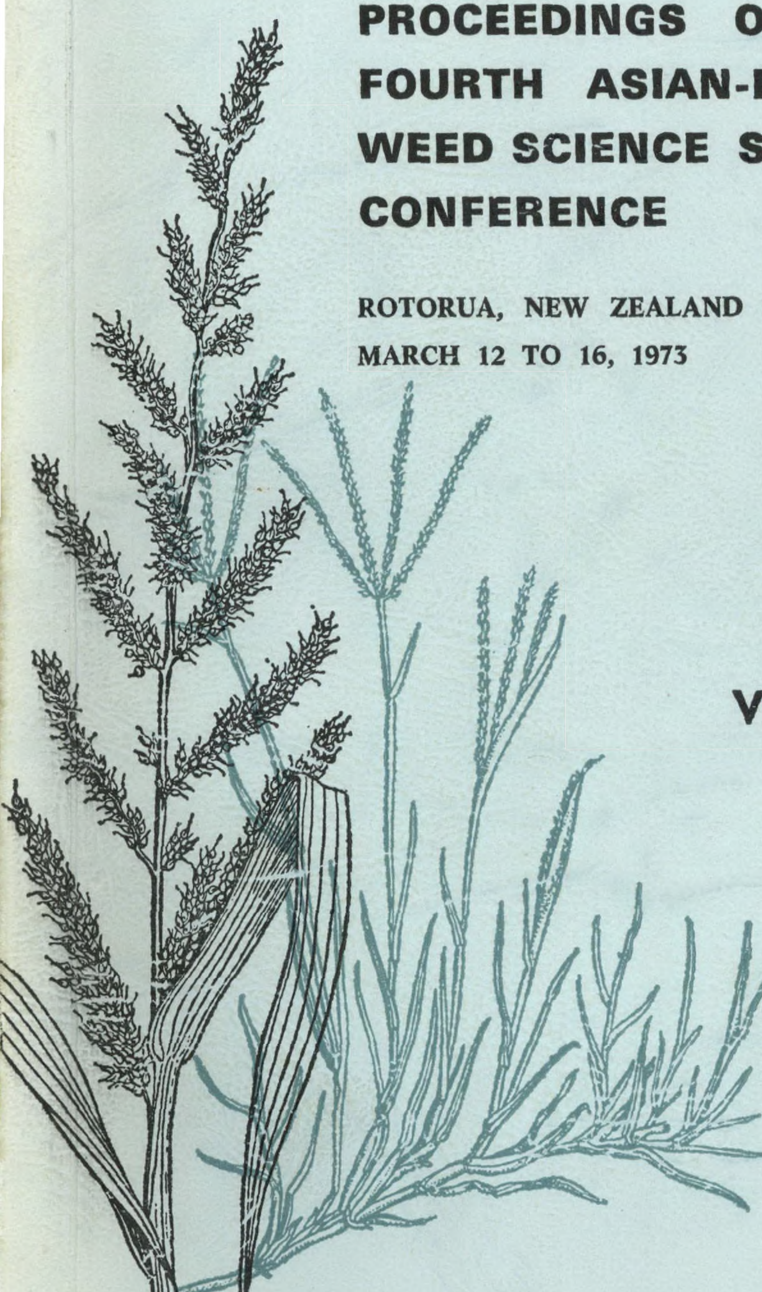
PROCEEDINGS OF THE FOURTH ASIAN-PACIFIC WEED SCIENCE SOCIETY CONFERENCE

ROTORUA, NEW ZEALAND

MARCH 12 TO 16, 1973



Volume I

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VOLUME 1

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ROTORUA INTERNATIONAL HOTEL

ROTORUA, NEW ZEALAND

MARCH 12 TO 16, 1973

Volume I

Co-hosted by

The New Zealand Weed and Pest Control Society

Published by

ASIAN-PACIFIC WEED SCIENCE SOCIETY

1973

Editorial work and production by

EDITORIAL SERVICES LIMITED, WELLINGTON, NEW ZEALAND

Printed by

SIGMA PRINT LIMITED, PETONE, NEW ZEALAND

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Weed Society of Japan

The Weed Society of New South Wales, Australia

The New Zealand Weed and Pest Control Society

The Weed Science Society of South Australia, Australia

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PREFACE

Papers to the Conference originated from a large number of countries and as a result involved a variety of usage in names and terms. To provide a degree of uniformity, a number of decisions had to be made, some of them necessarily somewhat arbitrary.

Common names of herbicides used are those adopted by the Agricultural Chemicals Board of New Zealand and published in their *Nomenclature of Agricultural Chemicals.* These are generally in agreement with international usage but two exceptions might be mentioned. Dalapon is commonly used in a number of countries but in New Zealand and some other countries is a registered trade name and thus unacceptable as a common name, the chemical name 2,2-dichloropropionic acid being used. For convenience, the abbreviation 2,2-DPA has been used in these papers. The other divergence from common usage in a number of the contributing countries is the use of the full chemical name, methylarsinic acid, instead of MSMA or DSMA. A list of the common and chemical names of herbicides referred to in these *Proceedings* appear on the following pages.

No attempt was made to standardize the common names of plants, which differ from one country or region to another. However, as they are all identified by their botanical names no confusion should arise. An index to weed species referred to throughout the *Proceedings* will be published in Volume 3.

In a number of the papers, statistical analysis has used Duncan's Multiple Range Test (Duncan. D.B., 1955: Multiple range and multiple F tests, *Biometrics, 11*: 1-42). Interpretation is as follows: Any two treatments are similar if they have a letter in common. If this is not the case they differ significantly. Capital letters represent 10% significance and small letters 5% significance. The letter "a" is always allocated to the *highest* value, whether or not this refers to the best or worst treatment.

Finally, metric units of measurement have been used throughout. A short conversion table follows the list of chemicals for the benefit of those more accustomed to working with imperial units.

V. J. WILSON,
Editor

COMMON NAMES AND CHEMICAL ABBREVIATIONS

Name	*Chemical Name*
alachlor	2-chloro-2,6-diethyl-*N*-methoxymethylacetanilide
Amchen 70-25	not available at time of printing
ametryn	2-ethylamino-4-isopropylamino-6-methylthio-1,3,5-triazine
amitrole	3-amino-1,2,4-triazole
AN-1232	not available at time of printing
AP-920	not available at time of printing
atrazine	2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine
azolamid	*N*-isobutyl-*z*-oxo-imidazolidine-1-carboxamide
barban	4-chlorobut-2-ynyl-3-chlorophenyl carbamate
Bay NTN 5006	not available at time of printing
benazolin	4-chloro-2-oxobenzothiazolin-3-ylacetic acid
bensulide	di-isopropyl *S*-(2-phenylsulphonyl = aminoethyl) phosphorothiolothionate
bentazon	3-isopropyl-(1H)-benzo-2,1,3-thiadiazin-4-one 2,2-dioxide
benthiocarb	*S*-(4-chlorobenzyl)-*N*,*N*-diethylthiol carbamate
bioxone	2-(3,4-dichlorophenyl)-4-methyl-1,2,4-oxadiazolidene-3,5-dione
bromacil	5-bromo-6-methyl-3-(1-methyl-*n*-propyl) uracil
bromofenoxim	3,5-dibromo-4-hydroxybenzaldehyde 2,4-dinitrophenyloxime
bromoxynil	3,5-dibromo-4-hydroxybenzonitrile
butachlor	2-chloro-*N*-(isobutoxymethyl) -2′,6′-acetoxylidide
butylate	*S*-ethyl di-isobutylthiocarbamate
C15935	not available at time of printing
carbetamide	D-*N*-ethyl-2-(phenylcarbamoyloxy) propionamide
chlomethoxynil	2,4-dichlorophenyl 3-methoxy-4-nitrophenyl ether
chlonidine	not available at time of printing
chloramben	3-amino-2,5-dichlorobenzoic acid
chloranocryl	*N*-(3,4-dichlorophenyl) methacrylamide
chlorbromuron	*N′*-(4-bromo-3-chlorophenyl)-*N′* methoxy-*N*-methylurea
chlorfenac	2,3,6-trichlorophenylacetic acid
chlornitrofen	4-nitro-2,4,6-trichlorophenyl ether
chloroxuron	*N′*-4-(*p*-chlorophenoxy) phenyl-*NN*-dimethylurea
chlorproham	isopropyl 3-chlorophenyl-carbamate
chlorthal	2,3,5,6-tetrachloroterephthalic acid
chlorthiamid	2,6-dichlorothiobenzamide
CP 27502	not available at time of printing
cyanazine	2-chloro-4-(1-cyano-1-methylethyl = amino)-6-ethylamine-1,3,5-triazine
cyprazine	2-chloro-4-cyclopropylamino-6-isopropylamino-1,3,5-triazine
2,4-D	2,4-dichlorophenoxyacetic acid
2,4-DB	4-(2,4-dichlorophenoxy) butyric acid
dalapon — see 2,2-DPA	
delachlor	*N*-butoxymethyl-2-chloro-2,6′-diethylacetanilide

Name	*Chemical Name*
2,4-DEP	*tris*[β-(2,4-dichlorophenoxy) ethyl]phosphite
di-allate	S-(2,3-dichloroallyl) di-isopropylthiocarbamate
diazinon	diethyl 2-isopropyl-6-methyl-4-pyrimidinyl phosphorothionate
dicamba	3,6-dichloro-2-methoxybenzoic acid
dichlobenil	2,6-dichlorobenzonitrile
dichlorprop	2-(2,4-dichlorophenoxy) proprionic acid
dinoseb	2,4-dinitro-6-*s*-butylphenol
diphenamid	*NN*-dimethyl-2,2-diphenylacetamide
diquat	9,10-dihydro-8a,10a-diazoniaphenanthrene
disul	2-(2,4-dichlorophenoxy) ethyl hydrogen sulphate
diuron	*N'*-(3,4-dichlorophenyl)-*NN*-dimethylurea
DNOC	2-methyl-4,6-dinitrophenol
2,2-DPA*	2,2-dichloropropionic acid
DSMA — see methylarsinic acid	
EMD 7060H	not available at time of printing
EPTC	*S*-ethyl dipropylthiocarbamate
fenoprop	2-(2,4,5-trichlorophenoxy) propionic acid
fentin	triphenyltin
fenuron	*NN*-dimethyl-*N'*-phenylurea
fluometuron	1,1-dimethyl-3-(3-trifluoromethylphenyl) urea
fluorodifen	4-nitrophenyl 2-nitro-4-trifluoromethylphenyl ether
"Frenock"	sodium salt of 2,2,3,3-tetrafluoropropionate
glyphosate	*N*-(phosphonomethyl) glycine
HCA	hexachloroacetone
ioxynil	4-hydroxy-3,5-di-iodobenzonitrile
isocil	5-bromo-3-isopropyl-6-methyluracil
karbutilate	*m*-(3,3-dimethylureido) phenyl *t*-butylcarbamate
"Kenapon"	diethyleneglycol ester of 2,2-DPA
lenacil	3-cyclohexyl-6,7-dihydro-1*H*-cyclopentapyrimidine-2,4(3*H*,5*H*)-dione
linuron	*N'*-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea
MBR 8050	not available at time of printing
MBR 8251	not available at time of printing
MC-4379	methyl-5-(2',4'-dichlorophenoxy)-2-nitrobenzoate
MCPA	4-chloro-2-methylphenoxyacetic acid
MCPB	4-(4-chloro-2-methylphenoxy) butyric acid
mecoprop	(±)-2-(4-chloro-2-methyl phenoxy) propionic acid
methiocarb	3,5-dimethyl-4-methylthiophenyl-*N*-methylcarbamate
methylarsinic acid	methylarsinic acid
metobromuron	*N'*-4-bromophenyl-*N'*-methoxy-*N'*-methylurea
metribuzin	4-amino-6-*t*-butyl-3-methylthio-1,2,4-triazine-5-one
molinate	*S*-ethylhexahydro-1*H*-azepine-1-carbothiolate
MON-0843	not available at time of printing
monuron	*N'*-(4-chlorophenyl)-*NN*-dimethylurea
MSMA — see methylarsinic acid	
napropamide	2-(α-naphthoxy)-*N*, *N*-diethylpropionamide
naptalam	*N*-1-naphthylphthalamic acid
NC 8438	2-ethoxy-2,3-dihydro-3,3-dimethyl-*s* benzofuranyl methane sulphonate

Name	*Chemical Name*
neburon	*N*-butyl-*N*′-(3,4-dichlorophenyl)-*N*-methylurea
nitralin	4-methylsulphonyl-2,6-dinitro-*NN*-dipropylaniline
nitrofen	2,4-dichlorophenyl-4′-nitrodiphenyl ether
noruron	*N*′-(hexahydro-4,7-methanoindan-5-yl)-*NN*-dimethylurea
oryzalin	3,5-dinitro-N^4,N^4-dipropylsulfanilamide
oxadiazon	2-tert butyl-4-(2,4-dichloro-5-isopropyl (oxyphenyl)-1,3,4-oxadiazoline-5-one
paraquat	1,1-dimethyl-4,4′bipyridilium
pebulate	*S*-propyl butylethylthiocarbamate
pentanochlor	*N*-(3-chloro-4-methylphenyl)-2-methylpentanamide
phenmedipham	3-methoxycarbonylaminophenyl *N*-(3′-methylphenyl) carbamate
picloram	4-amino-3,5,6-trichloropicolinic acid
prometryn	2,4-bisisopropylamino-6-methylthio-1,3,5-triazine
pronamide	3,5-dichloro-*N*-(1,1-dimethylpropynyl) benzamide
propachlor	2′-chloro-*N*-isopropylacetanilide
propanil	*N*-(3,4-dichlorophenyl) propionamide
propazine	2-chloro-4,6-bisisopropylamino-1,3,5-triazine
propham	isopropyl phenylcarbamate
prynachlor	2′-chloro-*N*-(1-methylprop-2-ynyl) acetanilide
pyrazon	5-amino-4-chloro-2-phenylpyridazin-3-one
S-18507	not available at time of printing
S-18797	not available at time of printing
simazine	2-chloro-4,6-bisethylamino-1,3,5-triazine
simetryn	2,4-bisethylamino-6-methylthio-1,3,5-triazine
sodium arsenite	complex of: sodium orthoarsenite and/or sodium metarsenite
swep	methyl *N*-(3,4-dichlorophenyl) carbamate
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
2,3,6-TBA	2,3,6-trichlorobenzoic acid
TCA	trichloroacetic acid
TCE-styrene	α-2,2,2-trichloroethyl styrene
terbacil	5-chloro-6-methyl-3-*t*-butyluracil
tri-allate	*S*-2,3,3-trichloroallyl diisopropylthiocarbamate
tricamba	3,5,6-trichloro-2-methoxybenzoic acid
trietazine	2-chloro-4-(diethylamino)-6-(ethylamino)-*s*-triazine
trifluralin	2,6-dinitro-*NN*-dipropyl-4-trifluoromethylaniline
vernolate	*S*-propyl *NN*-dipropyl thialcarbamate
U-27,267	not available at time of printing

METRIC CONVERSION

1 lb = 0.454 kg	1 kg = 2.20 lb
1 yd = 0.914 m	1 m = 1.09 yd
1 ac = 0.405 ha	1 ha = 2.47 ac
1 gal = 4.55 l	1 l = 0.22 gal
1 lb/ac = 1.12 kg/ha	1 kg/ha = 0.89 lb/ac
1 gal/ac = 11.25 l/ha	1 l/ha = 0.089 gal/ac
1 lb/sq.in. = 6.89 kN/m^2	1 kN/m^2 = 0.145 lb/sq.in.

N.B. N = Newton
N/m^2 has special name of the pascal (Pa).

CLIMATE AND SOILS OF NEW ZEALAND

T. W. WALKER

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CLIMATE

Important factors influencing climate in New Zealand (267,000 km^2) are:

(1) The country is long (1930 km) and narrow (400 km at widest part and no part more than 130 km from the sea), lying between latitudes 34° S and 47° S.

(2) It is very mountainous, the major range running NE-SW with parallel subsidiary ranges.

(3) Being surrounded by seas for hundreds of miles in all directions, the whole country is exposed to oceanic influences.

The mountains cause sharp rainfall gradients from west to east, particularly in the South Island, where average precipitation in Fiordland exceeds 5000 mm/yr and is only 330 mm in parts of Central Otago. When the prevailing western air-flow is strong enough, "Fohn" conditions occur, particularly in Canterbury, bringing heavy rain and mild weather to the west and warm dry conditions to the east.

Rainfall is largely controlled by relief and is fairly evenly distributed throughout the year. The Southern Alps are orientated on a line of 220° and winds from directions west or east of 220° are blocked from the east or west, respectively, so that slight changes in direction of windflow can influence one coast more than another; New Zealand is a windy country.

Mean annual temperatures vary from 10° C in the south (14° C in summer to 4° C in winter) and 14° C in the north (18° C in summer to 11° C in winter). There is only a short time during which temperatures are low enough to stop plant growth completely in the south, and some pasture species may make appreciable winter growth particularly in the North Island. It is not necessary to house farm animals during the winter.

Evaporation from open pan varies from 500 mm/yr at Lake Mahinerangi in Otago to 1100 mm at Blenheim. Except for small areas in the east of the North Island there are no significant deficiencies of moisture in the North Island and, except for the months of January and February, precipitation commonly exceeds transpiration. In the south and west of the South Island, precipitation commonly exceeds transpiration throughout the year. In the Canterbury Plains, MacKenzie Country and North Otago, there is a protracted summer deficit of rain, usually extending over three or four months, and in the driest parts of Central Otago there is a moisture deficit from October to April.

The climate thus embraces such extremes as subtropical Northland, the cold uplands of the alpine region, the semi-arid basins of Central Otago, and the very wet mountains and lowlands of Westland. Apart from some of the drier areas on the east coast, and some of the elevated areas, much of New Zealand was covered in forest before the arrival of Europeans. The natural tussock grasslands grew in drier eastern areas of both Islands, with subalpine scrub and fell-field on higher land.

SOILS

Soil is the product of its environment, of the parent material on which it forms in a certain kind of topography, of the climate which influences the rate of weathering of minerals and leaching of nutrients, and of the succession of vegetation under which it has developed over periods of time varying from hours to aeons. It is these five variable soil-forming factors — parent material, topography, climate, organisms and time — which govern the formation of soils, and provide a suitable framework for a general consideration of New Zealand soils. There are more recent, and probably to the layman more complex, ways of classifying the soils which will not be discussed.

The three main groups are:

(1) The *zonal soils,* which are defined as those occurring on normal parent materials on gentle slopes for sufficient time for the development of mature soils. This fixes three of the variable soil-forming factors and leaves the other two (climate and organisms) to influence the kind of soil formed.

(2) The *intrazonal soils* whose main characteristics are due to the strong impress of some local factor such as a particular kind of rock or high water-table.

(3) The *azonal soils* whose properties are modified by instability due to steepness of slope or youthfulness giving immature soils.

Zonal Soils

By definition, these soils are restricted to those formed on siliceous (quartzo-feldspathic) parent materials (schists, granites, greywackes, etc.), in different climates. The four climatogenic soil groups are brown-grey earths (300 to 500 mm), yellow-grey earths (500 to 900 mm), yellow-brown earths (900 to 1800 mm) and podzolized soils and podzols. Yellow-brown earths occur over much of the country and have been further subdivided on the basis of temperature to give the Northern, Central and Southern, and High Country yellow-brown earths. Figure 1 shows the relationship between the zonal soils and climate.

Intrazonal Soils

These cover all other parent materials (basalt, volcanic ash, sand deposits, calcareous deposits, etc.) as well as poorly drained

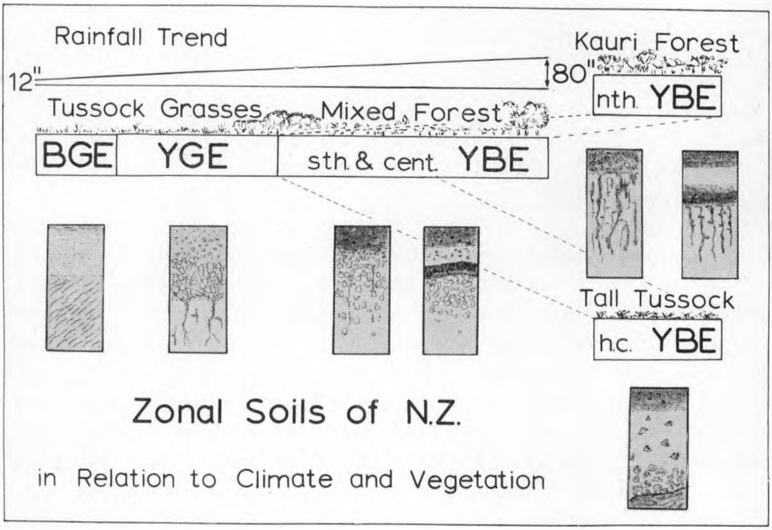

Fig. 1: Zonal soils of New Zealand in relation to climate and vegetation.

gleys and peats. Soils of various ages formed on several different volcanic ash showers cover large areas of central North Island. Early attempts to farm some of the pumice soils met with indifferent success owing to bush-sickness of sheep and cattle, now overcome by the use of cobalt, although considerable areas have been planted to exotic forests. The yellow-brown pumice soils and the yellow-brown loams (formed on fine-textured volcanic ashes) occupy some 3 million hectares.

