eradicated there were still practical difficulties, particularly under the environmental and economic circumstances associated with large scale and widespread infestations".

Molloy (1964a, b) reported intensive phenological studies and, commenting on seed dispersal (which he attributed to both birds and animals), stated "there is usually only one seed crop per season but individual plants may produce 1000 hips each containing as many as 23 fully developed achemes. These have high viability (80%) but do not germinate usually until the second spring following seed production under field conditions."

Under controlled glasshouse conditions, Molloy demonstrated that the most spectacular response in seedling growth occurs in the absence of grass and with added fertilizers. Grasses stimulated by added fertilizers provide the strongest competition. From field plots established under open grazing he showed also that first-year seedlings are very susceptible to close grazing. Decapitation at or below the level of cotyledons inevitably results in death.

Thus a competitive ground cover and controlled grazing will suppress the spread of sweet brier (Ludecke and Molloy, 1966) but since the almost total destruction of its main predator, the rabbit (*Oryctolagus cuniculus*), pastoralists seem to have been unable to achieve this suppression generally.

MATAGOURI

Confined mainly to coastal sand dunes in the North Island but scattered through some 3.34×10^6 ha of short tussock grasslands to 1070 m altitude in the South Island, this endemic species is unique in being New Zealand's only spiny, divaricating shrub.

According to Daly (1969), matagouri, which nodulates and fixes atmospheric nitrogen like legumes, plays a useful part in forming vegetation and soil on shingle fans, riverbeds and occasionally eroded slopes. However, in pastoral lands, mature colonies form dense thickets, generally reduce the productive area, and slow stock movements.

An important clue to a possible method of controlling spread of matagouri was the finding that about 80% of fresh seeds liberated from capsules in late summer remain dormant until subjected to several weeks of winter cold. Also seedling matagouri has been shown to be a poor competitor with vigorous pasture plants such as cocksfoot (*Dactylis glomerata*) and red clover (*Trifolium pratense*) and, in common with many colonizing plants, "appears to have little tolerance for shade". As herbicides have shown little promise against this species, the "combined effects of burning followed by periodic hard grazing and long spelling of topdressed and oversown blocks would seem to be the most effective approach to eradication of *Discaria*" Daly (1969) concluded.

BRACKEN

No recent study on bracken has been made, but its widespread occurrence demands remarks upon it here. Found throughout the higher rainfall districts of both main islands from sea level to about 900 m, it is an important seral endemic and in many areas of unploughable hill country dominates the landscape.

From an ecological standpoint, bracken should not be difficult to eradicate, "as it has four defects in its growth cycle," wrote A. H. Cockayne (1916). "These are —

"(1) the incapacity of its rhizomes to develop fronds except in special places,

"(2) the inability of the frond to grow when once broken off,

"(3) the extreme ease with which the frond may be broken before it curls and

"(4) the long dormant season extending from autumn to late spring."

Cockayne emphasized the importance of early burning on unploughable land and discing to cut the rhizomes on areas which could be cultivated. In all situations mob-stocking after burning is necessary to facilitate control of regrowth.

Inch (1962) commented that the restricted diet usually available on areas unimproved by oversowing and topdressing was not good for the animals which suffered from impaction, bracken poisoning and near starvation.

Spanish Heath

Erica lusitanica is a weed of more restricted distribution considered to be a problem in northern South Island districts and in parts of central North Island. The species is unpalatable to stock, does not burn well when green, and thrives on soils of low fertility in areas of moderately high rainfall.

Leonard (1958) reported on a series of herbicidal trials on this species and stated that "where land is too steep for cultivation spraying (with 2,4-D ester) in itself will not eradicate heath which regenerates from seed and should be tried only when raising the soil fertility is not enough".

Tauhinu

Beggs (1971) described the successful control of a dense infestation of this unpalatable indigenous shrub on hill country, Marlborough, without the use of herbicides or cultivation. The method used over an area of 10 ha was burning off followed by optimum economic application of pasture seeds and fertilizer. Subsequently, judicious spelling and grazing management played an important part in providing a clover smother considered to be a critical factor in preventing re-establishment of tauhinu from buried seed.

Similar practices were recommended for the control of *Hakea* spp. in Tauranga county by Allo (1959) who also reported Montpellier broom (*Cytisus monspessulanus*), tree lucerne (*Lupinus arboreus*), whatitiri (*Pomaderris phylicaefolia* var. *ericifolia*) and Spanish heath as troublesome woody plants on land under development.

No detailed ecological studies seem to have been conducted on these species and even their distribution is not well documented.

CURRENT RESEARCH

Of the plants listed by Leonard (1962) the only ones known to be under investigation at present are the poisonous tutu (*Coriaria* spp.) by the writer and Himalaya honeysuckle (*Leycesteria formosa*) by the N.Z. Forest Service (C. Anstey, pers. comm.).

A scheme for recording qualitatively the distribution of weeds in New Zealand was outlined by Molloy (1967) but it has been restricted to several noxious adventives — *e.g.*, sweet brier, barley grass (*Hordeum* spp.) and nodding thistle (*Carduus nutans*).

Recently this scheme has been expanded by the writer for the purpose of mapping the distribution of important scrub weeds in South Island and modified to include stratified quantitative sampling relative to major soil types and land-use patterns.

Surprisingly, no major study has been instigated on *Cytisus* spp. although, according to Pengelly and Ferguson (1964), the South Island form is difficult to eradicate chemically, and opinion claims that broom has a wider altitudinal range than gorse.

Several other shrubs constitute nuisances in particular regions but their rates of spread and potentials for adaptation are not known.

CONCLUSIONS

Constant vigilance and good husbandry by land holders, combined with thorough research by both laboratory and field-based scientists, must be the goals if troublesome plants like those discussed are to be contained.

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SCREENING HERBICIDES AND APPLICATION TECHNIQUES FOR THE CONTROL OF *CYCAS* SP. IN THE NORTHERN TERRITORY, AUSTRALIA

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Summary

Herbicides were screened for activity against *Cycas* sp. Organic arsenicals were very effective. The minimum dose rates were determined for picloram/2,4-D, picloram/2,4,5-T, and the sodium salt of cacodylic acid. The effect of applying the herbicides to the stump cut at three levels was examined. Foliar applications of picloram/2,4-D, picloram/2,4,5-T and organic arsenicals were compared.

INTRODUCTION

This paper is a progress report of several related trials being conducted on a *Cycas* sp. possibly *C. media,* in the Northern Territory of Australia. The standard treatment at present is as follows: One millilitre of picloram/2,4-D mixture is injected into two small cuts (2 cm × 1 to 2 cm deep) on the opposite sides of the trunk near ground level. An oil-soluble picloram/2,4,5-T mixture is sprayed on small plants which are not able to be stem-injected.

The use of fire improved efficiency of the control technique by improving the speed of working and because the plants are stimulated into growth, making location faster. The active growth improves the kill achieved.

SCREENING TRIAL

This work is aimed at reducing the cost of control through reducing the amount of herbicide required to kill the plant reliably, investigating different positions of the injection points and evaluating other herbicides which are possibly cheaper and as efficient as the present standard procedures.

Chemicals screened recently are potassium hexafluoroarsenite, fenoprop, dicamba, methylarsinic acid and an organic arsenical formulation containing cacodylic acid and triethanolamine cacodylate. Twenty plants were selected and one millilitre of product applied to cuts made at ground level in the trunk of the plant.

The methylarsinic acid hexahydrate was made into a 30% w/v mixture with water and a surfactant added.

Preliminary results are available one wet season after application of the chemicals. Promising kills were obtained with dicamba, and the two organic arsenicals. The KF_6As caused slight yellowing on the edge of the leaves and the fenoprop did not produce any lasting effects once the plants recovered from defoliation.

Of the readily obtainable organic arsenicals only methylarsinic acid has not been tested. This group of herbicides has shown considerable promise against *Cycas* sp.

Work will be continued to assess the minimum dose required and compare the economics of promising chemicals with existing recommendations.

MINIMUM DOSE TRIAL

The development of recommended control methods did not take into consideration the minimum amount of picloram-based herbicides needed to kill the plant. To determine this a series of treatments was applied to groups of twenty plants.

The chemicals used were picloram 5% and 2,4-D 20% amine formulation; sodium salt of cacodylic acid; picloram 5% and 2,4,5-T 20% amine formulation. Rates were 0.5, 0.2, 0.125, and 0.0625 ml/product/injection.

All plants were measured for height, diameter at ground level, and at 30 cm the growth phase noted. Results were as follows:

	Rates (ml)			
	0.5	*0.25*	*0.125*	*0.0625*
picloram/2,4-D:				
Killed %	85	25	10	0
Killed plus seriously affected %	100	44	45	5
picloram/2,4,5-T:				
Killed %	80	52	21	0
Killed plus seriously affected %	100	94	37	10
Cacodylic acid:				
Killed %	30	0	0	0
Killed plus seriously affected %	70	75	5	0

Most plants rated as severely affected will probably die, but it is necessary to wait until after two wet seasons to allow any regrowth to appear.

HERBICIDE PLACEMENT

Observations in the field indicated that the site of application affected the activity of the herbicides. If the picloram-based herbicide was placed on the undamaged crowns it would damage only about 30 to 40 cm of the trunk. Plants taller than 30 to 40 cm survived and sprouted from below the damaged trunk.

Groups of twenty plants were treated with 2 ml of the product placed in a small hole made on the cut trunk. The plants are quite soft and cutting off the crowns provides a very visible mark that the plant has been treated. Three positions were used — crown only removed, cut off half-way up the trunk and cut off at ground level. Two herbicides were used: picloram/2,4-D and the sodium salt of cacodylic acid.

Heights and diameter at ground level and at 30 cm were measured, and the growth phase noted. Results were as follows:

	Placement Position		
	High	*Mid-point*	*Ground Level*
picloram/2,4-D:			
Killed %	0	15	45
Killed + seriously damaged %	100	100	100
Cacodylic acid:			
Killed %	0	0	55
Killed + seriously damaged %	30	100	95

FOLIAR AND CROWN APPLICATIONS

This trial was to determine the most effective method of killing small, trunkless plants not suited to injection techniques.

Small groups of plants were sprayed with various dilutions of picloram-based herbicides in water and dieseline. Chemicals used were picloram 5%/2,4,-D 20% amine formulation; picloram 5%/2,4,5-T 20% amine formulation; picloram 10%/2,4,5-T 40% ester formulation. These were applied at dilutions of 1:10, 1:25, 1:50, and 1:100.

This trial is still in the early stages and not a great deal of information is available.

The oil-soluble formulation appears most effective, followed by the picloram/2,4-D. The foliar-sprayed application method appears to be slightly less effective than crown application methods.

SUMMARY

All this work is still in progress and when finally analysed some trials will be repeated to evaluate seasonal effects.

Cycas sp. has a large, underground tuber which is a large storage organ and is able to bud off new shoots when the main crown is damaged. The large tuber dilutes many of the chemicals and reduces their effect.

Patterns as revealed by the death or partial death of plants show that there is a great deal of vertical movement, but little horizontal movement of the chemicals in the trunk or tuber. This leads to problems of regrowth, as any part of the tuber can initiate shoots.

These factors make the plant quite difficult to kill and account for the many failures experienced when herbicides are misapplied.

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ASSESSING SEASONAL EFFECTS ON THE CONTROL OF *CYCAS* SP. IN THE NORTHERN TERRITORY, AUSTRALIA

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Summary

Current recommendations are outlined for the control of *Cycas* sp. The use of fire and seasonal conditions to improve the efficiency of the control methods are outlined. Four herbicides including the recommended herbicide were used in a seasonal effects trial to assess any seasonal effects on the kill achieved. Preliminary results do not indicate any marked seasonal effects on the kill achieved with three of the herbicides. Some seasonal influence on the effect of one of the picloram formulations has been observed. This is compared with the growth rhythm of the population.

THE PLANT AND CLIMATE

The taxonomy of the *Cycas* genus in the Northern Territory of Australia is in a state of uncertainty with at least three and possibly five species recognizable in the field. One, which may possibly be *Cycas media,* causes considerable economic losses in an area within 100 km to the south and south-west of Darwin. It causes chronic poisoning of cattle with a high percentage of deaths, and with no recovery.

The plant is palm-like, usually with one growing point, and may be up to 4 m in height, but is most commonly under 2 m high. The trunk is 10 to 20 cm in diameter, with a large underground tuber up to 60 cm deep and 50 cm across. Regrowth can occur from any part of the trunk or tuber.

The climate of the region is marked by a wet season from December to April, and a dry season from May to November. Average rainfall ranges from 1100 to 1600 mm.

The growth of *Cycas media* occurs mainly in August to December with leaves being shed by the majority of plants in February. Reproduction occurs from June to the end of August. Fires at any time during the year can cause rapid growth to large plants, and in May-June cause vegetative growth at the expense of reproduction growth.

Densities of over 1000/ha occur and over large areas densities averaging 100 to 150/ha are usual on well-drained slopes. The plant cannot tolerate waterlogged conditions.

TABLE 1: RESULTS OBTAINED TO DATE

(All plants assessed after at least 6 months after treatment if possible)

	Month											
			1971						*1972*			
	Aug.	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun.*	*Jul.*
*Growth Phase**												
Dormant %	23	5	4	4	1	2	15	85	88	76	45	40
Active growth %	1	5	4	4	9	3	39	6	7	19	5	30
Leaves only %	67	90	92	92	90	95	45	6	8	5	50	26
Herbicidal Results												
Picloram/2,4-D:												
Killed %	85	25	10	94	75	55	25	30	0	0	0	0
Killed plus seriously affected %	90	100	100	100	95	88	70	70	65	5	10	0
Picloram/2,4,5-T amine:												
Killed %	80	33	60	89	70	25	11	10	0	0	0	0
Killed plus seriously affected %	100	100	85	100	90	90	47	70	55	10	20	0
Picloram/2,4,5-T ester:												
Killed %	35	28	40	30	25	15	5	10	0	0	0	0
Killed plus seriously affected %	45	67	75	55	30	65	30	30	0	0	0	0
Cacodylic acid:												
Killed %	50	5	40	80	50	37	19	30	0	0	0	0
Killed plus seriously affected %	85	90	95	100	100	100	65	70	30	65	10	50

*Dormant — No active growth visible in crown and all leaves are senescent or have been shed.
Active growth — Crown visibly expanding or leaves emerging and expanding.
Leaves only — Leaves present on plant, appear to be metabolically active.

Improved pastures are possible over a large proportion of the area infested with *Cycas* sp. These are often aerially sown without any land preparation.

CURRENT CONTROL TECHNIQUES

Recommendations have been developed for the control of this plant, and are based on picloram and 2,4-D. Control costs are about \$7.40 to \$9.90/ha spread over 2 to 3 years for densities of 100 to 150/ha. The control method is to inject 1 ml of the mixture into a cut 2 to 3 cm wide near ground level and at least 2 cm deep into the trunk using two cuts per plant. Burning the area before treatment is recommended to speed up treatment by allowing easier location of the plants. This is repeated in subsequent years to treat any regrowth and plants missed. Small, trunkless plants are treated with a mixture of 1:45 of picloram and 2,4,5-T (oil-soluble formulation) and diesel fuel. It is recommended that this treatment be delayed until after some rain has fallen which stimulates the smaller plants into active growth.

The recommendations have been developed from experience in field experiments mainly conducted in August to October.

More recently it has been shown that liquid inorganic arsenical formulations can be used with good results. Problems of toxicity are much greater than with picloram-based formulations.

SEASONAL EFFECTS TRIAL

In an experiment to improve the efficiency of the recommended treatments for the control of this plant, testing of the recommendations during the whole year was carried out. Three formulations of picloram and phenoxy herbicides and one organic arsenical were included in the trial. Twenty plants were treated with each herbicide at monthly intervals.

The chemicals used and the amounts injected into each cut, two cuts per plants, were as follows: picloram 5%/2,4-D 20% (amine formulation) — 1 ml; picloram 5%/2,4,5-T 20% (amine formulation) — 1 ml; picloram 10%/2,4,5-T 40% (ester formulation) — ½ ml; sodium salt of cacodylic acid 26% — 1 ml.

This trial commenced in August 1971, and treatments were completed in July 1972. The final results are not expected to be obtained until after the 1974 wet season. This will allow enough time for any regrowth to occur.

Each plant is serially labelled, its height and diameter measured, and growth stage noted.

RESULTS

Results to date are set out in Table 1. It is not possible to evaluate the final results until all treatments have been through two wet seasons. This is to allow for any regrowth and possibly for the chemicals to be translocated into the new shoots developing from the tuber and then kill them.

The data show a decline in effectiveness commencing during the January-February period, which corresponds to an increase in number of dormant plants.

Assessing results is difficult as the plants treated with organic arsenicals dry out without decomposition, whereas the plants killed by picloram decompose quite rapidly.

Effect of Chemicals

The ester formulation of picloram and 2,4,5-T shows a much slower response than the amine formulations. It also appears to have less consistent results, with many plants showing little indication that the chemical had been absorbed. This is probably due to less effective translocation by the plants of the ester formulation.

IMPLICATIONS IN CONTROL PRACTICES

Results to date are not sufficient to show definite seasonal effects but visual assessment of the speed of killing between plants treated in August-December and April-May shows that this may well be the case.

As outlined before, the recommendations developed from the consideration of several problems and observations in the field will not need to be substantially changed if the seasonal effects prove to be significant in achieving consistent control of this plant, and follow the growth cycle of the plant. The use of fire and its effect of stimulating plants into active growth may effectively mask seasonal effects in the field.

ACKNOWLEDGEMENTS

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REVIEW OF THE CONTROL OF EUCALYPTS (*EUCALYPTUS* SPP.) BY STEM INJECTION WITH PICLORAM-BASED HERBICIDES AND ASSOCIATED PASTURE RESPONSE IN AUSTRALIA

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Summary

Experimental results and commercial experience in Australia show that picloram-based herbicides containing 2% picloram injected into the sapwood at 1 to 2 ml per injection pocket spaced approximately every 15 cm of basal circumference are effective on most mature *Eucalyptus* species. Soil moisture was higher and grass production was more rapid and greater in quantity in plots injected with picloram-based herbicide. Legumes broadcast-sown in chemically treated plots established normally. Injection of mature eucalypts with picloram-based herbicide at commercial use rates, 4 to 7 months prior to mechanical pushing, reduced lignotuber regrowth by at least 90% of the non-injected control plots.

Control of unwanted mature eucalypts with picloram-based herbicides[1] is widely practised in Australia. Spaced injections with these herbicides has generally replaced ringbarking and low frill application of amine salt or butyl ester of 2,4,5-T. The effectiveness of stem injections with picloram-based herbicides has been referred to in the Australian literature by several workers (Ferguson, 1965; Watson, 1967; Kimber, 1967; Murphy, 1968; Young, 1968). More recently, Murphy (1970) concluded that research in Australia with picloram since 1963 and observation of commercial work since 1966, indicated that an aqueous solution of picloram, containing 2% picloram, applied into the sapwood at 1 to 2 ml per injection pocket spaced approximately every 15 cm of basal circumference[2] was effective on most mature eucalypts.

[1] Referred to from hereon as picloram. Unless otherwise specified, it contains the amine salt of picloram plus the amine salt of 2,4-D or 2,4,5-T in a ratio of 1:4.

[2] Commercial use recommendation equivalent.

Robertson and Moore (1972) working near Talwood (Queensland) from 1964 to 1970 showed that waist-high injection of mature bimble box (*Eucalyptus populnea*), 70 to 100 cm in circumference at the base, was as effective as injection at the tree base when equal amounts of chemical were applied at each height of application. 2 ml of 1% picloram injected every 13 cm of basal circumference repeatedly killed more than 90% of injected bimble box. They found with bimble box that, when spacing injections between 8 and 18 cm, concentrations of chemical and volume of injection appeared to be important only as determinants of the amount of chemical applied per tree. They also found that curved, narrow-bladed (2.5 to 5.0 cm) application equipment was better than the standard axe with a 13 cm blade.

Results from the analysis of 6 867 trees from 30 experiments carried out by the writer (unpubl.) between 1966 and 1970 involving 27 *Eucalyptus* species in New South Wales and Queensland are similar to those found by Robertson and Moore (1972) for height of injection, dose rate and cut frequency and equipment type. However, results showed that larger trees were harder to kill, and that mature eucalypts are harder to kill in the winter in high altitude areas such as the New England in New South Wales. These results are summarized in Table 1. This variation with tree size and time of treatment was not evident on bimble box (Robertson and Moore, 1972).

TABLE 1: SUMMARY OF t-TEST AND χ^2 ANALYSIS OF RESULTS FROM 6867 MATURE EUCALYPTS INJECTED WITH PICLORAM-BASED HERBICIDES IN AUSTRALIA

	Not killed	*Killed*
Number of trees	1551	5316
Av. circumference (cm)	129	102
Standard deviation of mean	0.56	0.27

$t' = 17$. Correlation coefficient for diameter and picloram volume $r = 0.68$.

Season Injected	*% Killed*	*No. of Trees*	χ^2
Spring	90.06	1388	193 (12.84 sig. @ 99.5% level)
Summer	76.64	1648	0.95 (1.32 sig. @ 75% level)
Autumn	78.17	1246	17.7 (7.88 sig. @ 99.5% level)
Winter	70.75	2585	

It is common practice in Australia to reduce tree densities to increase grass and herbage production. In most cases the dead trees are left standing; however, the practice of pulling following chemical kill to prepare a seedbed is increasing in N.S.W. and Victoria. Walker *et al.* (1972) at Talwood, Queensland, found the highest dry weight of herbage from areas in which individual mature bimble box was chemically injected was 2600 kg/ha, compared with ringbarked 1540 kg/ha, and untreated 820 kg/ha. Growth response was also more rapid in chemically treated areas. Experiments near Oberon, N.S.W., by the writer (1971-2) evaluated growth of natural grass pasture comprising red anther wallaby grass (*Danthonia pallida*), tussock grass (*Poa sieberana*), Yorkshire fog (*Holcus mollis*), silver grass (*Vulpia megaleura*), silver hair grass (*Aira caryophylla*), as well as the growth of subterranean clover (*Trifolium subterraneum*) and white clover (*Trifolium repens*) which were broadcast with molybdenum-superphosphate on April, 1971, 49 days after timber treatments of picloram injection, ringbarking and untreated. Plots containing a high population of mature mountain gum (*Eucalyptus dalrympleana*) and white sallee (*E. pauciflora*) were basally injected at 15 cm spacings with the potassium salt of picloram and 1 ml of 2% and 2 ml of 2% picloram were compared per injection pocket. Four 460 m^2 randomized plots of each treatment were laid down. Average number of trees per 460 m^2 plot was 47 (1022/ha); mean total basal circumference per plot was 4048 cm (880 m/ha). Variation on tree size distribution in the experimental area was not significant ($F = 0.14$). Over such a dense tree population, the rates of picloram injected into trees was equivalent to a mean of 231 g/ha (2 ml of 2% picloram) and 115 g/ha (1 ml of 2% picloram). These injection use rates closely represent peak use rate practised in a few areas only. Normal average injection use rates are between 70 and 90 g picloram/ha. Good legume germination occurred in all treatments but low survival and slow growth were evident in all plots in 1971. Quadrat counts of white clover and subterranean clover throughout 1971 showed no significant differences in legume distribution and no visual growth differences were evident throughout the experimental area. A large proportion of legumes in the plots flowered and set seed in 1971 when only 3.8 to 5.1 cm high. Legume yield was not taken in the field in 1971. Legume measurements in the plots in August 1972 indicated that the area of clover plants and mature trifoliate leaf area of these plants was significantly different only in plots where mature trees were not treated chemically or ringbarked. These results (Table 2), in addition to observations in the field during 1971 and a quantitative bioassay glasshouse pot experiment in early 1972 with three levels of leaf mulch collected from the trial area in August 1971 (data not presented here), indicate that there was no significant difference in growth of subterranean clover or white clover with the treatments compared. No allelopathic effects from the leaves of mountain gum or white sallee in field or pot bioassay comparable to those described by del Moral and Muller (1969, 1970) for southern blue gum (*E. globulus*) and river red gum (*E. camaldulensis*) were evident.

TABLE 2: LEGUME MEASUREMENTS, AUGUST 1972, FOLLOWING TREATMENT OF EUCALYPTS

(Measurements are the mean area per plant from 24 quadrats ($0.36 \, m^2$)/plot. Treatments A-D were replicated 4 times)

Treatment of Trees (Feb., 1971)	*Mean Area of Clover Plants (cm^2)*	*Mean Area of Mature Trifoliate Leaf/Plant (cm^2)*
A. Picloram injected 115 g/ha	7.27	1.13
B. Picloram injected 231 g/ha	8.08	1.28
C. Collar ringbarked	8.22	1.19
D. Not treated	3.44	0.77
LSD ($P = 0.05$ for means)	1.04	0.34

Grass yields from the experiment were taken 8 months after picloram injection in 1971. Table 3 shows increased dry weight yield from picloram-injected plots as well as the benefit of ringbarking.

Nitrogen and phosphorus content of the dry pasture samples in Table 3 were found to be similar for each treatment, so quality was therefore consistent with yield.

Results from experiments in Australia also indicate that injection of mature eucalypts with picloram will control most stem coppicing or lignotuber regrowth which normally occurs after pulling, pushing or sawing-off. Robertson (1970) reported that kills of bimble box with mean basal circumference of 56 cm ranged from 87.5% for trees cut after one week and 95 to 100% kill for subsequent cutting times up to 64 weeks following basal injection with 2 ml of 1% amine salt of picloram plus 4% amine salt of 2,4-D at 13 cm spacing. Experiments by

TABLE 3: GRASS YIELD EIGHT MONTHS AFTER TREATMENT OF EUCALYPTS

(From four 1 m^2 quadrats/plot. Each treatment mean of 4 plots)

Treatment of Trees (Feb. 1971)	*Mean Dry Weight of Grass Pasture (kg/ha)*
A. Picloram injected 115 g/ha	2787
B. Picloram injected 231 g/ha	3127
C. Collar ringbarked	1545
D. Not treated	1360
LSD ($P = 0.05$ for means)	1056

the writer at Goulburn and Grafton, N.S.W., between 1970 and 1972 showed that lignotuber regrowth of forest red gum (*E. tereticornis*), grey ironbark (*E. paniculata*), red bloodwood (*E. gummifera*), swamp box (*Tristania sauveolens*), red stringybark (*E. macrorhyncha*) and scribbly gum (*E. rossii*) could be greatly reduced by application of commercial use rates of picloram 4 to 7 months prior to pushing and windrowing.

At Goulburn, red stringybark and scribbly gum were injected with picloram at commercial use rate in October 1970 and January 1971. 1.6 ha injected and untreated trial areas were pushed, windrowed and cultivated twice, including pasture drilling during May, 1971. Original tree density was 978 trees/ha. The number of regrowth plants in March 1972, which ranged from 0.4 to 0.8 m high were: Picloram injected, 15/ha, and untreated 852/ha. Results were similar for October and January 1971 at Goulburn. Figure 1 demonstrates this difference.

At Grafton, forest red gum, grey ironbark, red bloodwood and swamp box were injected with picloram in November 1970 and February 1971. Plots of 1.6 ha were pushed, windrowed, cultivated once, and pasture and fertilizer broadcast during May 1971. Original tree density in picloram plots was 630/ha and 714/ha in untreated plots. Table 4 shows the number of seedlings and lignotuber regrowth per hectare in March 1972 calculated from seven 405 m^2 quadrats per plot.

Results were similar for November 1970 and February 1971 injections. Figure 2 indicates the difference in lignotuber regrowth which ranged from 0.6 to 0.9 m high. Seedlings present cannot be seen in the long grass.

Fig. 1: Regrowth of red stringybark and scribbly gum in the foreground after pushing the untreated control and the original tree density and control of regrowth obtained when picloram injection preceded pushing, windrowing and two cultivations. (Goulburn, N.S.W.)

Randomized plots of picloram injection, ringbarking and nil treatment of red stringybark and scribbly gum were laid down at Goulburn in January 1971. Regular measurement of soil moisture during 1971 indicated that increased levels of available soil moist-

TABLE 4: EFFECT OF PICLORAM TREATMENT ON NUMBER OF SEEDLINGS AND LIGNOTUBER REGROWTH

Treatment of Trees	*No. Eucalypt Seedlings and Lignotuber regrowth/ha (and % of original tree density)*	*No. of Eucalypts from lignotuber regrowth only/ha (and % of original tree density)*
Picloram low injection	126 (20%)	12 (2%)
Picloram high injection	261 (37%)	27 (4%)
Untreated	741 (104%)	667 (93%)

Fig. 2: Regrowth of forest red gum, grey ironbark, red bloodwood and swamp box in the foreground after pushing the untreated control and the original tree density and control of regrowth obtained when picloram injection preceded pushing, windrowing and one cultivation. (Grafton, N.S.W.)

ure, especially during dry conditions, occurred early in picloram-injected plots and later in ringbarked plots. Such increased levels of soil moisture promoted pasture growth and made it easier to push trees. 16.7 cm of rain between January and March resulted in no difference in available soil moisture at the end of March, two months after injection.

By this time trees in injected plots were necrotic. At the end of April, after a further 1.7 cm of rain, soil moisture with picloram injection was 11.9% above ringbarked and untreated. Only 2.1 cm of rain fell from May to July. Over the period from mid-May to mid-July, picloram plots averaged 40.6% more moisture on a dry weight basis than ringbarked and untreated plots. 11.4 cm of rain fell through August-September. By this stage part necrosis was evident in ringbarked plots which showed 20% more moisture than untreated plots. In contrast, picloram plots showed 65% more moisture than untreated controls.

Cash flow cost analysis based on data from experiments, including grazing return following injection, shows that it is normally more profitable to inject eucalypts with picloram-based herbicides at commercially recommended use rates preceding pulling, than to pull and try to control subsequent regrowth manually, mechanically or chemically.

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FARM DEVELOPMENT OUT OF SCRUB ON THE VOLCANIC PLATEAU IN NEW ZEALAND

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INTRODUCTION

At the completion of World War 2, there was an unprecedented demand for farms from discharged servicemen. Under legislation enacted in 1929, the Lands and Survey Department had been developing unimproved land for settlement in the immediate pre-war years, so that the administrative and financial organization existed for an immediate expansion to meet the need. Up to the present, the Department has developed and settled some 4,268 farms for ex-servicemen and later for civilian settlement, and still farms 448,000 ha in various stages of development and consolidation, which will produce a further 1,419 farms for eligible young farmers.

It is not intended in this paper to analyse the soil types and vegetation of New Zealand or the pattern of farm settlement since colonization, but it must be pointed out that the great area of undeveloped land left at this time was on volcanic land in the centre of the North Island and in the more difficult clay country of North Auckland.

All attempts to farm the volcanic plateau up until the mid-1930s had resulted in failure, as stock wasted away from what was known as "bush sickness", but when Australian research workers pinpointed cobalt deficiency as the cause of the problem, the way was clear to develop the land for pastoral use. The economic depression of the thirties and the war, with its resultant manpower shortage and phosphate rationing, delayed any major work until 1946.

The soils of the volcanic plateau are derived from volcanic ash shower deposits, over a period of time from 7000 B.C. to 250 A.D. The soils vary from coarse, rubbly pumice to fine pumice particles; they are deficient in phosphate, potash, and nitrogen and in cobalt, selenium and magnesium. Rainfall varies from 100 to 200 m with an even spread, and altitude is mainly in the range 300 to 600 m. Since 1946, the Rotorua Branch of the

Lands and Survey Department has settled 100,000 ha in 1,000 farms and is still farming 68,000 ha of grass on 53 blocks.

Appendix 1 sets out the actual figures taken from the trading accounts of a recently developed block of 5,700 ha. Development first started in the spring of 1965 after completion of a land capability survey and inspection by the Land Utilisation Committee, to determine those areas which in the interests of conservation should be retained in a natural state or planted in trees, and those areas which were suitable for grassland development. One hundred and sixty hectares of contiguous steeper country were planted in exotic trees, and 800 ha were retained in the original cover as conservation and scenic reserves.

VEGETATION

Natural cover on the block was typical of the whole of the volcanic plateau and comprised 30% bracken (*Pteridium aquilinum* var. *esculentum*), which burns readily without any preparation other than firebreaking; 55% of the block was growing manuka (*Leptospermum scoparium*) 2.5 to 3 m high which was crushed with flanged rollers at a cost of $12.50 to $15.00/ha; and 15% was growing second-growth bush comprising five-finger (*Neopanax arboreum*), mahoe (*Melicytus ramiflorus*), koromiko (*Hebe salicifolia*), and *Coprosma* spp. The average height of this vegetation is 4 to 5 m, 100 to 200 mm in diameter and it is cleared by two D6 tractors pulling a 55 m anchor chain with a ¾ tonne centre weight at a cost of $19.50 to $24.70 per hectare.

Ten metre wide firebreaking costing from $3 per 20 m on easy contour, up to $6 on steep contour, and averaging $3.70 to $5.00 per hectare, completes all of the costs, totalling $22 per hectare shown under clearing costs in Appendix 1.

A hot fire is essential to clean up all surface litter before cultivation.

CULTIVATION AND GRASSING

In its formative years in land development, the Department learned the advantages of using contractors with their own machinery to undertake development operations. All cultivation is done on a tender and contract basis but with the Department reserving the right to alter individual operations to suit the needs of any soil type. A normal programme would consist of a super giant discing (750 mm blades) followed by a tandem discing and heavy harrowing to produce an adequate seedbed. At this stage bulk ground spreaders on the easier contour and aircraft on steeper country sow cobaltized potassic superphosphate at the rate of 1,230 kg/ha and this is followed immediately by grass and clover seed sown either from aircraft or from seed-boxes mounted on Cambridge rollers.

The seed mixture sown per hectare comprises: 5.6 kg perennial ryegrass (*Lolium perenne*), 3.4 kg 'Grasslands Ariki' ryegrass (L. *hybridum*), 3.4 kg Italian ryegrass (*L. multiflorum*), 4.5 kg cocksfoot (*Dactylis glomerata*), 1.1 kg timothy (*Phleum pratense*), 1.1 kg crested dogstail (*Cynosurus cristatus*), 3.4 kg white clover (*Trifolium repens*), 2.2 kg red clover (*Trifolium pratense*).

Clover nodulation has followed readily on areas up to 600 m altitude but on areas over this altitude the addition of a clover inoculant has been critical.

All pasture species have established quickly and are maintained with an annual dressing of 310 kg of potassic, sulphur-fortified, cobaltized superphosphate. Yorkshire fog (*Holcus lanatus*), browntop (*Agrostis tenuis*) and *Lotus major* volunteer in the pasture, but create no problem. Nodding thistle (*Carduus nutans*), broom (*Cytisus scoparius*), and ragwort (*Senecio jacobaea*) invade pastures over subsequent years and require chemical control, except that ragwort can be controlled with higher sheep to cattle ratios and grazing management.

OTHER IMPROVEMENTS

Improvements on the land are located and constructed to suit the needs of settled farms, from a preconceived plan of the area required to constitute a one-man farm. Water points, house and out-buildings are located on planned individual farms, and fences follow farm boundaries as nearly as possible. Changing technology and economics between development and settlement frequently make later changes essential.

In the years following the completion of clearing and grassing, 1,500 ha were split from the block and placed under separate management, and the following year the second sub-block of similar size was placed under independent management. It has since been run as three separate blocks.

STOCKING

During the period of development, the block was stocked with dry ewes transferred from other blocks in the spring. Some were retained over the winter but most were sent to the works in the autumn. Dry cattle, too, were transferred from other blocks and in numbers sufficient to control bracken regrowth in the spring and utilize available pasture supplemented with hay in the winter.

Breeding ewes were introduced in the 1968-9 year and breeding cows in the following year. Optimum stocking rates approximating 12.5 stock units per hectare were reached in 1970-1 in which year the block trading accounts showed a net profit.

COSTS

Analysis of Costs

Total capital costs	$1,125,586
Total capital costs per ha grass	$279
Total maximum debt (30/6/71) (includes cost of livestock and plant and uncollected interest on capital)	$1,496,876
Total maximum debt:	
per ha grass	$357
per stock unit	$29

Estimated Profits

On the assumption that breeding percentages will average 85% (they exceed 90% in 1972-3), that wool will return 75c per kg net, and that fat lambs will realize $6 per head, gross profits will not be less than $120,000 annually.

This represents a return of 8% on the total capital invested — or 7½% return on the present value of the asset of $1,670,000.