Azonal Soils

These comprise the recent soils from alluvium, the recent soils from volcanic ash, the skeletal and other soils of the steeplands, and the mountain soils. The recent alluvial soils constitute some of the most fertile and most highly productive in the country. Overgrazing by sheep, rabbits and deer, together with burning, has damaged the cover of many of the steepland soils and erosion is often spectacular. Removal of sheep and control of noxious animals lead to slow recovery.

SOIL FERTILITY

New Zealand's almost complete dependence on biological nitrogen fixation, in an agricultural system dominated by pastoral farming, entails a very different approach to problems of soil fertility, than where agriculture is centred on arable farming.

Two factors which need to be given little or no consideration, often vital in arable cropping, are the use of nitrogen fertilizers and the maintenance of soil organic matter. One of the major effects of grass-clover associations on soils is an increase in levels of soil organic matter and nitrogen and usually an improvement in structure. On many improved pastures, levels of soil nitrogen may reach 1% or more in the surface horizons. The basic principles underlying increased herbage production entail the correction of all nutrient deficiencies by nitrogen, correction of any heavy metal toxicities by liming, the introduction of clovers inoculated with efficient rhizobia if necessary, adequate grazing to avoid suppression of clovers by grasses through competition for light, and drainage or irrigation if necessary. Increased herbage production usually leads to a marked increase in animal production, but animal health problems may arise and will be mentioned later.

NUTRIENT DEFICIENCIES ON MAJOR SOILS

There is a pattern of nutrient deficiencies in the zonal soils which can be correlated with the increased leaching and weathering on proceeding from the brown-grey earths to the podzols. In the semi-arid climate of the brown-grey earths, there has been relatively little weathering of minerals and leaching of nutrients, pH levels are near 6.5, and available phosphate and potash levels are good. Levels of organic matter are low in this area of low rainfall and levels of soil nitrogen are also low. Often the only nutrient needed to stimulate the growth of legumes is sulphur, and in some soils sulphate levels in the subsoil may be adequate for unirrigated lucerne so that no responses are obtained to any nutrients.

Sulphur occupies a rather unique role in New Zealand agriculture. Nitrogen fixers need 1 kg S to fix 10 to 15 kg N and on most soils are dependent on addition of S from outside the ecosystem. As this is often less than 1 kg/ha/yr over vast areas of New Zealand, legumes in the pastures must be given fertilizer-S if they are to fix maximum amounts of N. Thus sulphur deficiency in pastures may occur on all soils getting low atmospheric returns. Sulphur accumulates with nitrogen, phosphorus and carbon in soil organic matter, which has rather constant N/S ratios of 8.5. In a pasture, grasses take up most of the mineral-N and S made available from soil organic matter, leaving the clovers dependent mainly on outside sources of S. On ploughing a pasture for cropping, if the crop gets enough nitrogen from the break-down of organic matter it should also get enough sulphur.

In the sub-humid yellow-grey earths, available phosphate is declining, pH levels have fallen to 5.3 to 5.5 and pastures may require phosphorus, sulphur, and lime and/or molybdenum to stimulate nitrogen fixation. The potassium status is still usually adequate. In the more humid zones of the yellow-brown earths, in addition to the above nutrients, potassium deficiency becomes more common, and some lime may be necessary to enable rhizobia to survive when inoculated seed is sown, or to correct toxicities from aluminium or manganese. The podzolized yellow-brown earths and podzols may need a wide range of elements to permit the establishment of a grass/clover pasture.

In a similar fashion to the influence of increasing precipitation, increasing age of soils also leads to a growing number of nutrient deficiencies, as does decreasing slope. Much of the work on fertilizers is carried out on sequences of soils where attempts are made to keep all but one soil-forming factor constant.

The major plant nutrients applied to the soils are phosphorus, sulphur, potassium, lime (rarely to supply calcium) and increasingly, but mainly for animal health, magnesium. Micronutrients commonly applied for increasing herbage production are molybdenum, boron and copper; iron, manganese and zinc deficiencies are very rare.

One of the results of depending on biological nitrogen fixation is that all nutrient deficiencies affecting clover growth must be corrected in order to obtain maximum herbage production.

Nutrient Requirements of Animals

Producers of arable crops for human consumption rarely have to worry about the mineral composition of the crops or even the calorific, protein or vitamin content. Where animals eat nothing but herbage on the same farm, often on similar soils, herbage quality is important. A pasture may appear excellent but harm stock; animals may suffer from deficiencies of Cu, Se, I, Co and Mg even though the herbage may not give increased yields from their application. In the case of Se and I, plants may not even need the element. In animals, Cu deficiency can be caused by high Mo content of herbage; Mg deficiency can be precipitated by many factors including high K content of herbage; Co deficiency can be intensified by liming; I deficiency may be caused by goitrogenic compounds in brassicas. Se deficiency is widespread in animals throughout New Zealand but little is known about its causes. Maintenance requirements of some of these elements are only roughly known and quality control of herbage, including organic and inorganic composition, is not yet possible.

Cropping

The total acreage of New Zealand is 26.5 million ha of which about 17 million are occupied for agriculture. The balance of 9.5 million ha includes indigenous forests, national parks, mountains, lakes, roads, rivers and towns. Of the 17 million ha occupied by farmers, 9 million are classified as improved and the vast majority are under grazed pastures. Of the 8 million ha occupied but unimproved, most of it is in tussock grasslands, scrub and forest and carries perhaps 10% of the stock. As the total carrying capacity in 1971 was 104×10^6 sheep equivalents (1 cow = 5 sheep) this means that some 90×10^6 sheep equivalents are carried on 9×10^6 ha of improved land.

Although arable cropping, including horticultural crops for processing, is increasing, only a very small acreage is cropped. Even where cropping is most intensive it is rare for more than two or three crops to be grown before sowing down a pasture for some years. This means that soil organic matter levels are usually high and few responses are obtained to nitrogen fertilizers; in some cases nitrogen fertilizers actually depress yields of wheat. With more intensive cropping, nitrogen responses do occur but in comparison with other developed systems of agriculture use of fertilizer nitrogen is negligible.

A SUMMARY OF THE VEGETATION OF NEW ZEALAND AND THE INFLUENCE OF LAND USE

K. F. O'CONNOR

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This paper gives some perspective on the character of the primitive New Zealand vegetation, the important elements in the continuing but changing cultural disturbance of that vegetation, and the resultant conditions of the New Zealand rural landscape. Man's impact on New Zealand vegetation is best understood as a succession of cultural phases which differed markedly in the traditional content of each one and in the influence that each one had on different sectors of the environment. Only by understanding the interplay of forces of cultural traditions will the stresses to which vegetation was subject be understood.

POLYNESIAN SETTLEMENT

Before human settlement about 1,000 years ago, New Zealand was probably three-quarters covered with evergreen forest. The main unforested areas were the high mountain tops and a smaller area of semi-arid land. In simplified terms the pre-Polynesian indigenous forests extended from north to south as outlined by McKelvey (1970):

Kauri/podocarp/mixed hardwood forests
Podocarp/mixed hardwood forests
Podocarp/beech forests
Pure beech forests

Extensive areas of unforested land were uncommon in the North Island apart from seral stages of succession: riverbeds, swamps, dune sands, parts of the central and eastern sectors affected by volcanic showers, and smaller areas above the tree line. The Polynesian settlers were skilled as hunters, fowlers and fishermen. Their traditional agriculture was a highly intensive, generally communal exercise.

In the zones of relatively closed forest, the Maori impact was probably small before the coming of Europeans. The limited agriculture of the Maori derived from his Polynesian cultural heritage involved yams, taro, gourds and kumara. None of these could withstand the cooler conditions of the southern half of New Zealand. Even in the North Island, gourds, yams and taro were restricted to the warmest sites and kumara demanded particular soil physical conditions. Whereas shifting cultivation with forest restoration of fertility had been possible in volcanic tropical soils, the brief retirement of land from kumara cultivation in warm temperate New Zealand allowed a succession only to bracken (*Pteridium aquilinum* var. *esculentum*) and manuka (*Leptospermum scoparium*) associations. In sites of soil suited to kumara, permanent cultivation was maintained, especially by digging of drains, fertilizing with wood ashes and seaweed, and conditioning where necessary with sand, gravel and shells. Bracken root, which was widely used as a staple, required no cultivation.

The combined effects of these limitations for a stone age people were to minimize the area of forest affected and to restrict the consequent zones of intensive settlement to the northern areas with fertile soils close to good fishing.

In the South Island the greater proportion of land with lower rainfall or of greater elevation had naturally resulted in more unforested land. The riverbeds and unforested high mountain slopes were most active and more extensive. In the driest zones inland were shrublands or shrubby grasslands. On the plains of Canterbury there were outliers of podocarp/beech forest, podocarp/mixed hardwood forest and primary podocarp forest in favoured situations. On some portions of the plains as well as on drier hill country to the north and south of them, were myrtaceous kanuka (*Leptospermum ericoides*) forests backed by extensive podocarp beech forests in the less arid mountains and hills — all a mosaic with open shrubby grassland, swampland and shrubland. To these lands with their large bird populations, the earlier Polynesian hunters may have been powerfully attracted just as European pastoral men were later attracted to the open grasslands and shrublands of the South Island rather than to the northern forests. Those hunters destroyed the moa and by accident or as a tool of hunting apparently triggered the reduction by fire of the area of the drier lowland and montane forests (Molloy, 1969) initiating the modern cycle of accelerated erosion and reducing the resources for the support of non-pastoral, non-agricultural Maori populations. Tall tussock grasslands, tolerant of periodic fire, remained in place of destroyed forests down to the times of European pastoral settlement.

MAORI-EUROPEAN AGRICULTURAL COMPETITION FOR FOREST LAND

The potato furnished a cultural bridge for the Maoris of the late eighteenth century to the commerce and culture of the outside world. Whereas their kumara crops had been for tribal subsistence, potatoes gave them trade with visiting ships, especially for iron goods. The wider valence of the potato, the advent of steel axes, and the superior performance of potato crops in newly-cleared ground in comparison with long-cultivated, less fertile ground combined to bring about a rapid increase in forest clearing in the late eighteenth and early nineteenth centuries, many years before the establishment of the New Zealand colony in 1840 (Cameron, 1964). From their early interest in potatoes, Maori agriculturalists widened and diversified their production, even to 1,000 acres of wheat in the Waikato. The North Island thus experienced a dramatic cultival exploitation of its natural resources just as the South Island had suffered from hunting. Changes begun in Polynesian times in two different cultural patterns were to be sustained and intensified in European times in a single dominantly pastoral pattern.

No matter what skills in agriculture the European settlers may have possessed from their former home, they lacked experience as colonists of a wilderness whose salient feature was a confusion of growth forms and unsettling evergreenness. How the early settlers must have longed for the leaf fall of a European winter so that they might just for once see the wood for the trees. If the Maoris themselves resorted to fire for the sake of new potato ground, need it be wondered that the colonists regarded the bush as an enemy?

The pace of sponsored settlement, the urgency of achieving self-sufficiency, the difficulties in marketing and in securing land from the Maoris, the hazards of floods, earthquakes, marauding wild pigs and even insurgencies of the Maoris, all made for crudity in the agricultural treatment of these new lands. At each of the major settlements, Bay of Islands, Taranaki, Wellington, Nelson, Christchurch and Dunedin, the immediate environment for agriculture even for modern equipment would have been difficult enough. Perhaps the Canterbury settlement was the easiest with its adjacent open mosaic of scrub and grasslands. Despite its crude vigour, European settler agriculture was by no means an instant economic success. Perhaps as important as the hostility of the forested land itself was the difficulty of assuring markets and the competition provided by the Maoris themselves.

The historian, Keith Sinclair (1957) has pointed to the effective commercial competition provided by Maoris for the early European farmer, by growing a large proportion of the food sold locally. They also controlled the coastal shipping and exported considerable quantities of potatoes, wheat and other foodstuffs to Australia. European settlers who could turned to pastoralism because they were beaten in agricultural competition by the Maoris to whom they had brought the arts and materials of a new agriculture but who themselves retained a greater adaptability to forest and fernland through their tribal organization and tenure of land. The forest was winning against European settlement in those early years. As the Polynesians had done before, the Europeans who had the means turned to the open country in the south. The Europeans were later to take a bitter revenge on the forest which thwarted them for so long.

EUROPEAN DOMINANCE OF OPEN COUNTRY

Many who turned to pastoralism were Australians. Pastoral skills in often difficult country were part of their cultural tradition just as they were part of the inheritance of the Scottish sheepmen and north country men who often managed the flocks of the more affluent English colonists. The flocks (or cattle herds in some districts) were brought into open country to be herded within the designated but unfenced boundaries of the leased land. The varied combinations of tall tussock, matagouri (*Discaria toumatou*), speargrass, manuka and kanuka thickets and lawyer vines (*Rubus* spp.) provided their own particular hazards and impediments to the movement of man and beast. In the unburnt condition none seemed to provide the prospect of much nutritious herbage. For much of this open country fresh fire was therefore essential to open up the grassland to allow stock to range in productive safety within its boundaries. By the early 1860s most of the country east of the Southern Alps was taken up in runs and stocked with sheep or cattle at rates high even by present standards. Stock numbers probably reached their first peak by the early eighties.

The impact of fire and animal on the vegetation was severe. On the plains of Canterbury, the open mosaic gave way to the short sward and soon to the wheat fields of the bonanza. In the mountain valleys and the semi-arid lands there were large areas of shrubland which were modified to a shrubby grassland or even to a sparsely shrubby semi-desert on the drier hills. Large areas of beech and beech/podocarp forests as well as New Zealand flax (*Phormium tenax*) lands were modified with varying success towards grassland, in Marlborough and northern parts of Canterbury and also in Southland. The most widespread consequence of fire and grazing, however, was the conversion of tall tussock grassland to short tussock grassland or tufted swards (Connor, 1969).

Such was the aim of the pastoralist, to use fire to induce and maintain a relatively short grassland. In some places he seemed, at least for a time, successful. In others he was dramatically unsuccessful as demonstrated in Hawke's Bay by swift and extreme depletion and erosion.

Many of the changes in mountain vegetation were accomplished sufficiently quickly to have escaped the notice of most of the sparse naturalists and scientists of the early twentieth century. Only in very recent years has it been possible to reconstruct with confidence the sequence of events which occurred in the different habitats. Such degradations and depletions induced instability, shown by the increase in unpalatable plants and physical vulnerability of the vegetation itself. In the more favoured areas such as Southland, less arid parts of Otago and in much of the foothills, a compensating cultural stability was achieved under pastoral culture, but on the steeper greywacke high country cultural stability was never achieved.

On the Canterbury Plains and downlands the rapid degrading of resources in the exploitive cropping that characterized the later years of the nineteenth century was halted and reversed with fertility rebuilding by ley farming through fencing and access to stock water.

On the hills and mountains a century of degradation of vegetation has been followed by a reversal of trend in the last 20 years. By recent cultural changes, new levels of stability are being sought and maintained where these are possible under pastoral systems. Soil and vegetation are amended by topdressing with fertilizer and oversowing with grass and legume seed. Such land improvement techniques are generally applied to a limited area of an extensive pastoral property and integrated into the total pastoral management. Very often the development of part of a pastoral run allows the retirement from grazing of a part where continuance of pastoral use would damage the residual vegetation and soil and watershed values.

In a pastoral culture, intensification of land use may not necessarily imply cultivation. However, the skills of arable agriculture and intensive ley farming have entered the scene of extensive pastoralism. The pied landscape of crop and ley and fallow now appear in the tussock country as nuclei of future development where for a hundred years there was only the isolated pastoralist's homestead. More significantly, the miles of new fences and bulldozed hillside tracks and firebreaks, the lines and clusters of conifers, and the summer smell of clover betray the presence of a new base to an increasingly productive vegetation.

THE ASSERTION OF EUROPEAN DOMINANCE ON RAIN FOREST LAND

More obvious and more widely known are the changes in the vegetation that have been wrought in the varied lands of forest and swamp of a century ago in higher rainfall New Zealand. The common elements are well known, the felling of forest, the burning to white ash in a hot fire, the sowing of bush-burn grass mixture in the rough seedbed, the fencing of cleared and sown blocks with podocarp post and batten and wire fences, the year-round management of stock on pastures, the continuing fight with axe and slasher and more stock against fern and scrub, whimperings of a scarred and battered forest.

Though the sequential details vary, the broad character of vegetation trend that had occurred in New Zealand on once forested lands for 50 years following European farming settlement can be summarized: rough but productive pasture in the early phase of forest ash fertility, declining sward vigour and pasture quality on all but those soils of inherently high fertility as the ash fertility declined, increasing weed, scrub or rush invasion in open swards on soils of lower inherent fertility, especially where climate or topography conspired against cultivation, drainage and resowing. The advent of fertilizer topdressing, especially the last 25 years of aerial topdressing, has resulted in divergence of trend between different districts and properties. The roots of this divergence are lodged not simply in different soils but in the crannies of New Zealand's social constitution.

As indicated earlier, the original sponsored, Wakefield planned, settlement in New Zealand failed in its design so far as agriculture was concerned. The effective settlement of the open country was carried out by big sheep men who were not envisaged in the early colonists' scheme. The effective settlement of the forested country, especially in the North Island, was carried out by post-Wakefield immigrants, and by young men who learned the adaptive skills of "near-enough" as labourers in the early settlement towns, on the sheep runs, as soldiers in the New Zealand wars, or as miners in the gold rushes of Otago or Westland. These men and women, though come from lowly station, learned to walk upright, to enjoy good, plain food and clothing and independence, to be no respecter of persons. As Governor Gore Brown cited the vulgar saying of the early colony, "every man is not only as good as his neighbour but a great deal better".

New Zealand bush farming began in earnest with this new blend of often case-hardened men. Their special pride was as owner-worker. Their special gift became "the charisma of number eight wire". Apart from their hand tools, flour and seed and the nucleus of their flock or herd, fencing wire was the most significant material they brought from the outside world to make one of the world's most spectacular pastoral cultures out of a rain forest.

These early farmers of bush country with a block of land to clear and farm had no cheap labour but their own. The tradition once established has persisted and New Zealand has seldom if ever suffered the "blessings" of cheap farm labour for hire. Where land attained high pasture vigour and productivity, the farmer could afford the labour to maintain and develop it. Where productivity declined with declining fertility, so did the farmer's ability to maintain his asset against its return to a state of nature.

This fight against the "second growth" of scrub and fern has not always been won. With the introduction of new farming technologies, especially those incorporating the use of aircraft, and with increasing cost brought on by a rising technology and the affluent urban society, the economic forces conspiring against maintaining cleared land on very difficult or marginally productive land have grown and intensified. While the landscape of the better soils has mellowed, the sub-marginal lands have deteriorated with each ill-founded but well-intentioned effort to bring them "back into grass".

For many years such deteriorating lands have been made available for afforestation, especially with conifers, for soil conservation and wood production where economically possible. Forestry has proved so successful that competition for land for exotic forestry and for pastoral farming now exists. Methods of multiple use are being evolved in which both pastoral and silvicultural purposes co-exist in very intensive systems. Where neither farming nor exotic forestry is practised, the trend of vegetation is the return of the native. The exceptions are in the mountain areas where in many circumstances natural revegetation is likely to be ineffectual in securing the physical stability of land itself.

THE FUTURE EVOLUTION OF LANDSCAPE

Cultural and commercial factors could conspire with edaphic, biologic and climatic elements to achieve the evolution of a new landscape in New Zealand. The primitive beauty of the green land that had lain empty consisted essentially in its natural order in natural variety. Future landscape beauty must essentially reside in the order of varied land culture integrated with the residual order of a varied land nature. Presently there are six million hectares of remaining indigenous forest. Approximately the same area of occupied land is in unimproved tussock grassland and related associations. For only about a quarter of these 12 million hectares can be found convincing evidence of ecologic or cultural stability in their present condition. The inefficiencies of modern man as a hunter of feral animals may be more serious in their consequences than the efficiencies of Polynesian man as a hunter of moa. There are nearly three million hectares of land cleared from forest on which pastoral farming has hitherto failed. There are about 10 million hectares on which farming is succeeding. A half million hectares are devoted to exotic forestry. In short, half the land area of New Zealand is occupied by life systems which have either ecological or cultural stability, half by systems which lack both.

Large areas of beech forest and tussock grassland must have watershed protection as their dominant role in the future. To ensure the achievement of this purpose, substantial portions of both indigenous forest and indigenous grassland may be culturally modified and perhaps converted to exotic forests and pastures where protection roles are not dominant. Such measures could release other land from the demands of timber harvesting and grazing to function solely for watershed protection. Healing is needed on protection land and potential production land alike, especially on steep lands in the mountains where pastoral culture has failed.

The simultaneous pursuit of ecologic order, economic stability and visual beauty in the shaping of the New Zealand landscape in the future requires integration of cultural and commercial forces with the variety of climate, soil, vegetation and animals with which New Zealand is or could be endowed. The artistic and ecologic evil of the early European settlers in rain forest was to fail to perceive the order in variety in the apparently hostile bush. Understandable as this was, it was followed by a land-clearing era in which human efforts were largely devoted to eliminating variety and achieving order in the form of productive pastures. One can now appreciate the fortune or discretion of those who contrived to save the crown of forest on a hilltop, the open parkland of kowhai and podocarp, the steep gullies of hardwoods, the shallow depressions of toetoe and flax. One can appreciate these conservings but can understand their cost. Those who have built post and wire fences know the appeal of a straight line where an appreciation of landscape or even of animal behaviour might call for a curve.

Likewise those who have known the winters of Southland and Otago and the need for supplementary crops for animals in those districts can appreciate the landscape sculpture by the plough on the rolling lands of those districts. Yet this sculpture was achieved first in the farmer's consciousness of the economic need for repeated cultivation even in his lifetime. He became a better landscape sculptor than many of his North Island counterparts by necessity not by virtue. Likewise one can understand the economic and managerial practicality of rectilinear *Pinus radiata* monocultures. Even so, the recreational and amenity significance of well planned production forestry, the value of pastoral management to offset the high costs of fire protection, the economic significance of social contentment of forest workers, and the revision of concepts and realities of forest size, scale and compactness, all contribute grounds for hope for variety in exotic forest landscapes. In agriculture itself the fitting of pasture plants to soils, the observation of the value for pastoral enterprises of crops of maize and lucerne in areas traditionally "grass only" are creating new climates of varied thinking from which order can be achieved in varied land use. In such a scene of the future no parcel of land, however large or small, will be considered as being of value only to one purpose and of concern only to one person. The role of design in management and planning will come of age. It is likely that the decisions about what, how, why, when and where is a weed will then require as much careful preliminary research as is now given to the question, how to kill it.

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AGRICULTURAL PRODUCTION IN NEW ZEALAND

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INTRODUCTION

Any prosperity that New Zealand has achieved must be attributed in no small part to the hard work and ingenuity of its people, combined with the tremendous development and output of its agriculture. But whether agricultural policies are complex or simple the basic features of any country's agriculture are determined by soil, topography and climate. New Zealand is a long, narrow, mountainous country with less than 20% of its total area reasonably good agricultural land.

In the broadest terms, nearly a third of the country is workable with machinery, something less than a third is farmable hill country, and about a third is very difficult hill country or quite unsuitable for any form of agricultural production. On the other hand, its well-distributed rainfall, ample sunshine and the absence, over most of the country, of extremes of heat and cold, mean that it is well adapted to livestock farming based on intensive pasture production. Animals can be grazed out of doors throughout the year, with hay and ensilage providing most of the winter supplements, though fodder crops are widely grown in the arable farming districts. However, a system where the farmer is able to a large extent to dispense with the plough, not house his stock in winter, and rarely buy concentrates, makes for low costs and a high level of output per unit of labour. In dairying, where comparisons are most readily made, the New Zealand farmer does not reach the levels of production per cow or per unit area of land that are attained in many countries, but this is considerably more than counter-balanced by the very much higher level of labour productivity.

Most of the land is not naturally very fertile, but its fertility has been built up over the years by heavy applications of phosphatic fertilizers which have initiated a fertility-building cycle. Legumes are an established part of pastures, improving the nitrogen status and stimulating growth. This in turn allows heavier stocking and as the greater part of the pasture nutrients are returned directly to the soil the process of fertility building is accelerated.

It is the 4 million hectares of ploughable land that is most significant; it is this land — less than 20% of New Zealand's total area — that produces all the dairy products, cereals, cash crops, fruit and vegetables, as well as a substantial share of the meat and wool. If there is ever to be any radical redevelopment of resources in New Zealand agriculture, it will have to take place in this class of land. The scope for change on the areas of hill and mountainous country is much more restricted.

Clearly defined lines of demarcation do not exist between one type of farming system and another, so that any system of classification is fairly arbitrary. Furthermore, the process of development has extended the productive capacity of land where the range of uses was once more limited.

Bearing in mind these various qualifications, some broad types of farming can be identified. High country sheep farming is found on the 4 million hectares of hard native grasses in the mountainous areas in the South Island. The productive capacity of this land is low and carrying capacity is also limited by the stock numbers that can be safely carried through the winter. Although this type of farming covers nearly one quarter of the occupied land, and it has sometimes been described in rather glamorous terms, its economic importance is very much less significant, with its main role being the production of most of the country's fine wool.

In the North Island, some 8 million hectares of hill country were cleared of forest last century and sown down in pastures. Sometimes a reasonable sward was maintained but on much of this land there is a very strong tendency for it to revert to the native fern and other indigenous species. With the development of aerial topdressing from 1950 onwards — something which New Zealand pioneered — and helped by more effective subdivision, a significant improvement has been made in the productive capacity of this class of country. More lambs are able to be fattened, and cattle, instead of being used to control fern and rank growth, have become a source of profit. But besides wool, lamb, mutton and beef, this class of land produces the store sheep and lambs that are fattened on the more fertile areas, and the older replacement ewes. These are sold to a farmer on the more fertile land who mates them with lamb sires to produce lamb for the export market.

New Zealand has developed the concept of intensive grassland farming further than anywhere else. On easy ploughable country where fertility is either natural or more often induced by regular topdressing, pastures made up predominantly of ryegrass and clover are established and then seldom ploughed up for many years. On such land, when it is carefully subdivided, 15 or 20 ewes per hectare with supporting beef cattle or one dairy cow to every 0.4 to 0.5 hectares can be carried. Supplementary crops, including specialized pasture strains, may be grown and surplus growth in spring and early summer is conserved as hay or ensilage, the latter being largely confined to dairy farms. In the main dairying districts, good pastures produce the equivalent of 14,000 to 16,000 kg of dry matter a year.

In areas where the rainfall is lower, intensive grassland farming merges into an arable system of management. The main cash crops are wheat, barley, oats, peas and potatoes, and the traditional fodder crops are also grown. A farmer will endeavour to assess the relative profitability of cash crops and livestock products and allocate the share devoted to each in order to maximize his returns. Cash crops, other than peas, are produced for the local market only, production for export being hardly profitable, and this sets limits on the place of such crops in New Zealand farming.

THE IMPORTANCE OF AGRICULTURE TO THE ECONOMY AND THE ROLE OF GOVERNMENT

Some 86% of the total export receipts are derived from agricultural production. The obvious national dependence on this contribution requires no further elaboration. Government policy has been to help farmers improve their efficiency through the provision of research and advisory services, to provide long-term capital to assist farm purchases and farm development, to ensure that the short-term credit is sufficient to meet farmers' seasonal requirements, to provide the necessary transport and communications infra-structure, and to assist exporters generally through trade negotiations and discussion with other governments. Another facet of Government policy has been the enactment of legislation to set up producer marketing bodies and to establish price stabilization schemes, self-balancing over a period and financed from producers' own funds for the major products. Commonsense and the hard lessons of experience have shown that, although support arrangements can cushion the effect of price fluctuations, they cannot for any length of time diverge far from the general trend of overseas market prices. Even if the community were willing to meet the cost of supporting the returns to the farmer for a particular product at levels above those provided by the market, such a policy would not lead to the rational exploitation of our resources and the consequences would be a long-term economic loss.

A CLOSER LOOK AT TYPICAL FARM UNITS

The typical farm unit in all branches of farming remains the family enterprise and, despite the pace of technological change and moves towards larger farms, it is likely to continue.

Dairy Farming

On the more fertile land and where rainfall is over 1100 mm annually, dairy farming usually offers the most profitable form of land use. New Zealand's total herd numbers about 5.5 million dairy cattle that are spread over some 22,000 farms. Approximately 80% of New Zealand's total dairy production comes from the Auckland, South Auckland, Waikato and Taranaki regions, all in the North Island.

In the 1969-70 season, the average dairy factory supplier milked about 90 cows and the typical supplier in the main dairying districts was milking some 120 to 130 cows. This would be done by the individual farmer with perhaps some help during milking time from members of his family. Taking account of present-day costs and prices, a two-man dairy unit, to be an economic proposition, would have to carry at least 150 cows and preferably nearer 200. It must be acknowledged that the high level of productivity on the New Zealand dairy farm has always been attained, to some extent, by a substantial contribution by members of the farmer's family, often more than is socially desirable.

Today's typical farmer is significantly different from that of ten years ago when he was likely to have been making a reasonable living by milking about 60 cows. This rapid change indicates the flexibility that exists within the industry in New Zealand. It is also a reflection of rising costs and reduced prices (at least up until 1970) that encourage farmers to readily adopt new technology, for example, in milking shed design, to achieve these new levels of production. Climatic variations probably have the greatest influence on production, because of the direct influence of climate on grass growth. In the 1965-6 season, average production per cow topped 135 kg of milkfat or approximately 2900 kg of milk per cow. However, in the dry season of 1969-70 production per cow fell below 115 kg of milkfat or 2400 kg of milk per cow.

In recent years there has been an effort on the part of dairy farmers to change from the dominant Jersey breed which has been the traditional dairy animal. This year nearly 60% of semen supplied by Artificial Breeding Centres (who service nearly 50% of the cows in New Zealand) has been of the Friesian breed. There are two major reasons for this change. First, high prices received of recent years for solids-non-fat products has encouraged the dairy farmer to move into the Friesian breed which produces a greater volume of milk and a greater yield of protein and other non-fat products. The second reason is that high prices for beef sold on export markets is reflected in the value of male Friesian calves which are suitable for diversifying into beef production.

The New Zealand dairy farmer has reduced his labour input per unit of output to a point where further savings will be difficult and costly to achieve. The ultimate potential of the present industry can be seen when we look to the achievements of highly efficient managers. Many are now stocked to a level of 2.5 cows per hectare and some have reached levels in excess of 3.8 cows per hectare. At these levels output of milkfat will exceed 450 kg per hectare. Leading managers are also increasing the size of their herds — more than 100 leading dairy farmers now have herds in excess of 300 cows.

Sheep and Beef Cattle Farming

Where rainfall is lower, farmers usually concentrate on specialized lamb and beef production, though there is no clear-cut distinction between the type of land for this type of farming or for dairying.

In sheep farming, the concept of the economic unit is rather more difficult to define as the farm enterprises may obtain revenue from wool, lamb meat and beef, the sale of older breeding stock, and in some districts, cash crops. But with present-day prices for meat and wool, an economic unit should carry at least 1,800 breeding ewes, though this figure is dependent upon the number of cattle that are run. The sheep farmer's labour requirements are more flexible than those of the dairy farmer and the labour required will depend on the system of management adopted, and the topography of the country. Cases can be quoted of one man running a property with 3,000 to 4,000 sheep, but this may be at the expense of good animal husbandry practices. On the other hand, contractors can undertake development and maintenance work and extra men taken on during lambing if they are available.

There are about 60 million sheep in New Zealand, 43 million being breeding ewes. The majority of the 5 million beef cattle herd in New Zealand are farmed in association with sheep; few farms are exclusively running cattle. Some 26,000 farms run more than 500 sheep and of these 21,000 have more than 1000 sheep. Sheep and cattle farming is carried out almost anywhere where grass can be grown for some period of the year — the high mountain areas of the South Island with stocking rates as low as 1 stock unit or ewe equivalent to 2 hectares to areas in the North Island carrying in excess of 20 stock units per hectare. Management systems range from extensive dry sheep for the production of wool to intensive for lamb and beef production. This range of production types makes it difficult to generalize on a typical farm situation.

Because of low income levels in recent years, many sheep farmers have had to reduce maintenance expenditure on their properties to a point barely sufficient to maintain the existing productive capacity of their farms. Government has provided some assistance in the 1971-2 season and favourable meat and wool prices received this year have hopefully gone some way to restoring the situation.

In dry regions or parts of New Zealand subject to droughts but where conditions are suitable, mixed arable farming is carried out, with the farmer earning revenue from lamb, wool, cereals, other cash crops and grass seed. The growing of crops in New Zealand is very much less intensive than that carried out in many other countries.

FUTURE OUTLOOK

The dependence on agriculture, which has been our strength in the past when markets were assured, could well be our "Achille's heel" in the future with recent developments in the European Economic Community and the possible requirements of our future markets.

New Zealand's total export trade has been growing over recent years, largely because of the buoyant demand for meat and dairy produce but the actual terms of trade have been most unsatisfactory. Such a situation would have been disastrous, but the country has been saved by the steady improvement in productivity both on the farm and in the processing plant. Vigorous efforts have been made to diversify exports and to process them to the point where they provide the highest net return. Meat cuts designed to meet the needs of the American supermarket buyer, sophisticated new types of dairy products, easy spreading butter for Western markets, and milk biscuits for countries deficient in protein, indicate the progress that is being made.

The future of our industry will depend on this capacity to rapidly accept and adopt new technology in order that the changing requirements of world markets can be met.

The bulk of New Zealand's overseas earnings and its whole prosperity will continue to depend on the country's farms and on the efficiency and resourcefulness of its farmers for as far as we can see into the future. Though they face many difficulties, there is every confidence that our farmers will be equal to the task.

ACKNOWLEDGEMENT

Th assistance of J. B. Hayes, Agricultural Economist, Wellington, with this paper is gratefully acknowledged.

PASTURE MANAGEMENT FACTORS AFFECTING WEED CONTROL IN GRAZED PASTURES IN NEW ZEALAND

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Summary

Weed problems of extensive and intensive systems of farming in New Zealand are described. The pasture management factors affecting weed control in grazed pastures under intensive farming are discussed in more detail. The interacting factors of grazing management, soil and climate on weeds are examined and it is pointed out that factors that produce productive pastures and techniques that give maximum utilization of these pastures by grazing animals will reduce pasture weeds to a minimum.

Farm management systems in New Zealand can be broadly classified into two main groups — extensive and intensive. Farming is still extensive over most of the remaining tussock or native grasslands of the lower (below 1000 mm per annum) rainfall areas of the South Island and on the more remote and steep hill country formerly under forest in the higher rainfall districts of the North Island. The weed problems of these two classes of country are, however, very different.

The species that invaded the tussock grasslands were those that could resist fire and grazing both by sheep and by the hordes of rabbits that infested the country until recently. Browntop (*Agrostis tenuis*) was a prominent member of this group. Browntop is one of many species that are weeds under more intensive farming but which have become the main source of sheep feed in this class of country. Weeds such as winged thistle (*Carduus tenuiflorus*) have even been described as the "runholders' sheet anchor" (Petrie, 1912) under conditions where the natural cover has been depleted. The impact of the sheep grazier and of rabbits and fire drastically altered the flora of the tussock grasslands of New Zealand, but, apart from a few weed problems such as sweet brier (*Rosa rubiginosa*), positive weed control measures in this class of country are not usually justified on economic grounds.

Different weed problems are found in the higher rainfall steep country previously in forest. After the forests were cut and burnt and pasture seeds sown on the ash, the management practices of extensive farming adopted by the early settlers led to the rapid depletion of the organic matter and mineral nutritive elements of the soil, a loss of the topsoil on much steep country, and gave rise to a massive weed problem. Settlers battled with a host of scrub species, weed grasses, and unpalatable and toxic species such as ragwort (*Senecio jacobaea*) with but little advice and knowledge on how to control these invaders. Periods of depressed prices for agricultural commodities such as the depression years of the 1930s led to the abandonment of large areas of marginal hill country and its reversion to scrub, gorse (*Ulex europaeus*) and, in some cases, forest. Unless and until the stocking pressure is raised above the equivalent of about 8 sheep per hectare, the problem of scrub weed control even today makes the farming of much of this class of country a doubtful economic proposition.

The weed problems of the intensively farmed country have proved more responsive to pasture management practices. New Zealand owes much to pioneer grassland scientists, such as Sir Bruce Levy and Dr Leonard Cockayne, who developed principles of pasture improvement and management which, together with a recognition and definition of the deficiencies of the soils for fertilizer nutrients, led to techniques being developed that put this country in the forefront of grassland farming (Levy, 1923). These pasture management practices, coupled with an increased use of fertilizers, rapidly increased the productivity and competitive ability of the pastures and were a major factor in the control of weeds.

The lesson cannot be too often repeated: namely, that weed control in grazed pastures is primarily a matter of making desirable species grow better. They must then be utilized to the full with maximum stocking pressure and using grazing systems designed to encourage the wanted species and discourage weeds. Herbicides have a place to play in weed control in grazed pastures but it is a very secondary one to the positive steps that must be taken to encourage competitive species.

Sears (1962) showed how grazing pressure fits into New Zealand's system of intensive grassland farming. He said: "[Pasture] species performance is also limited by continuous outdoor grazing: the ryegrass, timothy and white clover stand heavy treading, particularly in winter, much better than cocksfoot, Yorkshire fog, Poa trivialis and red clover. Thus as a result of high soil fertility and the associated heavy stocking, ryegrass and white clover combinations are in general the present upper limit of high-producing New Zealand pastures."

However, there are some classes of weeds that cannot be adequately dealt with by the grazing animal. Such weeds fall into the following categories:

(1) Remnant plants (after a development programme) that are past the stage of control by grazing (*e.g.*, mature gorse bushes).

(2) Toxic and unpalatable plants (such as Cape tulip (*Homeria breyniana*) and ragwort).

(3) Weeds specially adapted to environmental habitats less favourable to pasture species (*e.g.*, sedges).

(4) Weeds taking advantage of breaks in the pasture caused by adverse weather, especially droughts (such as thistles).

(5) Weeds that thrive under high fertility conditions (such as variegated thistle (*Silybum marianum*) and chickweed (*Stellaria media*).

PASTURE MANAGEMENT FACTORS AFFECTING WEED CONTROL IN PASTURES UNDER INTENSIVE FARMING

The two most effective tools for farmers to use in weed control in pastures are grazing stock and fertilizers. In some circumstances, other means such as mowing will also play a part. Some of these factors will be considered under the following headings.

(1) *Intensity of grazing*: Effect of lax grazing; effect of overgrazing; effect of winter poaching.

(2) *Type of grazing animal.*

(3) *Grazing management systems*: "Set-stocking" versus rotational grazing; effects of pasture conservation (hay, silage); selective grazing patterns; conservation of "standing" pasture (for example, "autumn-saved pasture").

(4) *Fertilizers in pasture management.*

(5) *Weed control in newly sown pastures*: Rate of seeding and pasture seed mixtures; method of sowing; grazing management of newly-sown pastures.

(6) *Mechanical means of pasture management.*

(7) *Control of pasture insects.*

(1) Intensity of Grazing

The number of stock per unit area and the time such grazing pressure operates have a profound effect on the production and botanical composition of pastures and the number and type of weeds (Brougham, 1970). Removing animals entirely (in the absence of fire), in the higher rainfall districts of New Zealand, results in a rapid reversion to "secondary" growth and then to forest. Pastures inadequately utilized by stock are prone to invasion by scrub species, bracken and other weeds (Suckling, 1964). Lax grazing for shorter periods often results in patchy grazing with neglected patches becoming invaded by a variety of pasture weed species depending on soil and climate.

Conversely, overgrazing, especially in periods of moisture stress, can open up pastures and give places for annual and biennial weeds to germinate and for weed grasses to gain a foothold (Round-Turner, 1970). Thistles, especially nodding (*Carduus nutans*), Scotch (*Cirsium vulgare*) and winged thistle are typical invaders under these conditions. A "thistle year" often follows a drought year. Bared areas in stock "camps" or on tracks provide spaces for thistles and barley grass (*Hordeum murinum*) to germinate and establish.

Winter poaching or pugging of soils by stock depends in part on the grazing intensity over the periods soils are at or above field capacity (for water). The soil type and its natural or induced drainage are, of course, also important. Poached soils offer suitable conditions for the establishment of weeds like buttercups (*Ranunculus* spp.) and the effects of grazing during winter months are often seen in the weeds that appear the following spring and summer.