While it is desirable to consolidate the land and pasture by farming for 8 to 12 years before settlement, the block could now be settled in 16 sheep and cattle farms of approximately 240 hectares of grass each. The farms would carry 1,600 to 1,800 ewes and replacements and 120 to 140 cows and replacements.

Further capital expenditure required would be

3 houses and implement sheds with water supplies and electric power reticulation	$43,000
13 woolsheds, yards, dip and plant	$49,000
Water reticulation	$11,000
Further conservation planting and fencing	$24,000
Fencing for closer subdivision	$60,000
Miscellaneous sundry expenditure	$20,000
Total further expenditure	$207,000

The value of these farms settled on a freehold, going-concern basis would be approximately $115,000 each or a total realization of $1,840,000. Thus, with cash outstanding as at 30/6/72 of $1,429,086, plus further capital expenditure of $207,000, a total cost to settlement of $1,636,000, the total profit if settled now would be $204,000.

In addition, the Crown retains 800 hectares of reserves and 160 hectares planted in exotic pine trees.

APPENDIX 1

Balance sheet figures as at 30 June for the years

	1965	*1966*		*1967*		*1968*	
	$	$	$	$	$	$	$
		For Year	*To Date*	*For Year*	*To Date*	*For Year*	*To Date*
Grassing:							
Cultivation (ha)		1,450		675		314	
Seed sowing (ha)		260	1,490	112	775	10	326
Total to date (ha)			1,490		2,265		2,591
Development Expenditure:							
Fencing	647	38,987	39,634	31,009	70,643	26,346	96,989
Clearing	18,109	26,195	44,304	31,718	76,023	8,774	84,797
Grassing	10,528	97,412	107,940	52,292	160,232	28,447	188,679
Conservation		1,195	1,195	4,583	5,779	3,465	9,244
Buildings		18,001	18,001	28,268	46,269	21,434	67,703
Roads & bridges	6,647	1,225	7,872	21,000	28,872	6,730	35,602
Water		6,148	6,148	17,244	23,392	16,532	39,924
Shelter							
Power				3,450	3,450	2,380	5,830
Total	35,931	189,163	225,094	189,564	414,660	114,108	528,768
Livestock:							
Breeding ewes					2,060		
Other sheep			4,946		10,861		17,021
Breeding cows	Nil						195
Other cattle			1,483		3,049		1,868
Stock units			8,898		20,772		18,854
Total running costs	199		10,291		25,913		55,154
Gross profit or loss	L199		L81,826		L85,200		L2,917
Interest	842		9,542		25,678		35,927
Net profit or loss	L1,041		L91,368		L110,878		L38,844
Total debt	36,760		390,016		754,369		843,942

1965 to 1972 of a 5,700 ha development block

1969		*1970*		*1971*		*1972*		
1,380								
212	1,590							
	4,181		4,060		3,900		3,840	
$ For Year	*$ To Date*	*$ For Year*	*$ To Date*	*$ For Year*	*$ To Date*	*$ For Year*	*$ To Date*	*$ per ha Grass*
49,822	146,811	32,777	179,588	34,679	214,267	14,883	229,150	57.0
6,400	91,197	2,013	93,210		93,210	213	93,423	22.0
141,907	330,586	13,640	344,226	3,065	347,291	554	347,844	86.50
1,439	10,683	1,458	12,141	423	12,564	5,540	18,104	4.80
65,203	132,906	44,568	177,473	28,900	206,373	9,037	215,411	54.0
37,768	73,370	4,973	78,343	4,405	82,748	3,082	85,830	21.0
35,518	75,442	24,889	100,331	17,733	118,064	4,881	122,945	30.0
				250	250	2,004	2,254	3.70
4,795	10,625		10,625		10,625		10,625	
342,852	871,620	124,318	995,937	89,455	1,085,392	40,194	1,125,586	279.00
	11,213		21,985		26,706		23,723	
	16,364		8,627		8,323		9,853	
			1,801		2,184		2,248	
	3,864		2,082		1,718		1,385	
	36,487		46,295		51,676		48,663	
	72,113		125,579		164,952		209,214	
	L59,056		P40,554		P71,223		P106,727	
	49,166		62,496		65,954		65,370	
	L108,222		L21,942		P5,269		P41,357	
	1,357,849		1,450,152		1,496,876		1,429,086	

HERBICIDES FOR THE CONTROL OF BARNYARD GRASS (*ECHINOCHLOA CRUS-GALLI*) IN MAIZE

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Summary

In the Murrumbidgee Irrigation Areas of New South Wales atrazine applied pre-emergence to control barnyard grass (*Echinochloa crus-galli*) in maize has sometimes given poor results. Some alternative herbicides and different ways of using atrazine have therefore been investigated.

Butylate and mixtures of atrazine with cyanazine and with butylate were used pre-plant incorporated. Atrazine, cyanazine, alachlor, propachlor and prynachlor were compared pre-plant incorporated and post-plant pre-emergence. Post-emergence treatments were atrazine with crop oil additive, cyprazine and mixtures of propachlor with atrazine and with cyprazine.

In one trial all post-plant pre-emergence applications were ineffective, perhaps because a relatively dry period followed treatment. Soil incorporation improved the performance of pre-emergence herbicides. Post-emergence applications of atrazine plus oil and cyprazine gave excellent results.

Since pre-plant incorporation is difficult in row crop husbandry and cloddy soils, it may be preferable to use atrazine (with crop oil) as a post-emergence treatment.

INTRODUCTION

In the Murrumbidgee Irrigation Areas of New South Wales, maize is usually grown as a row crop with furrow irrigation. Atrazine is used as a pre-emergence band spray to control heavy infestations of barnyard grass (*Echinochloa crus-galli*), but treatments have sometimes been ineffective. Poor results may perhaps be related to inadequate distribution of atrazine in the root zone of germinating weed seedlings.

Where similar difficulties have been experienced elsewhere, improved control with atrazine has been obtained by pre-plant incorporation or post-emergence spraying with oil additives (Le Baron, 1970). This paper reports attempts to evaluate these approaches to using atrazine, and the usefulness of some alternative herbicides.

MATERIALS AND METHODS

TRIAL 1

A trial for post-emergence herbicides (Table 1) was sited where a heavy infestation of barnyard grass occurred. Treatments

TABLE 1: THE EFFECT OF POST-EMERGENCE HERBICIDES ON BARNYARD GRASS APPLIED "EARLY" (E — applied 18/11/71) OR "LATE" (L — applied 24/11/71)

E/L	*Treatment (kg/ha)*	*Score for Effectiveness** 26/11/71	3/12/71	9/12/71	22/12/71
—	Control	1.0 a	1.2 a	1.0 a	1.1 a
E	Control oil (1.6%)	1.0 a	1.1 a	1.0 a	1.2 a
E	atrazine 1.1 + oil (1.6%)	6.5 b	5.4 b	6.1 b	3.9 b
E	cyprazine† 2.0	7.8 cd	7.2 c	7.4 c	4.2 bc
E	atrazine 2.2 + oil (1.6%)	8.0 c	7.7 cd	8.0 d	5.1 c
L	cyprazine† 2.0	—	8.0 de	8.7 e	6.9 de
E	atrazine 4.5 + surfactant (0.5%)	7.2 d	8.4 e	9.2 f	6.4 d
E	atrazine 4.5 + oil (1.6%)	9.2 e	9.3 f	9.4 f	7.5 ef
E	atrazine 2.2/propachlor 4.5 + oil (1.6%)	9.4 e	9.3 f	9.6 fg	8.1 f
L	atrazine 4.5 + oil (1.6%)	—	9.6 f	9.9 g	9.3 g

*Each score represents mean of 5 observations. 1 = little or no effect; 10 = complete kill. For one observation date means followed by the same letters are not significantly different at the 5% level as determined by Duncan's multiple range test.

†Wetter included in formulated product.

were applied when the weeds were 1 to 2½ leaves high and six days later when 3 to 4 leaves high. A precision sprayer was used at a pressure of 16.5 kPa and delivered 346 l/ha through four 730308 Teejet spraying nozzles spaced at 50 cm intervals. Each treatment was replicated five times in 16 m^2 plots.

TRIALS 2 AND 3

A site on a grey medium clay soil at Carrathool, New South Wales, was selected for Trials 2 and 3. Organic carbon, determined by the method of Tinsley (1950) was 1.6%; clay ($< 2\,\mu$) by pipette separation was 61%; and pH, at a ratio of 1 : 2.5 soil : 0.02 M calcium chloride, was 7.0. Maize was grown in beds 2 m wide.

Trial 2 treatments in kg/ha were: Pre-plant incorporated — atrazine 1.1, butylate 3.3, butylate 3.3 + atrazine 1.1; Post-plant pre-emergence: atrazine 3.3. Plots of 50 m^2 were treated in duplicate using a knapsack sprayer delivering 224 l/ha. Immediately after spraying on 26/11/70 pre-plant treatments were incorporated with Lilliston cultivators to a depth of about 7 cm. The soil was dry at spraying; irrigation was applied 24 hours later. Rainfall was 5, 1, 5, 5 and 3 mm after 8, 12, 13, 15 and 32 days, respectively. The trial was assessed 19, 27 and 40 days after treatment.

TABLE 2: THE EFFECT OF HERBICIDES ON CONTROL OF BARNYARD GRASS IN MAIZE (PLANTED 28/11/71)

Treatment (kg/ha)	*Score for Effectiveness** 22/12/71 *Mean*	*SE*	11/1/72 *Mean*	*SE*	1/2/72 *Mean*	*SE*
Pre-plant incorporated (applied 25/11/71)						
Control	0.8	0.5	1.8	0.1		
atrazine 4.5	7.1	0.4	7.1	0.8		
cyanazine 2.2	6.3	0.6	4.9	1.3		
cyanazine 2.2/atrazine 1.1	6.3	0.5	7.5	0.5		
alachlor 2.2	5.5	1.2	5.0	1.3		
propachlor 4.4	4.0	0.6	3.5	0.9		
prynachlor 4.5	5.0	0.0	2.9	0.4		
butylate 4.5	7.5	0.5	6.8	0.6		
butylate 4.5/atrazine 1.1	8.1	0.7	7.3	0.9		
Post-plant pre-emergence (applied 29/11/71)						
Control	0.6	0.3	1.1	0.5		
atrazine 4.5	0.6	0.3	3.2	0.3		
cyanazine 4.5	0.8	0.2	1.5	1.0		
alachlor 4.5	1.0	0.2	0.6	0.3		
propachlor 4.4	0.8	0.2	0.6	0.3		
prynachlor 6.8	1.6	0.6	2.5	0.7		
Post-emergence (applied 9/12/71)						
Control	0.8	0.2	0.9	0.3	0.0	0.0
atrazine 2.2 + oil (1.6%)	6.0	0.0	5.3	0.2	2.2	0.5
atrazine 4.5 + oil (1.6%)	8.7	0.2	9.1	0.4	8.7	0.5
cyprazine† 2.2	6.0	0.0	5.4	0.7	3.0	1.0
cyprazine† 4.5	8.7	0.3	8.5	0.3	9.3	0.4
atrazine 2.2/propachlor 4.5 + oil (1.6%)	7.7	0.3	7.6	0.2	7.8	0.2
cyprazine† 2.2/propachlor 4.5	8.0	0.4	8.4	0.4	8.2	0.6
Post-emergence (applied 16/12/71)						
Control	—	—	1.1	0.5	0.4	0.2
atrazine 2.2 + oil (1.6%)	—	—	3.4	0.6	2.8	0.8
atrazine 4.5 + oil (1.6%)	—	—	8.6	0.3	8.0	0.4
cyprazine† 2.2	—	—	5.1	0.4	2.8	0.8
cyprazine† 4.5	—	—	9.5	0.1	9.5	0.2

*Each score represents mean of 4 observations for pre-plant treatments; 5 observations for other treatments. 0 = no effect; 10 = complete kill.
†Wetter included in formulated product.

In Trial 3 a range of herbicides and mixtures and times of application were compared (Table 2). Each treatment was replicated five times in plots of 12 m^2. The precision sprayer described in Trial 1 was used. Pre-plant treatments were incorporated to a depth of about 7 cm using a rotary hoe. Maize was planted into wet ground on 28/11/71 and pre-emergence treatments applied the following day. Post-emergence treatments were applied 11 days after planting when grass was 2 to 3 leaves high and 7 days later when 4 to 6 leaves high. Rainfall within 3 weeks of planting was 6 mm.

In all trials weed control and crop damage were assessed visually by two independent observers.

RESULTS

In Trial 1 (Table 1) some post-emergence herbicides were compared. When applied at an "early" (1 to 2½ leaf) stage of grass growth, atrazine + oil (4.5 kg/ha) and atrazine + propachlor + oil (2.2 kg + 4.5 kg) gave excellent control. Atrazine with surfactant additive was marginally less effective. Cyprazine (2.0 kg) gave only moderate control. When applied at a "late" (3 to 4 leaf) stage, atrazine + oil (4.5 kg) was superior to cyprazine (2.0 kg), and was the only treatment effectively controlling later-germinating weeds.

In Trial 2, control plots were infested with about 400 plants/m^2 when observed 27 days after sowing. All herbicide treatments gave virtually 100% weed control and atrazine, when incorporated at 1.1 kg/ha, was as effective as the pre-emergence surface application.

Some results from Trial 3 are shown in Table 2. In pre-plant incorporated treatments, control with atrazine (4.5 kg), cyanazine + atrazine (2.2 kg + 1.1 kg), butylate (4.5 kg) and butylate + atrazine (4.5 kg + 1.1 kg) was moderate. All non-incorporated pre-emergence applications including atrazine (4.5 kg) were ineffective. Post-emergence, cyprazine + propachlor (2.2 kg + 4.5 kg) and atrazine + propachlor + oil (2.2 kg + 4.5 kg) gave good control; atrazine + oil (4.5 kg) and cyprazine (4.5 kg) were excellent. With the exception of cyprazine at higher rates, where moderate scorching was observed 1 to 2 weeks after treatment, there were no signs of crop damage.

DISCUSSION

Pre-emergence incorporation of atrazine gave moderate to satisfactory control of barnyard grass (Trials 2 and 3). However, pre-emergence surface applications gave variable results, perhaps related to surface soil moisture conditions after sowing. All post-plant, pre-emergence herbicides tested were ineffective when a relatively dry period followed treatment. These results contrast with reports of successful trials elsewhere with cyanazine (Warrell, 1971) and prynachlor (Luib and Behrendt, 1970; Wallace, 1971).

Post-emergence treatments of cyprazine and of atrazine with crop oil additive gave excellent control at 4.5 kg/ha. Lower rates gave variable results (Trials 1 and 3) although used successfully in New Zealand (Woon, 1970). In Trial 3 reduced rates (2.2 kg/ha) were effective when used in mixtures with propachlor, confirming the results of Woon (1971); this could be advantageous in reducing hazards from long-persistence in rotations of maize with other crops.

Previously, post-emergence treatments of atrazine have not been recommended for the Murrumbidgee Irrigation Areas and applications, with surfactant additive, have only been successful where it was possible to spray the weeds at a very early stage of growth. However, in Trial 3, where atrazine was used with oil additives, treatments were satisfactory even when delayed until the grass was 4 to 6 leaves high. The difficulties of post-emergence spraying in practice are:

(1) It is doubtful that commercial equipment will give as good a cover as the precision sprayer.

(2) An additional spraying operation is required at the busiest time of the year.

(3) The soil will often be too wet to spray when the barnyard grass is in the 1- to 6-leaf stage.

Atrazine performance was also improved by soil incorporation, but in row crop husbandry and cloddy soils a post-emergence treatment may be preferable.

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GRASS CONTROL IN LUPINS WITH ALACHLOR, CARBETAMIDE AND 2,2-DPA

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Summary

Two experiments comparing grass control in autumn-sown lupins by alachlor, carbetamide and 2,2-DPA were conducted in 1971. Alachlor was used pre-emergence and carbetamide and 2,2-DPA post-emergence (3- to 5-leaf stage). Trifluralin (0.56 kg/ha) was applied pre-sowing as a standard.

Carbetamide 1 and 2 kg/ha and 2,2-DPA 4 kg/ha controlled both wild oat (*Avena fatua*) and Wimmera ryegrass (*Lolium rigidum*). Alachlor and the standard, trifluralin, reduced ryegrass infestations but were less effective against wild oat. No herbicide controlled all the broadleaf species present.

2,2-DPA at all rates delayed crop maturity and reduced flowering. The other herbicides produced no toxic symptoms at the rates used.

INTRODUCTION

Following the introduction of wheat quotas into Australian agriculture in 1969, Riverina farmers looked to the high-protein, autumn-sown legumes and oilseed rape as alternatives to wheat. Trifluralin was used to control the volunteer grasses, particularly Wimmera ryegrass (*Lolium rigidum*), which are the major weeds of the high protein legumes, but results were inconsistent.

Good selective control of grasses has been obtained in other legumes with alachlor, carbetamide and 2,2-DPA, and without the need for incorporation (Miles, 1969; Scholl and Williams, 1969; Cargill *et al.*, 1970). They were therefore compared with trifluralin in lupin grain crops.

MATERIALS AND METHODS

Two randomized, complete block experiments were laid down on moderately fertile Gombalin clay loams (Gn 2.12 : Northcote 1971) heavily infested with Wimmera ryegrass. There were three replications and plot size was 3 × 20 metres.

Herbicides were applied at a volume of 225 l/ha and a pressure of 2.5 kg/cm^2 using a Landrover-mounted spray unit. The pre-sowing treatment was applied to the soil during the morning and incorporated into the surface 5 cm by working twice with weighted, diamond harrows. Lupins, cv. Uniwhite, inoculated with the appropriate rhizobia, were drill sown in the afternoon. Superphosphate (22% P_2O_5) was drilled in with the seed at 100 kg/ha.

The weeds present, including an unexpectedly heavy infestation of wild oat (*Avena fatua*), were Wimmera ryegrass, wireweed (*Polygonum aviculare*), fumitory (*Fumaria* spp.), yellow burr-weed (*Amsinckia hispida*), Cape weed (*Arctotheca calendula*), and skeleton weed (*Chondrilla juncea*).

Yields were obtained by removing all top growth in two, randomly placed 796 cm^2 quadrats a plot. Botanical composition was obtained by separation and the yields expressed as dry matter/ha. Grain yield was obtained by harvesting the grain in 3×796 cm^2 quadrats per plot. Analyses were carried out on log $(x + a)$ transformations of the data and the results compared by means of Duncan's multiple range tests.

Experiment 1

The treatments were an untreated control, trifluralin (pre-sowing) as a standard at 0.56 kg/ha, alachlor (pre-emergence) at 0.5, 1.0 and 2.0 kg/ha, carbetamide (post-emergence at 3- to 5-leaf stage) at 0.5, 1.0 and 2.0 kg/ha and 2,2-DPA (post-emergence) at 1, 2 and 4 kg/ha. The trifluralin was applied 17/5/71, the pre-emergence treatments on 18/5/71 and the post-emergence treatments, because growth was slow, not until 29/7/71. Two mm of rain fell on the experiment site 24 hours after the pre-emergence sprays were applied.

Experiment 2

The treatments were the same as in the first experiment except that 2,2-DPA was omitted. Trifluralin was applied 14/5/71, the pre-emergence treatments on 18/5/71 and the post-emergence treatments on 13/7/71. Rain (5 mm) fell on the experiment site 10 days after the pre-emergence sprays were applied.

RESULTS

Experiment 1

All treatments except carbetamide 0.5 kg and 2,2-DPA 1 and 2 kg/ha gave good control of ryegrass, but only carbetamide (1 and 2 kg/ha) and 2,2-DPA (4 kg/ha) controlled wild oat (Table

TABLE 1: EXPERIMENT 1 — MEAN SPECIES DRY MATTER YIELD AT FLOWERING AND LUPIN GRAIN YIELD

Treatment (kg/ha)			*Yield (kg/ha)*		
			Foliage		
	Avena fatua	*Lolium rigidum*	*Arctotheca calendula*	*Lupin*	*Lupin grain*
Control 0	2999 ab*	2146 a	0	1067 d	264 c
trifluralin (pre-sowing) 0.56	1104 abc	314 bc	251 a	2987 ab	1456 ab
alachlor (pre-em.) 0.5	5346 a	163 bc	0 b	1042 d	213 c
alachlor (pre-em.) 1.0	3512 ab	213 bc	13 b	1719 bcd	464 bc
alachlor pre-em.) 2.0	2146 ab	176 bc	38 ab	2347 abc	728 abc
carbetamide (post-em.) 0.5	3100 ab	552 ab	25 ab	1594 cd	515 bc
carbetamide (post-em.) 1.0	264 cd	125 bc	50 ab	3238 ab	1870 a
carbetamide (post-em.) 2.0	13 d	13 c	176 ab	3225 ab	2096 a
2,2-DPA (post-em.) 1.0	1142 abc	728 ab	13 b	2610 abc	213 c
2,2-DPA (post-em.) 2.0	966 bc	653 ab	13 b	3125 ab	326 bc
2,2-DPA (post-em.) 4.0	289 cd	251bc	25 ab	3389 a	213c
Transformation used	$\log(x + 2)$	$\log(x + 1)$	$\log(x + 1)$	$\log(x + 2)$	$\log(x + 1)$

*Figures not followed by the same letter differ significantly (Duncan's multiple range test, $P = 0.05$). Analyses of variance performed on appropriately transformed data.

1). Although grass removal increased lupin dry matter yield, only the trifluralin and the heavier carbetamide treatments increased grain yield. 2,2-DPA was toxic to the lupins, delaying maturity and reducing flowering. None of the other herbicides affected the crop at the application rates used. None of the herbicides affected Cape weed.

EXPERIMENT 2

Neither trifluralin nor alachlor gave effective grass control in this experiment, although alachlor (2 kg/ha) reduced ryegrass populations (Table 2). Adequate early, post-emergence grass control with carbetamide (1 and 2 kg/ha) increased grain yield several-fold as before. None of the herbicides affected crop growth. Alachlor was ineffective against the broadleaf weeds present but carbetamide (1 and 2 kg/ha) controlled fumitory and wireweed. Trifluralin controlled all broadleaf species present, including the perennial skeleton weed.

DISCUSSION

Alachlor, carbetamide and trifluralin controlled the ryegrass infestations at some or all application rates. However, except for carbetamide at 1 and 2 kg/ha none of the herbicides used can be recommended for the control of wild oats in lupins. 2,2-DPA is excluded because of its toxic effects on the crop.

The performance of soil-applied herbicides is influenced by soil type and rainfall incidence. Activity is greatest on sandy soils low in organic matter, where herbicides are leached into the soil surface shortly after application and, if rainfall is delayed, following incorporation (Poignant *et al.*, 1969; Wiese and Smith, 1970). As both experiments were on the same soil type, a similar level of herbicide activity could be expected. Thus the ten days which elapsed between pre-emergence spray application and the first rain on Experiment 2 probably contributed to the poorer performance of alachlor and, perhaps, trifluralin. In these circumstances, pre-sowing applications of alachlor incorporated shortly after application by the sowing operation require investigation.

The tendency towards greater broadleaf species infestations as application rates were raised is the result of reduced competition following suppression of the grass species. None of the herbicides controlled Cape weed. But, whereas alachlor and 2,2-DPA were ineffective against all broadleaf species, carbetamide controlled fumitory and wireweed and trifluralin all but Cape weed. The

TABLE 2: EXPERIMENT 2—MEAN SPECIES DRY MATTER YIELD AT FLOWERING AND LUPIN GRAIN YIELD

Treatment (kg/ha)	Yield (kg/ha) Herbage: Avena fatua	Lolium rigidum	Other Species	Lupins	Lupin Grain
Control 0	2723 ab*	452 b	1368 ab	25 c	13 c
trifluralin (pre-sowing) 0.56	3225 ab	364 bc	0 c	766 c	163 c
alachlor (pre-em.) 0.5	3072 ab	439b	226 c	339 c	13 c
alachlor (pre-em.) 1.0	4468 a	276 bc	515 c	251 c	63 c
alachlor (pre-em.) 2.0	3137 ab	163 cd	816 bc	527 c	125 c
carbetamide (post-em.) 0.5	1870 bc	828 a	1468 ab	941 bc	213 bc
carbetamide (post-em.) 1.0	100 d	0 d	1820 a	2472 ab	602 ab
carbetamide (post-em.) 2.0	0 d	0 d	766 bc	3514 a	853 a

*Figures not followed by the same letter differ significantly (Duncan's multiple range test, $P = 0.05$) by analysis of variance after transformation to log $(x + 1)$.

apparent suppression of the perennial skeleton weed by trifluralin is an important feature. The response is probably related to an inhibition of root bud development as reported by Parker (1966) in *Oxalis latifolia.* This warrants further investigation.

It was concluded that effective control of ryegrass in lupins was possible with trifluralin, alachlor and carbetamide. However, the presence of broadleaf species requires that other broad-spectrum herbicides also be considered as controlling agents.

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TRIFLURALIN AS A PRE-EMERGENCE HERBICIDE IN WHEAT

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Summary

In the 1970 season, six replicated field experiments were made in southern New South Wales, Australia, on the development of trifluralin as a pre-emergence herbicide in wheat. The problem weed species Wimmera ryegrass (*Lolium rigidum*), canary grass (*Phalaris* spp.) and wireweed (*Polygonum aviculare*) were satisfactorily controlled with rates of 0.28 and 0.41 kg/ha trifluralin without crop injury. Control of shallow-germinating wild oats (*Avena fatua*) seedlings was also obtained. Where weed infestations were severe, grain yield increases were obtained following trifluralin treatment. Larger farmer experience trials with treated areas up to 50 ha confirmed the experimental findings.

INTRODUCTION

In Australia, trifluralin has proved to be a reliable selective pre-emergence herbicide for use in a variety of crops. Currently trifluralin is registered as a herbicide for use in carrots, cotton, green and dry beans, linseed, lupins, orchards and vineyards, peanuts, peas, rape, safflower, soya beans, sugarcane, sunflowers, and transplants of broccoli, cabbage, cauliflower and tomato.

The development of trifluralin as a soil-incorporated pre-emergence herbicide for weed control in wheat and barley was commenced in Australia in 1968. The objective of the programme was to develop a method of application and incorporation of trifluralin to achieve broad-spectrum control of shallow-germinating annuals, such as Wimmera ryegrass (*Lolium rigidum*). canary grass (*Phalaris* spp.), wireweed (*Polygonum aviculare*), timothy (*Phleum pratense*) and wild oats (*Avena fatua* and *A. ludoviciana*) without damage to the germinating crop seed. These weed species are of economic importance in certain Australian wheat-growing areas. Currently ryegrass can be controlled by the use of alachlor, di-allate and tri-allate, wild oats by the use of tri-allate and barban, and dicotyledonous weed species with chlorinated phenoxy compounds and some other herbicides.

The biological basis for the selective use of trifluralin in wheat is that the sensitive coleoptile node of the wheat seedling must be kept out of the trifluralin-treated soil. Preliminary studies showed that separation could be obtained by use of the combine seed drill and harrows for shallow incorporation of trifluralin, and by accurately sowing wheat seed under the treated zone with the combine.

The experiments described form a part of the developmental programme for the use of trifluralin in wheat.

MATERIALS AND METHODS

In the 1970 season, trifluralin was applied on six wheat-growing properties in New South Wales. Time of application was from 14 days before to immediately before sowing, with rates of trifluralin from 0.28 to 0.84 kg/ha. Incorporation of the chemical into the soil was achieved by using a combination of two workings with a combine seed drill and heavy diamond harrows. Details of date of application, wheat cultivar, sowing date, depth and rate of sowing are shown in Table 1.

The experimental design used for all experiments was a randomized complete block. The treatment design consisted of a factorial containing all combinations of the two methods of incorporation and a number of chemical rates plus a control in two of the experiments. Number of replications and plot size used are given in Table 1.

Assessment of herbicidal efficacy was made by weed plant quadrat counts and visual weed control ratings:

(1) Weed plant quadrat counts: Ten to fifteen 0.09 m^2 counts per plot were made on each weed at the tillering crop stage. Counts were converted to a percentage weed control as compared with the control treatment count.

(2) Weed control ratings: control of individual weeds was visually rated on a 0 to 10 scale (0 = no control, 10 = 100% control) or the Barrett-Horsfall system at the heading crop stage (3 to 4 months after sowing). The ratings were again converted to a percentage weed control.
Assessment of crop response was by germination ratings, crop stand quadrat counts, root injury ratings, tiller counts and yield data.

Prior to carrying out analyses of variance, some form of square-root transformation was used on crop germination counts and

TABLE 1: AGRONOMIC DETAILS FOR THE APPLICATION OF TRIFLURALIN AND SOWING OF WHEAT FOR THE REPLICATED EXPERIMENTS IN THE 1970 SEASON

Site	*Trifluralin Application Date*	*Sowing Date*	*Wheat Cultivar*	*Soil Type*	*Depth of Sowing (cm)*	*Rate of Sowing (kg/ha)*	*No. of Replications*	*Plot Size (m)*
Borambola	22 May	29 May	Robin	Silt-loam	5	60	3	30 × 3.6
Coolamon (1)	5 May	19 May	Falcon	Clay loam	4	50	2	30 × 15
Coolamon (2)	3 May	12 May	Olympic	Clay loam	5	50	2	30 × 15
Milbrulong	25 May	26 May	Robin	Clay loam	5	60	2	30 × 15
Uranquinty (1)	6 May	13 May	Olympic	Clay loam	5	67	2	30 × 15
Uranquinty (2)	14 May	24 May	Robin	Clay loam	5	60	3	30 × 3.6

the other variables measured in an attempt to stabilize the error variances. Transformations were not made on grain yield data. Duncan's multiple range test was used to determine significance of difference between treatment means.

Additional farmer experience trials involving treated areas of from 5 to 50 ha were made in the 1970 and 1972 seasons in the south-eastern Australian wheat-growing region. Control strips were left adjacent to the treated areas. Weed control and crop response data were collected from each treated and control area.

RESULTS AND DISCUSSION

In three of four experiments in which initial trifluralin incorporation was made using harrows, significant grain yield increases were obtained (Table 2). This result was produced when competition from weed species was severe. At the Uranquinty (1) site where there was no effect on yield, the population of ryegrass was 0.4 plants per 0.09 m^2 and 2.4 plants per 0.09 m^2 for wireweed.

Control of ryegrass at the 0.28 kg/ha trifluralin rate was acceptable in all experiments (Table 3) and proved adequate to produce grain yield increases. The two higher rates of 0.41 and 0.56 kg/ha did not produce significantly higher yields than the lowest rate,

TABLE 2: GRAIN YIELD (kg/ha) FROM FOUR EXPERIMENTS
(Trifluralin was initially incorporated with heavy harrows. The second incorporation was either by a combine set to work to a depth of 5 cm or by harrows)

Incorporation Method and Trifluralin (kg/ha)	*Site* Coolamon (1)	Coolamon (2)	Milbrulong	Uranquinty (1)	*Mean*
Harrows + Combine:					
0	3172 ab	1452 b	1163 b	1626 a	1853
0.28	3387 a	1969 a	1566 ab	1808 a	2183
0.41	3111 ab	2016 a	1841 a	1613 a	2145
0.56	3447 a	2009 a	2016 a	1761 a	2308
Harrows + Harrows:					
0	2883 b	1505 b	1317 b	1431 a	1784
0.28	3138 ab	1922 a	1882 a	1552 a	2124
0.41	2843 b	2076 a	1875 a	1693 a	2122
0.56	3105 ab	2083 a	1888 a	1707 a	2196

Means in rows followed by a common letter are not significantly different at the 5% level as determined by Duncan's multiple range test.

TABLE 3: MEAN GRASS CONTROL % FOR RYEGRASS AND WILD OATS FROM FOUR EXPERIMENTS

Coolamon (1), Coolamon (2), Milbrulong and Uranquinty (1). Initial incorporation of trifluralin was by harrows. The second incorporation was either by a combine set to work to a depth of 5 cm or by harrows.

Incorporation Method and Trifluralin (kg/ha)	*Grass Control %*[1] *Ryegrass*	*Wild Oats*
Harrows + Combine:		
0	0 (5.1)[2]	0 (5.4)
0.28	74	54
0.41	74	74
0.56	96	92
Harrows + Harrows:		
0	0 (5.3)	0 (4.2)
0.28	84	79
0.41	94	89
0.56	92	87

[1] 95 to 100% control of wireweed was obtained at all trifluralin rates.
[2] Indicated number of plants/0.9 m^2.

TABLE 4: GRAIN YIELD (kg/ha) FROM TWO EXPERIMENTS

Borambola, Uranquinty (2). Initial incorporation was by either harrows or a combine set to work to a depth of 5 cm. The second incorporation was by harrows in both cases.

Incorporation Method and Trifluralin (kg/ha)	*Site* *Borambola*	*Uranquinty (2)*	*Mean*
Combine + Harrows:			
0	726 d	1667 bc	1196
0.28	1512 ab	2224 a	1868
0.41	1747 a	1949 ab	1848
0.56	1626 a	2218 a	1922
0.84	1559 ab	2097 a	1828
Harrows + Harrows:			
0	564 d	1646 bc	1105
0.28	1720 a	1915 b	1818
0.41	1814 a	2083 b	1949
0.56	1814 a	2224 a	2019
0.84	1633 a	1956 ab	1795
Control	806 cd	1546 c	

Means in columns followed by a common letter are not significantly different at the 5% level as determined by Duncan's multiple range test.

TABLE 5: MEAN GRASS CONTROL % FROM TWO EXPERIMENTS

Borambola and Uranquinty (2). Initial incorporation was by either harrows or a combine set to work to a depth of 5 cm. The second incorporation was by harrows in both cases.

Incorporation Method and Trifluralin (kg/ha)	*Grass Control %*[1] *Ryegrass*	*Wild Oats*
Combine + Harrows:		
0	26	13
0.28	79	44
0.41	82	64
0.56	80	68
0.84	93	76
Harrows + Harrows:		
0	25	5
0.28	80	58
0.41	84	71
0.56	84	79
0.84	82	75
Control	0 (25.4)[2]	0 (5.6)

[1] 95 to 100% control of wireweed was obtained at all trifluralin rates.
[2] Indicates number of plants/0.9 m^2.

although the weed control was better. At some sites trifluralin proved effective in controlling wild oats. Shallow germinating wild oat seeds were controlled but seedlings arising from greater depth were not affected.

Similar results to those described above were obtained at the Borambola and Uranquinty (2) sites (Tables 4 and 5). In both experiments satisfactory weed control and grain yield increases were produced at the 0.28 kg/ha trifluralin rate. There was a trend towards higher grain yields at the 0.41 kg/ha rate. In all six experiments little difference could be determined between either the methods used for the incorporation of trifluralin or the time of application before sowing.

The interesting feature of this work is that a grass herbicide has been used to control weed species in a susceptible cereal crop. A differential placement of the wheat and herbicide band was achieved by use of implements, harrows and combine seed drill, which resulted in incorporation of the chemical into a shallow surface band. Wheat seed was then sown accurately under this band with the combine. Even so, some retardation in germination did occur, although it was a transient effect, and was seldom noticeable by the time the wheat had tillered. At the low rates of 0.28 and 0.41 kg/ha, crop stands were not significantly affected. However, at the Coolamon (2) site with 0.56 kg/ha and Uranquinty (2) site with 0.84 kg/ha, there was a significant stand reduction. Even when this occurred, plant vigour and grain yield (Tables 2 and 4) were both higher than in the controls.

At least two morphologically sensitive regions in grass seedlings have been used to explain the site of trifluralin activity. Trifluralin has been shown to inhibit mitosis in the root tips (Lignowski and Scott, 1972) and to impede root development by changing the polarity of growth of the elongating cortical cells (Bayer *et al.*, 1967; Lignowski and Scott, 1971). The coleoptile node is also a sensitive site for the action of trifluralin. Rahman and Ashford (1970), in developing the use of trifluralin to control green foxtail (*Setaria viridis*) in wheat, showed that the coleoptile node of the wheat plant must be separated from trifluralin by a protective layer of untreated soil if damage is not to occur. Basically this condition has been achieved in the experimental work described in this paper by the incorporation and sowing methods adopted. The coleoptile node of the wheat seedling remains close to the seed and does not grow into the trifluralin-treated soil.

Larger area studies using a standard trifluralin rate of 0.41 kg/ha confirmed the experimental findings outlined above. Grain yields were determined in five trials. The yield increases following treatment ranged from 336 to 1680 kg/ha. Control of Wimmera ryegrass ranged from 85 to 99%, canary grass and wireweed control was rated at 95%. Where wild oats infestation occurred, control ranged from 55 to 95%. Results from the 1972 season will be reported.