(2) Type of Grazing Animal

A sheep-grazed pasture commonly has a different range of weed species from a cattle-grazed pasture. In New Zealand, sheep are widely used to control ragwort and, in fact, in many areas, such as the central pumice country of the North Island, it has been found essential to carry a relatively high ratio of sheep to cattle for this purpose.

Many other examples can be given of weeds that are associated with the type of grazing animal. Horses are selective grazers and weeds commonly flourish in horse padocks. Sheep graze closer than cattle; they are less likely to do serious damage to the turf with their hooves and in sheep-grazed pasture "flatweeds" such as catsear (*Hypochaeris radicata*) are common. Dairy pastures, on the other hand, are normally less closely-grazed and are more prone to damage by poaching. Weeds such as buttercups and chickweed are typical of such swards. Some species such as barley grass and Californian thistle (*Cirsium arvense*) will compete successfully in both cattle and sheep pastures, possibly because they are not readily grazed by either animal.

(3) Grazing Management Systems

Pastures under "rotational grazing" systems will, other things being equal, have fewer weeds than those under "set-stocking" systems. This is probably related to the factor of grazing intensity. High grazing intensities with rotational grazing give less scope for selective grazing and relatively unpalatable weeds may be grazed along with the pasture whereas they are neglected under set-stocking (Sears, 1956; Levy, 1956).

Pasture conservation systems will rapidly change the proportion and species of weeds in pastures. Hay-making in particular may encourage weeds by allowing weeds to mature seed, by opening up the sward, and by depleting mineral fertility by the removal of hay. Weed seeds are often spread around the farm in hay. Silage-making is usually much less harmful in this respect.

Grazing management systems and below-optimum rates of stocking that allow selective grazing by stock will encourage the spread of many weeds, especially those that are relatively unpalatable. These conditions encourage stock "camps" on the tops of ridges, along hedges and around trees. Stock camps are a source of many weed invasions. They are usually of high soil fertility owing to enrichment with dung and urine and are often bared of pasture cover. Barley grass is one of the worst weeds to take advantage of such conditions in New Zealand but other weeds such as variegated thistle also gain ingress to pastures in such places.

Grazing management systems that incorporate the saving of "standing" feed (such as autumn-saved pasture) will encourage some weeds. A common example in New Zealand is the increase in Yorkshire fog (*Holcus lanatus*) that may become serious when a pasture is "saved" too frequently for this purpose.

Each management system develops its own set of weeds. If the weed species are such as to adversely affect pasture and stock production, a change in the method of grazing, or possibly the use of herbicides, is indicated.

(4) Fertilizers in Pasture Management

The best system for weed control and maximum pasture productivity almost always includes fertilizer application to pastures as an essential feature. Most soils in New Zealand are deficient in phosphate for maximum pasture production — some are deficient in potash or sulphur, some need liming, and others trace elements such as molybdenum. Deficiencies of these elements must be corrected if one is to grow a competitive pasture relatively free of weeds. Pastures that can carry stocking rates of above about 8 sheep per hectare or 1½ cattle beasts per hectare normally have little to fear from scrub weeds such as gorse or weeds that infest soils of low to medium fertility. On the other hand, of course, some weeds such as barley grass respond to conditions of high fertility. These are the more important species in New Zealand and the ones that more frequently require herbicides for their control.

(5) Weed Control in Newly-sown Pastures

The pasture seeds mixture sown must contain those species suitable for the soil and climate and be free of weed seeds that are a potential danger for the area in question. Nodding thistle is thought to have been spread throughout New Zealand mainly by seeds sown in impure pasture seeds mixtures. Rates of seeding experiments have shown that very low pasture seeding rates may allow greater weed ingress, but this effect is often short-lived. The method of sowing is not usually an important factor. In drier districts, drilling seed is often necessary to get it satisfactorily established but the inter-drill spaces may in some conditions allow weed ingress (Saxby, 1948). Closely-spaced drills and "sub-surface broadcasting" have been tried but are relatively little used nowadays.

The grazing management of newly-sown pastures is more important. In most areas pastures are grazed soon after establishment to encourage tillering of grasses, to give better conditions for clover growth and to control weeds. Relatively little research has been done in New Zealand with sowing methods incorporating herbicide use before or shortly after pasture seed sowing, and there is a possible field of study here. Such studies should include those of grazing techniques of the newly-sown swards.

(6) Mechanical Means of Pasture Weed Control

The commonest mechanical weed control method in New Zealand pastures is mowing. It is the usual means of rush control. Thistles, especially Californian thistle, are commonly mown but mainly to encourage better pasture utilization rather than to control the weeds. Rotary slashers are used, where the terrain makes their use possible, on a variety of weeds up to quite large scrub (Parker, 1964).

Scrub-cutting (often by hand) and the use of fire have long been the main means of controlling scrub weeds such as manuka (*Leptospermum scoparium*), gorse and broom (*Cytisus scoparius*), but cutting is now largely confined to manuka control. The usual procedure with gorse, for example, is to burn, sow pasture seed on the ash, fertilize, and graze heavily with sheep at an early stage to control the young gorse seedlings before they become unpalatable. The plants that escape elimination by grazing will often be sprayed with 2,4,5-T a year or so later (Moss, 1960).

The success of this method depends very largely on the ability to mob-stock heavy concentrations of sheep on to the area to destroy the germinating gorse seedlings.

(7) Control of Pasture Insects

New Zealand pastures are attacked by a number of soil-inhabiting insects. The worst is the native grass grub (*Costelytra zealandica*), but Australian soldier fly (*Inopus rubriceps*), black beetle (*Heteronychus arator*), and porina (*Wiseana* spp.) are also serious pests.

Damage from grass grubs and other insects may destroy large areas of pasture and open them up for weed ingress. Consequently, in infested areas, weed control is often a matter of insect control, and pasture management techniques (that may or may not include the use of insecticides) are required to reduce the number of insects or the damage they cause. This is especially the case with porina caterpillar. Pasture management control consists of rapidly defoliating pastures by heavy stocking in mid-summer to expose the young caterpillar to desiccation in hot, dry weather.

SUMMARY

Weed control in New Zealand pastures must be considered in relation to the interacting factors of grazing management, soil

and climate. Factors that produce productive pastures, and techniques that give maximum utilization of these pastures by grazing animals with the least damage to the sward, will reduce pasture weeds to a minimum. The relatively few weeds that survive in such an environment are the important ones. Their control may require an alteration in commonly adopted pasture management techniques but only as a last resort should herbicide use be advocated.

The use of unsuitable herbicides and of those chemicals that are destructive to clovers and detrimental to pasture productivity is contrary to the thesis of weed control by the encouragement of desirable pasture species. There are some cases where herbicide use is essential for control of weeds in grazed pastures but even in these instances the benefits of weed control must be weighed against the effect of herbicides on desirable species. More research is needed to define more precisely the circumstances in which herbicide use on grazed pastures is justified in New Zealand.

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WEED CONTROL IN ESTABLISHING PASTURES AND CHEMICAL PASTURE RENOVATION

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INTRODUCTION

Of the 27 million hectares comprising the land area of New Zealand, two-thirds are occupied, and half of the occupied land (8.5 million hectares) supports sown — as distinct from native — pastures.

Pasture renewal arises partly from agronomic factors which influence species composition and productivity, but also from the crop-pasture rotation practised in cropping areas. Grazed "rye-grass/white clover" pastures have traditionally represented the soil-restorative phase in a cropping rotation so it is in cropping regions that most pasture renewal is done.

Because cropping, for various reasons, is carried out on arable land, most pasture renewal is associated with cultivation. Taking the amount of pasture seed sown from the air as a guide to the area of non-arable land, and comparing this with the published area of new pasture sown, it is estimated (N.Z. Dept. of Statistics, 1971) that about 340,000 ha are sown with pasture seed each year, of which about 70% involves conventional cultivation. Like any crop sown into bare soil, pastures encounter competition from weeds.

NATURE OF WEED PROBLEM

Because most pastures renewed by cultivation are preceded by a crop, there is usually an opportunity prior to pasture establishment to control perennial grass weeds. This means that, with the exception of regrowth Californian thistle (*Cirsium arvense*) and docks (*Rumex* spp.) new pastures compete initially with annual and seedling perennial weeds. Levy (1951) reported that one establishing pasture contained the results of the germination of over 100 kg/ha of weed seed.

History will obviously affect the nature of the weed competition confronting an establishing pasture. The extent to which viable weed seeds have been allowed to accumulate in the soil or the weedkilling effects of a possible fallow period prior to seed-sowing no doubt are influencing factors. However, the resources of viable weed seeds in any New Zealand soil are clearly sufficient to provide a significant weed population, given favourable agronomic conditions.

The spectrum of weed species in an establishing pasture varies regionally and is also affected by time of sowing. Most pastures are sown in autumn or spring, the autumn accounting for the great majority. In either case the sown species are exposed to weed competition which is of special importance to a pasture regime so dependent on nitrogen fixation by white clover — a species very susceptible to competition as a seedling.

Means of Weed Control

From the time that cultivation to remove an old pasture is begun, the principal means of preventing or controlling weeds in the new pasture are:

(1) To utilize cultivation as far as possible to destroy perennial weeds.

(2) To take any opportunities offered during the intervening crops to control perennial weeds — *e.g.*, couch (*Agropyron repens*) in potatoes or Californian thistle in peas or small-grain cereals.

(3) Efficient cultivation before sowing the pasture with the object of gaining further control of any surviving perennial weeds and providing a well-structured, consolidated seedbed to promote rapid and uniform establishment of the sown pasture.

(4) The sowing of a seed mixture of appropriate species, acceptable in terms of purity and viability, and capable of providing rapid ground cover. Pasture seed mixtures in New Zealand are inevitably dominated by some strain of ryegrass which, by virtue of its high seedling vigour, is a major factor in providing early competitive ground cover.
The row spacing involved in most seed drills can militate against early ground cover by sown species but drilling has advantages in some situations, too.
Sowing pasture with companion- or cover-crops, usually for reasons other than weed control, was very common prior to World War 2. The practice was subsequently discouraged but has regained popularity on some cropping farms.

(5) Judicious grazing, preferably with a stocking density high enough to permit defoliation over a period of only a few days and to avoid the selective escape of any weed species from the grazing animals. Mowing is also sometimes employed.

(6) The use of selective herbicides which, in New Zealand, means compounds to which young clover plants are tolerant.

USE OF HERBICIDES

Because of the unique place of clover in the New Zealand system of pasture production, the use of herbicides on young pastures dates from the introduction of the phenoxybutyric compounds MCPB and 2,4-DB. The high degree of clover tolerance to these materials is well known (Wain, 1954; Fryer and Evans, 1956) and they could have been expected to find not only ready, but widespread acceptance in this country (Fitzgerald, 1959). In fact, the extent to which MCPB and 2,4-DB are used on pastures generally falls short of what might have been anticipated.

However, apart from the very limited use of benazolin specifically for control of chickweed (*Stellaria media*) MCPB and 2,4-DB remain as the only suitable herbicides for use on young pastures. The question remaining is whether to use a herbicide at all and, if so, should it be MCPB or 2,4-DB?

Weed Species

The spectrum of activity of MCPB and 2,4-DB over weed species influences, not only the choice between the two compounds themselves, but also the decision on whether either one is employed at all. Notable weed species with effective resistance to both phenoxybutyric compounds are chickweed (mainly *Stellaria media*) daisies (mainly *Matricaria, Anthemis* and *Chrysanthemum* spp.), wild turnip (*Brassica campestris*), spurrey (*Spergula arvensis*), rushes (*Juncus* spp.) and ragwort (*Senecio jacobaea*). *Polygonum* species (mainly *P. persicaria, P. lapathifolium, P. convolvulus* and *P. aviculare*) are more susceptible to 2,4-DB than to MCPB but must be treated at a very early stage of growth. Docks (*Rumex* spp.) treated at the seedling stage are well controlled by 2,4-DB while this material also provides a check to spurrey. Where truly resistant weeds are present, grazing by stock is employed, even if circumstances are not otherwise conducive to grazing.

From a survey of opinions of fifteen experienced field workers covering most farming districts, the weed species requiring control in young pastures were listed. Viewing the various districts as predominantly either summer-dry or summer-moist, the most frequently-named weeds over-all were fathen (*Chenopodium album* agg.) and various thistles (the perennial *Cirsium arvense* and the biennial species *Carduus nutans, Cirsium vulgare, Carduus tenuiflorus* and *Carduus pycnocephalus*).

While fathen and thistles were named with about equal frequency from the dry and moist districts, docks, buttercups (*Ranunculus* spp.) and willow weed (*Polygonum persicaria, P. lapathifolium*) are more important in the summer-moist areas. Chickweed is widespread, wild turnip is common in the South Island, while other locally important weeds of young pastures are spurrey, daisies, fumitory (*Fumaria* spp.) cresses (*Coronopus, Lepidium, Thlaspi* and *Barbarea* spp.) storksbill (*Erodium* spp.) *Amaranthus* spp. and shepherd's purse (*Capsella bursa-pastoris*).

TREATMENT EMPLOYED

The proportion of new pastures which are treated with herbicide has not been accurately determined. However, where a herbicide is used on establishing pastures, MCPB is overwhelmingly the material of choice. The only exceptions are where seedling dock or *Polygonum* species are present (2,4-DB used) or the occasional case where benazolin is used specifically for chickweed control. MCPB is regarded as being more reliable in its effect than 2,4-DB, especially on thistles.

There seems little doubt that one reason for the use of what can now be regarded as very high pasture seeding rates in New Zealand is the early competitive characteristics of ryegrass (*Lolium* spp.). High seeding rates give a quick, dense, ground cover which in turn gives a considerable measure of annual weed control. But at the same time, the all-important white clover component, being slow to establish, can suffer serious suppression. The weed-suppressing effects of high rates of ryegrass seed (34 kg/ha) and similar suppression of slow-establishing grasses were shown by Cullen and Meeklah (1959). In the same paper, relatively high yields were reported from the use of much lower ryegrass seeding rates (9 kg/ha) along with an application of phenoxybutyric herbicide.

Various possible reasons can be advanced to explain why more use is not made of MCPB and 2,4-DB. The great majority of New

Zealand pastures are autumn-sown and this has an effect on the problem species arising. The presence of the resistant chickweed could discourage the use of, say, MCPB but, on the other hand, autumn-sown pastures frequently become infested with thistles for which MCPB can be used.

The most likely explanation lies in the critical timing of application in relation to weed growth stage demanded for success with the phenoxybutyric herbicides. This is especially true of biennial thistles which with MCPB should be treated within about four weeks of sowing. What most frequently happens is that the autumn-sown pasture remains untreated until the thistles are more obvious, when the most clover-conscious farmers will still use MCPB, some will use a mixture of MCPB and MCPA, while the remainder will probably wait until the spring and use MCPA with consequent clover damage.

CHANGES IN SPECIES COMPOSITION

High pasture production in New Zealand has traditionally been associated with a ryegrass/white clover sward. Even if pure associations of those species were possible initially, they certainly do not remain pure. Nor does the ingress of volunteer species represent just greater variety in pasture composition; it means as well an increase in species which were not sown — and presumably not wanted — and which are generally regarded as lower-yielding.

A further aspect of importance to New Zealand is the relationship between the grass component and nitrogen-fixing clover. A feature of the changes that occur is not only an increase in volunteer grasses but also, particularly in summer-moist regions, a decrease in clover.

Round-Turner (1970) showed, as a result of a nine-year study, that after four years the proportion of sown species, including white clover, declined in favour of volunteer "weed-type" grasses. Palmer (1970) indicated the wide range of such volunteer species to be found in regularly-fertilized New Zealand pastures.

Restoration of Composition

One way to redress the balance of species composition is to destroy the existing pasture by means of cultivation and to resow either directly to pasture — or, more commonly, to do so after an intervening crop. Apart from the vast amount of soil which must be moved back and forth during a cultivation sequence, soil consolidation is lost, the surface soil is exposed to erosion, and the problem of annual weeds is created.

Alternatively, pasture composition may be changed by the selective use of a herbicide.

CHEMICAL PASTURE RENOVATION

Because reversion of New Zealand pastures is generally associated with an increase in "weed" grasses such as Yorkshire fog (*Holcus lanatus*), sweet vernal (*Anthoxanthum odoratum*), *Bromus mollis, Poa trivialis* and browntop (*Agrostis tenuis*), and a corresponding decrease in the clover component, pasture renovation in New Zealand refers to a technique aimed at reversing these changes.

EARLY WORK

New Zealand interest in the use of herbicides as an aid to pasture improvement dates back many years. Early success resulted from the use of TCA and 2,2-DPA (Leonard, 1956; Maclean, 1956) or mixtures or 2,2-DPA and amitrole (Blackmore, 1961). At that time attention was focused mainly on pastoral areas of low productivity, especially on non-arable hill country.

With the discovery of the bipyridyl compound paraquat, however, the situation changed. The inactivation of paraquat on contact with soil, plus a degree of selectivity towards ryegrass at low rates, were of significance. But mostly, it was its selectivity to clovers which altered the course of research into pasture renovation. Instead of low-producing cloverless swards, pasture with a content of clover — and the soil fertility to support higher production — became the main subject of investigation.

By applying paraquat in autumn to pastures containing an element of white clover but dominated by undesirable grasses, Blackmore was able to introduce ryegrass which, coupled with the release of white clover from competition, resulted in a marked improvement in pasture composition (Blackmore, 1964).

PASTURE MANIPULATION

Quantitative trials reported by Williams (1967) showed that late autumn treatment with paraquat led to lowered production in the first winter, the extent of the depression being related to the rate of paraquat used. However, by early spring treated plots were producing more than untreated, this being paralleled by an increase in the ryegrass/white clover component and a reduction in species such as sweet vernal and Yorkshire fog.

These results stimulated research from which emerged a technique that has been referred to as pasture manipulation. For autumn pasture renovation, the rate of paraquat used has been 0.4 to 0.6 kg/ha and grass seed at least was sown. By changing the time of application to the late spring-early summer, however, it was possible, by the use of only 0.15 kg/ha, to remove or suppress many weed species, bring about a marked increase in clover content, and at the same time allow the recovery in the autumn of existing ryegrass.

Thus at very low cost it was possible to induce a period of clover dominance during summer and to reach the autumn with a rejuvenated and considerably "purified" ryegrass/white clover pasture, even without the sowing of seed.

Nutritive Value to Livestock

Early summer treatment produces a clover sward at a time when lambs are being weaned from their mothers. Several workers (McLean *et al.*, 1965; Johns, 1966; Palmer, 1967) have demonstrated the value of white clover as a feed for young stock. Taylor and Arnst (1968) showed paraquat-induced clover swards to give similar lamb carcass weights to rape (*Brassica napus*) while Williams and Palmer (1969), as well as recording increased growth rates of lambs on paraquat-treated pastures, indicated how pasture manipulation could become an economically important factor in sheep-farm management.

Apart from the obvious advantage of increased salable lamb meat, there is the more far-reaching aspect of the effect of liveweight on the breeding capability of young female sheep (hoggets). It has been officially stated (N.Z. Dept of Agriculture, 1972) that for every 4.5 kg increase in hogget body weight in October (within the range of 32 to 46 kg) a lambing percentage increase of 10% can be expected in each of the first three breeding seasons.

Present Day Situation

The place which chemical pasture renovation is likely to occupy in New Zealand is becoming clearer. Using paraquat as the means to control competition and provide a seedbed, research work was aimed mainly at pastures with an acceptable level of fertility, a potentially-useful clover component, and relatively free of the resistant grass, paspalum (*Paspalum dilatatum*).

As might be expected, experience is allowing these limits to be extended somewhat, although the need for adequate soil fertility remains and really dense paspalum situations are still avoided.

Pasture manipulation is being practised to some extent, usually to produce a summer clover forage crop primarily, but also with the aim of longer-term rejuvenation. It is in the classical pasture renovation field that rapid development is taking place.

Progress in Pasture Renovation

The reasons why pasture renovation is now being taken up more widely than the very simple, low-cost pasture manipulation, are a matter for speculation. A possible explanation is the desire by farmers to take some action which they traditionally associate with pasture renewal — namely, the sowing of seed. They then have the satisfaction of seeing drilled rows of grass seedlings as part of the renovation process.

Bear in mind, too, that two early drawbacks to pasture renovation have been overcome. First, detailed yield and species data have enabled the lowered winter production resulting from late autumn use of high rates of paraquat to be avoided, and, secondly, a suitable drill is now available to sow the seed.

Up to the last year or so, pasture seed used in chemical pasture renovation was sown into the undisturbed soil principally by means of conventional drills, often modified for the purpose. Taylor (1969) described the direct-drilling machinery then available and referred to the development of a specially-designed triple-disc drill. This drill is now a locally-manufactured reality as reported by Logan (Williams *et al.*, 1971) which, in the hands of agricultural contractors, is enabling the seed-sowing phase of the operation to be satisfactorily done.

It will probably come as a surprise to most interested New Zealanders to learn that there are now more triple-disc drills in use in the North Island than in the South Island.

The Future

Not only does New Zealand rely on the fixation of atmospheric nitrogen to promote the vigour of its pastoral system, but it also uses large quantities of phosphatic fertilizer to sustain the clover/grass relationship. Jackman (1969) showed that clover might not compete successfully for phosphate with such grasses as browntop. Bearing in mind the ubiquitous nature of browntop in New Zealand pastures, it could conceivably be a factor in the decline in the clover component of pastures and a consequent loss of productivity. New Zealand's phosphate resources are limited so attention to the release of clover from competition for nutrients is justified — assuming that there is continued reliance on clover as a source of nitrogen.

The increasing availability of suitable seed-sowing machinery is seen as important to the future on arable land. It should allow widespread application of the principle that, given suitable soil fertility, a pasture can be renovated by control of competition and provision of a suitable environment for the establishment of sown species.

On non-arable land, an appreciation of the value of even a brief period when competition from vegetation is under control, plus the protective value of plant litter, should aid pasture improvement there, too.

Work is also proceeding on other grass-killing herbicides with selectivity towards clovers. Grant (1968) showed that asulam was active in controlling Yorkshire fog though with limited selectivity to white clover. Carbetamide (Wasmuth and Miles, 1972) and pronamide (Paxman and Forgie, 1972) are quite selective to white clover and are active on many grass species. The situation regarding the relative tolerance of grass species is not yet clear, nor are the implications of the soil residual life of these compounds where pasture seed is to be introduced. No doubt more will be known about these aspects before long.

CONCLUSION

Pastures established by cultivation suffer competition from annual — and some perennial — weeds. The importance of clover in New Zealand pastures suggests that the phenoxybutyric herbicides could be more widely used on susceptible weed species. The major obstacle to wider use is the belief that these herbicides are lacking in effectiveness — an opinion arising to a large extent from failure to recognize and deal with the weed problem at an early enough stage of growth.

Mature pastures become weedy, too, with the ingress of volunteer grasses being accompanied by a decline in clover. Provided soil fertility is adequate, the grass/clover balance can be restored by use of a herbicide, while a related technique permitting a more comprehensive pasture renewal is becoming increasingly widely practised in New Zealand.

ACKNOWLEDGEMENT

Thanks are due to company colleagues on whose wide field experience references to present-day practices are largely based. Helpful comments from F. C. Allen are also acknowledged with thanks.

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WEED GRASSES IN NEW ZEALAND PASTURES

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Summary

The types of weed grasses found in New Zealand pastures are considered under three main headings — those species harmful to stock, those that become fully dominant on restricted areas, and those widespread invaders of most pasture land. The economic effects of weed grasses and methods of control are discussed.

INTRODUCTION

It is difficult to define a grass weed in the pasture situation because "one man's poison is another man's meat" to mis-quote a common expression. A weed is usually defined as a plant growing where it is not wanted. Though most grasses other than ryegrass are not favoured in productive ryegrass (*Lolium* spp.)/white clover (*Trifolium repens*) swards, and are thus regarded as weeds, they may be the only species that will survive some adverse conditions and therefore become desirable. Over much of the tussock country, which covers a substantial portion of the South Island, browntop (*Agrostis tenuis*) sweet vernal (*Anthoxanthum odoratum*), Yorkshire fog (*Holcus lanatus*) *Poa* spp. and the native *Notodanthonia* spp. are the main "producing" grasses. In some environments, with adequate nutrients, these grasses are as productive as ryegrass. The "weediness" of a grass, therefore, depends largely on the situation in which it is growing.

By far and away the most noticeable weed grasses of New Zealand have been introduced into the country either accidentally or deliberately for ornamental or misguided agricultural reasons. These grasses, such as nassella tussock (*Nassella trichotoma*), barley grass (*Hordeum* spp.) and Kikuyu grass (*Pennisetum clandestinum*) grow far more vigorously in New Zealand than in their native habitats. For instance, in many countries barley grass is an insignificant weed or a useful contributor to pasture production, as in parts of Australia, but over much of New Zealand it is regarded as a most undesirable species.

A grass may be considered a weed if it is displacing a more productive palatable species that could otherwise flourish in that situation, or if it is harmful to stock. Harm may be caused to stock either through physical damage, usually by the seed, or by some toxic component or associated toxic organism.

HARMFUL GRASSES

The most important and widespread of these grasses are the barley grasses, though *Bromus* spp. can also cause trouble. The barley grasses, of Mediterranean origin, are annuals and prolific seeders, the heads shattering into awned spikelets which penetrate sheep's eyes, skin and even flesh. This damage greatly reduces animal thrift as well as causing a downgrading of the animal products such as wool, pelts and carcasses. Such downgrading alone is estimated to cost the industry $½ million annually (Rumball, 1970) and this does not consider the probably substantial loss of animal productivity (Hartley and Atkinson, 1972).

Apart from direct damage to stock. the large seeds of barley grass germinate rapidly with autumn rains and establish before perennial species recover from summer stress, thus suppressing the better grasses. Though young barley grass gives an appreciable amount of palatable herbage for a short period in the autumn, and for this reason is accepted by some people, winter growth is slight and it is avoided by stock in the spring well before seedheads can be detected. When flowering (November-February) the grass becomes quite unpalatable, drastically reducing animal production from the ground it occupies. After seeding, the senescence of the annual plant leaves a space for further seed strike, thus perpetuating the species.

Another grass with similar obnoxious seed characteristics is needle grass (*Stipa variabilis*), an Australian introduction. Though less widespread than barley grass, being found mainly in the South Island areas of Marlborough and Banks Peninsula, the seed can be as harmful to stock as that of barley grass and the plant, being perennial, is more difficult to control.

Grasses such as tall fescue (*Festuca arundinacea*) and Yorkshire fog can harm stock indirectly via fungi. Tall fescue frequently carries the ergot fungus believed to cause footrot in cattle (Honore and Cumberland, 1970; Hilgendorf, 1967) and Yorkshire fog, because of its litter production, encourages *Pithomyces chartarum,* the fungus causing facial eczema (Jacques, 1962).

Kikuyu grass, a vigorous growing, frost-sensitive grass from East Africa, largely confined to warm zones, can cause harm to cattle but its productivity probably overcompensates for its dangers (G. L. B. Cumberland, Departmental reports).

FULLY DOMINANT GRASSES

There are a few introduced grasses that have become so aggressive they displace most other species. Most serious of these is nassella tussock, a South American species introduced in 1930. Twenty years later it occupied 1½ million acres of South Island tussock country to the almost complete exclusion of other species (Wilkie, 1970). Attempts to control this invader have to date cost $10 million in subsidies alone plus equal or greater amounts spent by the farmers themselves. Control measures consist initially of very heavy rates of 2,2-DPA (20 to 40 kg/ha), to kill the mature plants, with follow-up lighter doses (2 to 5 kg/ha), to stop new seedlings, and finally expensive, laborious, hand grubbing.

Two other grasses that have become extremely aggressive but are as yet limited to very small areas are pennisetum macrourum (*Pennisetum macrourum*), centred around Kaikoura in the South Island though found throughout New Zealand, and Manchurian wild rice (*Zizania latifolia*), mainly in Northland. These species, luckily, do not spread as rapidly as nassella but having become established they are almost impossible to control short of suppressing by forest trees or similar shade plants.

PASTURE SUPPRESSANTS

Now consideration must be given to the numerous grasses, generally widespread throughout the country, which invade pastures to the suppression, but not exclusion, of sown species. Accurate information on the frequency, distribution and productivity of most of these grasses is lacking.

In many parts of New Zealand, a ryegrass/white clover pasture is considered the most productive but even among the well-managed medium to high fertility pastures of the North Island pure ryegrass/white clover swards are almost impossible to find, and many have more than 50% other grasses present (Palmer, 1970). In less fertile hill country, ryegrass may occupy as little as 7% of the ground space (Suckling, 1949; Corkill, 1970) or be completely absent.

Common ingress grasses are Yorkshire fog, browntop, sweet vernal, bromus mollis (*Bromus mollis*) and *Poa* spp. Poa species are frequently the first to invade sown swards (Round-Turner, 1970a; Harris and Brougham, 1968) but browntop and Yorkshire fog generally become predominant over considerable areas, especially hill country (Ayson, 1968; Harris and Brougham, 1968; Palmer, 1970).

Ingress of grasses such as browntop and Yorkshire fog usually reduces dry matter production and is associated with a drop in soil fertility (Lynch, 1949; Harris and Brougham, 1968; Williams, 1968). However, it is unknown whether a drop in soil fertility favours weed grasses more than ryegrass or if weed grasses, by the displacement of clover, reduce fertility (Harris and Brougham, 1968). Barley grass invasion, on the other hand, is associated with high fertility conditions (Grant and Ball, 1970; Metson *et al.*, 1971) and as it occupies a niche suited to ryegrass its ingress must reduce productivity.

In the warmer parts of New Zealand paspalum (*Paspalum dilatatum*), a South American species, has become a problem in some situations since by its strong growth habit it displaces other grasses and rapidly becomes tough and unpalatable if not grazed hard. More recently, there are indications that other warm-zone grasses such as crowfoot grass (*Eleusine indica*) and summer grass (*Digitaria sanguinalis*) may become pasture weeds.

CONTROL OF WEED GRASSES

Control of the useless aggressive species such as nassella tussock is obviously essential and drastic, specialized measures are necessary. However, this paper will be confined to considering control of the widespread non-dominant ingress grasses where these are displacing more productive species.

Barley grass, for several reasons, requires individual attention. This species, unlike most weed grasses, comes into pasture under conditions of high fertility suitable to ryegrass. Being an annual with seed viability generally limited to less than a year (Harris, 1959; Rumball, 1971), it should not be difficult to control. However, the spread over the last twenty years shows theory and practice to differ.

Control measures depend on the location of the weed. When it is restricted to shelterbelts, stock yards and sheep camps, the usual nuclei of infestation, eradication measures are possible without serious loss of production and high rates of grass herbicides can be used. However, re-establishment of a vegetation cover is desirable to prevent occupation of the bared ground by new barley grass. When barley grass has spread into the paddock, selective control measures are required if pasture productivity is not to be excessively reduced. TCA and 2,2-DPA have been employed for a number of years and now a proprietary mixture and diester formulation of the two chemicals are showing promise (Moffat and MacDiarmid, 1970; McLean and Dixon, 1972). Good control of barley grass is also given by pronamide and carbetamide but pasture damage can be severe (Atkinson, 1970; Hartley *et al.*, 1972; Hartley and Atkinson, 1972; Wasmuth and Miles, 1972). None of these treatments is as yet satisfactory as a single treatment and more work is needed combining management and herbicide treatment.

Control of the other common ingress grasses is more complex because of their ubiquity and lack of knowledge of their true effects on pasture productivity. They are obviously well suited to prevailing conditions but it is probable that pasture productivity over much of New Zealand would increase if some of these weed grasses were not present.

One solution could lie in better pasture management and more careful control of grazing pressure on a rotational basis since ingress is greatest under continuous grazing (Harris and Brougham, 1968). However, over much of New Zealand's hill country, adequate control of grazing is impracticable and the country's dependence, especially in the North Island, on year-round grazing, with little conservation of feed, inevitably subjects pasture to excessive stress in cold, dry or wet periods and resultant damage allows ingress of weeds. Such damage can be alleviated by increased irrigation while improved drainage reduces pasture damage from pugging and assists in the control of wet land species such as tall fescue.

The use of herbicides to control grass weeds other than barley grass selectively has not been greatly exploited to date. Herbicides have been used for removal of cover prior to re-seeding, the so-called chemical ploughing (Blackmore, 1962, 1965), and to produce clover dominance (Palmer, 1968; Williams, 1968). Differential tolerance of grasses to grass herbicides such as pronamide (Paxman and Forgie, 1972) should offer a means of subtle pasture manipulation and control of some ingress grasses though this approach has not been adequately explored. However, present herbicides are not sufficiently sophisticated to control all grass except ryegrass and leave clover unchecked, if, in fact, ryegrass is the most desirable species.

Maybe more thought should be given to the suggestion by Corkill (1970) that plant breeders should consider improving the productivity of some of these well adapted ingress grasses as has been done with Yorkshire fog at Massey University. In comparable conditions, under mowing, Yorkshire fog (Jacques, 1962; Round-Turner, 1970b) and browntop (Round-Turner, 1970b) can yield as much as ryegrass but palatability is lower and would need improving.

In the writer's opinion control of grass weeds does not lie entirely in the use of herbicides. Herbicides could be very useful as a remedial action to check weed grasses but they cannot be expected to do this without at least temporary loss of production. If a considerable proportion of the sward is killed, even if this proportion is weed grass, some loss in pasture productivity must ensue until better species can re-establish.

Since weed grasses almost invariably invade sown pasture, they will also re-invade "cleaned up" pasture. If herbicides are relied upon, therefore, their use will be repetitive and continually depressive.

The answer may lie in management and for this to succeed New Zealand must decide whether she wants low cost grassland production, in which case weed grasses will persist and may limit productivity, or whether she wants higher productivity and is prepared to meet the cost of "managing" her grasslands.

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THE USE OF HERBICIDES IN ESTABLISHING IMPROVED PASTURES IN NEW CALEDONIA

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Summary

Profuse weed growth often interferes with the establishment of improved pastures. Trials were conducted to study the specific effects of three herbicides (2,4-D; 2,4-DB; dinoseb) at various rates of application and at two stages of growth (1 to 1½ months and 5 months after sowing).

From these trials it would seem that only dinoseb can control weeds without harming the established sward *(Chloris gayana; Setaria sphacelata; Paspalum plicatulum)* and the companion legume, siratro *(Phaseolus atropurpureus)*. Rates of application for this herbicide would seem to be 0.5 to 1 kg a.i./ha on a young pasture and 1 to 1.5 kg a.i./ha on pastures over 6 months old.

INTRODUCTION

Pasture improvement, which is necessary in New Caledonia to increase the grazing stock, consists of a series of techniques. Often, because of the nature of the original vegetation, but mostly because of unsuitable agricultural practices (late sowing, bad quality seeds, inadequate working of the soil), profuse weed growth can do a great deal of harm to young pastures. Moreover, weeds grow much faster during the winter when the growth of the established sward is slowed down.

As pastures usually contain two or three grasses and one or two legumes, an attempt has been made to select herbicides which, whilst keeping weeds under control as much as possible, do not interfere with the establishment of the grasses and legumes, especially the latter.

METHODS AND EQUIPMENT

Description of the Flora

Grasses and Legumes

The trial carried out at Nakutakoin, in the Dumbea area, was begun on 3 February 1971, after ploughing unimproved land and sowing the following mixed seeds:

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Grasses:

Paspalum plicatulum (3 kg/ha)
Chloris gayana (3 kg/ha)
Setaria sphacelata (3 kg/ha)

Legume:

Siratro (*Phaseolus atropurpureus*) (4 kg/ha)

The seeds were sown in rows with a spacing of approximately 30 cm.

Weeds

The number of crosses after each species indicates the relative profuseness of the plants.

Dicotyledons:

Sida acuta	+ +
Sida rhombifolia	+
Triumfetta rhomboidea	+
Ageratum conyzoides	+ + +
Bidens pilosa	+ +
Bidens bipinnata	+
Spilanthes acmella	+ +

Grasses and Cyperaceae:

Brachiaria reptans	+
Cenchrus echinatus	+
Digitaria adscendens	+
Eleusine indica	+
Panicum aff. *coloratum*	
Paspalum dilatatum	
Paspalum paniculatum	
Rhychelytrum repens	
Cyperus aff. *rotundus*	+ +
Kyllinga melanosperma	+ +

It will be noted that, with grasses and Cyperaceae, only *Cyperus* aff. *rotundus* and *Kyllinga melanosperma* can be a problem. It is not intended to deal with control of these weeds in this paper.

But amongst the dicotyledons, profuse growth of *Sida acuta; Ageratum conyzoides; Bidens pilosa* and *Spilanthes acmella* causes considerable concern.

Herbicides Tested

Three herbicides were used because of their selectiveness
P1 — 2,4-D amine salt at the rate of 550 g/litre
P2 — 2,4-DB potassium salts at the rate of 400 g/litre
P3 — dinoseb amine salt 20 at the rate of 200 g/litre

Experimental Design

Herbicides

Each herbicide was used at four rates of application (a.i. per hectare):

P1 —	C0	Control — no treatment
	C1	0.550 kg
	C2	0.960 kg
	C3	1.375 kg
P2 —	C0	Control
	C1	0.400 kg
	C2	0.800 kg
	C3	1.200 kg
P3 —	C0	Control
	C1	0.500 kg
	C2	1.000 kg
	C3	1.500 kg

Stages of Growth on Application

There were two applications for each product and each rate. The first (S1) was applied on 9 March 1971 for products P1 and P3 and product P2 was applied on 16 March 1971, in other words, between 1 and 1½ months after sowing.

The second (S2) was applied on 30 June 1971 on different plots of S1, or 5 months after sowing. A change was made in the concentration of the products at application S2 following observations made after application S1:

P1 —	C1	0.200 kg
	C2	0.400 kg
	C3	0.800 kg
P2 —	C1	1.000 kg
	C2	1.500 kg
	C3	2.000 kg
P3 —	No change	

Experimental Design

The trial was conducted on two blocks for each combination (different rates for each product). Each block had 12 plots. Each plot had an area of 8.75 m² of which 7 m² were treated.

Within each block, products P1, P2 and P3 were applied at random. For each of them, applications corresponding to each rate C0, C1, C2, C3 were also randomized. The application was made with a sustained pressure hand-sprayer with a quantity of water of 0.500 l per plot (approximately 700 l/ha).

Method of Checking the Effect of Herbicides

For each plot a surface count was made, average height was measured, and the volume of each species estimated. These checks were made on 5 to 18 May for applications at stage S1 and from 27 July to 6 August for applications at stage S2.

RESULTS

Applications at Stage S1

Results of applications at stage S1 are given in Table 1.

TABLE 1: VOLUME OF VEGETATION IN % OF VOLUME OF CONTROL (C0) FOR EACH PRODUCT AND EACH RATE
(Average of the 2 blocks)

	C0	*C1*	*C2*	*C3*
P1 — 2,4-D:				
Active ingredient kg/ha	0.0	0.550	0.960	1.375
Total volume of vegetation % C0	100	96.5	73.0	57.0
Volume siratro % C0	100	28.5	0.0	0.7
Volume weeds % C0	100	18.0	11.5	11.5
P2 — 2,4-DB:				
Active ingredient kg/ha	0.0	0.400	0.800	1.200
Total volume of vegetation % C0	100	103.0	86.0	92.0
Volume siratro % C0	100	12.0	10.6	13.0
Volume weeds % C0	100	130.5	53.5	54.5
P3 — dinoseb:				
Active ingredient kg/ha	0.0	0.500	1.000	1.500
Total volume of vegetation % C0	100	106.5	84.0	68.0
Volume siratro % C0	100	61.5	75.0	19.5
Volume weeds % C0	100	9.5	7.5	2.0

The effect of the three herbicides varies considerably two months after application.

Effect of 2,4-D

The effect of 2,4-D on the total vegetation is highly destructive as the concentrations increase. On the legume siratro, 2,4-D is too strong and kills it when used at high rates. A low rate (0.550 kg) seems sufficient to control the weeds.

Effect of 2,4-DB

2,4-DB has hardly any effect on the total vegetation even at high rates. A significant regression is obtained at the three rates on siratro. Its effect is inadequate on weeds, even at high rates.

Effect of Dinoseb

Dinoseb begins to be effective on the total vegetation at the high rate of application (1.5 kg). It is only really effective on siratro at the higher rate of application. At the low and medium rates of application (0.5 to 1 kg) enough siratro remains. It is highly effective on weeds at low and medium rates of application.

Applications at Stage S2

Results of applications at stage S2 are given in Table 2.