CONCLUSIONS

In replicated field experiments and farmer experience trials involving larger areas, trifluralin has been shown to be a safe and effective herbicide for the control of Wimmera ryegrass, wireweed and canary grass, and for the partial control of wild oats. Where weed infestations have resulted in competition with the wheat plants, grain yield increases have been obtained following treatment.

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TRIFLURALIN AND TRIFLURALIN PLUS LINURON AS PRE-EMERGENCE HERBICIDES IN CEREALS IN EUROPE

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Summary

Post-plant pre-emergence and post-emergence surface applications of trifluralin have been evaluated in wheat in Europe since 1967. Pre-emergence application rates ranging from 0.57 to 0.72 kg/ha and post-emergence rates from 0.72 to 0.96 kg/ha have selectively and effectively controlled all annual grasses (except *Avena* sp.) and a wide range of broadleaf weeds.

An emulsifiable concentrate formulation containing 24% trifluralin plus 12% linuron applied at 0.96 kg trifluralin plus 0.48 kg linuron per hectare has been evaluated since 1970 in Europe as a post-plant pre-emergence combination herbicide on winter wheat, winter barley, and winter rye. In addition to weeds controlled by trifluralin, the addition of linuron provides control of important weeds of the Cruciferae and Ranunculaceae families, *Matricaria* sp., and *Galium aparine*. The herbicide combination will not reduce crop yields when applied according to recommendations.

TRIFLURALIN — WHEAT

Research to evaluate trifluralin as a post-plant surface-applied herbicide in wheat has been conducted in Europe since 1967. Results have shown trifluralin surface-applied to wheat, at any stage after seeding, is a selective and effective herbicide in certain areas of Europe. Pre-emergence applications are to be made any time from immediately after seeding until the cracking stage. Important weeds commercially controlled by the applications are all annual grasses except *Avena* sp. These include *Alopecurus* sp., *Poa annua, Poa trivialis, Lolium italicum* (from seed), and *Apera spica-venti*. Broadleaf weeds controlled are: *Anagallis* sp., *Cerastium* sp., *Fumaria* sp., *Galeopsis* sp., *Lamium* sp., *Papaver* sp., *Polygonum* sp., *Spergula* sp., *Spergularia* sp., *Stachys* sp., and *Veronica* sp.

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Post-emergence applications are to be made from the soil-cracking stage of the crop until broadleaf weeds are in the 2- to 4-leaf stage, regardless of the wheat crop stage and weather conditions. Early post-emergence applications have generally been more effective against certain broadleaf weeds, such as *Fumaria officinalis* and *Polygonum* sp. Cruciferae and Compositae are partially controlled by overtop applications before they reach the 2- to 4-leaf stage. Pre-emergence application rates range from 0.57 to 0.72 kg/ha and post-emergence rates range from 0.72 to 0.96 kg/ha. Slight phytotoxicity seen from pre-emergence applications on heavy soils is believed to be due to non-uniform seeding depth as a result of poor seedbed preparation. Rolling after seeding and prior to herbicide application has improved crop selectivity. In choosing the best time of application, the wheat growth stage can be disregarded. However, consideration must be given to determining the most efficacious use of trifluralin, keeping in mind that weather may interfere with later applications. The initial commercial use area of pre-emergence and post-emergence surface applications of trifluralin in wheat in Europe is the Po Valley of Italy. The programme has been successful because:

(1) The climate, with heavy fog, clouds, heavy rainfall, and often snow during the winter up to March, allows good herbicidal efficacy from surface-applied trifluralin.

(2) Most of the weeds grown in wheat fields in the area are susceptible to trifluralin. Moreover, annual grasses (mainly *Alopecurus* sp.) have been a serious problem over the last few years. It has been reported that 100 plants of *Alopecurus* per m^2 reduce crop weight by 30%.

(3) The high yields in the area (4,000 to 6,000 kg/ha) allow the use of sophisticated herbicides. Where weed infestations were severe, grain yield increases were obtained in trifluralin-treated areas.

It is anticipated trifluralin will also find commercial acceptance in Germany and other Northern European countries.

TRIFLURALIN/LINURON

Trifluralin in combination with linuron has been evaluated in Europe since 1970 as a post-plant pre-emergence herbicide programme in winter wheat, winter barley, and winter rye. Winter wheat constitutes the major portion of the cereal acreage grown in France, Germany, and other northern and central European areas. Winter barley and winter rye are also important with winter rye acreages particularly significant in Germany. An emulsifiable concentrate formulation containing 24% trifluralin plus 12% linuron has been developed. Four litres per hectare (0.96 kg trifluralin plus 0.48 kg linuron) has been selected as the most widely applicable dosage. A total of more than 150 field experiments and demonstrations were conducted in Europe during 1970-72. The combination of trifluralin plus linuron demonstrated excellent selectivity in these experiments and demonstrations, regardless of soil texture when applied to wheat, barley, and rye. Surface application should be made after drilling and before emergence of the crop. The seedbed should be well prepared, free of large clods, and all seeds must be covered by soil to insure uniform germination and protection from direct application of the herbicide.

The combination product provides an increased spectrum of weed control as compared with control provided by either herbicide alone. In addition to important weeds controlled by trifluralin that were reported previously in this paper, the addition of linuron provides control of important members of the Cruciferae and Ranunculaceae families, *Matricaria* sp. and *Galium aparine*. In the small-grain research reported in this paper, *Matricaria* and *Galium* were observed to be important competitive weeds in cereals.

In summary, it appears that trifluralin and trifluralin plus linuron have the potential to become important cereal herbicides in Europe. The similarity of the New Zealand climate to areas in Europe where these programmes have been successful suggests that these programmes may have potential for use in New Zealand.

RATOON CLEARING OF PINEAPPLE WITH PARAQUAT

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Summary

Ratoon pineapple is traditionally cleared by cutting the plants at the base and burning them after 13 weeks. This paper reports the development of a chemical method in which pineapple is desiccated by paraquat. With this method, pineapple could be burnt after 5 weeks and it is cheaper by about M$86/=.

INTRODUCTION

Traditionally, ratoon pineapple is cleared by cutting the plant at its base and leaving it to dry under the sun for three to four months before it is heaped and burnt.

The main objective of the present study was to develop an alternative chemical method of ratoon clearing. Preliminary screening of six important post-emergence herbicides (paraquat, methylarsinic acid, MCPA, 2,4-D, 2,2-DPA and sodium chlorate) showed that paraquat was the most injurious herbicide to pineapple (Lee, 1972). Sodium chlorate and methylarsinic acid were also found to be effective, but at dosages much higher than those required with paraquat.

Paraquat is a desiccant — *i.e.*, it kills through a process of accelerated drying (Addicott and Carns, 1964). To date, there is little information on the use of paraquat for pineapple in Malaysia. In this experiment, the effectiveness of paraquat as a desiccant was evaluated on the basis of its rate and severity of scorching, period required for burning and costings.

MATERIALS AND METHODS

The trial was carried out on a six-year-old ratoon pineapple area. The experiment consisted of nine treatments and four replicates, arranged in a randomized block design. The plot size was 6 m × 15 m. The distance between the plots was 4 m and this area between the plots was filled with guard rows.

The treatments consisted of three concentrations of paraquat, mixtures of paraquat with sodium chlorate or methylarsinic acid or sodium chlorate and methylarsinic acid alone and finally, sodium chlorate mixed with methylarsinic acid (Table 1). Control plots (*i.e.*, using the traditional method) were included. The herbicides and herbicidal mixtures were sprayed in 1100 l/ha of water.

TABLE 1: HERBICIDES, HERBICIDAL MIXTURES AND RATE OF APPLICATION

Treatment	*Details of Treatments*
T_0	Plants slashed and cut at the base (control)
T_1	paraquat 0.56 kg/ha
T_2	paraquat 0.84 kg/ha
T_3	paraquat 1.12 kg/ha
T_4	paraquat 0.56 kg/ha + sodium chlorate 16.80 kg/ha
T_5	paraquat 0.56 kg/ha + methylarsinic acid 1.61 kg/ha
T_6	sodium chlorate 50.40 kg/ha
T_7	methylarsinic acid 4.62 kg/ha
T_8	sodium chlorate 11.20 kg/ha + methylarsinic acid 3.70 kg/ha

The number and the severity of plants scorched by the herbicides at various intervals after spraying were assessed using the following scale:

Slight scorching: Only small portions of the leaf scorched.

Intermediate scorching: Intermediate between slight and full scorching.

Full scorching: Almost all the leaves of the plant were completely scorched.

After spraying, the period that was required before burning could be carried out was assessed by burning replicates 1, 2, 3 and 4 at 3, 5, 7, and 9 weeks after spraying, respectively. For the control plots, burning was carried out for replicates 1, 2, 3 and 4 at 9, 11, 13 and 15 weeks, respectively.

The ease of burning was classified as follows:

Poor: The plants were difficult to burn. Only small portions of the leaves were burnt.

Satisfactory: The plants were slightly difficult to burn. Intermediate between "poor" and "good".

Good: The plants were easy to burn. Only the stumps were left behind.

The costings for the chemical and traditional methods of ratoon clearing were compared and the operations involved in the two methods outlined.

RESULTS AND DISCUSSION

Rate and Severity of Scorching

Figure 1 shows the percentage number of plants scorched by 0.56, 0.84 and 1.12 kg/ha paraquat at 2, 10 and 18 days after spraying. Paraquat at 1.12 kg/ha showed some initial advantage in effectiveness but there were little differences in the percentage number of plants scorched by the three concentrations after 18 days. The percentage number of plants scorched was broken down into the values relating to the severity of scorching, as shown in Fig. 2.

Here it can be seen that the best chemical treatment was paraquat at 1.12 kg/ha (T_3) and this was followed by paraquat at 0.84 kg/ha (T_2) and 0.56 kg/ha (T_1).

After 18 days, T_3 increased significantly (at $P = 0.05$) the percentage number of fully-scorched plants over T_1 but not over T_2. The difference in the percentage number of fully-scorched plants between T_2 and T_1 was non-significant at $P = 0.05$.

Mixtures of paraquat and sodium chlorate (T_4) or paraquat and methylarsinic acid (T_5) were not as effective as paraquat alone. At 18 days after spraying the increase in the percentage number of fully-scorched plants produced by paraquat at 0.56 kg/ha over that produced by mixtures of paraquat and sodium chlorate or paraquat and methylarsinic acid was non-significant at $P = 0.05$.

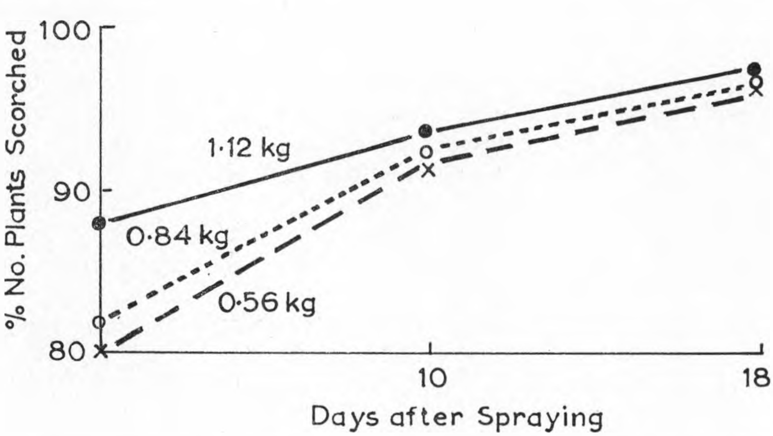

Fig. 1: Percentage number of plants desiccated by 0.56, 0.84 and 1.12 kg/ha paraquat at 2, 10 and 18 days after spraying.

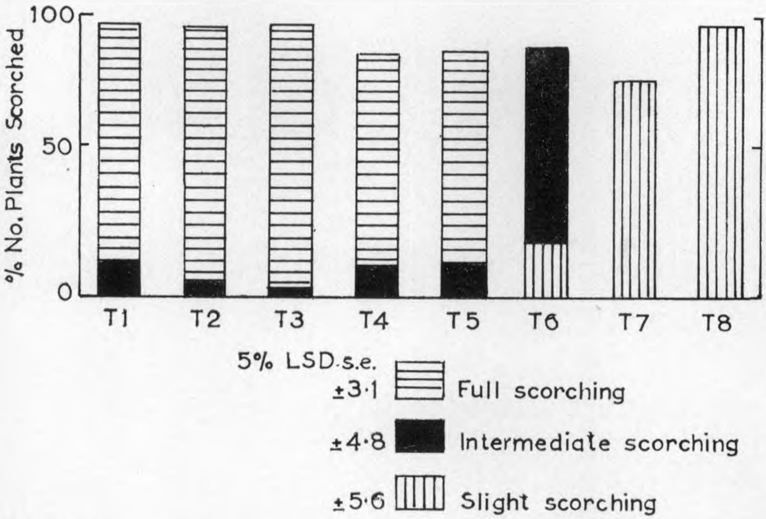

Fig. 2: Percentage number of plants scorched and degree of severity caused by various chemical treatments at 18 days after spraying.

Sodium chlorate at 50.40 kg/ha (T_6), methylarsinic acid at 4.62 kg/ha (T_7) and sodium chlorate + methylarsinic acid mixture at 11.20 + 3.70 kg/ha (T_8) did not produce severe scorching, which is essential for burning to take place effectively. The scorching produced by these three treatments was located mainly on the leaf-tips. Four weeks after spraying, most of the leaves were still green except for some that were slightly scorched. The suckers were also only slightly scorched. In short, these three treatments could not be used in ratoon clearing. The least effective treatments (T_6, T_7 and T_8), produced an almost complete scorching of all the leaves of each plant. Almost all the suckers were killed.

Period Required for Burning

The pineapple plants that were treated with paraquat (T_1 to T_5) could be burnt five weeks after spraying (Table 2). Paraquat at 1.12 kg/ha (T_3) produced a more complete burn than treatments T_1, T_2, T_4 and T_5 because of the more complete scorching. Sodium chlorate, methylarsinic acid, or sodium chlorate plus methylarsinic acid produced slight scorching of the plant and therefore the plants were difficult to burn even at the ninth week.

TABLE 2: EFFECT OF VARIOUS TREATMENTS ON THE PERIOD REQUIRED FOR BURNING
Ease of burning: P = Poor. S = Satisfactory. G = Good.

	Treatment (kg/ha)	*Weeks after start of experiment* 3 (57 cm)*	5 (70 cm)	7 (82 cm)	9 (119 cm)	11 (143 cm)	13 (148 cm)
T_0	Control (no herbicide)				P	S	G
T_1	paraquat 0.56	S	G				
T_2	paraquat 0.84	S	G				
T_3	paraquat 1.12	S	G				
T_4	paraquat 0.56/sodium chlorate 16.80	S	G				
T_5	paraquat 0.56/methylarsinic acid 1.61	S	G				
T_6	sodium chlorate 50.40	P	P	P	P		
T_7	methylarsinic acid 4.62	P	P	P	P		
T_8	sodium chlorate 11.20/methylarsinic acid 3.70	P	P	P	P		

*Figures in parentheses show the total amount of rainfall at various weeks after the start of the experiment.

TABLE 3: COST OF RATOON CLEARING BY TRADITIONAL AND CHEMICAL METHODS (M$/ha)

Method of Ratoon Clearing	*No. of Man-days**	*Labour Cost at $4.00/Man-day*
Traditional method:		
Plants cut at the base	26.7	106.80
Heaping and burning	12.5	50.00
Total cost		156.80
Chemical method:		
Spraying	5.4	21.60
Burning	2.5	10.00
Paraquat at 0.70 kg/ha		37.60†
Total cost		69.20

*One man-day equals one man working 8 hours a day.
†Cost of herbicide.

Using the traditional method, the leaves were only sufficiently dry for burning at the thirteenth week.

The more complete burn due to paraquat was attributed to its ability to desiccate the plants. Its principal mode of action is contact and this favours desiccation. The critical physiological process of desiccation appears to be injury to cell membranes that permits rapid loss of water (Muzik, 1970).

In the paraquat-treated plots, stumps of about 25 cm were left behind after the burning at five weeks. These stumps could be left lying in the field as they do not interfere with normal field operations.

Climatic factors also influence the period that is required before burning can be carried out. High temperatures and low rainfall enable burning to be done earlier. With rainfall totalling 70 cm, the plants treated with paraquat could be burnt after five weeks (Table 2) while the non-chemically treated plants could still be burnt after 13 weeks with rainfall totalling 148 cm.

COSTINGS

The cost of ratoon clearing by the traditional method was estimated to be $156.80/ha (Table 3). The item on cutting the plants at their bases constituted 68% of the total cost.

In order to obtain the costings on the chemical method, the effective chemical treatment must be chosen. Taking into account the rate and severity of scorching, period required for burning and cost of the herbicides, paraquat at 0.56 to 0.84 kg/ha was the appropriate treatment for ratoon clearing. The average concentration of 0.70 kg/ha was therefore used in the costings. This concentration was sufficient to dessicate a ratoon planting of 43,000 plants/ha. The total cost of ratoon clearing by the chemical method was $69.20/ha and paraquat alone constituted 54% of the total cost.

CONCLUSION

The above experiment is still in progress since it is important to study the effects of paraquat usage on the growth, yield and fruit quality. Visual observations showed that pineapple planted after chemical clearing grew normally.

The two methods of ratoon clearing are outlined below:

Traditional method

Plants cut at their base	13 wk later →	Burning in heaps	→ Planting

Chemical method

Plants sprayed with paraquat at 0.56 to 0.84 kg/ha	5 wk later →	Burning	→ Planting

The government is replanting about 400 ha of old ratoons with a new cultivar in 1972. It is therefore envisaged that paraquat will be used for ratoon clearing and this will not only lower the cost of production in the field but also enable planting to be done earlier.

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PRE-EMERGENCE HERBICIDES IN COFFEE IN PAPUA NEW GUINEA

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Summary

The pre-emergence herbicides evaluated in two trials in coffee were diuron, atrazine, simazine, prometryn, fluometuron, chlorbromuron, metobromuron, fluorodifen, C15935, chlorfenac, alachlor, lenacil and terbacil. They were applied alone, and in two-component mixtures, which mainly included diuron. The mixtures gave duration of control comparable to that obtained with single herbicides applied at twice the level that they were included in the mixtures. Numerous treatments equalled the control given by the present standard treatment, diuron 3.6 kg, but on a cost basis only atrazine 3.6 kg, simazine 3.6 kg, or diuron 1.8 kg plus either atrazine 1.8 kg or simazine 1.8 kg are likely to be acceptable. Repeat applications at the same or reduced rates gave far longer control than the initial applications.

INTRODUCTION

In coffee in the highlands of Papua New Guinea, the use of pre-emergence (soil-applied) herbicides offers the possibility of less frequent spray applications and hence easier management and lower labour costs. The initial cost of using pre-emergents is usually higher than that of foliar-applied herbicides, and later costs are often kept at a relatively high level by the need to make frequent applications with other herbicides to those species which the pre-emergence herbicide is not controlling.

There is a need for pre-emergence treatments which give long-lasting control of a wider range of species. If treatment with single herbicides cannot meet these requirements, then the alternatives are either to change the pre-emergence herbicide at each application or to apply herbicide mixtures. In the second of the two trials described here, a number of mixtures were evaluated. They were mostly combinations with diuron, which is the principal pre-emergent being used in coffee.

In general, pre-emergence herbicides on their own do not give effective control of perennial weeds at safe, economical rates, and these weeds require separate foliar treatment. In these trials no attempt was made to evaluate the herbicides on perennial species, and the trial areas were selected for their predominance of annual weeds.

EXPERIMENTAL AND RESULTS

TRIAL 1, AIYURA

The plots were laid out between rows of mature coffee spaced 2.74 m apart growing under *Albizia stipulata* shade. Plot size was 9.15 × 1.37 m. The treatments were in randomized blocks with three replications. Application, to freshly-weeded ground, was with an Oxford Precision Sprayer at a volume of 420 l/ha. The soil was a clay with 12% organic matter. Herbicides had not previously been used in the trial area. The main weed species were slender amaranth (*Amaranthus lividus*), thickhead (*Crassocephalum crepidioides*), knotweed (*Polygonum nepalense*), chickweed (*Stellaria media*), goatweed (*Ageratum conyzoides*), and potato weed (*Galinsoga parviflora*).

Table 1 gives the percentage ground cover at 12 and 16 weeks after treatment. The upper level of acceptable control is a cover of about 20%. The better treatments, which included diuron 4.5 kg, atrazine 4.5 kg, simazine 4.5 kg, metobromuron 5.6 kg, chlorbromuron 3.4 kg, fluometuron 6.3 kg, and chlorfenac 1.5

TABLE 1: PERCENTAGE GROUND COVER, TRIAL 1

(means of 3 replicates)

Treatment (kg/ha)	*% Ground Cover 12 wk**	*16 wk*
diuron 4.5	8 a	19
atrazine 4.5	9 ab	24
simazine 4.5	10 abc	28
prometryn 4.5	30 abcde	48
chlorbromuron 3.3	12 abcd	27
metobromuron 2.8	32 bcde	40
metobromuron 5.6	8 ab	19
fluometuron 3.6	30 abcde	39
fluometuron 6.3	12 abcd	29
fluometuron 9.0	40 def	52
chlorfenac 1.5	7 ab	14
chlorfenac 2.5	14 abcd	33
alachlor 2.1	48 ef	67
alachlor 4.2	37 cdef	47
fluorodifen 5.0	55 ef	65
fluometuron 1.8/fluorodifen 4.5	9 ab	27
Hand-weeded	65 f	78

*Results at 12 weeks were analysed using an arcsin transformation of the percentage figures. Any two treatments with the same letter in common are not significantly different at the 5% level according to Duncan's multiple range test.

or 2.5 kg, gave control for 12 weeks or longer. During this period there was 375 mm of rain and a further 143 mm fell in the following four weeks.

The good results with chlorfenac were not repeated in the second trial and appear to be anomalous. The poor control with the 9.0 kg rate of fluometuron was mainly attributable to one replicate and suggests an error in application. The poor result with fluorodifen on its own was largely due to its ineffectiveness against chickweed.

TRIAL 2, AIONORA

The plots of 12.8 × 1.7 m were set out between rows of mature coffee growing without shade trees. The layout was randomized blocks with four replications. Application, to clean-weeded plots, was at a volume rate of 337 l/ha with an Oxford Precision Sprayer. The soil was a well-drained clay with 10% organic matter. Herbicides had not previously been used in the trial area. The main weed species were cobbler's pegs (*Bidens pilosa*), potato weed, knotweed, crowfoot grass (*Eleusine indica*), slender amaranth, goatweed, and thickhead.

The treatments, with percentage ground cover at 4, 7 and 10 weeks after application, are given in Table 2. Again a ground cover of about 20% can be regarded as the upper level of acceptable control.

Although rates used in this trial were often lower than in Trial 1, in general the duration of control was shorter, and many treatments were no longer satisfactory at 10 weeks. Diuron at 3.6 kg can usually be expected to give about 12 weeks' control following a first application to soils similar to that present in this trial. In this instance it was giving barely satisfactory control at 10 weeks. The high rainfall of 729 mm (recorded about 3 km from the trial site) during the 10 weeks following application probably contributed to the reduced length of control.

Single Herbicides

A sharp decline in control was recorded with diuron, atrazine and simazine at rates below 3.6 kg. Fluometuron needs to be applied at higher rates than these herbicides to give comparable control. Chlorbromuron and metobromuron were not satisfactory at the rates tested. C15935 gave good results at 3.4 kg and was not significantly poorer at 2.2 kg. Chlorfenac was poor at both rates used. Alachlor was unsatisfactory at 4.7 kg, but at 6.7 kg

TABLE 2: PERCENTAGE GROUND COVER, TRIAL 2
(means of 4 replicates)

Treatment *(kg/ha)*	*% Ground Cover* *3 wk*	*7 wk*	*10 wk**
diuron 2.7	8	17	46 bcdef
diuron 3.6	5	10	23 abcd
simazine 2.7	8	19	46 bcdef
simazine 3.6	4	9	20 abcd
atrazine 2.7	4	13	36 abcde
atrazine 3.6	2	7	17 abc
fluometuron 4.5	8	18	38 abcde
fluometuron 7.2	3	6	15 ab
chlorbromuron 2.2	13	34	73 fgh
chlorbromuron 3.4	7	20	51 defg
metobromuron 3.4	9	19	47 bcdef
C15935 1.1	20	39	80 gh
C15935 2.2	6	15	36 abcde
C15935 3.4	4	10	22 abcd
chlorfenac 2.0	11	24	57 efgh
chlorfenac 3.0	7	17	42 bcde
alachlor 4.7	5	14	48 cdef
alachlor 6.7	2	8	35 abcde
lenacil 1.8	7	16	38 abcde
lenacil 2.7	5	13	32 abcde
diuron 1.8/simazine 1.8	3	9	25 abcd
diuron 1.8/atrazine 1.8	4	9	24 abcd
diuron 1.8/fluometuron 2.7	3	7	16 abc
diuron 1.8/chlorbromuron 1.7	6	18	47 bcdef
diuron 1.8/metobromuron 1.7	6	13	31 abcde
diuron 1.8/C15935 1.1	4	10	21 abcd
diuron 1.8/alachlor 3.4	2	9	36 abcde
diuron 1.8/lenacil 1.1	3	8	20 abcd
diuron 1.8/terbacil 0.4	5	11	38 abcde
diuron 1.8/terbacil 0.9	1	3	8 a
diuron 1.8/fluorodifen 3.5	2	7	23 abcd
simazine 1.8/chlorbromuron 1.7	6	19	48 cdef
simazine 1.8/metobromuron 1.7	5	15	40 bcde
simazine 1.8/fluometuron 2.7	4	11	21 abcd
fluometuron 2.7/ chlorbromuron 1.7	4	8	26 abcde
fluometuron 2.7/C15935 1.1	6	11	27 abcde
chlorbromuron 1.7/C15935 1.1	6	13	28 abcde
Hand-weeded	29	58	84 h

*Results at 10 weeks were analysed using an arcsin transformation of the percentage figures. Any two treatments with the same letter in common are not significantly different at the 5% level according to Duncan's multiple range test.

was just comparable with the better treatments. Its effectiveness dropped rapidly after 7 weeks. Lenacil was slightly poorer than the better treatments, although the differences were not significant at either rate.

Herbicide Mixtures

Diuron at 1.8 kg combined with either simazine 1.8 kg, atrazine 1.8 kg, fluometuron 2.7 kg, metobromuron 1.7 kg, C15935 1.1 kg, alachlor 3.4 kg, lenacil 1.1 kg, terbacil 0.9 kg or fluorodifen 3.5 kg gave control which at 10 weeks was not significantly different from diuron alone at 3.6 kg. Other mixtures which gave comparable results were fluometuron 2.7 kg plus either simazine 1.8 kg, chlorbromuron 1.7 kg or C15935 1.1 kg, and chlorbromuron 1.7 kg plus C15935 1.1 kg. Thus these mixtures gave comparable length of control to that obtained when single herbicides were applied at twice the rate that they were included in the mixtures.

On individual species, the mixtures generally either improved on the results obtained with single herbicides or gave comparable results. For example, the mixtures of diuron with atrazine or simazine gave complete control of thickhead (not controlled by 3.6 kg diuron) and good control of slender amaranth (not controlled by 3.6 kg of atrazine or simazine), while the control of other species was similar to that obtained with the herbicides applied individually. Thickhead was also controlled by diuron plus terbacil or fluometuron, and partly controlled by diuron mixtures with fluorodifen, metobromuron, chlorbromuron, lenacil and alachlor. The combinations of diuron with fluorodifen or alachlor were also notable for the improvement in control of knotweed over that obtained with diuron alone.

Retreatment

Follow-up applications of pre-emergence herbicides results in longer control than the initial treatments. This increased duration of control was demonstrated by re-applications made in this trial.

The plots were clean-weeded using paraquat and a follow-up hand-weeding (done so as to disturb the soil as little as possible) and then, 16 weeks after the first applications, they were retreated. One half of each of the original plots was retreated as for the initial treatment, while the other half of the plot was retreated with the herbicide (or herbicides) at half the initial rate.

Seventeen weeks after the re-applications, most treatments were giving good to excellent control, and there was little difference between retreatments made at the full (initial) rate and the corresponding retreatment at half this rate.

For the re-applications at the initial rates, the percentage ground cover at 17 weeks varied from 0.5% (diuron 1.8 kg plus fluorodifen 3.5 kg; simazine 1.8 kg plus fluometuron 2.7 kg) to 21% (chlorfenac 2 kg). For the re-applications at half the initial rates, the ground cover at 17 weeks varied from 1% (fluometuron 3.6 kg; simazine 1.8 kg plus fluometuron 2.7 kg) to 18% (chlorfenac 1 kg).

It was not possible to make observations at a later date, and at 17 weeks only the poorest treatments were becoming apparent, so that in most cases meaningful comparisons cannot be made. The results of some of the retreatments are given in Table 3. However, the results show, as has been the case in other trials, that, following a second application, even at a reduced rate, the duration of control is considerably increased. The rainfall during the 17 weeks following the re-applications was 856 mm, so the longer control was not due to soil moisture being unfavourable to weed germination.

TABLE 3: PERCENTAGE GROUND COVER FOLLOWING RETREATMENT, TRIAL 2
(means of 4 replicates)

Initial Treatment (kg/ha)	*Retreatment (kg/ha)*	*% Ground Cover 13 wk*	*17 wk*
diuron 2.7	diuron 2.7	3	4
	diuron 1.3	9	12
diuron 3.6	diuron 3.6	1	1
	diuron 1.8	1.5	1.5
fluometuron 7.2	fluometuron 7.2	1	1.5
	fluometuron 3.6	1	1
chlorfenac 2.0	chlorfenac 2.0	19	21
	chlorfenac 1.0	16	18
simazine 1.8/ fluometuron 2.7	simazine 1.8/ fluometuron 2.7	0.5	0.5
	simazine 0.9/ fluometuron 1.3	1	1
diuron 1.8/ simazine 1.8	diuron 1.8/ simazine 1.8	2	2
	diuron 0.9/ simazine 0.9	2	4
diuron 1.8/ fluorodifen 3.5	diuron 1.8/ fluorodifen 3.5	0.5	0.5
Hand-weeded		40	—

No treatment in either trial caused any visible toxicity to the coffee. However, the plots were between two rows of coffee trees so that only half the roots of any tree were in soil that received a given treatment. In a subsequent toxicity trial in young coffee, soil applications of terbacil caused severe injury at 1.6 kg/ha and fluometuron produced mild toxicity symptoms at 6.4 kg/ha. Diuron, simazine, atrazine, lenacil and C15935 appear to have a wide margin of safety to coffee.

At current herbicide prices in Papua New Guinea, only diuron, atrazine and simazine, of the herbicides tested, seem likely to be acceptable. However, the results from the second trial indicate that some of the other herbicides could have a place in particular situations if used at relatively low rates in mixtures with one of these three herbicides.

THE USE OF PARAQUAT-BASED TREATMENTS FOR WEED CONTROL IN COCOA IN MALAYSIA

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Summary

Several pre- and post-emergence herbicides were evaluated for use in weed control under young cocoa growing on inland sandy clay soil and coastal clay soil of West Malaysia. In general, the residual herbicides, diuron at 0.56 kg/ha, atrazine and simazine at 2.24 kg/ha, and prometryn at 8.96 kg/ha were found to be safe to the crop. Paraquat, methylarsinic acid, 2,2-DPA and sodium chlorate up to 2.24, 4.48, 8.96 and 11.20 kg/ha could also be used. In long-term trials, a mixture of paraquat at 0.56 kg/ha + simazine at 2.24 kg/ha was found to give long-lasting weed control and better plant growth than manual weeding. On a cost/efficiency basis, however, a programme application of paraquat at 0.28 kg/ha was the most promising treatment. Under conditions immediately after planting, when the crop offers limited shade and is most susceptible to injury by contact herbicides, a pre-emergence application of simazine or prometryn at 1.0 to 2.0 kg/ha could be used before embarking on the paraquat programme treatment.

INTRODUCTION

Until recently, attempts to grow cocoa on a plantation scale in Malaysia were unsuccessful, mainly because of the susceptibility of the varieties then grown to cocoa dieback fungal disease. However, the availability of the Upper Amazon selections and their hybrids, which are much more vigorous and tend to be relatively resistant to cocoa dieback disease, has resulted in an increased acreage of cocoa being planted in both East and West Malaysia. With this increase in crop acreage and an ever-increasing rise in crop maintenance and production costs, particularly that of labour, the need for development of more efficient management techniques has become very important. The use of herbicides to replace the labour-intensive operation of manual weeding under both young and mature cocoa offers one such management tool.

Kasasian and Donelan (1965) screened a large number of compounds in Trinidad and suggested that, for long-term weed control, 3.36 kg/ha simazine, linuron and possibly diuron, and for short-term weed control 0.56 to 1.12 kg/ha paraquat, 2.24 kg/ha 2,4-D, 2,4,5-T or MCPA and 5.60 kg/ha of 2,2-DPA can be safely used in young cocoa. Higher rates of many of these compounds were found to be toxic. However, they did not present any data from long-term field trials. Working on chocolate basalt soils in Sabah, Foster and Lim (1970) showed simazine at 4.48 kg/ha and alachlor at 2.7 kg/ha to be safe, but atrazine and diuron at 4.48 kg/ha and simazine at 8.96 kg/ha were toxic.

More recently, Tan *et al.* (1971), working on inland sandy clay loams in West Malaysia, showed atrazine, simazine and ametryn at 2.24 kg/ha, 2,2-DPA at 6.72 kg/ha, methylarsinic acid at 2.24 kg/ha and prometryn at 8.96 kg/ha to be safe to cocoa seedlings. They also found diuron at 0.56 kg/ha, simazine, ametryn and prometryn at 1.12 kg/ha, applied either alone or in mixture with paraquat at 0.28 kg/ha, to be safe and these treatments gave satisfactory weed control in short-term trials.

However, none of the Malaysian studies has attempted to establish the safe levels of the promising herbicides on different soil types or presented results from long-term weed control evaluations.

This paper presents results from selectivity trials on young cocoa in which various herbicides were compared on an inland sandy clay (Rengam series) and the coastal clay soil in West Malaysia. Results are also presented from long-term field trials in which paraquat, methylarsinic acid, atrazine and simazine-based treatments were evaluated on a cost and efficiency basis.

MATERIALS AND METHODS

Two unreplicated trials, one on coastal clay and one on inland soil, were started in 1970 to evaluate the safety of various pre- and post-emergence herbicides on young cocoa seedlings. Paraquat, methylarsinic acid, diuron, 2,2-DPA, 2,4-D, sodium chlorate, amitrole, prometryn, simazine and atrazine were applied at three different rates. Herbicide treatments were applied to a 1.2 m strip along the planting rows. The seedlings (2 months old at the time of application) were planted 0.6 m apart and there were 5 plants to each treatment.

Spraying was carried out using a pneumatic, hand-operated sprayer fitted with a cone nozzle. Pre-emergence and post-emergence herbicides were applied at a volume rate of 675 and 450 l/ha, respectively. With post-emergence herbicides, care was taken during spraying to avoid contact with the cocoa leaves. Weed growth was controlled by regular hand-weeding when regeneration had reached 30% ground cover.

The effects of chemicals on plant growth were assessed by measuring stem diameters and plant heights at monthly intervals.

Following the above trials, several of the more promising and readily available herbicides were applied singly or as mixtures in young cocoa plantings, grown under mature 'Malayan Dwarf' coconuts on the coastal clay soils of Perak. There was one replicated trial with 21 plants per plot and two larger-scale unreplicated trials using 0.8 ha plots. Spraying was carried out using a knapsack sprayer fitted with a blue "Polijet-tip" nozzle, operated at 153 kPa pressure and a walking speed of 1.6 km/hr, to give a volume rate of 450 l/ha. Manual weeding, either in a strip or in a circle around the plants, was carried out using a "changkul" (similar to a hoe). Both chemical and manual weeding rounds were carried out as necessary, using 60% weed cover as the criterion for retreatment.

Plant growth was assessed by measuring the diameter of the stem at 10 cm above the ground using a set of Vernier calipers. These measurements were taken once every 3 or 6 months.

The main weeds encountered in these trials were *Paspalum conjugatum* and *Ottochloa nodosa,* with small amounts of *Mikania cordata, Digitaria* and *Asystacia* spp. The degree of weed control following various treatments was assessed visually once every two weeks.

RESULTS AND DISCUSSION

Herbicide Selectivity in Cocoa

Treatment effects on the growth of young cocoa seedlings, indicated by stem diameter and plant height measurements, are presented in Table 1. The residual herbicides, diuron at 0.56 kg/ha, atrazine and simazine at 2.24 kg/ha and prometryn up to 8.96 kg/ha were found to be safe to young cocoa. Cocoa seedlings growing on heavy coastal clay soils were more tolerant of higher rates of residual herbicides than seedlings growing on inland sandy clay loams. This difference is probably due to the higher organic matter content and cation exchange capacity of the clay soils as compared with the light-textured sandy clays. Furthermore, the herbicides are likely to be more mobile in light soils, thus entering zones where they are not readily available to the plant roots.

The reverse effect was observed with the highly soluble post-emergent herbicides — *e.g.,* 2,4-D, 2,2-DPA, sodium chlorate and amitrole. These chemicals were more toxic to cocoa plants grow-

TABLE 1: AVERAGE STEM DIAMETER AND PLANT HEIGHT OF COCOA SEEDLINGS FOLLOWING TREATMENTS WITH VARIOUS HERBICIDES

(5 months after first application)

Treatment	*Coastal Clay*		*Inland Soil*	
(kg/ha)	*S.D.**	*P.H.*	*S.D.*	*P.H.*
diuron 0.56	10.16	51.8	6.95	37.2
diuron 1.12	8.63	47.1	7.30	40.1
diuron 2.24	6.58	32.8	6.00	31.7
atrazine 2.24	7.78	41.7	8.57	44.2
atrazine 4.48	8.32	40.1	6.00	28.9
atrazine 8.96	10.18	49.8	3.26	23.5
simazine 2.24	9.62	49.0	7.99	40.7
simazine 4.48	11.08	58.1	5.44	28.7
simazine 8.96	6.46	36.2	4.99	27.9
prometryn 2.24	9.05	50.8	7.52	41.0
prometryn 4.48	9.53	52.6	7.46	30.0
prometryn 8.96	8.57	46.3	8.16	47.8
sodium chlorate 5.60	10.16	57.6	6.14	35.9
sodium chlorate 11.20	11.12	53.2	6.63	39.6
sodium chlorate 22.40	8.23	37.4	7.18	42.8
2,2-DPA 4.48	9.64	59.4	8.14	46.8
2,2-DPA 8.96	10.53	58.2	6.61	33.5
2,2-DPA 17.92	6.60	38.2	7.73	52.2
paraquat 0.56	8.80	42.1	6.74	35.0
paraquat 1.12	10.01	54.0	7.46	39.9
paraquat 2.24	10.28	57.1	7.32	35.5
amitrole 0.56	9.71	47.5	7.51	41.7
amitrole 1.12	9.47	56.1	7.33	40.7
amitrole 2.24	6.35	31.9	8.36	40.7
2,4-D 1.01	8.03	35.7	7.02	34.6
2,4-D 2.13	8.81	41.9	6.02	34.5
2,4-D 4.03	7.29	33.4	6.01	26.5
methylarsinic acid 2.24	10.39	56.1	9.44	48.3
methylarsinic acid 4.48	9.97	52.1	6.44	43.1
methylarsinic acid 6.72	8.98	51.4	6.47	28.8
Control	9.81	52.9	7.38	39.1

*S.D. = Stem diameter taken 5 cm above cotyledon scars. P.H. = Plant height.

ing on coastal clay soils than on sandy clays. This implies that, in light-textured soils, highly soluble chemicals are rapidly leached but on heavy clays the chemicals remain in zones where they are available for root uptake. Paraquat was found to be safe on both sandy and clay soils.

The toxicity symptoms were found to differ with different herbicides. Leaf chlorosis with a blotchy or diffused inter-veinal pattern and somewhat reduced leaf size with tip scorch

TABLE 2: PERIOD OF EFFECTIVE WEED CONTROL (40% SCORCH) IN YOUNG COCOA (UNDER COCONUTS)
(Trial initiated 2½ months after field planting)

Treatment (kg/ha)	*Period of Control (weeks) following Spray Rounds* 1st	2nd	3rd	4th	5th	6th	*Av. Length (weeks) of Control/Round*
paraquat 0.56/atrazine 2.24	13	12	10	16	12	6	12.6
paraquat 0.56/simazine 2.24	16	14	12	14	12	—	13.6
methylarsinic acid 2.24/ atrazine 2.24	6	4	12	10	12	—	8.8
methylarsinic acid 2.24/ simazine 2.24	6	4	11	7	12	—	8.0
Hand-weeding	6	6	6	9	12	12	8.5

TABLE 3: MEAN STEM-DIAMETER IN MM (ADJUSTED) OF COCOA PLANTS AT VARIOUS INTERVALS FROM COMMENCEMENT OF DIFFERENT WEEDING PRACTICES

Treatment (kg/ha)	*Trial I* 6 mon.	12 mon.	18 mon.
paraquat 0.56/simazine 2.24	12.78	25.00	37.0
paraquat 0.56/atrazine 2.24	12.38	23.65	36.1
paraquat 0.28/simazine 2.24/methylarsinic acid 1.68	12.15	24.18	37.9
methylarsinic acid 1.68/simazine 2.24	11.22	21.75	33.8
methylarsinic acid 1.68/atrazine 2.24	11.65	22.40	35.2
Hand-weeding (strip)	11.83	22.08	33.3
SE	1.15	2.32	3.1
CV %	9.5	9.8	8.6
LSD 0.05	n.s.	n.s.	4.04

TABLE 4: AVERAGE PERIOD OF EFFECTIVE WEED CONTROL (40% SCORCH) OF VARIOUS TREATMENTS IN YOUNG COCOA PLANTED UNDER COCONUTS

Treatment (kg/ha)	*Av. Period of Control (weeks)* Trial II	Trial III
paraquat 0.28 (blanket spray)	—	8.5
paraquat 0.28	6.5	8.0
paraquat 0.56	8.7	—
paraquat 0.56/prometryn 1.12	8.7	11.0
paraquat 0.56/prometryn 2.24	9.0	—
paraquat 0.56/simazine 1.12	10.4	—
paraquat 0.28/urea 22.4	—	6.0
Hand-weeding (circles)	5.2	—
Hand-weeding (strips)	—	5.0
Manual slashing	—	4.0

was common with substituted triazines and ureas. 2,4-D and 2,2-DPA caused the characteristically deformed young leaves and die-back of the growing points. The symptoms produced by methylarsinic acid were found to be very similar to those caused by zinc deficiency in cocoa. These included characteristic dark-green, elongated and twisted leaves. Similar toxic symptoms following methylarsinic acid application were reported by Tan *et al.* (1971), Barnes and Evans (1971) and Brown and Boating (1971). Brown and Boating suggested that the toxic symptoms following methylarsinic acid spray may be due either to temporary reduction in the availability of zinc to the plants or to killing of the fine feeder roots by the chemical.

Weed Control in Field Plantings

The results from the field trials indicated several promising herbicidal treatments for weed control in young cocoa. In the first trial, paraquat 0.56 kg/ha + simazine 2.24 kg/ha gave the longest average period of weed control (Table 2) and also better plant growth (Table 3). It is possible that the improved plant growth was due to both better weed control and the direct effects of simazine on nitrogen uptake and metabolism and stimulation of root growth.

In Trial II, paraquat 0.56 kg/ha + simazine 1.12 kg/ha once again gave the longest period of control. In Trial III, paraquat 0.56 kg/ha + prometryn 1.12 kg/ha was the best treatment but it did not include a comparison with a similar simazine treatment (Table 4). Programmed application of paraquat at 0.28 kg/ha either in strips or as a blanket spray provided efficient weed control for 6 to 8 weeks after each spray. The addition of 22.4 kg/ha of urea to paraquat did not improve the efficacy of the treatment, but gave better plant growth, probably owing to the direct effects of urea as fertilizer.

Slashing of the weed cover under the coconut rows is commonly practised on most estates. Although blanket spraying of paraquat at 0.28 kg/ha uses twice as much chemical solution as strip spraying, this treatment removed the need for hand-slashing and also gave better overall weed control. Manual slashing alone does not completely remove weed competition, which probably accounts for the poorer plant growth observed in Trial III (Table 5).

Paraquat and paraquat-based treatments gave good control of *O. nodosa, Cleome rutidosperma, Digitaria, Isachne* and *Axonopus*

TABLE 5: MEAN STEM-DIAMETER (mm) OF COCOA PLANTS TAKEN AT 6 MONTHS FROM COMMENCEMENT OF DIFFERENT WEEDING PRACTICES

(Mean for 120 plants per treatment)

Treatment (kg/ha)	*Stem Diameter (mm)*	
	Trial II	*Trial III*
paraquat 0.28 (blanket spray)	—	26.1
paraquat 0.28	17.3	25.6
paraquat 0.56	18.2	—
paraquat 0.56/prometryn 1.12	18.8	25.8
paraquat 0.56/prometryn 2.24	18.3	—
paraquat 0.56/simazine 1.12	17.0	—
paraquat 0.28/urea 22.4	—	27.7
Hand-weeding (circles)	18.0	—
Hand-weeding (strips)	—	26.2
Manual slashing	—	24.5

TABLE 6: NUMBER OF SPRAYING ROUNDS PER YEAR AND RELATIVE COST OF VARIOUS HERBICIDE TREATMENTS FOR YOUNG COCOA PLANTED UNDER MATURE COCONUTS

Treatment (kg/ha)	*No. of Rounds per Year*	*Relative Cost of Treatments**
Strip spraying:		
paraquat 0.56	6	75
paraquat 0.28	8	63
paraquat 0.56/ prometryn 1.12	5	120
paraquat 0.56/simazine 1.12	5	130
Blanket spray:		
paraquat 0.28	7	103
Hand-weeding	6	100

*Cost of hand-weeding a 0.8 m circle/ha = 100.

spp. *Asystacia* is susceptible only when very young and is difficult to eliminate with paraquat once it has matured. Under the shaded conditions of these trials, *P. conjugatum* was well controlled by paraquat and paraquat/residual mixtures.

Cost/Efficiency of Treatments

A relative cost comparison of the more promising treatments is presented in Table 6. Significant savings in cost can be achieved with programmed application of paraquat. Paraquat/simazine treatments, although giving longer periods of control than paraquat alone, were more expensive than a manual weeding programme. However, when the cocoa plants are very young or when there is very little weed growth, such as would be experienced immediately after field planting, an initial application of simazine or prometryn followed by a programmed application of paraquat alone would appear to be the best programme. Blanket spraying with paraquat gave cleaner ground cover and in the long term should offer considerable savings in cost. An additional benefit could be improved growth of the coconut palms, leading to higher yields.

CONCLUSIONS

Several commonly available herbicides can be used safely at appropriate rates under cocoa in Malaysia. Long-term trials showed that the chemical weeding can provide good and lasting weed control of most common weed species encountered in plantations. On a cost/efficiency basis, programmed spraying of paraquat at 0.25 kg/ha was found to be the best treatment. However, under the conditions immediately after planting, when the crop offers limited shade and is most susceptible to injury by contact herbicides, a pre-emergence application of simazine or prometryn at 1.0 to 2.0 kg/ha could be used before embarking on the paraquat programme.

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OXADIAZON: A NEW PERSISTENT HERBICIDE FOR RICE, COTTON, AND VARIOUS OTHER CROPS

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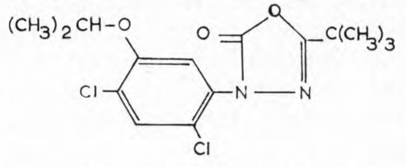
During the last thirty years, herbicides have largely taken the place of mechanical weed control in regions of intensive agriculture; without herbicides complete mechanization of ground crops would be impossible. The use of herbicides will continue to develop as manual work is considered more burdensome and becomes more rare.

Oxadiazon is the first of a new family of chemicals, the oxadiazoles. Tested in experiments in many countries, oxadiazon can be used for selective weed control in various crops and particularly in rice and cotton. Moreover, it is registered and used in Japan on rice, in Brazil on cotton, in France on vines, orchards and carnations, etc.

The chemical structure of oxadiazon is as follows:



The commercial formulation, "Ronstar", is an emulsifiable concentrate containing 250 g oxadiazon per litre. Experimental formulations are LFA 2015, granules containing 2% w/w oxadiazon, and LFA 2025, an emulsifiable concentrate containing 120 g oxadiazon per litre.

Oxadiazon is stable, non-volatile, and has a very low solubility in water (0.7 mg/l at 20° C).

It has a very low toxicity. The acute oral LD_{50} is about 8 g/kg for rats and mice. In one trial some rats and dogs received 150 mg per kg daily in their ration and no toxic symptoms were observed after 90 days of this regime.

It is important to emphasize that oxadiazon has a very low toxicity against birds and fish in particular.

Numerous residue studies have been carried out in Japan, the U.S.A. and in France: no residues have been recovered from rice, raisins, soya bean, etc.

BEHAVIOUR IN SOILS AND MODE OF ACTION

Oxadiazon is strongly adsorbed by soil humus and colloids. As it is practically insoluble in water, it is not leached by rainfall and remains at the soil surface where it is broken down slowly throughout the season. Oxadiazon has, therefore, a residual herbicidal activity lasting several months, but it does not remain permanently in soils.

The residue of oxadiazon is independent of the nature of the soil, although its activity tends to be greater on heavy soils or light, well-drained soils, and less on soils rich in humus.

There are three fundamental factors governing the activity of oxadiazon on plants:

(1) It acts on actively growing young tissues such as germinating seedlings, young shoots and leaves. Older plants or those in a period of retarded growth are less susceptible. Bindweed (*Convolvulus* sp.) is an exception, however.

(2) Light is essential and studies have shown that oxadiazon influences the process of photosynthesis. Oxadiazon will not work in the absence of light and therefore has no effect on roots.

(3) A minimum level of moisture is required to enable contact with and penetration of the plant tissues by oxadiazon.

ACTIVITY AND SELECTIVITY IN PLANTS

Oxadiazon is a contact herbicide, active in both pre- and post-emergence applications.

Pre-emergence: When applied to bare soil, oxadiazon forms a layer on the soil surface. At emergence, plant shoots come into contact with the chemical and are destroyed. Efficacy may be reduced if the soil is disturbed after treatment. Pre-emergence selectivity against some plants depends to an extent on the length of time the young stems are in contact with the layer of treated soil — that is, better selectivity is obtained under conditions favouring rapid emergence. For similar reasons, plants with bulbs, rhizomes or extensive root systems tend to be resistant.

Post-emergence: Oxadiazon is absorbed by the aerial parts of plants, shoots and young leaves in particular, which become necrotic and die. Warm temperatures and direct sunlight accelerate the appearance of toxic symptoms and the destruction of weeds.

These data show how oxadiazon has positional selectivity in many crops, which prevents contact between the chemical and sensitive parts of the crop plants. This applies to vines and orchards, but also to rice, cotton, soya bean, etc., where oxadiazon can be used satisfactorily.

Nevertheless it should be noted that oxadiazon has a physiological selectivity in carnations, and high rates are tolerated without damage.

HERBICIDE EFFICACY

Oxadiazon has an extremely broad spectrum of weed control.

Applied pre-emergence, it controls most annual weeds, both grasses and broadleaved weeds.

With post-emergence application, grasses are not very susceptible to oxadiazon and broadleaved weeds are much more susceptible when they are young and actively growing. The particular susceptibility of the aerial parts of bindweed (*Convolvulus* sp.) and *Oxalis* spp. at all stages of development should be emphasized. *Echinochloa crus-galli* is very susceptible pre-emergence and up to the 2- to 3-leaf stage post-emergence.

Plants with large food reserves — *i.e.,* plants with bulbs, rhizomes or large root systems — are generally resistant to oxadiazon. This applies to *Sorghum halepense, Cirsium arvense, Allium vineale,* but there are important exceptions like *Convolvulus* sp. and *Oxalis* spp.

Amongst the Caryophyllaceae the resistance of *Stellaria media* and the susceptibility of *Cerastium arvense* and *Spergula arvensis* should be noted in particular.

The different agronomic properties and mode of action of this herbicide are thus reviewed in brief. The uses of oxadiazon, both established and under trial, are already widespread.

WEED CONTROL IN RICE

Oxadiazon shows particular potential for weed control in rice and has been the object of trials over five years in rice in Japan, the U.S.A., South America, Mediterranean countries, Iran, etc. It is registered for rice in Japan, Italy, Brazil, Iran, and soon will be in the U.S.A., Argentina, Peru and other countries.

JAPAN

In Japan, oxadiazon was used successfully on more than 35,000 ha of transplanted rice (both by hand and by machine). It is estimated that 120 to 150,000 ha will be treated with oxadiazon in 1973 and by 1975 the area treated is estimated at 500,000 ha.

Oxadiazon is particularly suitable for weed control in rice for the following reasons:

(1) It is very active against *Echinochloa crus-galli* and also against the main aquatic weeds found in rice fields, such as *Monocharia vaginalis, Eleocharis acicularis, Elatine triandra, Cyperus* sp., and *Scirpus* sp.

(2) Oxadiazon has no effect on the environment. It is practically harmless to man, wild or domestic animals, birds, and above all fish. No residues are left in the rice grains or straw or in the soil. This safety in the environment has been much appreciated, particularly by the Japanese official bodies.

(3) The herbicidal activity of oxadiazon persists for at least two months on average in rice, and the chemical remains strongly fixed on the soil. This has three important consequences:

   (a) Movements of water do not affect the action of oxadiazon; accidental drying of the rice field does not affect its activity, whereas other rice herbicides are badly affected.

   (b) Footprints made by workers transplanting rice after application do not affect its activity.

   (c) A single treatment is generally sufficient to keep the rice field weed-free throughout the life of the crop.

The extensive work carried out in Japan by Nissan Chemical Co. has led to the successful introduction there of a new application technique. Oxadiazon is formulated as an emulsifiable concentrate containing 120 g oxadiazon per litre and supplied in a glass bottle of 500 ml having a plastic cap with three carefully calibrated holes, and designed to make it easy to grip. Dilution of the formulation is unnecessary and it is therefore applied direct from the bottle which is disposed of after use.

The farmer walks across the rice field, shaking the bottle alternately to the left and to the right. The product falls on to the water and spreads rapidly across the surface. A swath of 10 m is in theory treated with each pass. One bottle is sufficient to treat a distance of 100 m — *i.e.*, an area of 1000 m^2. This corresponds to 600 g/ha of oxadiazon (and rarely up to 800 g/ha).

The treatment is applied on to flooded fields (3 to 5 cm water) and is followed by a very slight incorporation in the soil (2 to 3 cm). Rice is transplanted either by hand or by machine 1 to 3 days after treatment; for direct-sown rice, 3 days must elapse after treatment.

Oxadiazon is very selective in rice provided care is taken not to exceed 3 to 5 cm water at the time of treatment and to ensure the seeds are not less than 3 cm deep.

The Japanese have shown that this technique gave important savings in time compared with normal techniques for applying both liquid and granular formulations: 4 to 5 minutes instead of 20 to 30 minutes for 0.1 ha. To this saving must be added the benefit from significant increases in yields.

U.S.A.

In the U.S.A. techniques of rice cultivation vary considerably from one region to another. In all, about 60 trials have been carried out over 3 years from Texas to California. Excellent results have been obtained with the commercial formulation on *Echinochloa crus-galli, E. colonum, Leptochloa filiformis, Brachiaria* sp., *Digitaria* sp., *Commelina communis,* etc. In spite of slight initial phytotoxicity, compensatory growth occurs, giving yield increases frequently greater than those for molinate or propanil.

Italy

In Italy, where rice is direct-sown into water, all researchers (official and non-official) are unanimous in recognizing the efficacy of oxadiazon as it gives virtually complete control of *Echinochloa crus-galli* and is much superior to molinate in controlling late flushes of weed emergence. (These are frequent under Italian conditions.) Oxadiazon is active against *Cyperus difformis* and also controls three weeds which are resistant to molinate: *Scirpus mucromatus, S. maritimus* and *Alisma plantago.*

In Italy, best results are obtained by applying oxadiazon on to dry or moist soil some days before flooding and sowing. Normally the treatment gives excellent weed control and facilitates strong growth of the crop.

France

French data confirm the Italian results, from which it may be stated that, if oxadiazon does not appear quite as selective as molinate or propanil in rice, it nevertheless gives much wider and more persistent weed control and very often gives the highest yields.

Very promising results have also been obtained under very variable conditions in Spain, Portugal, Greece, Iran, Argentina, Brazil, Peru, etc.

Future Trials in Rice

Based on existing knowledge the following suggestions are made for future trials:

Formulations

Normally the commercial emulsifiable concentrate containing 250 g oxadiazon per litre is adequate, but in really exceptional cases, where manual work or spraying presents difficulties, LFA 2025 (120 g/l emulsifiable concentrate) could be tested using the Japanese technique. Similarly, the 2% granular formulation LFA 2015 could be tested in transplanted rice at 50 to 60 kg/ha on to water but before transplanting.

Doses

The normal dose is 1 kg/ha. The average dose should be reduced to 750 g/ha on very heavy or very light soils easily drained; on soils rich in humus, the dose rate should be increased to 1.25 kg/ha.

Timing

Three important times may be distinguished:

(1) *Rice sown dry and before flooding.* The soil should be treated dry or moist, after sowing but before emergence. Flooding should follow spray treatment.

(2) *Rice sown direct into water.* The soil should be treated dry or moist, 3 to 8 days before flooding and sowing.

(3) *Rice transplanted into water.* The soil should be treated dry or moist, 1 to 3 days before flooding and transplanting.

Above all it should be remembered that:

(a) From germination to the 2- to 3-leaf stage, rice is particularly sensitive to changes in the level and temperature of water and, of course, to all chemical products. At this time rice has only a poorly developed root system and is at its weakest stage. All herbicide treatments should avoid this period.

(b) Spectacular weed control is obtained with oxadiazon and increased growth of the crop is facilitated. However, it is essential that trials with oxadiazon be followed through to harvest to measure yields.

COTTON

Because of its pre-emergence activity on many weeds and its long persistence, oxadiazon has great potential for use in cotton. This has been demonstrated by trials in Brazil, the U.S.A., Sudan and Madagascar.

Brazil

Oxadiazon applied after sowing but before emergence, and using a rate of 0.75 to 1 kg/ha, was shown to be very active on troublesome weeds in cotton such as *Amaranthus* sp., *Brachiaria plantaginea, Digitaria sanguinalis,* and *Eleusine indica.* Oxadiazon has longer persistence than trifluralin and does not require incorporation in the soil. *Bidens pilosa* is resistant to oxadiazon. "Ronstar" has been registered for over a year in Brazil and is now in commercial use.

Sudan

Trials have been carried out over 2 years at the Gezira Research Station, Wad Medani, on irrigated cotton. Pre-emergence applications at dose rates in the order of 1 to 1.5 kg/ha showed oxadiazon to be very active on two grasses (*Ischaemum afrum* and *Setaria pallide*) and on *Ipomoea* sp. (Convolvulaceae) which are very troublesome in the Sudan and are not controlled by fluometuron. Other grasses, like *Dinebra retroflexa* and *Brachiaria eruciformis,* and broadleaved weeds, like *Hibiscus feculneus* and *Sesbania* sp., are controlled by oxadiazon. At the higher dose rate, the crop is kept clean for over 3 months.

U.S.A.

Trials have confirmed the persistence of weed control with oxadiazon, but in some cases phytotoxicity has been observed at higher dose rates when cold temperatures after sowing cause slow germination and emergence of the crop.

To conclude, oxadiazon shows great potential for use in cotton and merits inclusion in further trials. A rate of 1 kg/ha should be applied after sowing and before emergence of the crop.

VINES AND FRUIT TREES

The behaviour of oxadiazon in soil explains the excellent positional selectivity it has in established perennial crops such as vines and orchards. Many studies have demonstrated that oxadiazon, once applied to the soil presents no risk of injury to the roots of crop plants, even over long periods. Oxadiazon is practically insoluble in water and is fixed in the soil surface so that the roots of crop plants do not come into contact with it. Oxadiazon is rendered inactive by the absence of light. A definite advantage in favour of oxadiazon is therefore established compared with other commonly-used herbicides like the substituted ureas or the triazines.

A second advantage of oxadiazon in vines and orchards is its activity on the aerial parts of bindweed (*Convolvulus* sp.) in addition to its very broad weed spectrum.

After several years of trials, "Ronstar" was registered in France (April 1971) for use in vines and orchards and is now being used on a commercial scale.

The difficult problem of weed control in vines and orchards cannot be resolved by the use of oxadiazon alone, since a number of weeds are resistant. Nevertheless, it can usefully be included in treatment programmes based on triazines or substituted ureas. Such programmes have been used over the last 15 years; crop damage has sometimes occurred but, more especially, these programmes have allowed the development of bindweeds which now constitute serious problems in many areas.

Although safe for the roots, oxadiazon should be applied with care because the aerial parts, young leaves and shoots in particular, are sensitive to spray drift. However, oxadiazon is not systemic and where foliar parts are accidentally sprayed, the phytotoxicity is much less severe than with hormone componds.

Oxadiazon should therefore be applied after flowering in vines or after fruit set in orchards. Oxadiazon may be used to complement the activity of residual herbicides by giving control of bindweed and other weeds. The materials may be applied as mixtures or separately.

The post-emergence activity of oxadiazon on bindweed is spectacular and ensures total destruction of the aerial parts in direct contact with the spray. Elimination of subsequent regrowth is obtained as it comes into contact with the treated soil surface. Further work after treatment is to be obviated. Repeated treatments over 2 to 3 years eventually exhaust the extensive root systems of bindweed and so achieve complete eradication.

The dose rate required is 2 kg/ha applied in at least 1000 l/ha of water and at very low pressure (0.5 to 1 kg/cm^2).

OTHER POSSIBLE USES

The main uses of oxadiazon have been described. However, the chemical has been tried in several other crops around the world. The most promising uses and those which merit further work are listed below.

Soya Bean

Apply 1 to 1.5 kg/ha pre-emergence; apply 0.75 to 1 kg/ha on light soils or in cold temperatures (U.S.A., Brazil results).

Groundnuts

Apply 1 to 1.5 kg/ha pre-emergence (U.S.A., Brazil, Sudan results).

Sugar Cane

Apply 1 to 1.5 kg/ha after planting but before crop emergence. Excellent control obtained on grasses, *Oxalis* spp., etc., for 8 to 10 weeks on moist soil (Mauritius, Cuba, Dominican Republic, Hawaii, Madagscar results).

Rubber

Apply 2 to 3 kg/ha post-emergence on relatively young weeds.

Other crop uses worth studying are tea, tobacco, asparagus, gladiolus, turfs and lawns (for *Digitaria* sp.).

CONCLUSIONS

Approximately 200 herbicides have found a place in agriculture with varying degrees of success. Oxadiazon merits addition to this list by virtue of its special properties and its proven activity in the field.

Oxadiazon has very low toxicity to mammals, birds and fish. Practically insoluble in water, it remains adsorbed at the soil surface where herbicidal activity persists for several months. The behaviour of oxadiazon in soil provides the basis for selectivity whereby contact between chemical and sensitive parts of crop plants is avoided or minimized.

A wide range of weed is controlled by oxadiazon, especially with pre-emergence treatments, and unlike other residual herbicides the persistence of weed control is not affected by rainfall or different soil types.

The use of oxadiazon in rice (direct-sown and transplanted), has met with widespread success throughout the world, particularly among small farmers in Japan where it is applied by hand from a glass bottle, especially designed for the purpose. This method has given considerable savings in application times compared with normal techniques for applying liquid or granular formulations, and, in addition, significant increases in yield have been obtained. The use of oxadiazon in cotton, vines, carnations and fruit trees is also well established. Promising results have been obtained with oxadiazon in soya bean, groundnuts, sugar cane and rubber. Other possible uses include tea, tobacco, asparagus, gladiolus, turf and lawns.

THE CONTROL OF GRASS WEEDS IN TROPICAL CROPS WITH ASULAM

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Summary

Problems with perennial grass weeds have arisen in many crops. Traditional hand-weeding methods and many new herbicides are ineffective in eradicating established perennial weeds such as *Imperata cylindrica, Sorghum halepense* and *Panicum purpurascens.* Effective control of a wide range of weed species including these grasses has been obtained with asulam, and selective weed control practices have been established for sugar cane, citrus crops and bananas. Current work is evaluating asulam for use in oil palm and rubber plantations. Results are reviewed and new information is presented.

INTRODUCTION

The properties of the benzenesulphonylcarbamates were first discovered in 1961 (Cottrell and Heywood, 1965), and a large number of trials have since been carried out in many crops, countries and conditions. Asulam is a systemic translocated herbicide. Uptake of the herbicide is via the roots or leaves and the sites of herbicidal activity are the root and shoot growing points, where the processes of cell division are inhibited, stopping all growth and killing the weed plants.

Extensive toxicological studies indicate that asulam is for all practical purposes pharmacologically inert. In acute toxicity experiments, the maximum non-lethal dose by mouth was found to exceed 5000 mg/kg in the mouse, rat and dog for both asulam and its sodium salt.

Safety studies have failed to demonstrate any potential direct hazard arising from the use of asulam to users, consumers, or the environment as a whole. The product is virtually atoxic to fish, birds and mammals and does not accumulate in the tissues of plants or animals. Food chain effects are therefore extremely unlikely.

As with other herbicides, the behaviour of asulam in soil is complex, but field observation suggests that it is unlikely to be widely dispersed from the site of application.

REVIEW OF ACTIVITY

The first use discovered for asulam was the selective control of grass weeds in sugar cane. Work by May & Baker personnel commenced in 1963-4 and marketing began in 1968-9. Asulam was shown to be effective when applied pre-emergence (Davies, 1966) and post-emergence (Ball and Tuckett, 1968; Cooke *et al.*, 1969). Subsequent work gave evidence of the very useful control by asulam of perennial grasses with rhizomatous rootstocks. These usually present very difficult weed problems when established. Promise for control of *Imperata cylindrica* was first reported by Parker (1970) and pot tests at May & Baker Ltd. Research Station at Ongar, England, and preliminary field trials in Malaysia (reported herein) have confirmed this.

Sorghum halepense (Johnson grass) was found to be highly susceptible to asulam during trials in Cuba in 1970 and trial work has since been carried out on control of this grass in Argentina, Peru (Ugaz Orrego and Garcia Abriles, 1970), Mexico, U.S.A., (Williams and Horsnail, 1972; Knobel and Crowley, 1972) and in Fiji, with excellent results.

Brachiaria mutica (syn. *Panicum purpurascens*) has also been found extremely susceptible to asulam in trials in the Dominican Republic in 1970 and 1971, and trials in many other areas have given very good results against this troublesome grass.

Two perennial grasses in citrus crops and bananas in the Caribbean, *Paspalum fasciculatum* and *Setaria poiretiana,* have been shown to be very susceptible to asulam treatment in field trials in 1972. Some results on these weeds are also reported here.

Some promise was reported (Parker, 1970) for control of *Digitaria scalarum.* Further work is needed on this species. Many other frequently occurring grasses, such as *Digitaria sanguinalis, Eleusine indica,* and *Echinochloa colonum,* are controlled very well by asulam.

The weed control spectrum of asulam also includes some weeds which are difficult problems in temperate situations, for example wild oat (*Avena fatua*) in flax (Hardisty, 1971), docks (*Rumex* spp.) in pastures (Savory and Soper, 1970), and bracken (*Pteridium aquilinum*) in pastures and rough grazing areas (Soper, 1972; Scragg *et al.,* 1972).

Sugar cane is the principal crop in which asulam is currently used in tropical situations.

The use of asulam, a grass weedkiller, in a graminaceous crop — sugar cane — implied that a careful study of crop tolerance was necessary. This was done and in 1970-1 in four large replicated trials in Trinidad, measurements of growth, cane yield, and juice quality were made with normal and double doses of asulam (3.36 kg a.i./ha and 6.72 kg a.i./ha). The growth, yields, and quality showed no significant differences from control weeded plots (Caroni Research Station, 1971).

Asulam is registered for use in sugar cane in Jamaica, Trinidad, Barbados, Guyana, Cuba, Venezuela, Peru, Ecuador, Argentina, U.S.A. (Experimental Permit) and Fiji. Registration is pending or applied for in Mexico, Guatemala, Honduras, Costa Rica, Nicaragua, San Salvador, Panama, Brazil, Mozambique, South Africa and Mauritius. Asulam is also registered in United Kingdom, France, Austria, Australia, New Zealand, and provisionally registered in Canada, Holland, Switzerland, West Germany, for the control of temperate weed problems mentioned.

Work during 1971 and 1972 has established that asulam can be safely and effectively used in both citrus and banana crops, and work now in progress in Malaysia is investigating its potential use in rubber and oil palm plantations.

EXPERIMENTAL RESULTS

These results are from work carried out in the period 1970-2. They have been selected to show the activity in field and pot trials of asulam against the perennial grasses already mentioned.

Materials Used

The following formulations were used:

"Asulox" 40 — 40% w/v aqueous solution of asulam as sodium salt.

"Asulox" 60 — 60% w/v aqueous solution of asulam as sodium salt (now obsolete).

"Actril" D — Emulsifiable concentrate of ioxynil octanoate and 2,4-D iso-octyl ester with a total acid equivalent of 35% w/v.

2,4-D amine — 75% w/v 2,4-D as amine salt.

"Ethylan" CP — non-ionic wetting agent based on ethoxylated phenols.

"Dowpon" S — 85% w/w soluble powder of 2,2-DPA as sodium salt, plus "Dalawet" wetter.

"Gramoxone" — 20% paraquat cation aqueous concentrate.

1. *Imperata cylindrica* (LALANG, ALANG-ALANG)

Pot Tests
(Ongar, Essex, England)

Plant material:

(a) Large potted plants of *I. cylindrica* grown from clusters of culms with rhizomes, in 13 cm pots. Mean plant height 56 cm.

(b) Smaller plants grown from rhizome pieces, in 13 cm pots. Mean plant height 40 cm.

Plot size: 2 pots per treatment.
Spray volume: 225 l/ha.
Date sprayed: 2/7/71.
Date cut: 30/7/71. Fresh weight of living shoots recorded.
Date re-cut: 10/8/71. Regrowth weight recorded, rhizomes examined.

Results are given in Table 1.

TABLE 1: POT TESTS — EFFECTS OF ASULAM ON *I. CYLINDRICA*

Treatment (kg/ha)	*Fresh wt (g) of Living Shoots, 4 wk after Treatment* Large Plants	Small Plants	*% Fresh wt Reduction of Regrowth 5½ wk after Treatment* Large Plants	Small Plants
asulam 1.68 + 0.5% of "Ethylan" CP	25.7	13.5	0	29
asulam 3.36 + 0.5% of "Ethylan" CP	7.9	0.0	33	95
asulam 6.72 + 0.5% of "Ethylan" CP	0.0	0.0	92	100

"Ethylan" concentrations as % of spray volume.

Field Tests
(West Malaysia)

Site 1: Tanah Merah Estates
Weeds: Dense stand of *I. cylindrica,* approximately 200 leaves per m², 1 to 1.2 m tall. Some *Mimosa pudica* and *Mikania scandens.*
Plot size: 11.6 m × 4.3 m.

Mikania scandens was killed by asulam treatments at 22 days but was not affected by 2,2-DPA plus wetter ("Dowpon" S).

Results are given in Table 2.

TABLE 2: % CONTROL OF *I. CYLINDRICA* AT VARIOUS INTERVALS AFTER APPLICATION

Treatment (kg/ha)	*Spray Volume (l/ha)*	*Days after Application* 11	22	38	61	71	88	101
2,2-DPA 19 + "Dalawet" wetter	900	80	85	90	90	90	60	60
asulam 6.72 + 0.25% "Ethylan" CP	450	yellow	90	95	95	95	95	90
asulam 6.72 + 2.81 l/ha "Actril" D	450	yellow	95	95	90	90	90	85

Site 2: Rasah Estate

Weeds: *I. cylindrica* in open aspect, 60 to 360 leaves/m^2.
Plot size: 4.6 m × 3.7 m.
Results are given in Table 3.

TABLE 3: % CONTROL OF *I. CYLINDRICA* AT VARIOUS INTERVALS AFTER APPLICATION

Treatment (kg/ha)	*Spray Volume (l/ha)*	*Days after Application* 20	37	56	68	83	96
asulam 3.36 + 0.25% "Ethylan" CP	450	95	91	86	83	76	70
asulam 5.04 + 0.25% "Ethylan" CP	450	70	91	90	88	85	77
asulam 6.72 + 0.25% "Ethylan" CP	450	66	97	95	90	88	81
2,2-DPA 14.34 + "Dalawet"	900	80	90	85	85	80	70

2. *Sorghum halepense* (JOHNSON GRASS)

Pot Tests
(Fiji*)

Assessment was by use of a weed control index from 1 to 10 (1 = 10% control of weeds, 10 = 100% control of weeds).