TABLE 2: VOLUME OF VEGETATION IN % OF VOLUME OF CONTROL (C0) FOR EACH PRODUCT AND EACH RATE
(Average of the 2 blocks)

	C0	*C1*	*C2*	*C3*
P1 — 2,4-D:				
Active ingredient kg/ha	0.0	0.200	0.400	0.800
Total volume of vegetation % C0	100	68.7	77.0	70.4
Volume siratro % C0	100	58.7	65.0	72.2
Volume weeds % C0	100	35.6	60.4	66.7
P2 — 2,4-DB:				
Active ingredient kg/ha	0.0	1.000	1.500	2.000
Total volume of vegetation % C0	100	86.0	81.4	87.7
Volume siratro % C0	100	10.6	24.8	14.6
Volume weeds % C0	100	72.0	39.9	38.4
P3 — dinoseb:				
Active ingredient kg/ha	0.0	0.500	1.000	1.500
Total volume of vegetation % C0	100	99.7	70.4	89.6
Volume siratro % C0	100	132.5	89.1	78.3
Volume weeds % C0	100	95.1	25.8	13.7

Effect of 2,4-D

2,4-D is quite destructive on the total vegetation even at low rates of application. It is less destructive for siratro than at stage 1 and therefore does little harm in view of the aggressiveness of that plant. It is quite inadequate on weeds.

Effect of 2,4-DB

2,4-DB has little effect on the total vegetation. It is quite effective against weeds at high rates (1.5 to 2 kg).

Effect of Dinoseb

Dinoseb has little effect on the total vegetation. The effect on siratro is negligible. Only a high rate of application (1.5 kg) will control weeds.

GENERAL CONCLUSIONS

Since the aim is to establish an improved pasture consisting of grasses and legumes, only dinoseb seems suitable.

2,4-D is too destructive at both stage 1 and stage 2. Its destructive effect on siratro at stage 1 is too strong. On pastures established more than 6 months and where there are weed problems, 2,4-D could be used at the low rate of application (0.2 to 0.5 kg).

2,4-DB is not too destructive on the total vegetation but it is too strong for siratro. Its effect on weeds is inadequate.

Dinoseb is very suitable for weed control without damaging siratro significantly. The rates of application should be 0.5 to 1 kg on a young pasture (stage S1) and 1 to 1.5 kg when the pasture is well established (S2).

ACKNOWLEDGEMENTS

The author extends his sincere thanks to: Amalgamated Chemical (Aust.) Pty Ltd and Imperial Chemical Industries of Australia and New Zealand Ltd which provided the herbicides used in the trials, free of charge.

EFFECT OF HERBICIDES ON IMPROVED TROPICAL PASTURE LEGUMES AND GRASSES[1]

D. F. NICHOLLS, D. L. PLUCKNETT and L. C. BURRILL[2]

Summary

Response of seedling pasture species to pre-emergence and post-emergence herbicide applications was studied in Hawaii. Eight pre-emergence herbicides were applied at two rates to 10 legume species and 2 grass species established from seed, and 13 post-emergence herbicides were applied at two rates to 10 legume species and 2 grass species established from seed and to 2 grass species established vegetatively. Results obtained can serve as a preliminary guide to susceptibility or tolerance of tropical and temperate pasture and forage species to herbicides.

INTRODUCTION

With advances in techniques of land development from scrub-infested areas to highly-productive pastures, more must be known about the effect of herbicides used to defoliate, desiccate or kill weedy species on the pasture species to be introduced.

In pasture renovation, selective herbicides are often used to retard pasture grasses in order that legume seedlings can become established (Murtagh, 1972). Where weedy species such as Hawaiian elephantsfoot (*Elephantopus mollis*), lantana (*Lantana camara*), guava (*Psidium guajava*), melastoma (*Melastoma malabathricum*), Java plum (*Syzygium cumini*), and Brazil peppertree (*Schinus terebinthifolius*) have naturally invaded the pasture owing to poor management, it is necessary to know what herbicides to use and at what rates, avoiding significant damage to the pasture species. Little work has been done to study herbicide effects on tropical legumes. Bailey (1970) presented some responses by tropical legumes to pasture herbicides. Wood (1970) and Fisher and Ive (1970) published weed control results in Townsville stylo (*Stylosanthes humilis*).

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[1] Jour. Series No. *1572* of the Hawaii Agric. Exp. Sta. This research was supported by a grant from the Intern. Plant Protection Center, Oregon State Univ., for a co-operative herbicides research programme in tropical pastures and crops with the College of Tropical Agriculture, University of Hawaii, Honolulu, Hawaii 96822, U.S.A.

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Another important application of the need for such legume-herbicide indexing is in the production of legume seeds, especially in tropical species where seed costs are high. This calls for maintenance of a pure legume stand to allow maximum seed yield as well as high quality seed, free of weed seeds. If adequate long-term weed control is not obtained at or soon after planting, it is necessary to know exactly the effects of selective herbicides or combination of herbicides used on the legume at such sensitive physiological stages as early post-emergence and floral initiation.

MATERIALS AND METHODS

Thirteen tropical legumes, 5 temperate legumes and 4 tropical grasses were planted in May, 1970 at the Kauai Branch Experiment Station on a Halii gravelly, silty clay (Gibbsihumox) with a pH of 5.7. The area was fairly heavily infested with a variety of broadleaf and grassy weeds, including common purslane (*Portulaca oleracea*), hairy beggarticks (*Bidens pilosa*), goosegrass (*Eleusine indica*), Bermuda grass (*Cynodon dactylon*), purple nutsedge (*Cyperus rotundus*), fingergrasses (*Chloris* spp.), seashore vervain (*Verbena littoralis*), buttonweed (*Borreria laevis*) and garden spurge (*Euphorbia hirta*).

Two of the grass species in the trial — pangolagrass (*Digitaria decumbens*) and Kikuyu grass (*Pennisetum clandestinum*) — were planted as vegetative cuttings after the pre-emergence treatments were applied. The other species were intortum (*Desmodium intortum*); stylo (*Stylosanthes guyanensis*); siratro (*Phaseolus atropurpureus*); glycine (*Glycine wightii* syn. = *javanica*) — Tinaroo, Clarence and Cooper cultivars; calopo (*Calopogonium mucunoides*); puero (*Pueraria phaseoloides*); lotononis (*Lotononis bainesii*); centro (*Centrosema pubescens*) — Baker cultivar; kaimi clover (*Desmodium canum*); koa haole (*Leucaena leucocephala*); lucerne (alfalfa) (*Medicago sativa*); white clover (*Trifolium repens*); red clover (*Trifolium pratense*); green panic (*Panicum maximum* var. *trichoglume*); and buffelgrass (*Cenchrus ciliaris*).

The experimental area was disced three times and a fine, firm seedbed was prepared. The equivalent of 160 kg of treble superphosphate per hectare and 120 kg of urea per hectare were applied and turned in with the final discing. Seeds were planted with 4 "Planet Junior" drill seeders rear-hitched to the tractor. Planting rows were 55 m long and 25 cm apart.

The herbicides used with rates and times of application appear in Tables 1 and 2. The chemical sprays and granular materials were applied in 0.9 m strips at right-angles to the planting rows. The pre-emergence sprays and granular materials were applied immediately after planting, and the post-emergence treatments were applied 9 weeks after planting.

Subjective rating of injury to species using a scale of 1 to 10 was recorded 4 weeks after application of both the pre-emergence and post-emergence treatments. Injury ratings were as follows: 1 = none, 3 = slight, 5 = moderate, 7 = serious, 9 = severe, 10 = complete control or dead.

RESULTS AND DISCUSSION

Tables 1 and 2 present post- and pre-emergence ratings for the herbicides. For clarity individual herbicide effects will be discussed separately.

SIMAZINE

At 1.12 kg/ha pre-emergence, simazine was lethal to all legumes except siratro, calopo, centro, kaimi clover and koa haole; however, it showed no effect on the two sown grasses, green panic and buffel. At the higher rate of 3.36 kg/ha, simazine killed green panic and buffelgrass but had little toxic effect on emergence and establishment of calopo, kaimi clover and koa haole.

As a post-emergence application, both levels of simazine provided excellent weed control and at the same time were less toxic to crops than when applied pre-emergence. Intortum, lotononis, kaimi clover, koa haole, lucerne, red clover and white clover as well as green panic, pangola, buffel and Kikuyu grasses were fully tolerant to 1.12 kg/ha. Actually, at this lower level there was no lethal effect on any of the species, stylo and the three glycine cultivars being most sensitive. Symptoms were marginal leaf chlorosis and shoot curvature. At the 3.36 kg/ha rate, siratro, all glycine cultivars, calopo, puero, lucerne, red clover and white clover were more sensitive but were not killed. Once again all four grasses were highly tolerant of simazine toxicity. Because of excellent broadleaf weed control, simazine, especially at rates higher than 3.36 kg/ha, could be used post-emergence to maintain pure grass stands, but could not be used in the introduction of legumes into a grass-dominant sward.

TABLE 1: RESPONSES OF LEGUMES AND GRASSES TO PRE-EMERGENCE HERBICIDE TREATMENTS

Subjective ratings of plant responses to herbicides were as follows: 1 = none, 3 = slight, 5 = moderate, 7 = serious, 9 = severe, 10 = complete control or dead.

Herbicides were applied in the following formulations: wettable powders - simazine, linuron, chlorthal, karbutilate, bromacil, and atrazine; emulsifiable concentrates - alachlor; granule - picloram (10% G).

	picloram		*chlorthal*		*atrazine*		*simazine*		*linuron*		*alachlor*		*bromacil*		*karbutilate*	
	Rate Applied (kg/ha)															
Species	*1.12*	*3.36*	*4.48*	*8.96*	*1.12*	*4.48*	*1.12*	*3.36*	*1.12*	*2.24*	*2.24*	*4.48*	*1.12*	*3.36*	*3.36*	*5.6*
Stylosanthes guyanensis	4	5	1	4	10	10	10	10	9	10	4	4	10	10	1	10
Desmodium intortum	5	10	8	9	10	10	10	10	10	10	9	9	10	10	5	10
Phaseolus atropurpureus	5	5	1	1	10	10	1	10	1	1	1	1	10	10	1	10
Glycine wightii (i)*	1	8	1	1	10	10	10	10	1	10	1	1	10	10	1	10
Glycine wightii (ii)	1	8	1	1	10	10	10	10	1	10	1	1	10	10	1	10
Glycine wightii (iii)	1	1	1	1	10	10	10	10	1	8	1	1	10	10	7	10
Calopogonium mucunoides	1	8	1	1	8	10	1	1	1	9	1	1	6	3	1	2
Pueraria phaseoloides	1	8	1	1	7	10	10	10	1	9	1	1	9	8	1	1
Lotononis bainesii	—	—	1	1	—	—	10	10	1	1	1	1	—	—	—	—
Centrosema pubescens	10	10	1	1	10	10	1	10	1	1	1	1	1	1	—	1
Desmodium canum	10	10	1	1	9	9	1	2	1	1	1	1	10	10	7	8
Leucaena leucocephala	1	1	1	1	1	1	1	1	1	1	1	1	—	—	1	1
Medicago sativa	10	10	1	1	10	10	10	10	10	10	4	10	10	10	10	10
Panicum maximum	1	1	10	10	1	10	1	10	1	1	10	10	10	10	10	10
Cenchrus ciliaris	1	1	10	10	1	10	1	10	1	1	10	10	10	10	10	10

**Glycine wightii* (i) = variety 'Clarence'; *Glycine wightii* (ii) = variety 'Cooper'; *Glycine wightii* (iii) = variety 'Tinaroo'.

ATRAZINE

As a pre-emergence treatment at 1.12 kg/ha, atrazine was highly phytotoxic to all the legumes except koa haole, whereas green panic and buffel were tolerant. At the higher level (4.48 kg/ha) even the grasses were significantly affected, but koa haole was tolerant. As a post-emergence treatment only centro, kaimi clover, koa haole, lucerne, green panic, pangola and buffel grasses showed tolerance to 1.12 kg/ha, whereas the only legume tolerant to 4.48 kg/ha was koa haole. Green panic, pangola and buffel grasses were still tolerant at the higher rates of the chemical.

As with karbutilate, atrazine could be used in the establishment of koa haole into existing grass swards; however, atrazine had less effect on grasses such as green panic and pangola, whereas at higher rates of karbutilate these grasses were very sensitive.

LINURON

At 1.12 kg/ha pre-emergence, the only species killed by linuron were stylo, intortum and lucerne, whereas at 2.24 kg/ha the only species showing tolerance were siratro, lotononis, centro, kaimi clover and koa haole and green panic and buffel grass. Linuron provided excellent pre-emergence broadleaf weed control, but grasses were highly tolerant.

As a post-emergence application, linuron was fairly toxic on all species at both levels. The only tolerant species were lotononis and koa haole at 1.12 kg/ha and all of the grasses except Kikuyu grass, which was slightly burned at 1.12 kg and killed at 2.24 kg/ha. This result indicates that linuron is far too severe at these rates for post-emergence use in pasture renovation other than to control broadleaf weeds in a grass-dominant stand. However, at lower rates (*e.g.*, 0.56 kg/ha) the effect on the legumes could be sufficiently low to allow its use in the introduction of legumes into a Kikuyu grass sward.

ALACHLOR

As alachlor is primarily a pre-emergence chemical for the control of grasses, one could expect to see lethal effects on green panic and buffel grasses even at a low rate of 2.24 kg/ha. However, among the legumes, intortum showed a lack of tolerance to alachlor at the lowest pre-emergence rate. At 4.48 kg/ha there was considerable dwarfing of intortum and lucerne and complete prevention of emergence of green panic and buffel grasses.

TABLE 2: RESPONSES OF LEGUMES AND GRASSES TO POST-EMERGENCE HERBICIDE TREATMENTS

Subjective ratings of plant responses to herbicides were as follows: 1 = none, 3 = slight, 5 = moderate, 7 = serious, 9 = severe, 10 = complete control or dead.

Herbicides were applied in the following formulations: wettable powders - simazine, 2,2-DPA, linuron, chlorthal, karbutilate, bromacil, and atrazine; emulsifiable concentrates - 2,4-D amine, dicamba, fenoprop, and 2,4-DB; granule-picloram (10% G).

	2,4-D		*2,4-DB*		*fenoprop*		*dicamba*		*picloram*		*2,2-DPA*		*chlorthal*		*atrazine*		*simazine*		*linuron*		*alachlor*		*karbutilate*		*bromacil*	
	Rate Applied (kg/ha)																									
Species	*0.56*	*1.12*	*1.12*	*7.74*	*1.12*	*4.48*	*0.56*	*1.12*	*1.12*	*3.36*	*5.6*	*11.2*	*4.48*	*8.96*	*1.12*	*4.48*	*1.12*	*3.36*	*1.12*	*2.24*	*2.24*	*4.48*	*2.24*	*5.6*	*1.12*	*3.36*
Stylosanthes guyanensis	1	1	1	1	2	10	3	8	1	7	6	7	1	1	9	10	4	5	6	8	1	1	4	10	9	10
Desmodium intortum	1	2	1	1	2	8	2	8	2	8	8	8	1	1	9	10	1	1	6	10	1	1	8	10	8	10
Phaseolus atropurpureus	1	1	1	1	5	10	2	10	2	7	4	6	1	1	8	10	3	7	8	10	1	1	4	10	10	10
*Glycine wightii (i)**	2	10	5	5	2	10	10	10	3	7	4	6	1	1	8	10	2	7	7	8	1	1	6	10	8	10
Glycine wightii (ii)	2	8	2	2	2	10	10	10	2	8	4	4	1	1	8	10	2	7	7	10	1	1	4	10	8	10
Glycine wightii (iii)	2	8	2	2	2	10	10	10	2	7	4	7	1	1	8	10	4	7	7	10	1	1	4	10	7	10
Calopogonium mucunoides	1	2	2	2	2	10	8	10	1	8	5	6	1	1	9	10	3	10	8	10	1	1	1	10	10	10
Pueraria phaseoloides	1	2	2	3	2	10	8	10	1	4	4	4	1	1	10	10	3	10	8	10	1	1	1	10	10	10
Lotononis bainesii	1	1	1	1	10	10	2	2	7	9	4	4	1	1	7	10	1	4	1	10	1	1	1	10	5	10
Centrosema pubescens	1	2	1	1	10	10	2	10	4	5	7	7	1	1	3	10	3	6	4	10	1	1	6	10	6	10

Desmodium canum	1	1	1	1	1	1	10	10	1	1	4	5	1	1	1	8	1	3	4	10	1	1	8	10	10	10
Leucaena leucocephala	1	1	1	1	1	8	1	9	1	8	1	1	1	1	1	4	1	1	1	6	1	1	1	1	10	10
Medicago sativa	8	10	4	4	7	10	10	10	6	8	3	4	1	1	3	8	2	8	6	8	1	1	8	8	4	5
Trifolium repens	1	1	1	1	10	10	10	10	1	5	2	6	1	1	1	10	1	8	8	10	1	1	1	10	1	10
Trifolium pratense	1	1	1	1	10	10	10	10	3	5	3	6	1	1	9	10	1	8	8	10	1	1	1	6	1	10
Panicum maximum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	10	1	10
Digitaria decumbens	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	10	1	10
Cenchrus ciliaris	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	8
Pennisetum clandestinum	1	1	1	1	1	1	1	1	1	1	1	10	1	1	7	8	1	1	5	10	1	1	1	10	4	10

**Glycine wightii* (i) = variety 'Clarence'; *Glycine wightii* (ii) = variety 'Cooper'; *Glycine wightii* (iii) = variety 'Tinaroo'.

As a post-emergence treatment, however, all species, both legumes and grasses, were unaffected at either the 2.24 or 4.48 kg/ha rates. Alachlor, therefore, could be used to maintain a pure legume stand for seed production, except perhaps for intortum and alfalfa.

Chlorthal

As a pre-emergence application, chlorthal had similar effects to those of alachlor. Intortum was the only legume which showed any significant sensitivity at the 4.48 and 8.96 kg/ha rates, and all of the grasses were killed. Intortum showed severe burning symptoms at emergence, with considerable dwarfing of the seedling.

As a post-emergence treatment, neither legumes nor grasses were affected by chlorthal and weed control was poor.

2,2-DPA

As a post-emergence spray at rates of 5.6 and 11.2 kg/ha, 2.2-DPA was severe on intortum, centro and stylo at the lower rate, but at the higher rate siratro, calopo, Clarence glycine, Tinaroo glycine, red clover and white clover were susceptible (over 6 on the rating scale).

None of the grasses showed any sensitivity to 2,2-DPA at either rate, except Kikuyu grass which was killed by 11.2 kg/ha.

Karbutilate

At 2.24 kg/ha pre-emergence, karbutilate significantly affected Tinaroo glycine, kaimi clover, lucerne, green panic and buffel grasses. However, at 5.6 kg/ha the only tolerant legumes were calopo, puero, centro and koa haole. Karbutilate showed very severe effects on grasses, allowing no emergence at all.

As a post-emergence treatment, the most sensitive legumes to the 2.24 kg/ha rate were intortum, Clarence glycine, centro, lucerne and kaimi clover. The general symptoms were severe chlorosis, burning and shoot curvature. There was no effect on any of the grasses at 2.24 kg/ha; at 5.6 kg/ha buffel grass was completely tolerant but green panic, pangola and Kikuyu grass were severely injured. All legumes except koa haole were sensitive to levels of karbutilate higher than 2.24 kg/ha. Koa haole is an extremely difficult legume to establish in a pasture, even if the grass component is weak. With its tolerance to karbutilate, the establishment of koa haole could be facilitated by using this chemical to hold back grasses and broadleaf weeds.

Bromacil

Applied as a pre-emergence spray, bromacil showed fairly severe toxicity on legumes even at 1.12 kg/ha. Only calopo was tolerant at this lower level; all other species including green panic and buffel grasses failed to emerge. Even at 3.36 kg/ha calopo and centro exhibited fair tolerance to bromacil.

As a post-emergence treatment, bromacil was lethal to most species, even at 1.12 kg/ha. Legumes showing significant tolerance at 1.12 kg/ha were lotononis, centro and lucerne. However, at 3.36 kg/ha only lucerne showed significant tolerance. Lucerne appeared to be extremely sensitive to all other chemicals and its unique tolerance to bromacil, even at high rates, could be important in the maintenance of weed-free, pure stands of lucerne hay crops. However, there are other herbicides such as simazine, diuron, and chlorpropham for use in established lucerne which are probably safer and have shorter persistence in the soil. All of the grasses were killed at 3.36 kg/ha, but only Kikuyu grass showed any sensitivity at 1.12 kg/ha.

Picloram

As a pre-emergence granular treatment, picloram significantly affected only centro, kaimi clover and lucerne at 1.12 kg/ha, but at 3.36 kg/ha the only species to show significant tolerance were stylo, siratro, Tinaroo glycine, koa haole and green panic and buffel grasses.

Effects were not as severe when picloram was applied post-emergence. At 1.12 kg/ha, only lotononis showed severe leaf curvature and death, whereas at 3.36 kg/ha all species except puero, centro, kaimi clover, red clover and white clover and all four grass species showed significant sensitivity to the chemical.