Trial No. 1

Plant material: Potted plants of *S. halepense*, 46 cm tall.
Date sprayed: 16/6/71.
Treatments:
(a) Asulam 3.36 kg/ha.
(b) Control — no treatment.
Results are given in Table 4.

*Results from Southern Pacific Sugar Manufacturers Ltd., Agricultural Experiment Station, Lautoka, Fiji.

TABLE 4: WEED CONTROL INDICES AT STATED INTERVAL AFTER APPLICATION
(means of 3 replicates)

Treatment (kg/ha)	*Days after Application* 21	35	56	70	84	134
asulam 3.36	5	9	10	10	9	9

Trial No. 2

Potted plant material.
Date sprayed: 15/7/71.

Results are given in Table 5.

TABLE 5: WEED CONTROL INDICES AT STATED INTERVAL AFTER APPLICATION
(means of 2 replicates)

Treatment (kg/ha)	*Days after Application* 21	35	42	56	70	107
asulam 3.36	5	9	10	10	10	10
asulam 6.72	10	10	5	0	0	0
2,2-DPA 9.5	10	10	5	0	0	0
2,2-DPA 19	10	10	10	0	0	0

Field Tests
(Cuba, 1970)

Results of post-emergence trials in sugar cane are given in Table 6.

TABLE 6: % CONTROL OF *SORGHUM HALEPENSE* WITH 3.4 kg/ha ASULAM PLUS 3.5 l/ha "ACTRIL" D

Trial Site Reference	*Days after Application*	*% Control of* S. halepense	*% Ground Cover of* Sorghum halepense on *Unsprayed Control Plots*
U2	28	92	40
U3	66	93	40
U7	41	88	70
U9	24	99	80
	45	93	70
U10	25	75	67
	44	75	67
U12	19	72	99
	40	92	100
U14	21	100	80
	40	70	85

Each site was of ½ to 1 hectare and was sprayed with commercial equipment, either knapsack sprayers or tractor rigs, at spray volumes of 400 l/ha.

3. *Brachiaria mutica* (PARAGRASS)

Post-emergence field trials in sugar cane were conducted in the Dominican Republic in 1971. Results are given in Table 7.

TABLE 7: % CONTROL OF *B. MUTICA cf.* PRESPRAY
(means of 5 to 10 observations)

Site Ref.	*Dose of asulam (kg/ha)*	*Dose of 2,4-D amine (kg/ha)*	*Wetting* Agent*	*% Control of* B. mutica *cf. Pre-spray — weeks after Spraying* 4	8	11
1†	3.36	1.96	+	90	—	90
2†	3.36	1.96	+	90	—	90
4†	3.36	1.96	—	96	—	96
6†	3.36	1.96	—	92	—	20
7	3.36	"Actril" D 2.81 l/ha	—	—	83	—
8	3.36	—	+	—	100	—
X3	3.36	—	—	97	regrowth	—
X5	3.36	—	—	98	regrowth	—
X6	5.94	—	—	80	100	—
X9	3.36	—	+	100	95	—
X10	4.70	—	+	75	100	—
X11	3.36	—	+	100	—	90
X16	3.36	—	+	100	—	—

*"Triton" — B1956.
†Applied by air. Sites of 3 to 4 ha.
Sites 7 *et seq.* were of 0.2 to 0.4 ha each. Applications were by commercial knapsack using TK3 floodjet nozzles or mistblowers, at volumes of 170 to 450 l/ha.

4. *Paspalum fasciculatum*

Results of post-emergence field trials in bananas and citrus, conducted in the West Indies in 1972 are given in Table 8.

5. *Setaria poiretiana*

Results of post-emergence field trials in bananas and citrus conducted in the West Indies in 1972 are given in Table 9.

DISCUSSION

The advent of chemical weedkillers brought a very great potential for controlling weed problems and increasing production. At the same time they created problems, some socio-economic ones — *e.g.,* how to usefully employ labourers released from hand-weeding work — and some technical problems.

Among the technical problems is that of resistance of groups of weeds or particular species to herbicide treatments. Hence the continued use of 2,4-D, for example, has given rise to problems of grass weed infestations, since grasses are not only uncontrolled

TABLE 8: MEAN % GROUND COVER OF *P. FASCICULATUM*
(mean of 3 or 4 replicates)

Site No.	*Crop*	*Weeks after Spraying*	*Treatments** *Asulam*	*Asulam/ "Actril" D*	*Paraquat*	*Unsprayed Control*
1	Orange	0	24	32	41	40
	(Sweet Valencia,	5	0	0	68	43
	15 years)	8	0	0	68	38
		12	3	15	88	44
3	Grapefruit	0	38	36	31	35
	(Marsh Seeded, 3 years)	5	4	2	18	29
		8	2	1	18	31
11	Orange	0	—	55	—	—
	(Sweet Valencia,	5	—	2	—	—
	15 years)	9	—	0	—	—
5	Bananas	0	33	—	35	42
	(Dwarf Cavendish,	5	3	—	35	43
	some 3-4 months,	8	0	—	50	43
	some mature)	12	3	—	60	43
12†	Bananas	0	0	—	—	0
	(Robusta, ratoon)	5	1	—	—	30
		9	8	—	—	68

*Rates: Asulam 3.36 kg/ha; asulam 3.36 kg/ha + "Actril" D 2.81 l/ha; paraquat 0.28 kg/ha.

†Sprayed pre-emergence. Sprayer — "Kestrel" knapsack with TK3 flood jets at 207 kPa. Volume rate — 450 to 530 l/ha, the latter on advanced weed growth.

TABLE 9: MEAN % GROUND COVER OF *S. POIRETIANA*
(mean of 3 or 4 replicates)

Site No.	*Crop*	*Weeks after Spraying*	*Treatment** *Asulam*	*Asulam/ "Actril" D*	*Paraquat*	*Unsprayed Control*
2	Grapefruit	0	31	53	41	34
	(Marsh Seedless	5	30	44	18	48
	35-40 years old)	8	1	1	24	50
		12	5	1	26	56
8	Banana	0	19	—	—	12
	(Robusta 4th Ratoon)	5	5	—	—	25
		8	4	—	—	30

*Rates: Asulam 3.36 kg/ha; asulam 3.36 kg/ha + "Actril" D 2.81 l/ha; paraquat 0.28 kg/ha.

by 2,4-D but are actually encouraged by elimination of broadleaf weed competition. The more sophisticated recently developed herbicides also frequently have species gaps in their weed control spectra — *e.g.*, *Parthenium hysterophorus* is unaffected by paraquat, *Brachiaria mutica* is unaffected by ametryn — and there is a tendency for these problem species to multiply. Thus the important perennial grass species for which results are given in this paper now constitute serious agronomic problems in various areas of the world.

Although developed, and now widely accepted, for general use in sugar cane, it is in control of these problem species that asulam has been found particularly effective. The translocation of asulam within perennial grass weeds, together with its mode of action, enables a kill to be made of the underground culms and rhizomes as well as the top growth. The significance of this lies in preventing the regrowth of these weeds from their extensive root and rhizome systems, which usually enable them to survive herbicide treatment.

These troublesome weeds are not confined to any one crop, and it has now been established that asulam can be safely and effectively used in citrus crops and bananas. Work is continuing in Malaysia to establish the value of asulam for control of *Imperata cylindrica* and for general weed control, in rubber and oil palm crops with encouraging results to date.

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OBSERVATIONS ON THE SUBSTITUTED URACILS AND ON THEIR USE FOR SELECTIVE WEED CONTROL IN CROP PLANTS

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INTRODUCTION

The announcement of the discovery of the substituted uracils in December 1961 by the Du Pont Company (Varner, 1961) brought to the agricultural world a new family of weedkillers. The first compound to be released for testing was isocil, which proved to be an excellent general weedkiller with particular activity against both annual and perennial grasses. However, a closely related analogue, bromacil, was selected for further development because it proved more effective on weed species of the Compositae family.

Early evaluations of the substituted uracils indicated that bromacil would be useful principally for weed control on non-crop sites but further testing not only showed that it could be safely used in crops like citrus and pineapples but also uncovered some promising candidates for selective weed control in other crops. In fact, in 1962 a new formulation, lenacil, was successfully evaluated for the control of weeds in sugar beets and soon after terbacil appeared on the scene with considerable promise for selective weed control in deep-rooted perennial crops.

The present paper deals in a summarized form with the characteristic features of the uracils and of their present status in regard to selective weed control in crop plants.

CHARACTERISTIC FEATURES

The uracils are substitution compounds of the pyrimidine uracil base and differ in their molecular structure as shown in Fig. 1.

The three uracils, bromacil, terbacil and lenacil, available for selective weed control in crops, are odourless, white, crystalline solids with water solubility at 25° C as shown in Fig. 1. They are stable in common organic solvents and are also temperature-stable. They are obtainable as wettable powder formulations containing 80% active ingredient. Bromacil is also available as a granular form, a liquid formulation, and a water-soluble powder for use mainly on non-crop sites.

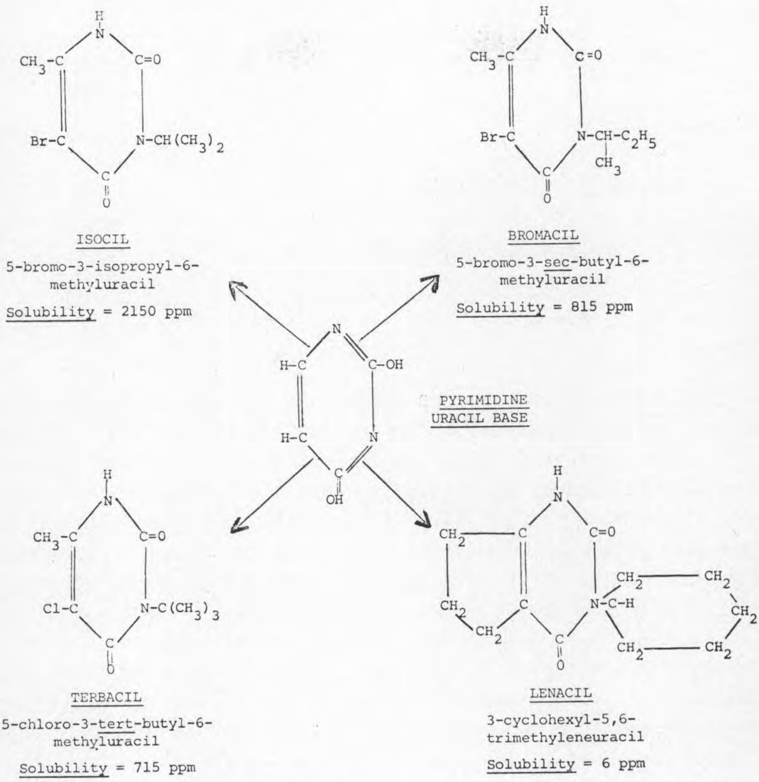

Fig. 1

These chemicals have a low mammalian toxicity and are relatively non-irritating to skin and eyes. They are in general safe to handle and present no significant health hazard when applied according to use directions.

MODE OF ACTION

The uracil herbicides are primarily absorbed from the soil through the root system but they can also enter through the foliage. Upward translocation through the stems of plants occurs readily but no evidence of downward translocation has been demonstrated. The effect on the plant is primarily one of inhibition of photosynthesis and plant response is characterized by chlorosis of the leaves and stems. Their mode of action may be diagrammatically represented thus:

$$\begin{array}{ccc} \text{light} & & \\ \downarrow & & \\ \text{chlorophyll} & \xrightarrow{\text{uracil block}} \underset{}{\overset{\text{chain of reactions}}{A \rightarrow B \rightarrow C \rightarrow D}} \longrightarrow & \text{photosynthetic products} \\ \updownarrow & & \\ \text{toxic substance accumulation} & & \end{array}$$

Of the three chemicals, bromacil is the most aggressive herbicide and it is followed closely by terbacil, while lenacil is relatively the least phytotoxic member of the family.

WEED AND CROP ASPECT

The substituted uracils are applied to the soil and persist long enough to kill weeds as they germinate. While lenacil is effective only when applied before weed emergence, bromacil and terbacil may also be applied during early stages of weed seedling development. As they exercise their toxic action by root absorption, sufficient moisture from rainfall or artificial means is necessary for their activation in the soil. The amount of water required will vary depending upon soil type and depth of weed roots.

The uracils are effective against a broad spectrum of both annual and perennial weeds and in particular against grasses. Bromacil is the best known member of this group because of its extensive usage as an overall spray against hard-to-kill perennial grasses such as *Cynodon dactylon, Sorghum halepense* and *Panicum repens* in total vegetation control. It also gives excellent control of nut grass (*Cyperus rotundus*) and has been widely used in citrus and pineapples in that respect, while terbacil has proved safer for the control of this sedge in peppermint, apples and peaches.

Because they are formulated as wettable powders, they require some means of agitation to maintain uniform suspension of the chemicals in the spray tank, otherwise injury to crop may result from over-dosage during the spraying operation. Rates of application will depend upon soil type, rainfall, weed population and crop safety. In general, rates from 0.56 to 2.24 kg/ha are applied on soil of medium texture such as sandy loams and loams, and rates from 2.24 to 4.48 kg/ha in heavier soils. They are mainly used in post-emergence treatment in perennial crops and may be applied as a broadcast spray after planting (bromacil in pineapplies, lenacil in European beet crops); as a directed spray on the soil in established crops (terbacil in apples and peaches).

Their safe use in crops will depend upon:

(1) The inherent tolerance of the crop to their herbicidal activity.

(2) The proper timing of their application in relation to the crop growth phase.

(3) The retention of the herbicide in the soil horizon above the roots of the crop.

(4) The proper depth of seed placement so that root development takes place well below the herbicide-treated zone.

With regard to the concept of "depth protection", it must be observed that weeds will react in a similar way to crops in that respect. Some weeds will be inherently tolerant, others though susceptible may survive a uracil treatment when root development takes place below the soil horizon where the herbicide occurs in lethal concentrations.

Combinations of the uracils with diuron have proved most interesting in broadening the spectrum of weed control in crops. Bromacil plus diuron is finding wide acceptance in citrus and pineapples, whereas terbacil plus diuron is rapidly developing in usage in pome fruit orchards. It must be pointed out here that areas treated with the uracils should not be replanted to any crop within two years after application unless otherwise directed, as injury to crop may result.

SOIL RELATIONSHIPS

The uracils may persist for some time in the soil and their residual life will depend on rate of application and soil type. However, as they are much less subject to adsorption on soil organic colloids than many other herbicides, they perform more consistently in a broad variety of soil types.

They have in general sufficient water solubility to facilitate phytotoxic action on shallow-rooted weeds but are sufficiently insoluble to resist leaching to the root zone of deep-rooted crops growing in medium textured soils. The disappearance of their phytotoxic effects from treated soils occurs at a favourable rate and this appears to be due to decomposition by the soil microflora rather than by leaching. As their decomposition by sunlight is negligible, they can exercise their herbicidal activity after a drought period once their moisture requirements become reestablished through rainfall.

The regular use of herbicides to control weeds in perennial crops has now and again raised the question of their possible deteriorating effect on soil physical conditions. The following work recently published on citrus has shed some light on this important question.

Long-term effect investigations conducted by the CSIRO, Division of Irrigation Research, have shown that bare-surface treatment in citrus orchards by chemical sprays led to more vigorous growth and higher yields of better quality fruit (Cary and Evans, 1972). It was also observed that the bare-surface treatment promoted the formation of abundant near-the-surface roots and that they were particularly profuse in under-tree areas. The marked increase in such roots apparently improved the trees' efficacy in uptaking applied nutrients, hence resulting in better crop growth. From this work it was also established that the initial deterioration of the soil physical conditions, in particular infiltration rate, under bare-surface treatment was not aggravated after 17 years under the same kerosene treatment and that the highest yield and best quality fruit were produced from this treatment. Bromacil used instead of kerosene on the site of the experiment since 1968 appears to have increased infiltration rate, which would indicate that such chemicals would not severely affect water penetration. In another long-term experiment in progress, bromacil applied as a bare-soil treatment since 1967 in young citrus plantings six months after their transplantation in the field is giving both effective weed control and good crop response. Some of the benefits of bare-surface culture with chemicals are thought to result from higher root temperatures registered in non-cultivated bare-surface soil than in cultivated soils (Cary, 1970).

Experimental work in Florida also showed that non-tilled chemical weed control using bromacil plus diuron resulted in better citrus growth as compared with the mechanically cultivated check (Bear, 1972), indicating that those chemicals had not affected the soil physical conditions. In fact, the larger trees were more resistant to frost damage and as a result a substantial increase in fruit yield was recorded in bare-surface treatment in comparison with that in cultivated plots.

SELECTIVE USE IN CROPS

The use of substituted uracils has become a standard practice for selective weed control in some crops, while in others field experimentation has so far given promising results from a crop safety viewpoint. The present status of their established uses as well as those uses that might eventually find application in crop plants may be considered hereunder.

ESTABLISHED USES

Apples and Peaches

The use of terbacil in established apple and peach orchards has found world-wide acceptance as it provides effective weed control down the row close to the tree and therefore crop damage that often results from mechanical methods is avoided. It may be used as a single band or broadcast application to the ground beneath and/or between trees before weed emergence or during the early seedling stage of weed growth.

Terbacil may be applied at 2.24 to 3.36 kg (all rates in kg a.i./ha) in established orchards three years old and over. It has proved safe to the crop in moderate to heavy clays which are provided with adequate organic matter. It should not be used in sandy soils as crop injury may occur.

Terbacil does not leach far down in the soil profile as shown in experimental work carried out by Skroch *et al.* (1971). In this work, terbacil applied annually at 2.2 and 4.5 kg for three consecutive years showed no residues one year after the third application in the 30 to 60 cm layer both in surface and in soil-incorporated treatments. This would explain why the chemical is effective against shallow-rooted perennial weeds and can be used safely for their control in deep-rooted perennial crops, such as apples and peaches.

The safety of terbacil in apples has been well established in three long-term trials carried out in New Zealand where annual applications made during four years showed no phytotoxic effects on the crop. In one trial at Massey University, terbacil at 2.24 and 4.48 kg was applied in established apples, Sturmer, Granny Smith and other commercial varieties, from 1968 to 1971. In another trial initiated in young apples at the Levin Horticultural Research Station, chlorosis showed up initially in the 6.72 kg treatment but disappeared after the second application when the crop was 2½ years old and did not occur again with subsequent annual applications of the chemical. In the third trial rates up to 14.34 kg applied to established apple trees proved safe to the crop after four annual applications.

Asparagus

Bromacil has been the standard treatment for controlling weeds in established plantings in Australia during recent years. It is generally applied 3 to 4 weeks prior to spear emergence in spring or before the early cutting period. After harvest, a second application may be made to keep fields free from weeds. Rate of application varies between 1.12 and 3.36 kg depending upon soil type. The lowest rate, 1.12 to 2.24 kg is used in light soil, while the highest rate, 2.24 to 3.36 kg is applied in soils high in clay or organic matter. Contact of the spray with the asparagus fern should be avoided as injury to the crop may result. Best results are obtained when the field is irrigated before application and then again as soon as possible after application.

Recent experimental work carried out in New Zealand with bromacil and terbacil in established plantings indicated that spray applicaitons made before cutting commenced were preferable to sprays made at closing-up under conditions of unreliable rainfall in summer.

The uracils should not be applied to newly seeded asparagus. They should not also be applied to young plants during the first growing season after setting or to plants whose roots are exposed, as injury to the crop may occur.

Beet Crops

Lenacil is widely used in sugar beet, red beet, mangolds and fodder beet in most European countries and more recently in New Zealand.

Lenacil is generally applied at time of drilling or immediately afterwards before weed emergence. It should be used as a band or as an overall spray at rates between 0.9 and 2.24 kg, depending upon soil type, the lowest rate being used in light soils and the highest rate in medium loams. It is essential that the spray be applied evenly to the soil surface at the recommended rate as overdosing may lead to crop damage. Lenacil controls a wide range of weeds occurring in beet crops with adequate safety.

The unsatisfactory performance of lenacil in peat soils because of unreliable rainfall in the spring-summer period has led to the development of its application as a pre-plant soil-incorporated treatment in New Zealand. Experimental work carried out by the Agricultural Engineering Institute, Lincoln College (J. S. Dunn, pers. comm.) has established that lenacil applied as a pre-plant soil-incorporated treatment in fodder beet gave increased weed control efficacy when the herbicide was incorporated in the top 3 to 5 cm in comparison with the normal soil surface application technique.

Citrus

Bromacil and terbacil are widely used in all citrus-growing countries and are well known to the citrus orchardist. They are generally applied as a band or broadcast treatment and/or between the trees prior to weed emergence or during the early seedling stage of weed growth.

Most annual weeds can be controlled on a year-round basis by split application treatment of 2.24 to 4.48 kg. For the control of perennial grasses, rates from 6.72 to 8.96 kg may be applied as a directed spray just prior to the period of most active growth. Care must be taken to avoid contact of spray drift to crop foliage as this may cause temporary foliar chlorosis. These uracils should not be applied to citrus orchards in which established trees are under three years old nor should they be used on sandy soils low in organic matter and on poorly drained soils. Terbacil has proved safer in young plantings and in light soils.

The use of the uracils in citrus could cause substantial yield increase as shown in experimental work carried out with bromacil in Israel. In that study (Monselise, 1967) the eradication of *Cynodon dactylon* and *Pennisetum clandestinum* by bromacil in a 30-year-old sweet lime orchard increased fruit production by 30%. The same workers also showed that in citrus orchards treated with bromacil a higher relative growth rate was registered in comparison with untreated orchards based on trunk increment measurements.

That no harmful residues remain in the crop from the regular use of bromacil and terbacil was established by investigations carried out at the University of California (Day *et al.*, 1967). In fact, none was detectable in citrus fruits and leaves sampled in citrus orchards that had received treatments ranging from practical rates of 2.24 to 4.48 kg/ha to rates as high as 36 to 72 kg.

As discussed previously in the section on soil relationships, it might therefore be concluded that the bare-soil treatment technique with chemicals such as bromacil should receive the attention it deserves for the production of higher yields and better quality fruits in this crop.

Lucerne (Alfalfa)

The use of the uracils in cirtus can cause substantial yield for a period of at least twelve months is of recent introduction and is finding expanding application in New Zealand and South Australia. In New Zealand extensive test work, followed by commercial usage, has shown that terbacil applied at 0.84 to 1.40 kg as a broadcast spray to lucerne stands during the dormant period would give effective weed control with adequate crop safety. In South Australia, experimental work carried out by the Department of Agriculture (Kloot and Dawes, 1971) showed terbacil to be most effective for the control of weeds in lucerne. Even at the lowest rate used, 0.56 kg, weed control obtained was most satisfactory. Following this work, terbacil has been registered for use in that crop this year at rates of application 0.67 to 1.40 kg.

In general, terbacil must be applied before or just after weed emergence and the ground must be damp. The higher rate should be used in heavier soils. Terbacil should not be used on sandy or gravelly soils and on soils low in organic matter. It should not be applied more than once per year, as crop injury may result.

Peppermint (*Mint; Mentha*)

Wherever peppermint is grown, terbacil finds its way because of its safety to this crop and its effectiveness against the range of weeds that are usually encountered in climatic areas best suited for its cultivation. It is usually used in a single broadcast application at the rate of 1.12 to 2.24 kg before the crop emerges from newly planted roots or in the established crop. Treated areas may be replanted to peppermint one year after last application.

Terbacil is widely used for selective weed control in peppermint in the United States and more recently it found useful application for economic production of this crop in India where *Cyperus rotundus,* the dominant weed species of the peppermint-growing areas, constituted a grave menace to the development of a peppermint oil industry. It is of interest to mention here that experimental work conducted in that country (B. C. Gulati, S. P. S. Duhan, R. Dupta and V. M. Bhan, pers. comm.) showed that the use of terbacil at 2.0 kg in providing effective control, led to higher crop and oil yields. It was also established that its use had no adverse effect on the quality of the oil.

Pineapples

Bromacil has gained wide acceptance for selective weed control in pineapples. It is extensively used in Hawaii, South Africa, Puerto-Rico and Australia and has contributed in a large measure to the economic production of this crop in those countries.

Bromacil is usually applied at rates varying from 1.80 to 3.60 kg as a broadcast spray prior to weed emergence, immediately after planting, or before planting material begins to grow. An additional application of 1.80 kg may be made prior to flower differentiation as a directed inter-row spray.

Recently introduced in India, it showed excellent performance when used alone at rates of 2.4 and 3.2 kg (Anon., 1971). As *Cyperus rotundus* is the major weed species of the pineapple-growing areas in this country, its effective control by bromacil will contribute to the economic expansion of this developing industry.

It must be observed that the use of a mixture, diuron and bromacil, is becoming rapidly established as a standard practice in pineapples as it broadens the spectrum of weed control, particularly in fields which have become invaded with *Cyperus rotundus* through prolonged usage of diuron.

Sisal

The evaluation of bromacil in sisal nurseries by the High Level Research Station in Kenya (Richardson, 1965) has led to the use of this chemical in that crop. It was found that bromacil at the low rate of 2.24 kg followed a year later by a second application at 1.33 kg could give 18 to 24 months' weed control with no crop injury. Best results were obtained when applied soon after planting.

It must be observed that at higher rates of application it may cause leaf chlorosis, the persistence of which will depend upon the nature of the soil. However, its use in heavy clay soils has shown a marked degree of crop safety, and bromacil-treated nurseries produce larger and stronger nursery plants of a deep blue colour.

Strawberries

Lenacil is a well-established herbicide in strawberry in most European countries and is generally safe to all commercial varieties. It may be applied to runners immediately after planting and also to established plantings. Rates of application vary from 1.68 to 2.80 kg using the lowest rate in light soils and the highest rate in medium loams. To ensure effective weed control results, lenacil should be applied before weed germination and rain or irrigation is essential to activate the herbicide.

Sugar Cane

The use of terbacil in sugar cane has found application only in Louisiana, Hawaii and Puerto-Rico in cane varieties which have shown good tolerance to the chemical. It is applied at 0.90 to 2.24 kg as a broadcast treatment in plant canes and ratoons before cane emergence. It should not be used where cane is grown on thinly covered subsoils or on rocky areas as injury to cane may result.

Terbacil has found application in Louisiana for the control of Johnson grass (*Sorghum halepense*) as a broadcast treatment at 1.80 kg after planting, before cane emergence and with a repeat application in early spring.

It is interesting to note here that exploratory work carried out with lenacil used alone and in combination with diuron has also shown promise in that crop.

Ornamentals

Bulbous Types

Lenacil has found usage in all varieties of daffodils, narcissi and tulips at rates varying from 2.24 to 2.80 kg depending upon soil type. It should be applied to a weed-free soil before or shortly after crop emergence in daffodils and narcissi and before crop emergence in tulips.

Other Ornamentals

Lenacil has also found usage in most varieties of roses, dahlias, daisies and chrysanthemums at the above-mentioned rates of application. It is also being used in a wide range of ornamental trees, shrubs, herbaceous and nursery stock.

PROMISING USES

Coffee

Although the standard residual herbicide in coffee is diuron, it would appear that lenacil might hold a place in this crop either used alone or in combination with diuron to broaden the spectrum of weed control. Experimental work in 1970 in Papua New Guinea (G. Pritchard, pers. comm.) showed that in established coffee plantations, lenacil, when first applied at 1.80 and 2.69 kg with a retreatment 10 weeks after at the same rate and at half those rates, caused no crop phytotoxicity at 17 weeks after the second application. The use of diuron at 1.80 kg in combination with lenacil at 1.12 kg also proved both effective and safe to the crop.

In a replicated phytotoxicity trial recently laid down on coffee plantings 9 months old in the field at spraying time, Pritchard found lenacil safe at 3.2 and 6.4 kg 16 weeks after treatment, while at 12.8 kg only 2 plants out of 24 in the six replicates of the treatment showed temporary chlorosis.

Those results would indicate that lenacil might prove safe to use in coffee and in particular in the heavy clay soils of Papua New Guinea which are well provided with organic matter.

Grapes

Preliminary testing indicates that lenacil could be applied to "vine cuttings" at rates up to 1.80 kg provided the spray is made soon after planting. This observation might lead to exploratory testing in established vines in combination with diuron to broaden the spectrum of weed control.

Grass Seed Crops

Exploratory work on the evaluation of terbacil and lenacil for selective weed control in grass seed crops in Europe has shown some promise in that field. Both chemicals have shown good selective control of *Poa annua* in Kentucky blue grass (*Poa pratensis*) grown for seed production and, of the two, terbacil was the more effective herbicide.

Experimental work in Australia has also indicated that terbacil at rates up to 3.60 kg would cause no crop damage in *Phalaris tuberosa* and cocksfoot (*Dactylis glomerata*) grass seed crops. The herbicide was applied in early post-emergence of the weeds and at late dormancy for the crop.

Passion Fruit

Exploratory work with bromacil and terbacil at rates up to 1.80 kg showed the chemicals to be fairly safe when applied as a pre-emergence treatment to weeds in 10-months-old established passion fruit. However, there are indications that it might not prove safe to this crop when applied soon after transplanting.

Rubber

Preliminary investigations with bromacil in Malaysia have shown rubber to be fairly tolerant to this chemical and have opened the possibility of its usage in that crop.

Experimental work carried out in young rubber (Hwang Ting Min *et al.,* 1971) with bromacil used alone at 0.90, 1.80 and

7.17 kg and at 0.9 and 1.8 kg in combination with diuron, plus a repeat application of all treatments six months after the first spraying, showed bromacil safe to the crop as measured on a trunk increment basis.

Tea

The use of residual herbicides in mature tea, and in particular diuron and simazine, is now an established practice in most of the tea-growing countries of the world. Recent experimental work, however, may indicate that lenacil could find a place in this crop when used alone or in combination with diuron as described hereunder.

Exploratory work carried out by the Tea Research Institute, Ceylon (Wettasinghe and Rajendram, 1969) on the evaluation of a number of herbicides in mature tea indicated that lenacil at 0.67 and 1.33 kg was the only chemical which gave extremely good control of all weed species present with no phytotoxic effects on the crop.

Investigations carried out in Papua New Guinea in 1969-70 showed that lenacil could be used safely in the peat soils of that territory and more comprehensive work was carried out during 1970-1. Lenacil was tested alone at 3.60 kg and at 1.80 and 2.69 kg in combination with diuron at 0.90 and 1.80 kg. Those treatments repeated about 3 months after did not lead to any injury when crop phytotoxicity was assessed at the end of the experiment. Weed control was excellent on all weed species present.

In experimental work carried out by the Department of Agriculture, Stock and Fisheries in 9-month-old tea seedlings 23 to 30 cm high, lenacil at rates up to 4.8 kg applied as a broadcast cast spray also proved safe to the crop, and confirmed the tolerance of the crop to this chemical.

Those results would indicate that lenacil is presumably safe to tea, at least in peat soils, and that it could find application in this crop in mixture with diuron because of the broader spectrum of weeds that would be controlled.

Tobacco

The use of lenacil in tobacco might become an agronomic proposition for selective weed control in this crop.

Belgian Work by De Beats *et al.* (1966) reported at the 4th World Tobacco Scientific Congress in Athens that lenacil applied as a pre-planting treatment at 0.96 kg gave effective weed control with no crop damage. A mixture of lenacil and linuron at 0.48 plus 0.24 kg, respectively, gave even better results.

CONCLUDING REMARKS

The substituted uracils brought to the agricultural world during the last decade have made considerable progress in their use for selective control of weeds in crop plants. First introduced for chemical weeding in citrus, pineapples and sugar beet, their application has actually extended to commercial usage in nine crops as well as in ornamentals and with promising acceptance in seven others. Such a result could be attributed to advanced crop technology and to a better understanding of soil-herbicide relationships which in turn led to safer use in crop plants. For it must be recalled here that crop phytotoxicity has often been overstressed because of imperfect knowledge of application techniques in regard to crop phasic growth.

The potent herbicidal activity of the uracils certainly warrants further research into their safe use in crops on which limited experimental data are available and also in other crops in which no exploratory testing has been done.

If this brief account of the actual and promising uses of the uracils in crop plants could stimulate further investigational work on other selective uses, the aim of this paper would have been achieved.

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ENVIRONMENTAL FACTORS AFFECTING THE HERBICIDAL ACTIVITY OF PRONAMIDE

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Summary

Pronamide is a selective herbicide and has been used commercially in lettuce, lucerne, clover, and related small-seeded legumes, and in Bermuda grass turf. The herbicidal effectiveness of pronamide over a range of application procedures and environments was measured. Effects of the environmental factors such as temperature, soil type, moisture content in soil, leaching, and runoff of pronamide on the herbicidal activity are reviewed. The amount of degradation of pronamide by the environmental factors can be measured by the herbicidal activity since there is a direct correlation between them.

INTRODUCTION

Pronamide is a selective herbicide that has been registered for use in lettuce, lucerne (alfalfa), clover, and related legumes, and in Bermuda grass turf. A general description of pronamide as a herbicide has been reported (Laude *et al.*, 1969; Swisher, 1971; van de Loo, 1970), and many papers dealing with its specific herbicidal utility have been published, for example, pre-emergence and post-emergence weed control in lucerne (Duke, 1969; Ilnicki and Hist, 1969; Parochetti, 1969), clover (Paxman and Forgie, 1972; Viste *et al.*, 1970), Bermuda grass (Burt and Gerhold, 1970), lettuce (Lavalleye *et al.*, 1969; Braden and Cialone, 1970; Robinson, 1970), strawberries (Altman and Stadelbacher, 1970), and quackgrass control (Duke, 1970; Viste and Sanborn, 1970; Viste, 1972). Subsequent publications describe the degradation of pronamide in soils (Yih *et al.*, 1970) and its metabolism in soils and plants (Yih and Swithenbank, 1971a), and in animals (Yih and Swithenbank, 1971b).

In this paper the environmental factors will be discussed in relation to herbicidal activity and its correlation with the degradation of pronamide.

RESULTS AND DISCUSSION

EFFECTS OF TEMPERATURE

Trends in the data obtained from field trials over the last several years strongly suggest that pronamide is more active in cool than in hot environments. At 1.12 kg/ha, pronamide weed control was good in Mississippi when used in May, fair to poor in June. At 1.68 kg/ha, pronamide weed control was excellent in late August. At 3.36 kg/ha in Mississippi, weed control by pronamide was excellent when applied in April or May, only good when in June, and excellent again when applied in late August. A similar pattern has been observed in Pennsylvania. Both in Mississippi and in Pennsylvania, the temperature in May or in August is lower than the temperature in June or July.

A wheat bioassay method was used to determine the amount of pronamide in soil. Pronamide soil residues were determined on 1 April 1971 following treatment in late autumn 1970. About 40% of the pronamide was lost during the winter at the warmer southern test locations as compared with 15% loss in the colder northern test sites.

In the laboratory studies, soil was treated with ^{14}C labelled pronamide and stored in incubators at four different temperatures. The amount of pronamide was determined at various time intervals. At 37° C, less than 10% of pronamide remained after 120 days, whereas very little loss of pronamide occurred at 5° C. Intermediate amounts of pronamide have disappeared at 15° C and 26° C. A rapid loss of pronamide took place between 120 and 180 days when the 5° and 15° C samples were transferred to 37° C. The rate of loss of pronamide was stabilized when the two highest temperature samples were stored at 5° C.

These results strongly suggest that pronamide is more active in a cool than in a hot environment, because it is more stable in cool than in hot conditions.

Effect of Soil Type, Surface Applied *vs.* Soil Incorporation, and Rainfall

Early experiences with pronamide indicated that the compound was more active when soil-incorporated than when applied to the soil surface. Field experience with pronamide points strongly to the conclusion that weed control relating to surface or incorporated treatments depends on water.

Under dry conditions, incorporation of pronamide resulted in better weed control than surface treatments. Under conditions of moderate rainfall, pronamide was generally more active surface-applied than incorporated. Under conditions of heavy rainfall, surface treatments were again superior to those incorporated. The fact that pronamide was so much more active under moderate than heavy rainfall on the sand-rock soil would indicate that the compound might be subject to leaching on light soils.

Transformation of ^{14}C labelled pronamide occurred in six soil types examined under laboratory conditions. There is no obvious correlation between the rate of transformation of pronamide and physical and chemical properties of the various soils. There was a tendency, however, for pronamide to disappear at a faster rate in medium to heavy textured soils (loams and clays) than in sandy textured soils (sand loams and sands).

EFFECT OF LEACHING

Radioactive ^{14}C labelled pronamide was applied to columns of soil representing five different soil types. Distribution of the radioactivity was determined after the columns were leached with 20 cm of water. Pronamide is not readily leached in most of the soils of this study except sandy soil. The majority of the pronamide applied remained in the surface 3 cm of soil. These results suggest poor herbicidal activity on sandy-rock under heavy rainfall conditions.

EFFECT OF RUNOFF

Pronamide runoff trials were conducted at five locations over four states. Average pronamide soil residues from both the treated and non-sprayed field areas of these five tests were determined. No pronamide residues were measured outside the treated plot area in any of the trials. This finding is not unexpected in view of the laboratory leaching test results and the relatively low water-solubility of pronamide.

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INTERACTION OF SODIUM CHLORATE AND 2,4-D IN THE CONTROL OF WEEDS

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Summary

The herbicides 2,4-D and sodium chlorate are often applied in a mixture for weed control in rubber cultivation. At the dosages of the herbicides used in the experiment, 2,4-D was found to interact antagonistically, synergistically and additively with sodium chlorate when applied on *Mikania cordata, Ottochloa nodosa* and *Paspalum conjugatum,* respectively. In the case of *Mikania,* it is likely that the scorching effect of sodium chlorate has injured the symplast system, thereby inactivating the translocation of 2,4-D within the plant.

INTRODUCTION

Recognizing the hazards of using sodium arsenite for weed control in rubber (*Hevea brasiliensis*) cultivation, several alternatives have been recommended from time to time (Woo, 1969; Pushparajah and Woo, 1971; Rubber Research Institute of Malaya, 1971). These alternatives are usually mixtures of two or more chemicals. Interactions, either synergistic or antagonistic, have been shown to occur between two herbicides when they are applied in combination on different weed species (Riepma, 1962; Seth, 1971). Currently, a mixture of sodium chlorate and 2,4-D is found to be relatively effective as well as economical. Earlier trials indicated that these chemicals interact differently when sprayed on different weed species. The work described here confirms the interaction between these two herbicides when they are applied in combination against three common weeds in rubber plantations, namely, *Mikania cordata, Ottochloa nodosa* and *Paspalum conjugatum.*

EXPERIMENTAL

The field experiments were laid down in open areas (without shade) with "pure" stands of the three weed species. The experimental design was one of complete randomization with three replications of each treatment. The plots were 10 m^2 in size and the chemicals were applied through a 1/16 inch Fan-jet nozzle

(1.6 mm orifice) from a knapsack sprayer at the equivalent of 620 l/ha solution. The amine salt of 2,4-D was used in the experiment. A non-ionic surfactant was incorporated at 6.5 ml/l solution.

In assessing the effectiveness of the treatments, the point quadrat method (Riepma and Wong Phui Weng, 1963) was used. Percentage inhibition of growth was calculated as:

$$\% \text{ inhibition } (X) = 100 \times (a - b)/a$$

where a = No. of 1st contacts before spraying
b = No. of 1st contacts after spraying

Fortnightly observations were made. At each observation, 200 pins per plot were used in 20 frames of 10 pins each to assess the percentage coverage of the respective species. For each observation, the expected response from any given combination was calculated (Gowing, 1960). Thus if X is the mean percentage inhibition by herbicide A at p kg/ha and Y is the mean percentage inhibition by herbicide B at q kg/ha, the expected percentage inhibition (E) by herbicides $A + B$ at $p + q$ kg/ha may be expressed as follows:

$$E = X + Y - (XY/100)$$

Synergism between two herbicides is indicated when the observed response is greater than expected, additivity when the observed and the expected responses are approximately equal, and antagonism when the observed response is less than the expected.

RESULTS AND DISCUSSION

The percentage inhibitions of *Mikania cordata* by the herbicidal treatments are given in Table 1. The observed inhibition by the mixture of both chemicals is seen to be much less than the

TABLE 1: PERCENTAGE INHIBITION OF *MIKANIA CORDATA*

Treatment (kg/ha)	*Duration after Spraying (wk)* 2	4	6	8
2,4-D 1	71.9	84.2	68.0	47.9
sodium chlorate 18	56.8	28.1	6.3	3.7
2,4-D 1/sodium chlorate 18	77.6	83.2	53.8	21.6
5% LSD	1.4	5.5	4.5	6.9
Expected % of inhibition by combined herbicides	87.9	88.6	70.0	49.8
Difference	—10.3	—5.4	—16.2	—28.2

expected inhibitions in all four observations. The results therefore indicate that sodium chlorate interacts antagonistically with 2,4-D in the control of *Mikania cordata*. 2,4-D is absorbed and translocated readily in most dicotyledonous plants (Ashton, 1958) via the symplast and phloem vessels (Fryer and Evans, 1970). It is likely that the dosage of sodium chlorate used was sufficient to cause scorching of the plant tissue (Crafts and Robbins, 1962) and consequently inhibit the movement of 2,4-D in the plant.

TABLE 2: PERCENTAGE INHIBITION OF *OTTOCHLOA NODOSA*

Treatment (kg/ha)	*Duration after Spraying (wk)* 2	4	6	8	10	12
2,4-D 1	35.1	35.5	20.6	20.0	18.4	14.1
sodium chlorate 18	51.9	40.0	36.6	24.0	29.0	16.2
2,4-D 1/sodium chlorate 18	98.9	93.2	88.9	74.2	73.0	68.2
5% LSD	1.4	2.8	4.5	6.2	5.9	6.9
Expected % of inhibition by combined herbicides	68.8	61.3	49.7	39.2	42.1	28.0
Difference	+30.1	+31.9	+39.2	+35.0	+30.9	+40.2

Table 2 presents the results obtained with the grass *Ottochloa nodosa*. In this case, the observed inhibition by the mixture of both herbicides is much greater than the expected value in all the observations. It is known that sodium chlorate is an efficient herbicide for controlling grasses while most monocotyledons are relatively tolerant to 2,4-D (Gallup and Gustafson, 1952). The results therefore indicate that the presence of 2,4-D has enhanced the efficacy of sodium chlorate synergistically when sprayed against *O. nodosa*.

The inhibition of *Paspalum conjugatum* by the herbicidal treatments are shown in Table 3. There is very little difference

TABLE 3: PERCENTAGE INHIBITION OF *PASPALUM CONJUGATUM*

Treatment (kg/ha)	*Duration after Spraying (wk)* 2	4	6
2,4-D 1	15.4	9.8	14.1
sodium chlorate 18	46.0	23.4	15.5
2,4-D 1/sodium chlorate 18	54.5	35.5	26.2
5% LSD	2.1	2.6	3.6
Expected % of inhibition by combined herbicides	54.3	30.9	27.4
Difference	+0.2	+4.6	—1.2

between the observed and expected inhibition by the mixture of the two herbicides. This suggests that 2,4-D and sodium chlorate when applied in combination against *P. conjugatum* interact additively.

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SEED PELLETING AS AN APPROACH TO HERBICIDE SELECTIVITY IN DIRECT-SOWN RICE[1]

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Summary

A technique was devised to use carbon-pelleting of rice seed to protect direct-sown rice from herbicides which are toxic or lethal to rice seedlings. The most suitable adhesive for pelleting was polyvinyl acetate; the best adsorbent coating was activated carbon. Triple carbon coatings gave better herbicide protection than single or double coatings. In field experiments carbon pelleted seeds were protected against herbicide toxicity, and grain yields were equal to the hand-weeded control. Seedling mortality was high when uncoated seeds were used, and grain yields were significantly lower than in hand-weeded plots or when carbon-pelleted seeds were used.

INTRODUCTION

Although selectivity of herbicides depends primarily on herbicidal properties in relation to plant characters, their safe and effective use in crop production can be greatly improved by systematic manipulation of plant-herbicide relationships. Many compounds considered toxic under the usual screening procedures (Obien *et al.*, 1973) are often found selective under specific situations through careful and deliberate manipulation of plant-herbicide interactions by varying the time and method of herbicide application, addition of surfactants, depth of planting, irrigation methods, and other farming practices.

In recent years the use of herbicide adsorbents such as activated carbon ("charcoal") has been studied as a potential tool against herbicide damage to planted crops. By its high adsorption capacity,

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activated carbon, when positionally applied, can reduce the amount of herbicide available for plant absorption, with little or no alteration in herbicide activity on weeds. Better seedling establishment was obtained by dusting moistened roots of sweet potato slips with activated carbon because of effective protection from 2,4-D injury (Arle *et al.*, 1948); also, strawberry runners dipped in activated charcoal were protected from the effects of simazine, prometryn, neburon, bensulide, and tricamba (Schubert, 1967: Kratky *et al.*, 1970). Likewise, various band applications of activated carbon—subsurface band (Ripper, 1956), incorporated surface band (0.5 m) (Locascio, 1967), and slurry on narrow (2.5 cm) surface band Linscott and Hagin, 1967) — have been utilized to protect row-sown crops, such as alfalfa, sugar beet, cucumber, tomato, and ryegrass from herbicide injury. A mixture of carbon + vermiculite (5:3) applied on a planting hole (2 cm deep by 2.5 cm diameter) over cucumber or tomato seeds was effective against the effects of simazine, chlorthal, and nitralin (Kratky and Warren, 1971). It has been estimated that the amount of carbon required in band application ranges from 28 to 55 kg/ha to as high as 130 to 192 kg/ha (Linscott and Hagin, 1967; Burr *et al.*, 1972).

Another approach to the use of carbon as a protective agent is to coat seeds with it before planting. Pelleting seeds with various materials has been utilized in agriculture for different purposes:

(1) Better seed establishment — seeds pelletized with inoculant and fertilizer to improve pasture establishment in acid soils (Norris, 1967; Plucknett, 1971), seeds pelleted with insecticides or fungicides to repel or control pests (Russell *et al.*, 1967), and rice seeds pelleted with kaolin, bentonite, and talc to add weight to prevent seeds from floating when broadcast on flooded soil (Seaman and Brandon, 1971).

(2) Precision in planting — seeds encapsulated in pressed vermiculite tablets or clay-coated to facilitate precision placement by machine planters (Robinson and Johnson, 1970).

(3) Better plant growth — seeds pelleted with plant growth regulator to promote rooting and hasten emergence of the seedlings (Crocker and Barton, 1953).

In view of the above successes with seed pelleting, this technique was investigated to determine the effectiveness of activated carbon secured on seed with suitable adhesive for protection of direct-sown rice from herbicide injury. This approach was a significant departure from band application of activated carbon previously discussed, but it appeared basically sound because the carbon pelleted around the seed would adsorb the herbicide and prevent it from injuring the germinating seedling. The process was found to be more complex than is suggested here, but the results point out some alternatives in seedling protection. This report is a part of an extensive study of the process.

PELLETING PROCESS

Seed pelleting requires two principal materials, adhesives and adsorbents, preferably those which are commercially available. The pelleting technique must be one that would most likely succeed under field conditions. Therefore the best pelleting materials observed in the laboratory must again be tested in the greenhouse and in the field with different herbicides, soils, methods of application, climatic conditions, and other factors in order to evaluate the potentials and limitations of the tested materials.

The process of pelleting seeds is simple if the required materials have already been selected. The choice of pelleting materials is basic to the pelleting process; this subject will be discussed later in this paper. Plucknett (1971) has described pelleting of seeds in which fertilizers were incorporated into the coating materials to improve seedling establishment in pasture.

For a small amount of seeds (such as are needed in small-pot experiments), pelleting was accomplished by mixing the seed and coating materials in a small beaker with a stirring rod. For large amounts, however, a 5 gal concrete mixer was used in mixing the materials and the seeds. A larger concrete mixer would, of course, be suitable in pelleting seeds for large hectarage. Thus any durable container could be utilized for pelleting depending on the amount of seeds needed.

The steps in pelleting rice seeds are as follows:

(1) Seeds to be used are soaked for 24 hr and incubated for 48 hr. Pregerminating the seeds will hasten seedling emergence from the soil; this improves the tolerance of rice to herbicide and flooding treatments.

(2) Mix pregerminated seeds and adhesive(s) in a beaker or drum. After thorough mixing (wetting of seeds), add adsorbent; stir and mix thoroughly.

Based on preliminary studies, the materials should be mixed in the following proportions: 5 ml adhesive and 5 g adsorbent for every 10 g rice seeds.

(3) To increase coating with adsorbent, repeat the above procedure after the seeds have been dried for at least 60 min under room temperature. Add slightly more adhesive and adsorbent for second and third coatings.

SELECTION OF PELLETING MATERIALS

Pelleting materials should possess the following basic properties: (a) They must be nontoxic to rice, easy to handle, and provide a stable coating under adverse climatic conditions; and (b) they must provide sufficient protection to direct-sown rice from toxic herbicides. The cost of the materials is also a very important consideration, since the cost/benefit would limit its application in crop production.

ADHESIVES

Plucknett (1971) reported that aqueous solutions of 45% gum arabic, 5% methyl cellulose, and 4% methyl ethyl cellulose have been used successfully in seed pelleting work in New Zealand, Australia, and Hawaii. Seaman and Brandon (1971) reported also that 50% polyvinyl acetate and 20% dry casein glue were potentially good adhesives for pelleting rice seeds.

The above five adhesives were compared for their coating quality and stability by varying their concentrations and coating layers of adsorbents. The adsorbents used for evaluation of coating quality and stability were activated carbon Darco G-60 and anion and cation exchange resins.

An excellent coating quality would be one which could cover the entire surface of rice seed with easy separation of the surplus adsorbent from the coated seed. In Table 1, pelleting quality was arbitrarily classified as excellent, good, fair and poor. Evaluation of coating stability was obtained by shaking 20 coated seeds in a vial containing 20 ml water for at least 2 min (shaking time was standardized to 2 min) on a Burrell wrist-action shaker. After shaking, the coated seeds were placed on dry paper for visual determination of coating stability. A score of 10 was given to coating which remained intact after shaking, and a score of 0 to coatings which completely dispersed in water. This stability test proved to be better and more practical than other methods such as subjecting coated seeds to simulated rainfall, or placing the seed on wet filter paper and observing the movement of adsorbent away from the seed with time.

TABLE 1: PROPERTIES OF FIVE ADHESIVES AS MATERIALS FOR COATING RICE SEEDS WITH ACTIVATED CARBON DARCO G-60

Adhesive and Concentration (%)	*pH*	*Viscosity*	*Coating Quality*	*Coating Stability**	*Germination (% Control)*
Methyl cellulose:					
1	8.3	low	poor	7	98
2	8.2	low	excellent	6	96
3	8.1	medium	excellent	4	102
4	8.1	high	excellent	4	98
5	8.1	very high	excellent	3	102
Methyl ethyl cellulose:					
2.5	7.9	low	poor	3	104
5.0	7.5	low	poor	2	89
7.5	7.5	low	excellent	2	98
10.0	7.4	high	excellent	2	93
12.5	7.5	very high	excellent	2	102
Gum arabic:					
35	5.0	low	poor	1	98
40	4.5	low	good	1	96
45	4.5	low	good	1	100
50	4.4	low	good	1	100
55	4.4	low	good	1	93
Dry casein glue:					
15.0	12.4	low	fair	9	80
17.5	12.4	low	good	9	69
20.0	12.3	low	excellent	10	74
22.5	12.1	low	excellent	10	77
25.0	12.1	low	excellent	10	65
Polyvinyl acetate:					
35	4.3	low	fair	10	102
40	4.1	low	good	10	100
45	4.2	low	good	10	96
50	4.4	low	excellent	10	96
55	4.4	low	excellent	10	100
LSD (0.05)				2	12

*Coating stability: 10 = most stable (2-4% dispersed); 0 = least stable (completely dispersed upon contact with water).

In general, increased concentrations of adhesives increased quality and weight of carbon coatings. However, with methyl cellulose and methyl ethyl cellulose increased concentrations were accompanied by increased viscosity. Highly viscous adhesive solutions were undesirable because of the difficulty in coating seeds with the adsorbent. On the basis of coating quality alone, the optimum concentrations of the adhesives were 2, 7.5, 45, 20 and 50% for methyl cellulose, methyl ethyl cellulose, gum arabic, dry casein glue, and polyvinyl acetate, respectively.

The coating stability of the five adhesives was strikingly different. Gum arabic coatings were very unstable, thus easily dispersed as soon as the coated seeds touched the water. The coating stability of both methyl cellulose and methyl ethyl cellulose was fair, but dry casein glue and polyvinyl acetate provided the most stable coatings. Coating stability was generally not affected by the concentrations of the adhesives.

Between dry casein glue and polyvinyl acetate, however, the choice was determined by their effects on seed germination and seedling growth. Seeds soaked for 5 min in 20% dry casein glue had only 36% germination compared with 96% for seeds soaked in 50% polyvinyl acetate (Table 2). Dry casein glue had a high pH of 12.3 which might explain its severe effects on rice germination. Dry casein glue used in combination with activated carbon was less toxic than dry casein glue alone, but seed germination was still significantly lower than with polyvinyl acetate (Table 1). Increasing the number of coatings from one to three layers (using the optimum concentrations of methyl ethyl cellulose, gum arabic, dry casein glue, and polyvinyl acetate) did not improve their stability. It was also observed that multiple coatings with dry casein glue for seed pelleting resulted in poorer germination of rice seed. It was clear that polyvinyl acetate was the best adhesive for seed pelleting.

TABLE 2: EFFECT OF SOME ADHESIVES ON PERCENTAGE GERMINATION AND GROWTH OF RICE SEEDS

Adhesives	*Germination (% Control)*	*Length at 6 DAS* (% Control)*	
		Shoot	*Root*
gum arabic 45%	98	98	95
methyl cellulose 2%	100	107	106
methyl ethyl cellulose 7.5%	96	102	99
dry casein glue 20%	36	28	4
polyvinyl acetate 50%	96	98	96
LSD (0.01)	12	15	23

*DAS = days after sowing.

Adsorbents

The nature and properties of adsorbents also determined coating quality (Tables 3 and 4). The cation exchange resin was poor even when 50% polyvinyl acetate was used as an adhesive. This was due to the tendency of the cation resin to form granules as soon as it came into contact with water. Anion exchange resin coating was good although the coating layer was very thin compared with activated carbon. Combining the exchange resins with activated carbon prior to coating them on seeds improved the coating quality but not the coating stability. Cation exchange resin was also slightly toxic to rice seed compared with other adsorbents.

Table 5 shows the comparative coating quality of three activated carbons, Darco G-60, Norit A, and Witco 249. It was shown that coarse activated carbon such as Witco 249 provided a relatively poor coating in terms of coating weight and quality owing to the larger size of its particles; this result was obtained even with large addition of adhesive and/or with additional pelleting. For excellent coatings mesh size should be greater than 200. In fact, rice was more easily coated with Norit A than Darco G-60 because Norit A had finer particles.

TABLE 3: COATING QUALITY OF THREE ADSORBENTS USED SINGLY OR IN COMBINATION WITH 50% POLYVINYL ACETATE AS AN ADHESIVE

Adsorbent	*Coating Quality*	*Coating Stability**	*Coating Weight (mg/seed)*	*Germination (%)*
Anion exch. resin (AER)	good	10	5.2	97
Cation exch. resin (CER)	poor	2	6.8	90
Activated carbon (AC)	excellent	10	4.9	99
AER fb.† CER	poor	4	5.6	93
AER fb. AC	excellent	10	8.0	94
CER fb. AC	poor	4	9.4	90
AER fb. CEC fb. AC	fair	7	8.4	92
AC + AER (2:1)	excellent	10	5.1	99
AC + CER (2:1)	excellent	4	5.4	93
AC + AER + CER (3:2:1)	excellent	7	5.3	97
AC coated 3 ×	excellent	10	14.3	98
LSD (0.05)		2	2.2	5

*Coating stability score: 10 = most stable; 0 = least stable.
†fb. = followed by.

TABLE 4: PROPERTIES OF ACTIVATED CARBON AND EXCHANGE RESINS

Adsorbent	*Mesh Size*	*Exchange Capacity (meq/100 g)*	*Ionic Form*	*Functional groups*	*pH (1:4)*
Activated carbon Darco G-60	325	—	—		6.40
Anion exchange resin	200-400	400	Cl^-	Alkyl, Quarternary amine	3.75
Cation exchange resin	200-400	900	H^+	Carboxylic	2.82

USE OF PELLETED RICE SEEDS IN FIELD EXPERIMENTS

Further tests both in the greenhouse and in the field were necessary to ascertain the coating quality, stability, and protective capacity of the pelleting materials. To test the protective capacity of the pelleting materials, herbicide rates used were higher than rates considered safe to rice without the pelleting materials. For example, oxadiazon at 0.56 and 1.12 kg/ha was selective on

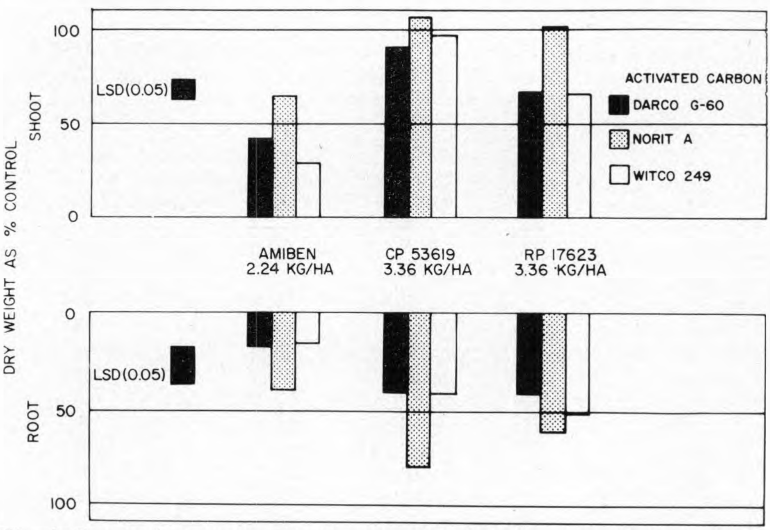

Fig. 1: Comparison among three types of activated carbon in their ability to protect direct-sown rice from chloramben (amiben), delachlor (CP 53619) and oxadiazon (RP 17623) as measured by dry weights of shoot and root.

TABLE 5: PROPERTIES OF ACTIVATED CARBONS DARCO G-60, NORIT A, AND WITCO 249 AS COATING MATERIALS FOR RICE SEEDS

Activated Carbon	*pH (1:4)*	*Mesh Size*	*Coating Weight (mg/seed)*	*Coating Quality*
Darco G-60	6.45	325	13.6	excellent
Norit A	9.66	325	16.5	excellent
Witco 249	9.35	80	9.8	fair

direct-sown rice (Obien *et al.,* 1971), but the rate of 3.36 kg/ha used in this study would be toxic to rice. In this instance, the use of pelleting materials would be a means to improve herbicide selectivity at rates which would control all weed species.

Figure 1 summarizes the comparative efficiency of three activated carbons, Darco G-60, Norit A, and Witco 249, in protecting rice seeds from injury by amiben. delachlor, and oxadiazon. The effectiveness of Norit A as a pelleting material far exceeded that of Darco G-60 and Witco 249 in all the herbicide treatments. There were no significant differences in seedling survival among the three carbons, but the dry weights of either roots or shoots of seedlings grown from seeds coated with Norit A were significantly higher than those from seeds coated with Darco G-60 and Witco 249. Seedling survival ranged from 80 to 96%. Excellent coating quality and high adsorption capacity are the combined factors which explained the superiority of Norit A compared with the other two activated carbons, Darco G-60 and Witco 249, as evidenced by the fast recovery of seedlings from herbicide injury.

As discussed in Table 5, Witco 249 provided relatively poor coating in terms of coating weight and coating quality owing to its larger particle size. Although relative herbicide adsorption on the three charcoals was found (by equilibrium adsorption measurements) to be Witco 249 > Norit A > Darco G-60, the data in Fig. 1 showed, nevertheless, that adsorption capacity was not the only criterion for determining the degree of protection afforded by adsorbent coatings. Coating quality and the amount of adsorbent which can be coated on seed were also equally important (Table 5). Decrease in herbicide toxicity as a result of an increase in coating weight was demonstrated by increasing the number of coating layers from one to three. With toxic herbicides such as chloramben it was also found in a separate experiment (data not reported here) that complete protection was achieved when the seed was covered with 200 to 400 mg of activated carbon Darco G-60.

The performances of activated carbon, anion exchange resin, and cation exchange resin, used singly and in combination, as one layer and three layers of coatings are presented in Table 6. Seeds coated with exchange resin showed some degree of injury by delachlor and oxadiazon, but their fresh weights (not in the table) taken at five weeks after sowing were not significantly different from the control. However, coated seeds treated with amiben performed very poorly. The triple carbon-coated rice seeds, on the other hand, showed negligible herbicide injury, and their fresh weights were comparable to that of the control treatment.

These results suggest that both coating quality and quantity were important in overcoming herbicide toxicity in direct-sown rice. One of the causes of the failure of exchange resins as well as activated carbon to perform effectively was probably poor coating quality. The failure of single carbon-coated seeds to perform as well as triple carbon-coated seeds was probably due to insufficient adsorbent to neutralize herbicide toxicity around the seeds. Activated carbon and exchange resin mixtures would probably have done well, too, if they were coated two to three times

Fig. 2: Excellent stand of seedlings from triple carbon-coated seeds in the background, with complete kill of uncoated seeds in the foreground, when both seeds were treated with disul (sesone) at 3.36 kg/ha.

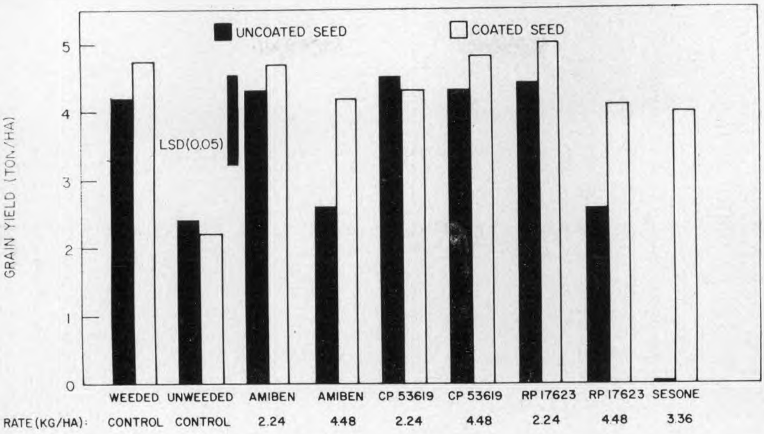

Fig. 3: Grain yields of uncoated and triple carbon-coated rice seed in soil treated with two rates of chloramben (amiben), delachlor (CP 53619) and oxadiazon (RP 17623) and one rate of disul (sesone).

but this was not done because of cost. Exchange resins were five times more expensive than activated carbon.

In a field test conducted on plots measuring 1.7 by 2.7 m, triple carbon-coated seeds and uncoated seeds were compared for their tolerances to two rates of chloramben, delachlor and oxadiazon, and one rate of disul. Figure 2 shows the excellent stand of seedlings that were protected from the herbicide disul (3.36 kg/ha) as a result of seed pelleting, and Fig. 3 gives the grain yield of rice from the various treatments. The weed control yielded 4.2 to 4.7 MT/ha of grains, almost twice that of the unweeded control. The large reduction in grain yield of the unweeded control was due to a dense population of barnyard grass (*Echinochloa crus-galli*). The grain yield of coated seeds in all the herbicide treatments ranged from 4.0 to 5.0 MT/ha, and was not significantly different from the weeded control. The grain yield of uncoated seeds treated with both rates of delachlor and low rates of chloramben and oxadiazon was comparable to the weeded control because seedling mortality was compensated for by increased tiller production per hill. Only uncoated seeds treated with 4.48 kg/ha chloramben, 4.48 kg/ha oxadiazon, and 3.36 kg/ha disul produced significantly lower grain yields than the weeded control. Their flowering was also delayed by 5 to 8 days. The reduction

TABLE 6: EFFECT OF AMIBEN, DELACHLOR, AND OXADIAZON ON SEEDLING SURVIVAL, HEIGHT AND NUMBER OF TILLERS OF RICE SEEDS COATED WITH DIFFERENT ADSORBENT COMBINATIONS

	Control				*chloramben (2.24 kg/ha)*				*delachlor (1.5 kg/ha)*				*oxadiazon (3.36 kg/ha)*				*Means*			
Coating Types	*Survival (%)*	*Height I (cm)*	*Height II (cm)*	*Tillers/Hill*	*Survival (%)*	*Height I (cm)*	*Height II (cm)*	*Tillers/Hill*	*Survival (%)*	*Height I (cm)*	*Height II (cm)*	*Tillers/Hill*	*Survival (%)*	*Height I (cm)*	*Height II (cm)*	*Tillers/Hill*	*Survival (%)*	*Height I (cm)*	*Height II (cm)*	*Tillers/Hill*
Uncoated seed	90	17	34	3.4	10	5	13	1.8	20	11	34	4.7	20	10	21	1.6	35	11	26	2.9
Activated carbon (1×)	90	16	33	3.0	20	9	20	2.7	70	15	34	3.5	50	14	29	4.1	58	14	27	3.3
Activated carbon (3×)	90	16	33	2.7	80	14	31	4.9	70	16	34	4.1	80	14	30	3.4	80	15	32	3.8
AC + CER (2:1)	90	17	32	2.9	20	10	29	2.7	70	16	35	3.0	80	15	30	3.0	65	15	33	2.9
AC + AER (2:1)	90	19	33	3.2	40	13	30	7.0	80	17	33	3.4	80	15	31	3.5	73	16	32	4.3
AC + AER + CER (3:2:1)	100	17	33	3.5	30	9	18	2.2	70	16	33	3.6	80	14	30	4.4	70	14	29	3.4
Means	92	17	33	3.1	33	10	24	3.5	63	15	34	3.7	77	14	28	3.3				

LSD (0.05)

	Herbicides (H)	*Coatings (C)*	*H × C*
% Survival	25	14	41
Height I	2	4	5
Height II	4	5	NS
Tillers/Hill	NS	1.0	2.3

TABLE 7: EFFECT OF ACTIVATED CARBON WITH METHIOCARB PELLETING ON THE GROWTH OF RICE TREATED WITH HERBICIDES

Treatment (kg/ha)	*Coating Type**	*Tillers per m^2*	*Tillers per Hill*	*Dry Matter of Rice (tonne/ha)†*	*Dry Weight of Weeds (kg/ha)†*
Unweeded	U	226	1.2	4.2	5541
control	C	300	1.4	6.5	4769
Weeded	U	525	2.8	14.9	112
control	C	544	2.5	16.2	170
amiben 2.24	U	175	11.7	5.3	186
	C	470	5.2	11.3	0
delachlor 2.24	U	288	19.2	7.4	0
	C	500	3.3	14.6	0
2,4-D IPE 0.9	U	30	5.0	0.3	3717
	C	368	6.2	8.8	2491
LSD (0.05)	—	112	—	2.7	673

*U = uncoated rice seeds and dusted with methiocarb (3%); C = coated with activated carbon after dusting it with methiocarb.
†Harvested at flowering stage of rice (105 days after sowing).

in grain yields of these treatments was due to extremely high mortality of the uncoated seeds which could not be adequately compensated for by production of either tillers or panicles.

The unweeded plot was extremely weedy and its dry matter production was only 30 to 40% of the weeded control. The dry matter production of coated seeds treated with delachlor was comparable to that of the weeded control, while coated seeds treated with chloramben and 2,4-D IPE yielded 30 to 40% lower than the weeded control, but significantly higher than the unweeded control. In 2,4-D-treated plots the uncoated seeds did not tiller as well as the others because the available space was quickly taken over by weeds which emerged as soon as 2,4-D lost its persistence. Like disul, 2,4-D was not effective under water management which favoured the survival of coated rice seeds. Flooding the soil as soon as 2,4-D was applied generally controlled most of the annual weeds (De Datta *et al.*, 1971), but delayed flooding appeared to reduce its effectiveness.

DISCUSSION

Pelleting rice seeds with activated carbon was devised as an approach to improved herbicide selectivity to direct-sown rice because of the knowledge that carbon, with its high adsorption capacity, may be able to protect rice seedlings by reducing through adsorption the amount of herbicide around the germinating seeds. By pelleting the carbon around the seed, protection is limited within the immediate and narrow environment of seed, and should not affect weed control. However, as the rice seedlings grow, the roots and shoots penetrate areas beyond the protective limits of the carbon coating. Also, the carbon coating may disperse when the field is flooded, thus decreasing protection for the rice seeds. Weed control then would also decrease because the dispersed carbon adsorbs herbicide at greater distance from the rice seeds.

The foregoing considerations are basic for the seed pelleting technique to be effective under a given field condition, herbicide type, and planting method. For example, seed pelleting should provide better protection from herbicides with low solubility and/or short persistence but may be of little help if the herbicide has high solubility and long persistence in soils. Flooding is necessary to minimize weed seed germination, but it also complicates the use of seed pelleting because flooding also disperses the carbon coating, moves the herbicide to the root zone, and brings the solution in contact with the rice shoot for easy absorption.

Thus, selection of pelleting materials, both adsorbents and adhesives, was determined by evaluating coating quality and stability on the seed, and nontoxicity to rice germination. Factors such as pH of the adhesives, mesh size of the adsorbent and coating layers were all important in establishing coating quality and stability. Because carbon coating alone did not repel birds when seeds were broadcast in the field, a bird repellent was also added to the coating materials and successfully protected the seeds from serious bird damage.

There was conclusive evidence that pelleting rice seeds with activated carbon provided some protection from herbicide injury. The degree of protection varied with the type of herbicides used; in some treatments rice germination and growth were comparable with those of the untreated weeded control. The complex factors attributed to the success or failure of this technique were further elaborated and will be presented in future publications.

It should be pointed out that the technique was successful, provided certain modifications were made in sowing, flooding, spraying schedules, and other field practices.

The economics of the technique — pelleting and pelleting materials, added details of land preparation, sowing, and flooding, and other factors — have not been determined, but must be considered if the technique is to be used by farmers. Furthermore, a few herbicides have been shown to be selective to direct-sown rice even without the added protection from carbon coating (Obien *et al.*, 1971; De Datta and Bernasor, 1970). If, for some reason, a cheap herbicide, such as one of the phenoxy compounds, is used for direct-sown rice, then seed pelleting should definitely be used because germinating rice is susceptible to all known phenoxy compounds. The phenoxy herbicides are effective preemergence herbicides and are being used for transplanted rice (Obien *et al.*, 1971; De Datta *et al.*, 1971). Future research must explore those facets of weed control in direct-sown rice where increased selectivity and economy are required for the technique to be adopted.

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EFFECT OF OILS ON THE TOXICITY OF TWO HERBICIDES TO BONESEED (*CHRYSANTHEMOIDES MONILIFERUM*)

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Summary

The herbicides 2,4-D and 2,4,5-T showed increased activity on boneseed (*Chrysanthemoides moniliferum*) after nine days when applied in an isoparaffinic oil carrier rather than water. The herbicidal activity was enhanced to a lesser extent when non-phytotoxic mineral oils were added to water at a concentration of 10%. Toxicity as measured only one day after spraying was greatly increased with both 2,4-D and 2,4,5-T when applied in isoparaffinic oil. Mineral oils increased the effect of 2,4-D but not of 2,4,5-T. Uptake experiments showed that there was at least a two fold increase in rate and amount of 2,4,5-T taken up using isoparaffinic oil as a carrier rather than water.

INTRODUCTION

Boneseed (*Chrysanthemoides moniliferum*) is unique amongst the noxious weeds of Victoria. It does not have any effect upon agriculture and is not poisonous to humans or animals but it does affect native flora reserves by crowding out native species. The history, distribution and problems have been previously outlined by the author (Welsh 1970).

Increased activity has been observed for several herbicides when applied in a non-phytotoxic oil (Saunders and Lonnecker, 1967; Barrentine and Warren, 1970; Burr and Warren, 1971). The object of this experiment was to determine the influence of several oils upon the effectiveness of two herbicides on boneseed.

MATERIALS AND METHODS

Boneseed seedlings with an average of 4 leaves were collected in the field and transplanted individually into 80 mm diameter pots. The plants were maintained in a glasshouse at approximately 20° C and normal day length for about 2 months before treatment. At treatment the plants had 8 to 14 leaves and were 15 cm average height. Plants were sprayed with a laboratory sprayer to the point of run-off. Each herbicide was applied at three rates, to four individual plants, in water and three oils.