The long-term effect of such slow-release granular materials must be evaluated more fully before specifying their effects on species.

2,4-D

Lucerne was the only species affected significantly at the 0.56 kg/ha post-emergence rate of 2,4-D. Glycine showed slight marginal leaf burning. The 1.12 kg/ha rate was lethal to all three glycine cultivars as well as to lucerne. Species that showed no sensitivity to even the highest rate of 2,4-D were stylo, intortum, lotononis, kaimi clover, koa haole, red clover, white clover and the four grasses — pangola, green panic, buffel and Kikuyu.

Dicamba

Even at the low post-emergence rate of 0.56 kg/ha, dicamba was severe on most legumes. Those showing most tolerance at this lower rate were stylo, intortum, siratro, lotononis, centro and koa haole. However, at the higher 1.12 kg rate, only lotononis showed any tolerance.

The grasses were unaffected by even the highest rate of the chemical, which is expected as dicamba is generally more effective against broadleaf species.

Fenoprop

As a post-emergence treatment fenoprop was not as toxic on most legume species as dicamba, and the selectivity of the two chemicals showed some interesting differences.

For the low rate of fenoprop (1.12 kg/ha), stylo, intortum, the 3 glycine cultivars, calopo, puero and kaimi clover were tolerant (compared with the susceptibility of the glycines, calopo, puero and kaimi clover to 0.56 kg/ha dicamba). Lotononis and centro were sensitive to fenoprop but not to dicamba. Actually, at the low rate of fenoprop, only lotononis, centro and the clovers were susceptible. The high rate of fenoprop (4.48 kg/ha) was lethal to all species except kaimi clover and the grasses.

These results have an important application in the control of *Elephantopus mollis* which appears throughout Hawaii in most Kikuyu grass/kaimi clover pastures. It has been shown (Nicholls and Plucknett, 1972) that best control of this broadleaf weed was obtained by mowing the stand and spraying with a mixture of 2.24 kg/ha of 2,4-D and 1.12 kg/ha of either 2,4,5-T, dicamba or fenoprop. However, from both of these trials it was evident that dicamba was too toxic on kaimi clover, whereas fenoprop and 2,4,5-T were not.

2,4-DB

As a post-emergence treatment applied 9 weeks after emergence when the plants were well established and vigorous, 2,4-DB showed very weak effects on all species at both 1.12 and

2.24 kg/ha rates. Perhaps the most sensitive species were Clarence glycine and lucerne; the main symptom was burning of the entire leaf. Even this damage appeared to be insufficient to affect the life of the plants.

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SIDA SPECIES: SIGNIFICANCE IN TOWNSVILLE STYLO PASTURES IN THE NORTHERN TERRITORY, AUSTRALIA, AND PROGRESS TOWARDS CONTROL TECHNIQUES

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Summary

Sida acuta and *Sida cordifolia* have become the most serious weeds of Townsville stylo (*Stylosanthes humilis*) in the wet areas of the Northern Territory. A wide range of pre- and post-emergent herbicides were screened for selective activity. Several chemicals showed promise. The promising post-emergent chemicals were tested on a larger scale under various conditions. Anomalous results were obtained with bromoxynil and partial success with dinoseb.

INTRODUCTION

Two *Sida* species are causing extreme concern in Townsville stylo (*Stylosanthes humilis*) pastures of the higher rainfall areas of the Northern Territory (> 890 mm).

These have been identified as *Sida acuta*, and *S. cordifolia*. Of lesser importance are two other species, *S. rhombifolia* and *S. spinosa*.

HISTORICAL NOTES

These weeds are pantropic in distribution. *Sida cordifolia* was collected at Port Essington in 1845, and in the Darwin area in the 1850s. *Sida rhombifolia* was collected at Port Essington in 1845, and *S. spinosa* was collected in 1802-5 by Robert Brown from the north coast of Arnhem Land, and by Von Muller in the Victoria River District in 1845-6. It appears that these plants preceded European settlement, and were possibly carried by Malay traders, or migrating birds.

Sida acuta appears to be a later arrival. It appears to have spread from the Darwin area. Some "old-timers" refer to the plant as broom brush, in reference to its use by Chinese who arrived during the gold rushes late last century.

ECOLOGY

These plants are vigorous, woody, semi-perennials. In favourable conditions they can perennate, but mostly behave as annuals. They begin to flower late January or early February and continue to grow and set seed until moisture runs out. The plants are erect growing, up to 2 m high in favourable conditions, but normally about 1 m. The carpels have two spikes which aid in the distribution. These spikes make the separation from Townsville stylo seed difficult.

Spread of these weeds is principally by contaminated pasture seed and hay, on vehicles and farm machinery, along streams, and to a lesser extent, by attachment to animals.

Areas particularly prone to invasion by these weeds include disturbed land — *e.g.*, improved pastures and creekbanks. From creekbanks invasion into virgin grasslands can occur; however, annual fires appear to suppress the invasion of these areas.

THE PROBLEM

These plants are not used by cattle, horses or buffalo to any extent. The erect habit allows the plants to dominate Townsville stylo pasture. Any area of pasture which is disturbed at all and allowed to become over-grazed becomes densely covered by these weeds. Areas around stockyards are often densely covered. Pastures for seed production are invaded but the spread of the weed in this situation is slower. Grazing animals spread the weed rapidly since seed can pass through the gut undamaged. Pasture seed being submitted for certification must be free of *Sida* spp. — either in the paddock before harvest or in the seed produced. There is a great danger that gains in carrying capacities of the order of 1000% due to improved pastures could be substantially nullified by these weeds.

CONTROL METHODS

Mechanical

Mechanical methods such as pasture topping with a slasher during the growing season provide some measure of control. This treatment reduces the competitive advantage the weeds have over Townsville stylo through their erect growth habit. It is not practicable to slash large areas of Townsville stylo pasture as most of the pastures are sown by aircraft direct into uncleared bushland. Phosphate fertilizer, spread at the same time to stimulate the

TABLE 1: HERBICIDES USED AND RESULTS OBTAINED—1971 TRIAL

Treatment (kg/ha)	*Method of Application**	*Remarks†*
alachlor — 1.12	pre	
amitrole — 2.24, 5.6, 11.2	post	
atrazine — 1.12, 2.24, 3.36, 6.72	pre	
bromacil — 1.12, 2.24	pre post	
bromofenoxim — 1.12, 2.24, 4.48	pre post	To be re-examined.
bromoxynil — 0.56, 1.12, 1.76	post	Promising; selected for continuing trials.
chlorfenac — 4.48, 8.96	post	
chloroxuron — 2.24, 5.6, 8.96	pre	To be re-examined.
chlorthal — 5.6, 7.84, 11.2	pre	Slight selection against *Sida;* not to be pursued because of cost.
cyanazine — 2.24, 4.48, 6.72	pre	Promising; needs further work to evaluate under large-scale trials.
2,4-D amine — 0.11, 0.35	pre	
2,4-DB — 1.12, 2.24	post	Selected for large-scale trials; proved to be too toxic to Townsville stylo, at rates showing selectivity.
dicamba — 0.56, 1.12, 3.36	post	
dinoseb — 2.24, 6.72, 11.2	pre	
dinoseb — 2.24, 6.72, 11.2	post	Promising, but rates too high when tested on mature *Sida.*
diphenamid — 5.6, 8.96	pre	
diquat — 0.28, 0.42, 0.56	post	
diuron — 0.56, 1.22, 2.24	pre	
2,2-DPA — 1.12, 4.48, 8.96	pre	
2,2-DPA — 0.84, 2.24, 4.48	post	
fenoprop — 0.56, 1.12, 2.24, 4.48	post	
fluometuron — 1.12, 2.24, 4.48	pre	
ioxynil — 0.56, 1.12, 2.24	post	
lentacil — 2.24, 4.48, 6.72	pre	To be re-examined.
linuron — 1.12, 2.24, 4.48	pre post	
mecoprop — 1.68, 2.7	post	
methylarsinic acid — 2.8, 5.6, 11.2	post	
metobromuron — 1.2, 2.24, 4.48	pre	
nitralin — 1.4, 2.1	pre	
	post	To be re-examined.
nitrofen — 2.24, 4.48, 6.72	pre	To be re-examined.
noruron — 1.12, 2.24, 4.48	pre	

TABLE 1 — contd

Treatment (kg/ha)	Method of Application*	Remarks†
paraquat — 0.14, 0.21, 0.28	post	
picloram (+ 2,4-D amine) —	pre	
0.035, 0.07, 0.105	post	
propachlor — 2.24, 3.36, 6.72	pre	
	post	To be re-examined.
pyrazon — 2.7, 5.4	preplant	
	pre	
	post	
siduron — 2.24, 4.48, 6.72	pre	To be re-examined.
siduron — 2.24, 6.72	post	
2,3,6-TBA — 11.2, 22.4	post	
trifluralin — 1.12	preplant incorporated	

*Preplant; pre = pre-emergence; post = post-emergence.
†No comment indicates that no selective effect was observed and that the chemical is not to be continued with.

growth of the Townsville stylo, increases the growth of the weeds as well.

CHEMICAL

Little information was available for the selective removal of *Sida* spp. from Townsville stylo pastures apart from negative results obtained in a series of small *ad hoc* trials conducted over the years by the writer. Some control had been achieved with 2,4-D ester at 1 kg/ha when the plants were seedlings less than 10 cm high. A 50% mortality of Townsville stylo was incurred at the same time, but this result has proved difficult to repeat.

CHEMICAL SCREENING TRIAL

A screening trial was set up, designed to screen efficiently and rapidly a large number of herbicides for useful selective effects.

METHOD

Under sprinkle irrigation, a series of small plots were laid out (90 × 51 cm). One row each of *Sida acuta, S. cordifolia* and Townsville stylo was planted in each plot. Treatments were applied using a hand-held CO_2 pressurized experimental sprayer in 360 l/ha. A frame, 60 cm deep, the size of the plot, was used to minimize spray drift.

The herbicides used and the results obtained are given in Table 1. Results were assessed from a 0 to 10 rating scale several times after application. Little rain fell during the trial.

This trial was not replicated in 1971, but the selected chemicals will be re-tested in 1972 in a similar trial and will be further evaluated in larger plots if promising.

LARGE-SCALE TRIALS — 1971 WET SEASON

VISUAL TRIALS

From the post-emergence section of the trial any chemical showing promise was screened in large-scale, visually assessed trials, during the 1971 wet season.

These trials were applied using a boom sprayer set at a particular rate, then decreasing the speed by factors of 2 and 3 to increase the amount by these factors.

Bromoxynil at 1½ kg/ha appeared the most promising in the first of these trials, killing 90% of perennated *S. acuta*. Although repeated during the season, these results could not be repeated and damage to the *Sida* decreased as the plants aged. In the first experiment, the first rains had occurred only two weeks before, and the *Sida* must have been caught at a sensitive stage.

Dinoseb and 2,4-DB were tested in this way as well but did not show any spectacular results.

RESULTS FROM YIELD TRIALS

These trials did not yield useful results with bromoxynil or 2,4-DB but showed some useful effects with dinoseb. Yields measured by quadrat cutting showed a 75% reduction in *S. acuta* at 3.36 kg/ha, with 5% reduction of Townsville stylo yield.

DISCUSSION

Not a great degree of selective activity was shown in even the most "selective" herbicides. Many of the other chemicals showed selective activity in favour of the *Sida* spp.

A great deal of work is needed to evaluate any of the selective chemicals to relate observed effects and the growth phase of the plant. Rapid changes in the susceptibility of the plant to bromoxynil has been shown.

Chemical control approach is only a stop-gap measure which is being developed to allow time to develop a more ecologically integrated control method. So far no selective methods can be recommended.

ACKNOWLEDGEMENTS

Many thanks for samples supplied by various chemical companies of many herbicides which are either in the late developmental stages, or are not widely available in Australia.

PROBLEMS OF WEED INTRUSION OF UNIMPROVED PASTURES IN THE BRITISH SOLOMON ISLANDS PROTECTORATE

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Summary

The introduction of cattle into the Solomon Islands, particularly in coconut plantations for grazing, has led to the development of foci of undesirable weeds as the grass cover becomes reduced. Whereas in large plantations rotational grazing is possible and some weed control practised, on smaller estates overgrazing of unimproved pastures has led to a serious weed problem. Probably, the most serious weed threat at the moment is that of the Navua sedge, although this is confined to small areas at present. The lack of basic information on plant nutrition, particularly with regard to the establishment of the legume component of pastures, has exacerbated the problem. Species of *Sida, Mimosa, Stachytarpheta, Mikania, Solanum* and *Cassia* have developed in the cattle-raising areas.

The development of agriculture in the British Solomon Islands until comparatively recently has been free of serious weed incursion problems. For subsistence agriculture, hand-weeding was quite sufficient to contain weed growth. Herbicides were very rarely used and even now their use is confined to the larger (expatriate) plantation companies. Even for rice, the weed problem was far smaller in magnitude than that resulting from insect pests; certainly little research effort was required to solve weed problems as, from time to time, these occurred.

Although plantings of cacao can suffer serious weed intrusion, the problem has been more associated with dispersive planting and poor upkeep generally than with the serious competitiveness of the weeds *per se* or with any intransigence of the problem from the fundamental research aspect. In oil palms, the excellent encouragement of the leguminous (*Pueraria*) cover has brought about the exclusion of most weeds and none can be considered noxious within this context.

This generally satisfactory situation has been radically changed by the introduction of cattle. The grazing of coconut plantations by cattle to keep the undergrowth under control has led to the establishment of foci of undesirable weeds in certain areas.

Although obviously the very early introductions of cattle reflected an interest in the beasts themselves, for the dominant period of this century, cattle utilization has been for the underbrushing of coconuts to enhance nut pick-up, reduce labour costs, and hence improve the economics of copra production. Since the grass cover largely associated with coconuts in the Solomons was not designed to yield any nutritional benefit to the coconut, the fact that weeds gradually replaced some of the grass cover was left unchecked. There has never been for coconuts the intensive development of a ground cover quantitatively assessed in relation to palm performance, as there has been in recent years for oil palm, although some areas have been planted with leguminous covers which appear to sustain tolerably well. Overall there was little evidence that grasses were beneficial to coconuts and the fact that legumes might both encourage phosphate mobilization and add nitrogen to a situation in which amounts of that element were limiting was not considered of sufficient significance to be worthy of detailed pursuit.

A situation has therefore been created in which the so-called pastures under coconuts now contain a high proportion of dangerous weed species. For the larger estates this is less of a problem than might at first appear; these better endowed land-owners can move cattle over extensive areas and by this means avoid the over-grazing which gives the more serious weeds their competitive advantage. Coupled to a carefully controlled herbicide usage, therefore, the weed situation appears tolerable in such circumstances, although hardly consistent with a modern concept of agriculture. For the smaller estates and the Solomon Island farmer the situation is, however, very different. One is faced with a situation in which the areas available for grazing are quite small. Although the land mass of the Solomons is very considerable in relation to the total population, very complex land tenure problems have placed a considerable constraint upon development. Although very healthy signs are now appearing of community effort, it is often very difficult to achieve more than about thirty acres of good land indisputably owned by one Solomon Islander. Registration of land also presents social problems. Thus at the present time the notional and superficial opinion that large areas are available proves illusory. Continuous grazing of the unimproved pastures therefore leads to serious displacement of nutritious grasses by noxious weeds.

Under these conditions the most serious weeds appear to be *Stachytarpheta iamaicensis, Sida acuta, Sida rhombifolia, Mimosa* *pudica, Mikania scandens, Solanum torvum* and *Cassia alata*. In many areas of the Protectorate where cattle have been and are being raised, these species appear almost dominant, with palatable grasses at a minimum. Since the character of these weeds is for the most part well understood, comment will be made only on the last. *Cassia alata* in the humid tropics and in the absence of cattle presents no problem. In West Malaysia for example, *C. alta* is confined to the edges of swampy land and does not spread from there naturally — over 11 years of observation it has presented no problem and even the occasional movement of the Malayan buffalo through those areas does not induce spread. In certain areas of Guadacanal subjected to uncontrolled grazing, this weed now stands dominant as a robust shrub forest, seeding profusely and spreading outward at an alarming rate. Although quite susceptible to a range of herbicides, control is now costly and essentially one is confronted by a need for rehabilitation of derelict land.

In many cases these weeds have spread through neglect from comparatively small areas originally. Serious consideration must therefore be given to eliminating small weed patches within and at the edges of areas intended for grazing, before such areas have cattle put on them. In a number of cases hand-weeding would suffice, although the efficient use of herbicides might prove more economic in the Western sense of that word. It is evident that weed control must be considered as a community problem since poor upkeep and management in one area can endanger progress made in contiguous small-holdings. Perhaps most significant in this is the case of Navua sedge. The precise identification of this plant is still in doubt. Samples have been classified internationally as *Cyperus aromaticus* but more correctly the dominant sedge may be *Cyperus melanospermus,* while the Fijian authorities state that their dominant Navua sedge is correctly *Kyllinga elata.* Further samples of Solomon Island Navua sedge are being sent for expert classification and there is always the possibility of more than one species being present. Nevertheless, Navua sedge is presently confined to very small areas of the Protectorate and it can be expected to spread rapidly through grazing. At this point in time, therefore, the decision has been reached to attempt the complete elimination of Navua sedge. With determination, it should be possible to achieve this within 1973. The cost of herbicides for this operation will be considerable, and their use must be carefully controlled if this very resistant plant is to be eliminated.

There is, of course, a much more rational approach to the long-term problem of weed intrusion through the establishment of well-balanced mixed legume/grass pastures. Progress in this has not been at all satisfactory. In general, the growth of nourishing and beneficent legumes in the Protectorate has been exceedingly poor. Only the establishment of the *Pueraria* cover for oil palm planting and of leucaena shade for cacao have been truly successful; into both of these, considerable management/research skill has been injected. For most pastures for cattle the growth of legumes has been scanty to poor. The consequence is that nitrogen must be supplied if the grasses are to be maintained against grazing at reasonable intensities. The basic principles of good legume husbandry have been neglected: the rhizobium inoculum has been rarely utilized effectively and, for natural grassland areas, the young legume seedling seldom receives its symbiont necessary to give it competitive advantage. Work on the trace elements necessary to efficient symbiotic nitrogen fixation has been minimal. Probably most seriously the timing of the planting of the legume has been such that in fact the grasses dominated the legume before the latter could achieve any significant growth. In sum, therefore, there exists a considerable need for much more basic work on legume/grass pastures with the emphasis clearly being placed on the legume contribution. Given such basic work, it should prove possible to develop largely self-sustaining pastures capable of withstanding weed intrusion under moderate and possibly high grazing intensities. Without such a fundamental change in method, weed intrusion will present the most serious problem to cattle development. Already some areas have been significantly damaged.

It is thus possible to summarize the situation and the need under simple broad heads:

(1) Unimproved pastures give serious evidence of weed intrusion under moderate grazing intensities. Investigations into methods of pasture improvement and into pasture management are already proposed and will in due course be undertaken.

(2) Most weed problems arise from comparatively small areas at the start of grazing; prophylactic treatment of such areas would bring considerable benefit. Even so, mismanagement of improved pastures will lead to weed intrusion.

(3) Certain noxious weeds could be eliminated before serious intrusion can occur; Navua sedge is the outstanding example.

(4) Present pastures are unbalanced, the growth of the legume component being poor; such pastures cannot be considered self-sustaining and will prove inadequate for the peasant sector.

(5) Community effort will be required to prevent weed intrusion from contiguous areas.

(6) The lack of sound information on plant nutrition and soil fertility has contributed to poor pasture establishment.

Although the requirements are formidable, there is every sign that the Solomon Island farmer is tackling them with skill and a small injection of expertise could bring much benefit.

GERMINATION AND DORMANCY IN THE SEEDS OF CERTAIN EAST AFRICAN WEED SPECIES

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Summary

Laboratory germination tests were conducted with seeds of 22 weed species. Fresh seed of the majority of species possessed a high level of innate dormancy. In most cases appropriate treatment could reduce the proportion of dormant seed. Dry storage, seed coat damage or removal, stratification and temperature alternation were all effective in different species. Optimum temperatures for germination varied widely. Light was essential for maximum germination in some species and in a few germination in the light was actually increased as a result of a period in darkness. The possible relevance of results to field behaviour is briefly discussed.

The species investigated here all occur as weeds of cotton in Kenya, at an altitude of 1,100 to 1,200 m, but many are important in other crops and in other parts of the world. In Kenya germination itself is limited by rainfall but the seeds of these species exhibited a range of dormancy mechanisms and various factors were involved in the imposition and elimination of dormancy.