TABLE 1: PROPERTIES AND RATES OF OILS USED IN EXPERIMENT

	Isoparaffinic	*Mineral Oil A*	*Mineral Oil B*
Trade name	Isopar M (Esso Chem.)	D - C Tron (Ampol Petrol.)	Albarol - White Oil (Amalg. Chem.)
% Active ingredient	80% Isoparaffinic oils	99% Paraffinic oils	70% Paraffinic oils
Rate	Undiluted	10% oil in water	10% oil in water
Unsulfonated residue	98%	96.4%	95%
Viscosity 0° C	5.11 c p	380 c s	
Average molecular weight	191	310	
Distillation I.B.P.	207° C	350° C	

The herbicides and rates used were as follows:

1. Ethyl ester of 2,4-D (80% a.i.) — 0.08% a.i.; 0.04%, 0.02%.
2. Butyl esters of 2,4,5-T (80%) — 0.053%; 0.027%, 0.013%.

Specifications and rates of the oils used are given in Table 1. Untreated plants were included as controls and sprays of oil without herbicide were applied to check if the oils alone were phytotoxic. Toxicity was assessed visually 1 day and 9 days after spraying by estimating the percentage of necrotic tissue on each plant.

RESULTS AND DISCUSSION

The oils alone were not toxic to boneseed although isoparaffinic oil produced some small necrotic areas on the leaf.

The phytotoxicity of both 2,4-D and 2,4,5-T to boneseed was enhanced when the herbicides were applied in an oil rather than in water (Table 2).

The initial toxicity, as measured after one day, was increased significantly only by isoparaffinic oil for both herbicides. However, at the highest rate of 2,4-D, the other oils also increased toxicity.

Rates of herbicide had been selected from a preliminary trial so that the maximum rate applied in water would produce a complete kill of the plant after nine days. This was achieved with 2,4-D but not with 2,4,5-T in this experiment. However, because of the sub-optimal rate being used with 2,4,5-T the enhancement of effect at the high rate was clearly shown. With 2,4-D there was no difference between carriers at the highest rate.

The results also demonstrate how the rate of herbicide can be reduced if some carrier other than water is used. The same

TABLE 2: PERCENTAGE NECROTIC TISSUE OF BONE SEED PLANTS ASSESSED ONE DAY AND NINE DAYS AFTER SPRAYING
(Mean of 4 plants)

Herbicide and Rate	*Water*	*Isoparaffinic Oil*	*Mineral Oil A*	*Mineral Oil B*
ASSESSMENT ONE DAY AFTER SPRAYING				
2,4-D 0.08%	43.5 (41.25)† c*	98.3 (82.50) e	69.1 (56.25) d	75.0 (60.00) d
2,4-D 0.04%	10.0 (18.44) b	95.6 (77.89) e	50.0 (45.00) c	32.3 (34.61) c
2,4-D 0.02%	2.8 (9.69) ab	50.0 (45.00) c	30.9 (33.75) c	10.0 (18.44) b
2,4,5-T 0.053%	20.8 (27.11) d	95.6 (77.89) f	13.2 (21.33) c d	25.0 (30.00) d
2,4,5-T 0.027%	7.3 (15.68) bc	62.9 (52.50) e	7.3 (15.68) b c	5.0 (12.92) b c
2,4,5-T 0.013%	1.3 (6.46) ab	50.0 (45.00) e	3.7 (11.07) b c	0 (0) a
Untreated control (both herbicides)	0 (0) a			
ASSESSMENT NINE DAYS AFTER SPRAYING				
2,4-D 0.08%	98.3 (82.46)† fgh*	99.9 (88.56) gh	100 (90.00) h	100 (90.00) h
2,4-D 0.04%	69.7 (56.60) cd	98.7 (83.54) fgh	94.5 (76.46) fg	78.4 (62.32) de
2,4-D 0.02%	30.1 (33.28) b	89.7 (71.25) ef	54.6 (47.66) c	17.4 (24.67) b
2,4,5-T 0.053%	76.2 (60.79) de	99.5 (86.07) f	88.3 (70.01) ef	98.1 (82.14) f
2,4,5-T 0.027%	50.0 (44.99) cd	97.8 (81.50) f	54.3 (47.45) cd	77.6 (61.78) de
2,4,5-T 0.013%	16.5 (23.98) b	75.1 (60.05) de	26.1 (30.70) bc	16.0 (23.58) b
Untreated control (both herbicides)	0 (0) a			

*Numbers followed by the same letter within one herbicide do not differ at the 0.05 level using Duncan's multiple range test. The untreated control applies to both herbicides.

†Arcsin √ % transformation.

kill as produced by 0.08% 2,4-D can be achieved by using 0.04% 2,4-D with mineral oil A or only 0.02% 2,4-D with isoparaffinic oil. Similarly with 2,4,5-T the 0.053% rate can be reduced to 0.026%, and 0.013% with mineral oils and isoparaffinic oil, respectively.

The mineral oils are normally used as insecticides for control of scale and mites but this experiment has demonstrated their value also as adjuvants to herbicide solutions. They remain on the leaf surface much longer than water. A number of workers overseas using similar materials have suggested the improved phytotoxicity is brought about by cuticular modification (Saunders and Lonnecker, 1967; Barrentine and Warren, 1970; Burr and Warren, 1971). This may well be the case with boneseed as some more recent experiments by the writer on penetration of aqueous solutions of 2,4,5-T into this plant show a low uptake compared with other plants. However, when applied in isoparaffinic oil, uptake of 2,4,5-T by boneseed is markedly increased. Rate of uptake is increased threefold and total uptake is more than doubled. The isoparaffinic oil remains on the leaf surface for only a short period and its action is one of increasing penetration rather than modifying the cuticle as do the mineral oils.

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GERMINATION AND GROWTH INHIBITORS IN *CROTON BONPLANDIANUM*, A PERENNIAL WEED

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Summary

The occurrence of germination and growth inhibitors in the aqueous extract of *Croton bonplandianum* was demonstrated, their distribution in parts of the plant assessed, and their physico-chemical properties determined.

Numerous investigators have demonstrated in a wide variety of plant extracts, the presence of substances causing varying degrees of inhibition (Refs. 3-12, 16-8, 21-4, 26, 29, 32). These inhibitory substances play an important role in the structure and composition of plant community (1-2, 13-5, 20, 25, 27-8, 30-1, 33-4).

Despite the distribution and significance of inhibitors, very little has been done in India to ascertain the problem of phytotoxicity in some of the important weeds. It is needless to point out that almost all work along this line has been carried out on temperate species and that tropical plants have received scant attention.

The present study deals with *Croton bonplandianum,* a member of the Euphorbiaceae, which is a common perennial weed of widespread distribution in India and covers large areas from the Punjab in the north to Tamil Nadu in the south and (West) Bengal and Assam in the east.

MATERIALS AND METHODS

Actively growing plants of *C. bonplandianum* were collected from various sites in and around Calcutta. Extracts of root, stem, leaf, inflorescence, fruit and seed were made by crushing 100 g of fresh tissue in mortar and pestle with washed sand. The extracts were filtered off, the filtrate taken in a volumetric flask, and the volume made up to 250 ml. This formed the stock aqueous solution from which various dilutions were prepared.

Responses of germinating rice, pea, mustard and lettuce seeds were employed to judge inhibitory activity in the extracts of

C. bonplandianum. The bioassay consisted of placing surface-sterilized (2% sodium hypochlorite for 10 min) seeds in a sterile petri dish (11 cm in diameter) containing 1 disc of filter paper (Whatman No. 1) and 10 ml of water or test solution. The number of seeds varied in each experiment: 25 in pea, 50 in rice and 100 in mustard as well as lettuce. The dishes were kept at room temperature (30 ± 4° C) for 3 days (but 7 days for rice). At the end of this period, the number of seeds germinated was counted and the root and hypocotyl lengths were recorded.

RESULTS AND DISCUSSION

The best effect of inhibition was exhibited by the leaf extract, being followed in order by the extracts of inflorescence, seed, fruit and stem. No inhibition arose from the root extract. As the leaves constitute a more potent source of inhibitor, extract of this material was mostly used in the present investigation.

Both germination and seedling growth were completely inhibited at full concentration and inhibition was still evident up to 1/8 concentration. While the germination of pea remained practically unaffected, its root growth was adversely affected. The roots were much shortened and thickened; the root-hair zone was appreciably discoloured, became thread-like, and finally dried up; short lateral roots developed above the discoloured zone and the tip of the primary roots assumed a hook-like appearance. These observations on pea root growth are in accord with those of Le Tourneau and Heggeness (19) obtained with leafy spurge extract.

Comparison of aqueous extract of dry leaves with that of fresh leaves shows that the former also resulted in loss of some inhibitor activity. Bioassay of the extract of leaves in various stages of maturity suggests that the inhibitory components decreased as the leaf became mature.

The aqueous leaf extract contained a thermostable inhibitory material. Boiling the stock solution caused little reduction in inhibitor activity, for both germination and seedling growth were still less than the corresponding controls. When similar solution is subjected to chilling (8° C) or storage (at 30 ± 4° C), there is little decreased inhibitor activity at the lower temperature. Furthermore, the inhibitory action of the extract was more conspicuous in the dark than in diffuse or continuous light.

Experiments made with the extract at two different seasons displayed greater inhibition in winter than in summer. Little or no inhibitory activity remained after one aqueous extraction. Also, extraction with ethanol removed all the inhibitors from the leaf material. Acetone removed some activity, but it was less effective than ethanol and more effective than *n*-butanol. Whereas benzene did not extract the inhibitors, chloroform extracted them slightly from dried leaves and none at all from aqueous solution. Other experiments indicated that the inhibitory fractions were dialysable and more stable to autoclaving at pH 2 and pH 11 for 1 hr at 1 kg/m^2 pressure. Activity was not lost from the aqueous extract when filtered through a sintered funnel operated under the reduced pressure of a water aspirator. Autoclaved extract was slightly less inhibitory than unautoclaved one.

The treatment of aqueous leaf extract with increasing amounts of Norit did not remove all the inhibitors from the extract. Extract of the ground leaf tissue made with 0.01 N HCl was essentially colourless and yet inhibitory.

When test seedlings inhibited by the higher concentrations of leaf extract were removed from the treated dishes and washed with distilled water, they did not resume growth in control dishes. It was, however, noted that the extract became alkaline during the germination period. The addition of KH_2PO_4 in amount sufficient to overcome this pH change did not alter the effect of inhibition. No inhibition resulted from adding the ash of dried leaves to the dishes.

Adverse effects on plant growth were noticed when the leaf extract was sprayed on pea, mustard and rice foliage. But the soil application of the extract did not affect the test plants. The lack of activity in the soil may be due to adsorption by the soil colloids or to microbial decomposition.

From the characterization experiments, certain classes of compounds may be eliminated as the cause of inhibition. The solubility in alcohol, acetone, etc., and dialysability eliminates the presence of large molecules like pectin, protein or polysaccharides.

As the leaves of *C. bonplandianum* appeared to be highly phytotoxic, they were systematically extracted with various solvents and almost all of the inhibitors were removed with ethanol extract which, when concentrated, resolved into ether-soluble and ether-insoluble parts. Since the ether-insoluble part was highly inhibitory, T.L.C. experiments revealed that the inhibitory activity resided in fractions III and IV. These two fractions were found to be homogeneous. That the active fractions contained a hydroxyl and a carbonyl function were shown by UV and IR spectral studies. Since phasic or abscisic acid bears both ketonic and hydroxyl groups besides a carboxyl one, it is probable that the active constituents belong to this group of substances. If the constituent can be isolated and purified, it may have potential as a herbicide for general weed control.

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BARNYARD GRASS (*ECHINOCHLOA*) IN THE ASIAN-PACIFIC REGION, WITH SPECIAL REFERENCE TO AUSTRALIA

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INTRODUCTION

The taxonomy of many important weedy genera, including *Echinochloa,* is confused. This makes the proper interpretation of results of research on weeds very difficult. The name of a plant should be the key to its literature. If the correct name of a plant is not known, care should be taken to describe it adequately and to retain herbarium material for later examination by experts if necessary.

This paper will list species of *Echinochloa* recorded in various parts of the Asian-Pacific region, make some general comments on the taxonomic problems and then give a more detailed account of the weedy species that occur in Australia.

Finally, it is proposed to illustrate the practical importance of knowledge of the taxonomy of the genus and of variation within individual species in ecological and physiological terms.

SPECIES RECORDED IN THE ASIAN-PACIFIC REGION (EXCLUDING AUSTRALIA)

The species (and varieties) listed here are given for various countries (or regions) as recorded by the authors cited, except for occasional spelling corrections.

BURMA, INDIA, CEYLON AND PAKISTAN (Bor, 1960):
E. colonum; E. crusgalli vars. *crusgalli* and *breviseta; E. cruspavonis; E. frumentacea; E. glabrescens; E. pyramidalis; E. stagnina.*

CEYLON (Paul and Senaratna, 1941):
E. colonum; E. crusgalli; E. stagnina.

CALIFORNIA (Gould *et al.,* 1972):
E. colonum; E. crusgalli vars. *crusgalli, frumentacea* and *oryzicola; E. cruspavonis* vars. *cruspavonis* and *macera; E. muricata* vars. *muricata* and *microstachya.*

FIJI (Parham, 1955):
E. colonum; E. crusgalli and var. *frumentacea; E. cruspavonis; E. stagnina.*

HAWAII (Rotar, 1968):
E. colonum; E. crusgalli and forma *longiseta; E. cruspavonis; E. frumentacea; E. polystachya; E. stagnina; E. walteri.*

INDO-CHINA (Lecomte, 1922; Schmid, 1958):
E. colonum; E. crusgalli and var. *frumentacea* (*E. frumentacea*); *E. cruspavonis; E. stagnina.*

JAPAN (Ohwi, 1962):
E. crusgalli vars. *caudata, formosensis, oryzicola* and *praticola; E. utilis.*

JAVA (Backer and Bakhuizen van den Brink, 1968):
E. colonum; E. Crusgalli; E. stagnina.

NEW GUINEA (Henty, 1969):
E. colonum; E. crusgalli; E. cruspavonis; E. stagnina.

PHILIPPINES (Pancho *et al.*, 1969):
E. colonum; E. crusgalli; E. cruspavonis.

TAIWAN (Hsu, 1963):
E. colonum; E. crusgalli vars. *formosensis, oryzicola* and *praticola; E. utilis.*

U.S.S.R. (Komarov, 1934):
E. caudata; E. colonum; E. crusgalli vars. *mutica, breviaristata* and *longiseta; E. frumentacea; E. macrocarpa; E. oryzicola; E. spiralis.*

TAXONOMIC PROBLEMS

The following comments on the above lists are made as a result of a long study, now almost completed, of *Echinochloa* in Australia in collaboration with Dr J. W. Vickery of the National Herbarium of New South Wales.

It appears to us that probably all of the species listed in Asian countries as *E. cruspavonis* do not belong to that species. *E. cruspavonis* is a native of South America with distinct characters. Plants listed as *E. crusgalli* or one or other of its varieties may belong not only to *E. crusgalli* but also to other species including *E. oryzoides* (syn. *E. macrocarpa* and *E. coarctata*), *E. phyllopogon* (probably the valid name for *E. oryzicola* or *E. crusgalli* var. *oryzicola*) and perhaps others. Much of the material from subtropical or tropical areas called *E. crusgalli* may be referrable to *E. hispidula* usually taken as a synonym of *E. crusgalli*. We are undecided, as yet, whether to consider *E. hispidula* as a subtropical subspecies of *E. crusgalli* or as a species in its own right. It may or may not be appropriate to consider forms of *E. crusgalli* as varieties on the bases of absence of awns (as in var. *mutica*), presence of short awns (as in var. *breviaristata*) or long awns (as in f. *longiseta*). Awning, at least in some forms of *E. crusgalli*, is a very variable feature depending on environmental conditions. The plants, commonly referred to in Japan as *E. crusgalli* var. *caudata* are almost certainly referrable to *E. crusgalli* but not to *E. caudata* listed in the U.S.S.R. flora. *E. spiralis* may simply be another form of *E. crusgalli*.

E. glabrescens and *E. crusgalli* var. *formosensis* appear to be synonymous. They appear to form part of a species complex, not yet properly understood, occurring in India and eastern Asia.

E. crusgalli var. *frumentacea* (*E. frumentacea*) may include both *E. frumentacea* (an Indian cultivated millet derived from *E. colonum*) and *E. utilis* (the true Japanese barnyard millet derived from *E. crusgalli*). See Ohwi, 1962.

It is clear that there are many difficulties ahead, if a proper understanding of the genus *Echinochloa* in the Asian-Pacific region is to be reached. The writer would appreciate herbarium material and seeds for growing from all parts of the region. The recognition by weed scientists of species or forms not yet occurring in particular regions may be important from the point of view of plant quarantine.

WEEDY SPECIES IN AUSTRALIA

In Australia, *Echinochloa* spp. are especially important in rice, cotton and many other field and vegetable crops. They are of greatest significance in the irrigated rice-growing areas of south-eastern Australia (*E. colonum; E. crusgalli; E. microstachya* (syn. *E. muricata* var. *microstachya*); *E. oryzoides*), in the Burdekin valley in Queensland (*E. colonum*) and in the Northern Territory and north-western Western Australia (*E. colonum* and an undescribed native species); in the coastal summer cropping areas of New South Wales and Southern Queensland (*E. crusgalli*) and central and northern Queensland (*E. colonum*); and in irrigated crops in the river valleys west of the Great Dividing Range in central and northern New South Wales (*E. colonum* and

E. crusgalli). *E. cruspavonis* occurs to a very limited extent in and near Sydney. The perennial *E. stagnina* is rare in northern Australia and does not occur as a weed as it does in the more tropical areas in the Asian-Pacific region.

Both *E. colonum* and *E. crusgalli* are very variable in Australia, with a number of forms or apparent ecotypes. Forms in both species vary in growth habit and heading time. *E. crusgalli* is the most variable. One form which commonly has many long awns sometimes has almost no awns. The size of the inflorescence is variable. One form has rather crowded spikelets. Forms are expected to vary in dormancy and germination requirements.

ECOLOGY AND PHYSIOLOGY

Research on the physiological behaviour of different species or forms of barnyard grass or other weedy species, for that matter, can be properly interpreted only if their identity is known. Most of the Japanese work has been done on *Echinochloa crusgalli* var. *oryzicola* (*E. oryzicola,* probably referrable to *E. phyllopogon*). Kasahara and Kinoshita (1952) showed that this species was, unlike two varieties of *E. crusgalli,* capable of germinating under water of depths varying from 5 to 20 cm. Chirila (1967), in Rumania, showed that *E. oryzoides* and *E. phyllopogon* could germinate from the surface of soil, under up to 15 cm of water, but that, when seed was buried under as little as 0.5 cm of soil, germination of *E. oryzoides* was very much more suppressed than that of *E. phyllopogon.* Both these species appear to be obligate weeds of rice, having been especially adapted through the ages to paddy-field conditions. Both are late flowering species which do not shed spikelets readily. *E. oryzoides* appears to be the more important of the two species in warmer rice-growing areas (Ceylon, parts of U.S.S.R. and Europe), while *E. phyllopogon* (*E. oryzicola*) is the more important in the cooler areas (Japan, parts of India and U.S.S.R.). Arai and Miyahara (1960, 1962) have shown that the germination of the latter is improved by previous exposure to cold conditions, while Hejny (1957) has shown that germination of the former is not. It is possible to relate these observations to the world distribution of the two species.

Differences in response to herbicides have been demonstrated by Roché and Muzik (1964) in U.S.A. with 2,2-DPA and five biotypes of *E. crusgalli,* and by Michael and van Rijn (1970) in Australia with diuron and two forms of *E. colonum.*

Further investigations on the physiological and ecological behaviour of *Echinochloa* will undoubtedly reveal much interesting information which may well prove to be useful in the development of better methods of control.

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CHEMICAL CONTROL OF GUINEAGRASS (*PANICUM MAXIMUM*), NAPIERGRASS (*PENNISETUM PURPUREUM*), AND WILD SUGARCANE (*SACCHARUM SPONTANEUM*) IN HAWAII[1]

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Summary

Chemical control experiments on mature guineagrass (*Panicum maximum*), napiergrass (*Pennisetum purpureum*), and wild sugarcane (*Saccharum spontaneum*) were conducted at two locations under subtropical conditions in Hawaii. One test was conducted on a dark magnesium montmorillonitic clay soil with 4 to 5% organic matter, a pH of 6.3, and an annual rainfall of 120 cm (Waimanalo). The other test which involved only guineagrass was conducted on an aluminous ferruginous latosol with 6 to 7% organic matter, a pH of 4.9, and an annual rainfall of 230 cm (Kauai). The herbicides, applied at high rates (11.2 to 44.8 kg/ha), were as follows: various formulations of bromacil, karbutilate, diuron, HCA, 2,2-DPA, a diethylene glycol ester of 2,2-DPA (2,2-DPA DGE), and an experimental compound, AP 920. Results obtained at Waimanalo showed that, in general, susceptibility to all treatments was wild sugarcane $\geqslant$ napiergrass $>$ guineagrass. Of the herbicides karbutilate was the most effective, followed by bromacil, whereas bromacil + HCA and diuron were about the same in their total effectiveness against the three grass species. Comparative herbicidal activity against each species was as follows: wild sugarcane — bromacil $>$ karbutilate $>$ bromacil + HCA $>$ diuron; napiergrass — karbutilate $>$ diuron $\geqslant$ bromacil $>$ bromacil + HCA, and guineagrass — karbutilate $>$ bromacil $>$ bromacil + HCA $\geqslant$ diuron. In the experiment on Kauai, rapid and effective control of guineagrass was obtained with AP 920 $>$ 2,2-DPA DGE $>$ karbutilate $>$ bromacil + 2,2-DPA. Granular bromacil, a highly concentrated (85%) slow-release formulation, had low initial activity but had long residual persistence of 10 to 14 months. A suspected antagonistic relationship between bromacil and 2,2-DPA was not

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confirmed, but there was an indication that control of guineagrass appeared better when 2,2-DPA was applied first followed by bromacil than when both compounds were mixed in a spray. One other significant observation on these two experiments was the secondary weed infestation of plots where the primary test plant was completely controlled, beginning at 6 months. This phenomenon indicated to some degree the short residual persistence of the herbicide treatments. There was clear evidence that high rates of active compounds (from 11.2 to 44.8 kg/ha) provided only temporary "soil sterilization" of 6 to 10 months. This result points to the need to reevaluate the concept of "soil sterilization" under tropical conditions.

INTRODUCTION

For many years weed scientists have emphasized chemical control of weeds at the pregermination and early seedling stages. Because the major objectives have been directed towards weed control in crops, this approach was consistent with the aim of protecting the crops from early weed competition. Consequently, herbicidal rates derived from such studies on pre-emergence and early post-emergence applications are often low and ineffective against mature and established plants. The control of full-grown weeds or mature economic plants, particularly grasses, is a problem of increasing magnitude, yet the process is often difficult and comparatively very much unexplored (Obien *et al.*, 1972).

Studies on established vegetation have dealt mostly with the control of woody and brushy broadleaf species for the development of new pasture areas and the improvement of yields of grass pastures (Quinn *et al.*, 1956; Motooka *et al.*, 1967: Swesey and Montano, 1968; Young, 1968; Gibson and Grumbles, 1970). The compounds commonly used have been low rates (0.5 to 5 kg/ha of systemic herbicides such as 2,4-D, 2,4,5-T, fenoprop, picloram and dicamba. Comparatively higher rates (10 to 40 kg/ha) of these compounds have been used for the control of perennial grasses. Similarly, studies for soil sterilization purposes have employed high rates (10 to 90 kg/ha) of herbicides such as 2,4-D, 2,4,5-T, fenoprop, diuron, monuron, simazine (Wiese and Rea, 1960; Carder, 1963; Upchurch *et al.*, 1968).

Much of the information on perennial weed control has been derived from herbicidal treatments applied to a mixed population of few to many species of varying densities (Quinn *et al.*, 1956; Swesey and Montano, 1968; Upchurch *et al.*, 1968; Gibson and Grumbles, 1970). Herbicidal activity obtained from such studies on mixed weed population may be poorly estimated because of (a) lack of uniform weed stands, and (b) possible uneven spray distribution on individual species owing to competitive leaf coverage of the various species. Thus, Upchurch *et al.* (1970) suggested the use of single species maintained separately (monocrop culture) for testing the activity of several herbicides. Tests that have been reported by Obien *et al.* (1972) and those presented in this paper were conducted either on established native grass vegetation with a uniform stand (at least 90 to 95% pure stand), or on species planted in field plots which were allowed to develop to full maturity before treatment.

The reasons for the need to control established grasses, whether growing as weeds or as crops, were discussed in an earlier paper (Obien *et al.,* 1972). Although most grasses are useful in many ways as animal feeds, lawns, or for erosion control, situations may arise where they become undesirable and should be controlled. Based on this premise, the control of three grass species, napiergrass, guineagrass, and wild sugarcane, was studied in Hawaii. Both napiergrass and guineagrass are natives of Africa; they were introduced into Hawaii as pasture grasses in 1880 and 1912, respectively (Whitney *et al.,* 1939). Wild sugarcane has been utilized as a source of genes in breeding work for disease resistance in sugarcane (*Saccharum officinarum*). The literature rarely mentions it as a weed, and it is seldom a problem in Hawaii. However, Panje (1970) reported that one of the ecotypes of wild sugarcane is a pernicious weed in Central India owing to its deep subterranean rhizomes which enable it to persist through long, dry seasons or deep ploughing and cultivation.

MATERIALS AND METHODS

Two experiments were conducted to study the effects of various herbicides for the control of napiergrass, guineagrass, and wild sugarcane. All three species were used in the experiment at Waimanalo Experimental Farm (Oahu), but only guineagrass was used at Kauai Branch Station (Kauai). Of the six herbicides used, only bromacil and karbutilate were tested in both locations (Tables 1 and 2). Therefore, few direct comparisons can be made between the results of the two experiments.

WAIMANALO EXPERIMENTAL FARM (OAHU)

The farm is 20 m above sea level and receives an annual rainfall of about 120 cm. The soil is dark magnesium montmorillonitic clay containing 4 to 5% organic matter and with a pH of 6.3.

Seed pieces (about 30 cm of the lower stem, with roots) of guineagrass, napiergrass, and wild sugarcane were transplanted in single rows in field plots in mid-August, 1968. The herbicide treatments (Table 1) were granular bromacil, karbutilate, and bromacil + HCA, and a wettable powder diuron. The treatments were applied on 7 November, 1968, about 3 months after planting. Guineagrass (2 m tall) was already flowering at the time of treatment; napiergrass (1 m) and wild sugarcane (1.5 m) were both well established with numerous tillers. The three granular herbicides were broadcast by hand, whereas the wettable powder diuron was sprayed with a back-mounted fiberglass sprayer (360 l/ha of solution) on 30 to 60 cm of the basal portion of the plants. Each treatment was replicated twice. Plots were arranged in randomized complete blocks with the herbicides as the main plots and the three grass species as the subplots. Plots were 6 by 4.5 m in size and were separated by 1.5 m buffer strips.

Kauai Branch Station (Kauai)

The Station is 160 m above sea level and receives an evenly-distributed annual rainfall of 230 to 250 cm. This soil is a well-drained aluminous ferruginous latosol containing high amounts of oxides of Fe and Al, about 10% 1:1 clay minerals, 6 to 7% organic matter, and a pH of 4.9.

Seed pieces of guineagrass were transplanted on 4 October, 1969 into field plots 3 by 6 m in size separated by 1.5 m buffer strips. The herbicide treatments (Table 2) were replicated three times and arranged in a randomized block design. An extruded, highly concentrated 85% granular bromacil, karbutilate, and 2,2-DPA were applied on 22 January 1970, while AP 920 and 2,2-DPA DGE were applied (as they became available) on 5 and 17 February, respectively. The liquid sprays were applied with a CO_2-pressurized hand sprayer, while the granules were broadcast by hand. The plants in the first replication were 1 to 1.5 m tall and some were flowering, and those in the second and third replications were 0.5 to 1 m in height.

Evaluation

A subjective evaluation method (0 = no control, and 10 = complete control) was used; each of the values obtained was then multiplied by 10 to give the percentage control of the above-ground portion of the plant. The response of weeds other than the test plants was also recorded to help interpret the effects of the treatments on the total vegetation. Data analysis by using replication means (Obien *et al.*, 1972) was considered sufficient and valid for the purpose of the study.

RESULTS

WAIMANALO EXPERIMENTAL FARM (OAHU)

The varying responses of the three grass species to the herbicides were observed for 18 months but only the data at 1 to 12 months are presented here (Table 1). During the first 2 weeks, the treatments showed very little activity; wild sugarcane was essentially unaffected, while napiergrass and guineagrass suffered about the same degree of injury. However, at 1 month the general susceptibility to the treatments, in increasing order, was as follows: wild sugarcane (15 to 70% control) < guineagrass (25 to 90%) < napiergrass (30 to 90%).

TABLE 1: RESPONSE OF THREE GRASS SPECIES TO VARIOUS HERBICIDE TREATMENTS

Waimanalo Experimental Farm (Oahu), 1968-1970

Treatment (kg/ha)*	*Control at indicated period (mon.)† — %* 1	2	3	4	5	6	8	10	12	*Period with 90+% control (mon.)*
					A. Wild Sugarcane					
bromacil (G):										
11.2	35	70	85	95	95	100	100	95	100	4-14+
22.4	50	95	95	100	100	100	100	100	100	2-12+
33.6	55	95	100	100	100	100	100	100	100	2-12+
bromacil + HCA (G):										
11.2	30	15	25	30	25	30	55	65	35	0
22.4	45	60	80	80	85	90	95	85	100	6-12+
33.6	60	80	95	95	100	95	100	100	100	3-12+
karbutilate (G):										
11.2	45	75	80	85	85	85	90	80	93	8-12
22.4	55	100	100	100	100	100	100	100	100	2-12+
33.6	70	100	100	100	100	100	100	100	100	2-12+
diuron (WP):										
22.4	15	10	10	15	15	0	10	0	0	0
33.6	20	60	60	55	60	50	55	55	45	0
44.8	25	50	65	70	65	45	65	70	40	0

TABLE 1—*contd*

*Treatment** *(kg/ha)*	*Control at indicated period (mon.)*† — % *1*	*2*	*3*	*4*	*5*	*6*	*8*	*10*	*12*	*Period with 90+% control (mon.)*
				B. Guineagrass						
bromacil (G):										
11.2	50	30	50	40	55	15	15	25	5	0
22.4	80	65	75	80	75	70	75	80	75	0
33.6	85	80	85	85	100	80	95	95	95	8-12+
bromacil + HCA (G):										
11.2	25	20	25	15	10	5	15	5	0	0
22.4	50	30	45	30	25	0	5	10	0	0
33.6	60	50	65	50	45	35	25	30	10	0
karbutilate (G):										
11.2	85	100	100	95	95	95	95	90	95	2-12+
22.4	90	100	100	100	100	100	100	100	100	2-12+
33.6	90	100	100	100	100	100	100	100	100	2-12+
diuron (WP):										
22.4	25	20	25	20	15	0	15	10	0	0
33.6	55	75	70	30	30	5	20	20	0	0
44.8	30	50	45	20	20	5	20	15	15	0
				C. Napiergrass						
bromacil (G):										
11.2	60	65	70	60	55	50	60	65	80	0
22.4	85	100	100	100	100	95	95	95	100	2-12+
33.6	85	90	100	100	90	100	100	100	100	2-12+
bromacil + HCA (G):										
11.2	30	25	35	30	15	5	20	25	0	0
22.4	50	50	50	45	55	20	40	30	15	0
33.6	65	60	80	75	70	55	55	65	45	0
karbutilate (G):										
11.2	80	90	95	95	90	75	80	100	83	2-10
22.4	90	100	100	100	100	100	100	100	100	1-12+
33.6	85	100	100	100	100	100	100	100	100	2-12+
diuron (WP):										
22.4	60	75	75	75	75	65	60	60	60	0
33.6	85	100	100	100	100	100	100	100	100	2-12+
44.8	90	100	100	100	100	100	100	90	100	1-12+

*G = granular; WP = wettable powder. Granular bromacil was 10% active ingredient and bromacil + HCA was 2% a.i. each.

†Observation after 12 months was no longer significant as it was merely a repetition of earlier ratings, such as complete control or slow recovery of few remaining plants.

Granular bromacil completely controlled wild sugarcane at all concentrations: the high rate (33.6 kg/ha) in 3 months, the middle rate (22.4 kg/ha) in 4 months, and the third rate (11.2 kg/ha) in 6 months. The two high rates (22.4 and 33.6 kg/ha) of bromacil + HCA and karbutilate provided complete control, but a few plants survived the third rate (11.2 kg/ha). The degree of control persisted, but, as will be pointed out later, other weed species encroached into the plots after 6 months.

In general, guineagrass was more resistant to the treatments than wild sugarcane. For example, diuron and bromacil + HCA caused only negligible injury to guineagrass and the plants that survived completely recovered in 10 to 12 months. Only karbutilate (22.4 and 33.6 kg/ha) caused complete control, but some guineagrass survived the low rate (11.2 kg/ha). Granular bromacil did not control all the guineagrass at the high rates (22.4 and 33.6 kg/ha); the plants at the low rate (11.2 kg/ha) recovered in 6 months. Guineagrass was more resistant than napiergrass to diuron and to the bromacil formulations, but appeared to be slightly more susceptible than napiergrass to karbutilate.

Napiergrass was effectively controlled by karbutilate and by the high rates (22.4 and 33.6 kg/ha) of bromacil and diuron. Bromacil + HCA was rather ineffective against napiergrass; the best control recorded (80% by 33.6 kg/ha at 3 months) was only as good as the effects of the low rates of karbutilate, diuron, and bromacil.

In general, resistance of the species to the herbicide treatments was guineagrass > napiergrass ⩾ wild sugarcane. Of the herbicides, karbutilate was the most toxic, followed by bromacil, whereas diuron and bromacil + HCA were about the same in their total effects on the three species. Herbicide activity against each species was as follows:

Wild sugarcane: diuron < bromacil + HCA < karbutilate < bromacil

Napiergrass: bromacil + HCA < bromacil ⩽ diuron < karbutilate

Guineagrass: diuron ⩽ bromacil + HCA < bromacil < karbutilate

The population of a second generation of weeds was evaluated as one measure of herbicidal persistence in soils (data not included here). The predominant weed species were as follows: red tasselflower (*Emilia sonchifolia*), garden spurge (*Euphorbia hirta*), graceful spurge (*Euphorbia glomerifera*), smooth rattlepod

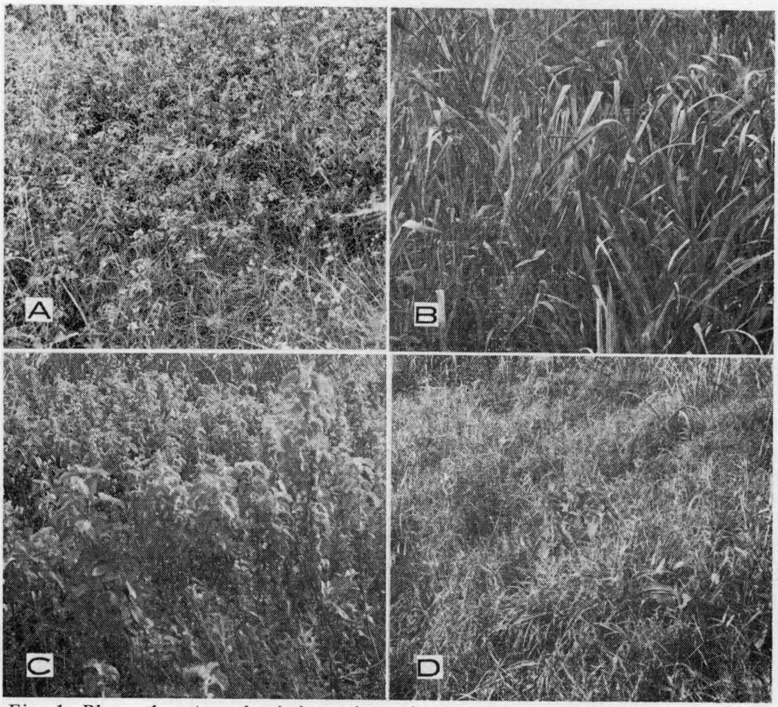

Fig. 1: Plots showing the infestation of secondary weed species after the primary test plants have been controlled: (A) Karbutilate 22.4 kg/ha at 18 months (Waimanalo) — dense growth of garden and graceful spurges and Bermuda grass following control of wild sugarcane, guineagrass, and napiergrass. (B) Control of untreated plot at 10 months (Kauai) — thick stand of guineagrass with the conspicuous absence of other weed species. (C) 2,2-DPA DGE 22.4 kg/ha at 10 months (Kauai) — thick and vigorous growth of tropic ageratum following control of guineagrass. (D) Karbutilate 33.6 kg/ha at 10 months (Kauai) — uniform growth of pangolagrass released as a result of effective control of guineagrass.

(*Crotalaria mucronata*), southern sandbur (*Cenchrus echinatus*), junglerice (*Echinochloa colonum*), and Bermuda grass (*Cynodon dactylon*). Bermuda grass, and garden and graceful spurges were particularly numerous in the plots treated with karbutilate (Fig. 1A). The distribution of these weed species in the different treatments was very uneven. However, the following significant points can be made. First, the fact that weeds germinated within 6 to 10 months and not earlier suggested that the herbicidal rates had diminished considerably to a level tolerated by various species. Second, although karbutilate appeared to be the most toxic to the three grass species, its persistence was shorter than the other compounds as shown by the fact that plots treated with karbutilate had the highest weed density, followed by bromacil + HCA, diuron, and bromacil alone. Bromacil (33.6 kg/ha) plots were weed-free at 18 months when the experiment was terminated.

Kauai Branch Station (Kauai)

The response of guineagrass to various herbicide treatments was observed for 14 months. Control of guineagrass at 3.5 months was 13, 50, and 73% by rates of 11.2, 22.4 and 33.6 kg/ha of granular bromacil, respectively. At 10 months bromacil (33.6 kg/ha) provided almost complete control of the plant tops, with the basal portions remaining alive. The fact that the basal portion was not killed explained the subsequent recovery and refoliation of guineagrass in plots treated with bromacil (22.4 and 33.6 kg/ha).

Karbutilate showed strong initial activity against guineagrass, with 33.6 kg/ha causing almost complete control at 3.5 months. Subsequent ratings showed no apparent recovery of guineagrass at the high rates, indicating that the whole plants were killed and not just the top portions as in plots treated with bromacil. 2,2-DPA DGE also showed good initial activity and provided more than 90% control of guineagrass in 2.5 months. In fact, control of guineagrass was better with 2,2-DPA DGE than with karbutilate. An experimental compound, AP 920, at 33.6 kg/ha, gave complete control of guineagrass but not at the lower rates. The mixture of bromacil + 2,2-DPA gave good initial control of guineagrass; their effects persisted for less than 4 months after which recovery ensued.

One aspect of this test was to verify a suspected antagonism between bromacil and 2,2-DPA when applied as mixed sprays. Thus, bromacil (11.2 kg/ha) + 2,2-DPA (22.4 kg/ha) were applied as mixed sprays; also, bromacil was applied first followed by 2,2-DPA 10 days after, or vice versa. The data taken reflected no conclusive evidence of antagonism between 2,2-DPA and bromacil (Table 2). However, the data at 14 months seemed to indicate that the effects of 2,2-DPA + bromacil (2,2-DPA applied first) persisted longer than when bromacil was applied first, or when both were applied as mixed sprays.

Observations on the growth of other weed species showed that pangolagrass (*Digitaria decumbens*) had developed a good stand throughout the plots about 2 months after planting. Spreading dayflower (*Commelina diffusa*) and tropic ageratum (*Ageratum*

TABLE 2: RESPONSE OF GUINEAGRASS TO VARIOUS HERBICIDE TREATMENTS

Kauai Branch Station, 1969-1971

Treatment (kg/ha)*	*Control at indicated period (mon.) — %*				
	1	*2.5*	*3.5*	*10*	*14*
bromacil (G):					
11.2	8	7	13	33	23
22.4	25	27	50	75	50
33.6	30	33	73	90	53
bromacil (WP) + 2,2-DPA (WS) (mixed):					
5.6 + 22.4	77	60	58	55	53
11.2 + 22.4	88	84	80	63	40
16.8 + 22.4	85	88	94	75	60
bromacil (WP) + 2,2-DPA (WS)†:					
11.2 + 22.4	82	94	90	65	40
2,2-DPA (WS) + bromacil (WP)†:					
22.4 + 11.2	75	83	92	70	60
2,2-DPA DGE (EC):					
11.2	33	92	93	90	90
22.4	46	95	95	95	95
33.6	57	93	98	98	98
karbutilate (G):					
11.2	13	18	33	60	52
22.4	23	33	73	90	87
33.6	40	73	95	95	92
AP 920 (WP):					
11.2	43	47	65	50	40
22.4	67	80	90	85	77
33.6	87	100	100	100	100

*G = granular; WP = wettable powder; WS = water soluble; EC = emulsifiable concentrate. Granular bromacil was 85% active ingredient.
†Applied separately; 10 days elapsed after the second compound was sprayed.

conyzoides) were less numerous and the stand less uniform, while red tasselflower, smooth rattlepod, sensitive plant (*Mimosa pudica*), and nettleleaf vervain (*Stachytarpheta jamaicensis*) were found at random throughout the plots. The response of pangolagrass, tropic ageratum, and spreading dayflower to the herbicide treatments was evaluated in spite of stand variations in some plots (Table 3). The most significant response observed was the apparent resistance of the broadleaf species — tropic ageratum, spreading dayflower, and smooth rattlepod (data for the third species not included in Table 3) — to 2,2-DPA DGE of up to 33.6 kg/ha. In fact, the population of tropic ageratum increased several times more in the treated than in the control

TABLE 3: CONTROL OF THREE WEED SPECIES FOUND IN PLOTS OF GUINEAGRASS BY VARIOUS HERBICIDE TREATMENTS AT 3.5 AND 14 MONTHS

Kauai Branch Station, 1969-1971

Treatment (kg/ha)*	*Pangolagrass 3.5*	*Pangolagrass 14*	*Tropic ageratum 3.5*	*Tropic ageratum 14*	*Spreading dayflower 3.5*	*Spreading dayflower 14*
	Control at indicated period (mon.) — %					
bromacil (G):						
11.2	33	83	100	47	100	90
22.4	90	92	100	57	100	90
33.6	100	100	100	70	100	100
bromacil (WP) + 2,2-DPA (WS) (mixed):						
5.6 + 22.4	98	67	63	23	80	70
11.2 + 22.4	100	63	100	33	80	65
16.8 + 22.4	98	87	100	47	100	63
bromacil (WP) + 2,2-DPA (WS)†:						
11.2 + 22.4	97	82	100	40	83	67
2,2-DPA (WS) + bromacil (WP)†:						
22.4 + 11.2	97	65	100	27	85	65
2,2-DPA DGE (EC):						
11.2	100	40	0	0	0	57
22.4	100	40	0	0	0	53
33.6	100	33	0	0	0	50
karbutilate (G):						
11.2	10	47	100	73	100	67
22.4	33	27	100	70	100	60
33.6	88	17	100	67	100	60
AP 920 (WP):						
11.2	56	73	100	53	100	67
22.4	90	53	100	77	100	43
33.6	96	70	100	100	100	33
Control	—	70	—	57	—	73

*G = granular; WP = wettable powder; WS = water soluble; EC = emulsifiable concentrate. Granular bromacil was 85% active ingredient.
†Applied separately; 10 days elapsed after the second compound was sprayed.

plots (Fig. 1B), creating a thick coverage (Fig. 1C) and preventing the growth of other weed species. 2,2-DPA DGE stunted the plants at the early stage; when they recovered they became more "bushy" and grew more vigorously.

Thus, control of one species may actually result in greater vigour, growth, and dominance of another. For example, karbutilate effectively controlled guineagrass and this gave pangolagrass a chance to grow vigorously without competition (Fig. 1D) — that is, the growth of pangolagrass was better in plots treated with the high rate (33.6 kg/ha) of karbutilate than with the low rate (11.2 kg/ha). Since a considerable number of guineagrass survived the treatment, tropic ageratum and spreading dayflower had difficulty becoming established in plots treated with low rate of karbutilate. Likewise, the populations of pangolagrass, tropic ageratum, and spreading dayflower were less in the control plots (untreated) than in the plots treated with karbutilate and 2,2-DPA DGE (Table 3), because of excellent growth of guineagrass in the former. The above results point to the need to consider the total vegetation cover when attempting to understand the implications of the data presented in Tables 2 and 3.

DISCUSSION

There are essential considerations in the use of high herbicidal concentrations, among which are (a) to induce rapid vegetation kill, and (b) to maintain complete control (soil sterilization) for a long period of time. Thus, if the purpose is not soil sterilization but simply the suppression of existing vegetation to allow cultivation of another crop species, then a compound with a rapid initial activity and short persistence may be used. The herbicides used in the above experiments have characteristics that can fulfil the two objectives outlined above. For instance, karbutilate showed good control of the three grass species within the first 2 to 3 months, followed by a rapid decline in herbicidal activity in 6 to 10 months. On the other hand, the granular formulation of bromacil showed its maximum activity in 3 to 4 months but allowed only very little secondary weed infestation.

The relatively poor activity of diuron as presented earlier is interpreted here to be mainly due to species resistance, since napiergrass was controlled in 2 months by diuron rates of 33.6 to 44.8 kg/ha, whereas the same rates only slightly affected wild sugarcane and guineagrass. Diuron is a long residual herbicide; post-emergence application of diuron (44.8 kg/ha) along with monuron and simazine kept 16 different weed species under control (soil sterilization) for 1 year (Upchurch *et al.,* 1968). Likewise, Carder (1963) reported that monuron (44.8 to 89.6 kg/ha), a close relative of diuron, affected the growth and yield of wheat (*Triticum vulgare*), oat (*Avena sativa*), and barley (*Hordeum* sp.) 10 years after application for the control of quackgrass (*Agropyron repens*).

The antagonistic behaviour of mixed sprays of 2,2-DPA and bromacil was not conclusively shown by our experiment. However, other workers have found that: (a) 2,2-DPA activity on conifers was reduced by atrazine (Newton, 1971); (b) combined pellets of bromacil and picloram were less effective than bromacil alone, particularly on grasses (Sterrett *et al.,* 1971); and (c) picloram interfered with bromacil activity on oats and wheat in soil and nutrient cultures (Sterrett *et al.,* 1971). Thus, it is clear from the above studies that the addition of other compounds to 2,2-DPA or bromacil can reduce herbicidal activity. This type of relationship implies that greater activity may be expected from separate applications of 2,2-DPA and bromacil and less if both compounds are mixed in a spray.

In these experiments, the grass species were transplanted in field plots and treated when they were about 3 months old. Therefore, if the herbicide treatment completely controlled the test plants, reinfestation of the plots by the same species was not possible because there was no source of plant material from which regeneration could occur. Lack of competition from the main test plants favours the growth of secondary weed species as the herbicidal toxicity declines.

The data showed that "soil sterilization" was a temporary phenomenon, lasting for a period of 6 to 10 months, with high rates (22.4 to 44.8 kg/ha) of very potent herbicides. This temporary sterilization encourages a change in the vegetation species, which may be partly due to inherent species resistance to specific herbicides, as well as to the presence of plant species in the immediate environment in sufficient number to complete with other tolerant species.

The results of these studies clearly illustrate the need to re-evaluate the concept of "soil sterilization," since the residual persistence of highly active, broad-spectrum compounds can be very short under moderate to high rainfall tropical areas. In order to obtain complete vegetation control for extended periods, it may be necessary to apply rapid-acting compounds to kill existing vegetation, and then to apply compounds with long residual activity to prevent reinvasion by perennial species or by hardy annual species.

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CONTROL OF KUDZU (*PUERARIA THUNBERGIANA*) WITH PICLORAM-TREATED WOODEN NEEDLES

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Summary

A deep-rooted perennial weed, kudzu *(Pueraria thunbergiana),* which coils up and severely suppresses the growth of transplanted conifers, has been causing a very serious problem to forestry management in Japan. For the control of this noxious liana, Manabe *et al.* developed a unique method of inserting into the root crown a wooden needle that had been impregnated with picloram. Field trials carried out since 1968 prove that a single needle containing 6 mg of picloram is adequate to destroy a kudzu plant having a root crown of up to 5 cm in diameter. The control of other vines and of some perennial weeds by this method is also being investigated.

INTRODUCTION

Kudzu (*Pueraria thunbergiana*) is a deciduous woody vine of world-wide distribution. In Japan, it is found throughout most of the country in land where cultivation seldom takes place. It regenerates either from seed or from a tuberous root and proliferates by forming secondary root systems on the tips of stolons. The herbaceous stems that emerge from the root crown in the early spring grow very rapidly as the atmospheric temperature increases. It is said that the rate of growth can exceed one metre a day. The stems which become ligneous during the summer reach 10 to 30 m in length and 2 to 8 cm in diameter. When this vine infests crop lands such as afforested areas and forestry nurseries, it twines round the plants, choking them and seriously reducing their stand. Thus it has been one of the most serious problems to Japanese forestry management.

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CONVENTIONAL METHODS OF CONTROL

Several methods of controlling kudzu have so far been developed and practised, especially in the forestry area.

1. *Cutting*: This is the simplest way of controlling kudzu. Labourers patrol the forest routinely during the summertime and cut with a scythe any vines that have climbed trees. This method requires much manual labour and does not prevent resprouting.

2. *Cutting followed by Chemical Treatment*: To eradicate kudzu completely, it is essential to destroy its main tuberous root. Herbicidal chemicals applied to the cut surface of kudzu stems have been used. Sodium chlorate, phenoxy compounds and petroleum (kerosene) have been found to be effective. The usual method of application is to put the chemical into cuts made with a hatchet in the main root crown. This method, however, is not popular because of the intensive labour requirement and the difficulty in finding the root crowns under the dense coverage of floor vegetation found during the summer period.

3. *Foliar Treatment with Chemicals*: Some of the phenoxy compounds, such as 2,4-D and 2,4,5-T, are effective in defoliating kudzu when applied to its leaves. This fact has opened up the possibility of aerial application of chemicals. Although this method requires very little labour, it does not completely eradicate the vines. Furthermore, recent controversy on environmental problems has put aerial application of herbicides into disfavour.

CONTROL WITH PICLORAM-TREATED WOODEN NEEDLES

The susceptibility of kudzu to the translocated herbicide picloram had been known for some time (Brender and Moyer, 1965; Miyake, 1966), but picloram had not been actually applied in forestry areas in Japan because of its possible phytotoxicity to conifers (Miyake, 1966). In 1968, Manabe developed a method of controlling this vine with picloram, minimizing possible phytotoxicity. This method uses a wooden needle, approximately 5 cm in length, shaped like a piece of a match. The needle has a sharp point at one end and a round, coloured tip at the other. The sharp end of the needle is impregnated with 6 mg of active picloram. This rate had been found to be adequate in a preliminary experiment (Manabe, 1971).

The needles are inserted into holes made with an awl in either the root crown, the stolon, or the stems of the kudzu plant. Early stage experiments showed that only one needle per kudzu plant was adequate.

Some typical examples of experiments using this method are given below.

EXPERIMENT 1

Location: National Forestry Research Station, Saitama prefecture.

Dates of application: As indicated in Table 1.

Replication: 20 vines per treatment.

Assessment: Results were assessed over a six-month period by visual ratings of both aerial parts and roots.

Results: The results shown in Table 1 use the following ratings:

A. Vine completely eradicated.

B. Aerial parts killed but the roots incompletely killed.

C. No visual effects.

TABLE 1: EFFECT OF PICLORAM-IMPREGNATED WOODEN NEEDLES ON KUDZU VINE APPLIED IN DIFFERENT SEASONS AND AT DIFFERENT POSITIONS ON THE VINE. SAITAMA.

Date of Application	*Date of Assessment*	*Part of Kudzu Treated*	*Ratings vs % of Treated Plants* A	B	C
20/11/69	22/5/70	Root crown	100	0	0
		Stolon	100	0	0
		Twining stem	100	0	0
2/ 2/70	22/5/70	Root crown	100	0	0
		Stolon	100	0	0
		Twining stem	85	15	0
10/ 6/70	15/7/70	Root crown	100	0	0
		Stolon	100	0	0
		Twining stem	100	0	0

EXPERIMENT 2

Location: National forest in Kumamoto prefecture. Land planted with Japanese cedar (*Cryptomeria japonica*) 25 years ago.

Dates of application: As indicated in Table 2.

Replication: 50 vines per treatment.

Results: The results are shown in Table 2 using the same rating system as in Experiment 1. A record taken of the labour required for this treatment revealed that it took on average

0.80 minutes per vine treated, which was 40% of the time required for standard cutting treatment followed by sodium chlorate. No adverse effect on Japanese cedar was observed in this experiment.

TABLE 2: EFFECT OF PICLORAM-IMPREGNATED WOODEN NEEDLES ON KUDZU VINE APPLIED IN DIFFERENT SEASONS AND AT DIFFERENT POSITIONS ON THE VINE. KUMAMOTO. (Assessed August, 1972)

Date of Application	*Part of Kudzu Treated*	*Ratings vs % of Treated Plants*		
		A	*B*	*C*
Jan. 1971	Root crown	100	0	0
	Stolon	95	5	0
	Twining stem	100	0	0
Feb. 1971	Root crown	100	0	0
	Stolon	100	0	0
	Twining stem	90	10	0
Mar. 1971	Root crown	90	10	0
	Stolon	100	0	0
	Twining stem	90	5	0
Apr. 1971	Root crown	95	5	0
	Stolon	90	5	5
	Twining stem	90	10	0
May 1971	Root crown	95	5	0
	Stolon	90	5	5
	Twining stem	80	15	5
Jun. 1971	Root crown	90	5	5
	Stolon	95	5	0
	Twining stem	85	10	5

Other Field Experiments

Similar results to the above were obtained in experiments laid down at several locations throughout Japan in the 1970 and 1971 seasons. In almost all cases, no phytotoxicity to conifers was observed. In one experiment in Hiroshima prefecture, however, it was noted that approximately 10% of young Japanese cedar plants (less than 140 cm in height) were slightly affected by treatment of kudzu vines situated within 45 cm of the trees. The phytotoxic symptoms were a slight bending and a discoloration of the apical portion of the trees; however, these effects were transient.

DISCUSSION

The experiments conducted indicate that the method is capable of practical application under Japanese forestry conditions, with several significant advantages over conventional methods:

(1) Much less labour is required for application.

(2) Eradication of more than 80% of treated kudzu is possible, regardless of time of application. (This is a great advantage because it enables even seasonal distribution of forestry lab our.)

(3) The chemical requirement per hectare is very small (assuming the density of kudzu is 3,000 plants per hectare, only 18 g/ha of picloram is required). There is therefore no possibility of environmental contamination.

(4) There is less danger to non-target plants than from other methods of chemical treatment. However, because of the susceptibility of conifers to picloram, the following precautions are recommended: (a) Do not exceed 3,000 treatments per hectare. (b) Do not treat areas where the conifers are less than 150 cm in height.

FUTURE

To date, studies on this method have concentrated on the establishment of use recommendations against kudzu. However, preliminary experiments indicate its applicability against other species of vine weeds and certain perennial herbaceous weeds. It is hoped that recommendations will be expanded to those weeds in the near future.

ACKNOWLEDGEMENT

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CHEMICAL CONTROL OF WILD BASIL (*OCIMUM GRATISSIMUM*) IN NEW CALEDONIA

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Summary

Wild basil *(Ocimum gratissimum)* was introduced into New Caledonia about 1930. This fast-spreading weed is a major threat to the establishment of improved pastures. Dissemination of its seeds, by tractors in particular, during land clearing and preparation, when improved pastures are established, raises a serious weed control problem.

The chemical control trials that were carried out show that this plant is very sensitive to such selective herbicides as 2,4-D, especially when treated young before flowering, at the rate of 1 kg to 1.5 kg a.i./ha. When wild basil is older (mature and in seed), rates must be increased (2 kg to 2.5 kg a.i./ha). It was found that, at these rates, seed germination is inhibited whereas untreated seeds from control plots had a germination percentage of about 75.

In the conclusions a programme of cultural practices and treatments is advocated to avoid heavy control costs before establishing improved pastures. Failing this, preparing the ground would, alone, create a new problem of basil eradication within a very short time, since enough seeds would remain to re-infest the land.

Wild basil (*Ocimum gratissimum*) belongs to the family Labiatae which probably originated in Eastern India and spread to virtually all tropical areas of the globe. It is thought to have been introduced into New Caledonia at the beginning of the century. This fast-spreading weed is a major threat, in particular to the establishment of improved pastures, as the local practice is to clean up natural pastures by means of a rotary cutter every year or every two years to keep down undesirable and non-palatable species. Unfortunately, tractors and other agricultural machines carry the weed seeds that are most likely to re-infest pastures, as is the case with basil.

Furthermore, any programme for the establishment of improved pastures using fodder mixtures (*Paspalum plicatulum, Chloris gayana, Setaria sphacelata, Phaseolus atropurpureus, Glycine*

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javanica, etc.) requires the soil to be conditioned to give the seeds of these grasses and legumes a good start. Frequently, tractors used for soil conditioning (ploughing, harrowing) have been used a few days previously for clearing basil-infested plots, and therefore carry the seeds of this plant to an ideal environment for their growth.

In 1971, control trials in natural pastures were carried out.

METHODS AND EQUIPMENT

Composition of Natural Pastures

The number of crosses after each species indicates the relative profuseness of the plants.

Grasses

Cynodon dactylon	+++
Brachiaria reptans	++
Imperata cylindrica	+

Cyperaceae

Kyllinga sp.	++
Cyperus gracilis	+

Dicotyledons

Ocimum gratissimum	+++
Desmodium adscendens	++
Desmodium triflorum	++
Stachytarpheta jamaicensis	++
Sida acuta	+
Lantana camara	+
Leucaena glauca	+
Desmanthus virgatus	+
Acacia farnesiana	+
Mimosa pudica	+
Psidium guayava	+
Solanum torvum	+
Ageratum conyzoides	+

Herbicide Tested

In this trial, the only herbicide used was the amine salt of 2,4-D at a rate of 550 g/litre. The rates of application in active ingredient per hectare were:

1 kg (Treatment C1)

1.5 kg (Treatment C2)

2 kg (Treatment C3)

Experimental Design

Applications were made at two stages of growth:

Young basil before flowering (stage S1)

Mature basil (stage S2)

For each stage and each rate of application of the product, there were 4 replicates. All plots had an area of 2 m^2. The trial was conducted at Nakutakoin in the Dumbea area. The applications were made on 10 August 1971.

RESULTS

Global Composition of the Flora before the Application

There were three groups of plants:

Ocimum gratissimum

Grasses and grouped Cyperaceae (G + Cyp.)

Legumes and miscellaneous (Leg. + Misc.)

Table 1 gives the volume of each of these groups. The percentage area multiplied by the mean height gives the volume of vegetation per square metre for each group.

The mean heights before treatment were:

S1		S2	
Ocimum	40 cm	*Ocimum*	85 cm
G + Cyp.	10 cm	G + Cyp.	10 cm
Leg. + Misc.	5 cm	Leg. + Misc.	10 cm

TABLE 1: VOLUME IN DM^3 PER M^2 BEFORE APPLICATION

Plots and Blocks	*I*	*II*	*III*	*IV*	*Total*	*Mean*
S1-C1:						
Ocimum	210	160	240	200	810	202
G. + Cyp.	20	40	30	40	130	32
Leg. + Misc.	12	7	4	5	28	7
S1-C2:						
Ocimum	240	220	240	260	960	240
G. + Cyp.	35	40	36	30	141	37
Leg. + Misc.	3	3	4	3	13	4
S1-C3:						
Ocimum	160	240	300	260	960	240
G. + Cyp.	50	20	14	20	104	26
Leg. + Misc.	3	5	5	5	18	4.5
S2-C1:						
Ocimum	280	380	490	280	1430	375.5
G. + Cyp.	50	40	20	50	160	40.0
Leg. + Misc.	10	5	5	5	20	6.2
S2-C2:						
Ocimum	380	700	700	700	2480	621.0
G. + Cyp.	40	1	3	0	44	11.0
Leg. + Misc.	5	10	5	10	30	7.5
S2-C3:						
Ocimum	280	400	300	420	1400	350.0
Leg. + Misc.	50	40	52	35	177	44.2
G. + Cyp.	10	2	5	5	22	5.5

Effect of 2,4-D on the Vegetation

Young Basil (S1)

A check on 19 September 1971 on the treated plots showed that basil was completely destroyed at the C1 rate. There were a few green leaves at the base of the stems.

At the C2 rate, all stems were completely destroyed down to the base. The same results were obtained with the C3 rate.

It seems therefore that when 2,4-D is applied on young basil (before flowering) a rate of 1 kg to 1.5 kg a.i./ha is sufficient to destroy it.

Mature Basil (S2)

The same control on 19 September 1971 showed that, applied at C1 and C2 rates, 2,4-D is ineffective. At the C3 rate (2 kg a.i./ha) basil was almost totally destroyed.

In August 1972, the remaining vegetation on plot S2 was checked and results are given in Table 2.

TABLE 2: VOLUME IN DM^3 PER M^2 ONE YEAR AFTER APPLICATION

The figures in parentheses show volumes before application.

	Ocimum	*G + Cyp.*	*Leg. + Misc.*
S2-C1	111 (375.5)	163 (40.0)	14 (6.2)
S2-C3	54 (350)	195 (44.2)	10 (5.5)
S2-C2	235 (621)	126 (11)	107 (7.5)

From these figures it would seem that the rate to be applied, to keep basil sufficiently in check, should be at least 2 kg a.i./ha.

Effect of 2,4-D as Germination Inhibitor

At stage S2 basil seeds were taken from plants one month after application and from plants on non-treated control plots. These seeds were sown in a germinator. After 28 days, germination was 76% for seeds from control plants and nil for seeds from plants treated with 2,4-D.

The inhibiting effects of 2,4-D on germination are worth mentioning as they do not seem to have been reported before and, when pastures are treated on a large scale, 2,4-D could reduce considerably the spread of basil in natural pastures.

CONCLUSIONS

Chemical control of wild basil is possible and in established pastures 2,4-D is recommended. Maximum effectiveness is obtained with rates of 1 kg to 1.5 kg a.i./ha on young basil; prior use of a rotary cutter to clear old vegetation, and an application of 2,4-D about two months after that, seems an efficient control technique.

For improved pastures establishment, however, if the grazier intends to sow mixed grazing seeds on land infested with basil, there is no need to apply a herbicide before conditioning the soil and sowing since soil conditioning will assist existing seeds to germinate and control measures will still be required at a later stage.

After emergence (1 to 2 months), pastures can be treated with 2,4-D at the rate of 1 kg a.i./ha to control basil and other weeds. To prevent new pastures from becoming infested, soil conditioning implements (specially tractors) should be cleaned before use. Patches of basil should be removed by mechanical means (rotary cutter) before flowering.

CONTROL OF PARAGRASS (*BRACHIARIA MUTICA*) WITH GLYPHOSATE AND OTHER HERBICIDES[1]

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Summary

Two experiments were conducted to compare the activity or glyphosate against paragrass (*Brachiaria mutica*) with 2,2-DPA, bromacil, paraquat, "Frenock" and "Kenapon". Of the compounds used, glyphosate was most active against paragrass at both immature and mature (flowering) stages. Rates of 2 and 4 kg/ha gave 71 and 80% control, respectively, of mature paragrass at 80 days after treatment; lower rates were ineffective on the mature grass. 2,2-DPA, "Frenock" and "Kenapon" did not differ in control of mature stands. For immature, actively growing stands, glyphosate was effective in control at rates from 1 to 6 kg/ha. Almost complete stand kills were obtained with 3, 4 and 6 kg/ha rates. 2,2-DPA, "Frenock" and "Kenapon" at 20 kg/ha gave only about 45% control of immature paragrass at 46 days after treatment. Paraquat was ineffective against either mature or immature paragrass.

INTRODUCTION

Paragrass (*Brachiaria mutica*) is a perennial grass that grows vigorously under wetland conditions in most tropical and subtropical regions. In Hawaii, paragrass is utilized for pasture in areas of high to medium rainfall, but it also becomes a pernicious weed along irrigation ditches and field margins as well as in-field areas of sugarcane (*Saccharum officinarum*) and pineapple (*Ananas comosus*) plantations. It is a weed of banana, papaya, vegetable crops and industrial areas. Herbicides commonly used for paragrass control in Hawaii are 2,2-DPA and paraquat (Obien *et al.*, 1973). Other compounds that can also affect paragrass at high rates are bromacil, diuron, and methylarsinic acid, although these compounds are infrequently used because of expense and sometimes long residual effects.

[1] J. Ser. No. 1561 of the Hawaii Agric. Exp. Sta., Univ. of Hawaii, Honolulu, Hawaii, 96822.

One aspect of weed control research at the University of Hawaii deals with screening new herbicides, followed by early advanced evaluation. In the 1971-2 screening test, glyphosate was found to be an effective post-emergence herbicide against a wide range of species including perennial grasses, broadleaf weeds and sedges.

This paper presents data which compare the activity of glyphosate with established herbicides, 2,2-DPA, bromacil, and paraquat, and some new compounds, "Frenock" and "Kenapon".

MATERIALS AND METHODS

The effects of six herbicides on paragrass were evaluated in two very similar experiments conducted in two locations. Experiment 1 was conducted in a Halii soil series (typic gibbsihumox, pH 4.9; organic matter 4 to 6%) with 250 cm annual rainfall, and Experiment 2 was on a Hanalei soil series (typic fluvaquents, pH 5.4; organic matter 14%) with 120 cm rainfall. The Halii soils are used for pasture or for growing papaya, banana, and other field crops, while the Hanalei soils are used for growing flooded rice or taro or for swampy pasture. Paragrass in Experiment 1 was at the early and late flowering stage (mature), whereas in Experiment 2 the plants were at a vigorously growing stage and far from flowering (vegetative stage). The experimental plots measured 2 by 10 m; treatments were replicated three times and were completely randomized.

The herbicide solutions (350 l/ha) were applied with a CO_2-pressurized hand spray boom, between 10 a.m. and 2 p.m. There was slight precipitation in the evening following treatment applications of Experiment 1. The day was sunny when Experiment 2 was established, and there was no precipitation in the next 3 days. Subjective evaluations (0 = no control; 100 = complete control) on stand and growth reductions were taken at time intervals. Stand reduction is equivalent to control or death of the plant, and growth reduction indicates the degree of injury such as leaf chlorosis, burning or drying, and other leaf and stem malformations that can contribute to growth inhibition. Data were statistically analysed when deemed necessary to interpret herbicide performance.

RESULTS AND DISCUSSION

Although the two experiments with almost identical treatments were conducted at two locations differing in rainfall conditions and soil types, there was no attempt to relate results to these two factors. What appeared relevant was the growth stage of paragrass at the time of treatment which differed at the two locations.

EXPERIMENT 1 (JAN. 1972)

Both "Frenock" and "Kenapon" are derivatives of 2,2-DPA; they were included in this study to determine if their chemistry has any influence in their ability to control paragrass. The four rates of glyphosate were based from tests conducted in Latin America (Larry C. Burrill, International Plant Protection Center, Oregon State University, pers. comm.) which showed that glyphosate at 0.5 kg/ha was active against some perennial grasses.

It is well known that paraquat is poorly translocated in plants and its effect is manifested mainly by rapid leaf burn and chlorosis. On the other hand, 2,2-DPA and its derivatives are easily absorbed by leaves and roots, and unless the rates are high their effects are not clear until after about a week. Glyphosate is also absorbed effectively by the leaves and then translocated to the roots; this process enables it to affect the whole plant and not just the above-ground plant parts. If the herbicide is applied to the soil, however, it is very unlikely that the roots will absorb lethal amounts of glyphosate because it is easily adsorbed on soil and has little residual activity.

TABLE 1: EFFECTS OF GLYPHOSATE AND OTHER HERBICIDES ON MATURE PARAGRASS AT 35 AND 80 DAYS

(Experiment 1, Kauai, January 1972)

Treatment (kg/ha)	*Stand Reduction 35 days (%)*	*Stand Reduction 80 days (%)*	*Growth Reduction 80 days (%)*
glyphosate 0.5	36.6	3.3	40.0
glyphosate 1	71.6	13.3	46.6
glyphosate 2	80.3	71.6	86.6
glyphosate 4	83.3	80.0	90.0
2,2-DPA 10	31.6	33.3	76.6
2,2-DPA 20	48.3	53.3	81.6
"Frenock" 10	10.0	33.3	78.3
"Frenock" 20	58.3	56.6	85.0
"Kenapon" 10	31.6	40.0	78.3
"Kenapon" 20	33.3	43.3	78.3
paraquat 1	26.6	23.3	48.3
LSD 0.05		11.0	18.9
LSD 0.01		15.0	25.8

Table 1 shows the evaluation data taken at 35 and 80 days on the effects of five herbicides on the growth and stand (control) of paragrass. Glyphosate was clearly the most effective treatment against paragrass. 2,2-DPA, "Frenock", "Kenapon" and paraquat caused some extensive leaf burning but most of the stems remained green and subsequently recovered. Paraquat was particularly ineffective in killing paragrass; limited spray penetration through the thick mat of vegetation seemed to have contributed to poor control. The effects of 2,2-DPA, "Frenock", and "Kenapon" were manifested gradually, unlike paraquat which was visible the following day after treatment, and consisted of leaf burning and death of the youngest leaf. Only a rate of 20 kg/ha gave as much as 43 to 58% control. On the other hand, glyphosate at rates of 2 and 4 kg/ha controlled 80 to 83% of paragrass at 35 days. The data at 80 days showed slight recovery, although growth was still very much inhibited (86 to 90%). The low rates of 0.5 and 1 kg/ha, although causing intense leaf chlorosis, did not cause serious injury to the stems, particularly the lower portions, and the plants eventually recovered as shown by the data at 80 days. As the plants recovered, it was also observed that numerous small shoots developed from the nodes, giving the impression that growth hormones had been applied. This phenomenon was observed more in plants treated with 0.5 kg/ha than in those treated with higher rates. It would seem, therefore, that glyphosate and/or its derivatives may have some effects which might be useful in other aspects of crop production.

Experiment 2 (March 1972)

It was observed in Experiment 1 that plants that were in an active vegetative stage were more seriously injured by glyphosate than those at the flowering stage and older. Therefore, it was decided to run another similar test using rates of 1 to 6 kg/ha of glyphosate, and 20 kg/ha each of 2,2-DPA, "Frenock", and bromacil. Bromacil was included here because it is a potential grass herbicide.

The results with 2,2-DPA, "Frenock", and paraquat did not differ much from those obtained in the first experiment (Table 2). Bromacil had the same range of activity (48% control) as 2,2-DPA and "Frenock". Paraquat showed less activity in this experiment than in the first test, probably owing to spray volatilization caused by relatively better sunshine at the time of treatment.

TABLE 2: EFFECTS OF GLYPHOSATE AND OTHER HERBICIDES ON YOUNG, ACTIVELY GROWING PARAGRASS AT 12, 20, AND 46 DAYS

(Experiment 2, Wailua, Kauai, March 1972)

Treatment (kg/ha)	*Growth Reduction 12 days (%)*	*Growth Reduction 20 days (%)*	*Stand Reduction 20 days (%)*	*Stand Reduction 46 days (%)*
glyphosate 1	28.3	81.6	63.3	81.6
glyphosate 2	30.0	86.6	78.3	91.6
glyphosate 3	41.6	90.0	81.3	96.6
glyphosate 4	61.6	91.6	91.6	98.3
glyphosate 6	73.3	96.0	96.0	98.3
2,2-DPA 20	6.6	41.6	0.0	46.6
"Frenock" 20	5.0	25.0	3.3	43.3
bromacil 20	13.3	43.3	0.0	48.3
paraquat 1	10.0	40.0	0.0	6.6
LSD 0.05	5.56	8.32		20.49
LSD 0.01	6.76	10.11		24.88

Glyphosate at all rates used was effective against paragrass (Table 2), reducing the stand by 81 to 98% at 46 days. The effects consisted of intense leaf chlorosis at about 5 to 7 days, then drying up of the leaves, followed by death of the stems. In some instances, the base of the stem (stump) remained green, and this produced new shoots in two months. Glyphosate at 1 kg/ha, although it caused 81% control, had to be used cautiously and only on young plants because, as shown in the first experiment, it would not be effective against mature plants. The relative growth stage of the plants should indicate which of the rates shown in Table 2 would be recommended for application. Plants that survive for one reason or another should be re-treated as soon as they are about 0.3 m high so that a lower rate can be used.

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