Germination tests were carried out in petri-dishes and were usually continued for 28 days. The main object was to gather basic information on germination characteristics which could later be used in attempts to explain the behaviour of seeds under natural conditions. In addition, the data may be helpful to those who wish to grow any of the weeds for experimental purposes.

Of the 22 species studied in some detail, only 2 had seeds which usually germinated freely when freshly collected. These were blackjack (*Bidens pilosa* L.) and *Euphorbia geniculata* Orteg. Seeds of 10 of the species — *Boerhaavia erecta* L., spindlepod (*Cleome monophylla* L.), crow's-foot grass (*Dactyloctenium aegyptium* (L.) Beauv.), thorn apple (*Datura stramonium* L.), macdonaldi (*Galinsoga parviflora* L.), *Heliotropium subulatum* (DC.) Vatke, double thorn (*Oxygonum sinuatum* (Meisn.) Dammer), guinea-fowl grass (*Rottboellia exaltata* L.f.), puncture vine

(*Tribulus terrestris* L.) and late weed (*Trichodesma zeylanicum* (Burm.f.) R.Br.) — gave less than 5% germination when tested at room temperature soon after collection. Pigweed (*Amaranthus graecizans* L.), jungle rice (*Echinochloa colonum* (L.) Beauv.), goosegrass (*Eleusine indica* (L.) Gaertn.) and redtop grass (*Rhynchelytrum repens* (Willd.) C. E. Hubb.) showed germination of up to 15% of fresh seed, again when tested at room temperature. The other species — tar-vine (*Boerhaavia diffusa* L.), *Lagascea mollis* Cav., wild lettuce (*Launaea cornuta* (O. & H.) C. Jeffrey), wandering Jew (*Commelina benghalensis* L.), purslane (*Portulaca oleracea* L.) and PWD weed (*Tridax procumbens* L.) — had less dormant seed of which over 20% usually germinated when fresh.

Innate dormancy in the seeds of almost all these species could be at least partly broken by appropriate treatment. The exceptions were puncture vine and *Heliotropium* whose seeds resisted all provocation and would not germinate in the laboratory. In the field puncture vine germinated readily after very prolonged exposure to hot, dry conditions at the soil surface, and the same may be true of *Heliotropium.*

Different species had different optimum temperatures for germination and often various treatments affected germination at one temperature but not at another. Tests were carried out at 4° C, room temperature (19 to 26° C), 30° C and 40° C. Temperature effects described here refer to seeds whose initial dormancy, if any, had been partly broken. In several species — *e.g.*, pigweed, wandering Jew and PWD weeds — seeds taken from the same sample at different times showed considerable fluctuation in germination at room temperature. This was probably due to differences in room temperature at different times of the year, because germination at 30° C was not so variable and the effect was more noticeable in species whose seeds germinated better at higher temperatures.

The optimum temperature for germination of pigweed and purslane seeds was 40° C, and 30° was more advantageous than room temperature. In tar-vine, wild lettuce and guinea-fowl grass, there was little difference between germination at room temperature and at 30° C but germination was inhibited at 40° C. Seeds of blackjack, jungle rice, redtop grass, *Lagascea* and crow's-foot grass germinated more readily at room temperature than at 30° C and none germinated at 40° C. In most of the other species 30° C was more favourable than either 40° C or room temperature. Germination, if it took place at all, was very slow at 4° C. Nevertheless, both pigweed and purslane seeds gave a higher percentage germination after 28 days at this temperature than did comparable samples tested at room temperature.

After collection, seeds were air-dried and then stored at 4° C, room temperature or 30° C. Only in guinea-fowl grass, pigweed and spindlepod did storage at 4° C for several months reduce the proportion of dormant seeds. Guinea-fowl grass, redtop grass and double thorn lost their dormancy more quickly and effectively when stored at 30° C than at lower temperatures. Double thorn seeds which were totally dormant when fresh gave over 80% germination when tested after storage at 30° C for 15 months, whereas seed stored at room temperature for 18 months showed 20% germination.

Room temperature storage tended to increase the germination of spindlepod, guinea-fowl grass, double thorn and redtop grass whether the seeds were tested at 30° C or room temperature; and of crow's-foot grass, pigweed, jungle rice and *Euphorbia* when tested at room temperature, but less effectively in tests at 30° C. The effects of storage were always gradual, progressively more seeds being affected as the length of storage increased.

Some of the seeds of blackjack, spindlepod and pigweed apparently lost their viability as a result of being stored at 30° C for a year or more. In blackjack some loss of viability was noticed after seeds had been stored at room temperature for 2 years. Storage at any temperature for some months induced dormancy in some purslane seeds. This dormancy was most evident in tests at room temperature and was gradually lost with prolonged storage. Seeds of the remaining species either appeared to be unaffected by storage or gave variable, inconclusive results.

To test the effects of stratification, imbibed seeds were held at 4° C for up to 4 weeks before being transferred to outdoor shade temperatures. The action of fluctuating temperature on imbibed seeds was also examined by chilling them at 4° C for 19 hours each day and moving them to outdoor shade for the remaining 5 hours, this cycle being maintained throughout the germination test. Purslane seed responded well to both treatments. 100% germination was reached after 14 days of temperature alternations and over 90% of the seeds germinated just 3 days after transfer to higher temperature following stratification for 3 weeks or more. Both treatments also led to greater germination of pigweed seeds than in samples continually at outdoor shade temperatures although the results were not so dramatic as with purslane. Goosegrass seed, unaffected by stratification, gave nearly 70% germination as a result of alternating temperatures, as against 15% at room temperature. Fluctuating temperatures caused germination of over 50% of late weed seeds: no other treatment of any kind resulted in more than 6% germination in this species. Seeds of all other species tested were quite unaffected by either treatment.

Damaging the seed coat by pricking, chipping, cracking it or abrading it with fine sand-paper tended to break dormancy in the seeds of some species, including pigweed, wandering Jew, goosegrass, purslane and crow's-foot grass, this effect only occurring, or being more obvious, at room temperature. An equal number of species, such as blackjack, macdonaldi and PWD weed, had their germination inhibited by these treatments. Seed of other species was either unaffected or the results were inconsistent. Complete removal of the seed coat, which was practical only in larger-seeded species, stimulated germination in many species. Germination of macdonaldi was actually suppressed by such treatment. *Boerhaavia erecta* and thorn apple both responded favourably to seed coat removal and this was the only way in which seeds of these 2 species could be made to germinate. In the 5 species of grasses, removal of the caryopsis from the enveloping palea and lemma increased the proportion capable of germination and this was more effective in seeds which had been previously stored for some time.

In all the tests described so far, the seeds were exposed to diffuse laboratory light during the hours of daylight. The effect of light on germination was studied by comparing the behaviour of seeds held in total darkness for up to 7 days with that of seeds exposed to light each day. In general, seeds which were dormant in light remained so in darkness. Results quoted here are for seeds whose innate dormancy had already been reduced, usually by storage. In one test seeds of tar-vine germinated much better in darkness than in light, a result that was not repeated in later tests.

Over a period of 7 days, marginally more guinea-fowl grass seeds germinated in darkness than in light: this was true of both intact seeds and dehusked caryopses. Pigweed seeds also germinated slightly better in darkness than in light when tested at either room temperature or 30° C. Germination of *Euphorbia* and double thorn seeds was slightly inhibited in darkness and that of blackjack was more strongly suppressed. Very few seeds of purslane and PWD weed germinated in darkness.

In most species in which darkness restricted germination, return to the light merely allowed germination of those seeds which would have germinated anyway had the test been in light. However, the behaviour of pigweed, purslane and PWD weed when their seeds were returned to light after spending 5 to 7 days in darkness was of great interest, for total germination in seeds so treated was far higher than in seeds left in the light. In PWD weed this happened at both room temperature and 30° C: in the other 2 species it took place only at 30° C. Purslane seed showed the greatest reaction. Only 1% germinated during 7 days in darkness but within 3 days of their transfer to light 93% had done so. In the light 12% germinated in 7 days and 41% in 28 days.

The effects of different temperature regimes on laboratory germination are probably not very important in the field because soil surface temperatures during the rains are fairly uniform and very rarely fall below about 15° C.

Innate dormancy restricts germination of newly matured seeds. External factors, such as prolonged drought, lead to a gradual reduction in this dormancy so that, after a certain time, some seeds will be able to germinate at once in response to suitable conditions whilst others may remain in the soil for two or more dry seasons before they become capable of germination. In the laboratory damaging or removing the seed coat often causes some loss of dormancy but there is little evidence that this is responsible for breaking dormancy under field conditions, although dry storage may exert its effect on dormancy by altering some property of the seed coat.

In some species burial, by imposing darkness, can enforce dormancy of the seeds. Any disturbance which returns the seed to the surface will at once restore its ability to germinate. In pigweed, purslane and PWD weed burial could actually enhance the seed's chances of germination when it is later brought back to the soil surface.

Laboratory tests were invaluable as a guide to factors which may influence dormancy and germination in the soil. The next step was experiment and observation on seeds in their natural environment and results of these will be published later.

EFFECTS OF SEVERAL HERBICIDES ON THE GERMINATION OF SEEDS OF SELECTED WEED SPECIES

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Summary

The effects of 15 commonly used herbicides on the germination of pigweed *(Amaranthus retroflexus)*, lambsquarter *(Chenopodium album)*, quackgrass *(Agropyron repens)*, and johnsongrass *(Sorghum halepense)* seeds were studied. Low concentrations of herbicides used either had no effect or slightly promoted seed germination, while at higher concentrations these herbicides had variable effects on seed germination. It appeared that the herbicides are species specific in their action, and the degree of activity depended on the concentrations used.

INTRODUCTION

The ability of many plant species to reappear in areas denuded of vegetation is principally due to dormancy of seeds. Dormancy or resting period of seeds buried in the soil is particularly long in a large number of species, especially those depending on natural conditions for propagation. Once the land has become clothed with a natural cover of vegetation, it is virtually impossible for any agency to destroy this cover permanently, since many seeds that may shatter on the ground will remain in a dormant state, perhaps for many years. The small proportion of seeds that germinate in any year may reach maturity and add more seeds to those already present in the soil.

Germinating seeds may exhibit their own responses to herbicides, as distinct from those of established plants (Bingham, 1968; Crafts, 1961; Lewis *et al.,* 1969). Many herbicides permit the establishment of seedlings prior to exerting a lethal effect; death of seedlings may be preceded by malformation of roots or shoots (Friesen *et al.,* 1964).

The effects of several herbicides on germination, survival and early growth of selected weed seeds were investigated by Grover (1965). These investigations indicated that pre-emergence application of trifluralin, chlorthal, and diphenamid had no effect on the retardation of weed seed germination. However, the young seedlings were either killed or retarded in growth as the experiment progressed. Trifluralin, diphenamid, and dichlobenil at most rates tested caused injury to seedlings in greenhouse tests.

The objective of this investigation was to determine the effects of certain herbicides at different concentrations on the germination of seeds of four selected weed species.

MATERIALS AND METHODS

Seed materials used in this study were johnsongrass (*Sorghum halepense*), common lambsquarter (*Chenopodium album*), redroot pigweed (*Amaranthus retroflexus*), and quackgrass (*Agropyron repens*). The herbicides used were 2,4-D, picloram, chlorfenac, 2,4-DEP, dicamba, simazine, diuron, EPTC, naptalam, dichlobenil, trifluralin, diphenamid, chlorthal, 2,2-DPT, and chlorpropham. Water solutions or suspensions of the chemicals were made and diluted to give 0.01, 0.1, 1, 10, 100 and 500 ppm (mg/litre) of active ingredient. The pH of the solutions was adjusted to 7.0. Concentrations of 100 and 500 ppm for dichlobenil were omitted owing to this chemical's low solubility.

Germination tests were conducted by placing 50 seeds of a given species in sterile petri dishes upon two sheets of Whatman No. 2 filter paper moistened with 5 ml of water or test solutions. The dishes were placed within a germinator maintained at 26 ± 1° C for 16 hours and 19 ± 1° C for 8 hours, under continuous darkness. Germination counts were made daily for 8 days. There were two replications per treatment.

RESULTS AND DISCUSSION

The germination of johnsongrass seeds as affected by various herbicides is shown in Table 1. At 0.01 ppm, 2,4-D and picloram slightly increased the germination percentages, while EPTC decreased the germination. At 0.1 ppm, picloram, chlorfenac and trifluralin considerably increased the germination. Germination percentages similar to control were obtained with all the herbicides when used at 1 and 10 ppm except for dichlobenil which at 10 ppm completely inhibited the germination. The germination of johnsongrass seeds was inhibited by EPTC and naptalam at 100 ppm, and at 500 ppm 8 of the 15 herbicides tested considerably reduced the germination percentages.

Table 2 shows the effect of various herbicides on the germination of lambsquarter seeds. At 0.01 ppm, picloram, 2,4-DEP, simazine, and diphenamid slightly increased the germination percentages. At the same concentration, however, dichlobenil reduced the germination percentages by about 50% as compared with control. At 0.1 ppm, only naptalam and chlorthal slightly promoted the germination. Diphenamid and chlorthal at all concentrations used gave higher germination percentages as compared with the control. At 10 ppm, simazine and EPTC also increased the germination. None of the herbicides used, up to a concentration of 100 ppm, significantly decreased the germination of lambs-

TABLE 1: PERCENTAGE GERMINATION OF JOHNSONGRASS SEED AS INFLUENCED BY DIFFERENT CONCENTRATIONS OF HERBICIDES

	Concentration (ppm)						
Herbicides	*0*	*0.01*	*0.1*	*1*	*10*	*100*	*500*
2,4-D	18	29	22	24	20	22	22
picloram	18	29	36	28	29	19	4
chlorfenac	18	24	42	24	20	19	4
2,4-DEP	18	14	14	13	16	16	1
dicamba	18	15	13	19	13	13	18
simazine	18	17	5	13	13	28	27
diuron	18	19	15	19	20	14	12
EPTC	18	8	14	15	24	9	6
naptalam	18	13	18	11	11	11	9
dichlobenil	18	14	22	15	1	—	—
trifluralin	18	24	30	13	17	13	9
diphenamid	18	13	21	21	18	18	15
chlorthal	18	20	18	15	25	17	17
2,2-DPA	18	16	17	19	20	18	14
chlorpropham	18	23	23	14	14	13	7

W.05 (2.3) 7 levels

TABLE 2: PERCENTAGE GERMINATION OF COMMON LAMBSQUARTER SEED AS INFLUENCED BY THE DIFFERENT CONCENTRATIONS OF HERBICIDES

	Concentration (ppm)						
Herbicides	*0*	*0.01*	*0.1*	*1*	*10*	*100*	*500*
2,4-D	29	25	26	37	31	29	19
picloram	29	36	23	21	27	23	17
chlorfenac	29	25	27	23	25	31	10
2,4-DEP	29	36	30	28	28	35	0
dicamba	29	30	22	26	24	36	12
simazine	29	36	27	33	40	29	38
diuron	29	31	20	30	20	33	17
EPTC	29	24	31	26	41	23	22
naptalam	29	27	38	21	28	30	13
dichlobenil	29	15	32	34	29	—	—
trifluralin	29	33	33	29	35	31	31
diphenamid	29	36	34	50	45	51	34
chlorthal	29	32	40	39	39	42	30
2,2-DPA	29	33	30	37	34	21	32
chlorpropham	29	31	26	28	24	32	31

W.05 (6.1) 7 levels

quarter seeds. Treatment of seeds with picloram, chlorfenac, 2,4-DEP, dicamba, diuron, and naptalam at 500 ppm reduced the germination considerably.

The germination of pigweed seeds as affected by various herbicides is shown in Table 3. Considerable increase in germination was noted when these seeds were treated at most concentrations up to 100 ppm of chlorfenac, 2,4-DEP, simazine, diuron, trifluralin, diphenamid, chlorthal, 2,2-DPA, and chlorpropham. At 500 ppm, chlorfenac, 2,4-DEP, dicamba, EPTC, and naptalam severely inhibited germination, while trifluralin, diphenamid, chlorthal, 2,2-DPA and chlorpropham promoted germination.

Table 4 shows the germination of quackgrass seeds as affected by various herbicides. Sixty-eight percent. of the untreated seeds had germinated. Most of the herbicides used up to a concentration of 1 ppm had little effect on their germination except that dichlobenil and chlorpropham inhibited the germination. Considerable reduction in germination occurred when the seeds were treated with 10 ppm of 2,4-D, dichlobenil, diphenamid, and chlorpropham. At 100 and 500 ppm, all of the herbicides used, with the exception of simazine, diuron, chlorthal, and 2,2-DPA, either completely or considerably reduced the germination percentages.

The results of this study show that the responses of the seeds

TABLE 3: PERCENTAGE GERMINATION OF REDROOT PIGWEED SEED AS INFLUENCED BY THE DIFFERENT CONCENTRATIONS OF HERBICIDES

	Concentration (ppm)						
Herbicides	*0*	*0.01*	*0.1*	*1*	*10*	*100*	*500*
2,4-D	25	61	30	42	31	24	15
picloram	25	22	20	17	35	43	29
chlorfenac	25	48	45	15	42	22	6
2,4-DEP	25	39	44	20	46	21	0
dicamba	25	45	41	29	11	20	6
simazine	25	31	46	43	32	40	16
diuron	25	20	42	15	51	53	31
EPTC	25	22	22	29	16	26	4
naptalam	25	20	13	33	18	18	0
dichlobenil	25	28	23	32	13	—	—
trifluralin	25	50	29	40	41	16	38
diphenamid	25	39	26	42	38	60	43
chlorthal	25	36	43	40	43	27	39
2,2-DPA	25	19	34	33	30	44	37
chlorpropham	25	45	15	39	33	43	41

W.05 (12.1) 7 levels

TABLE 4: PERCENTAGE GERMINATION OF QUACKGRASS SEED AS INFLUENCED BY THE DIFFERENT CONCENTRATIONS OF HERBICIDES

	Concentration (ppm)						
Herbicides	*0*	*0.01*	*0.1*	*1*	*10*	*100*	*500*
2,4-D	68	78	65	55	36	8	5
picloram	68	74	81	62	52	7	0
chlorfenac	68	74	64	61	53	14	0
2,4-DEP	68	51	77	55	52	16	0
dicamba	68	64	63	69	61	13	0
simazine	68	59	74	66	66	73	59
diuron	68	70	56	66	61	62	61
EPTC	68	64	64	62	59	20	15
naptalam	68	57	71	66	62	56	14
dichlobenil	68	70	35	0	0	—	—
trifluralin	68	70	60	56	47	28	0
diphenamid	68	64	70	61	17	6	0
chlorthal	68	63	70	71	58	53	62
2,2-DPA	68	74	60	70	61	55	56
chlorpropham	68	63	61	17	27	0	0

W.05 (10.0) 7 levels

of different plant species to the same herbicide vary immensely. With so many herbicides, concentrations and species involved, it is a difficult task to summarize the results. On an over-all basis, it can be said that the germination of the seeds of johnsongrass and lambsquarter were less affected by the herbicides used as compared with the other two species. Germination of quackgrass seeds was inhibited by a large number of the herbicides used, while several of these herbicides promoted the germination of pigweed seeds. It is suggested that, depending on the plant species, the herbicidal effects may be due in part to their effects on seed germination, in addition to other deleterious effects on the seedlings and mature plants.

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WEIGHT AND NUMBER OF WEED SEEDS

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Summary

The weight of 1000 seeds and the total number of seeds per plant in 140 weed species of rice-fields are recorded. Notes on individual species are provided, and some generalizations are made on seed weight and seed number.

A knowledge of the number of seeds produced by a weed species is essential for studies in crop ecology. To a seed analyst, the approximate weight of individual seeds is of use in ascertaining the percentages obtained in samples of crop seeds.

The literature on weeds contains several references to seed production by plants of various species in North America and Europe. Pammel and King (1910) recorded the results of seed investigations for 1908 and 1909. Stone (1915) checked the weed seed contents of seeds. Korsmo (1930) gave valuable information on seed weights and numbers of individual plants. Stevens (1932) presented data upon the seed production of common weeds and other plants with particular reference to selection of specimens and cleaning of seeds to a definite plan and in 1957 published a further list of seed weights and seed numbers per plant, and supplied explanatory notes on individual species. Salisbury (1942) made ecological and statistical studies of a variety of species, but still commented on the paucity of data on weights of seeds and numbers per plant. Tadulingam and Venkatanarayana (1932) made a thorough study of the morphological structures of seeds of some South Indian weeds; however, he did not attach much importance to the study of seed weight and seed number for individual weeds.

The present investigation was started to secure educative material and has been continued for three years (1968-71) with the hope that a comprehensive report would permit some generalizations about a topic on which very little is known from India.

MATERIAL AND METHOD

The methods of collection given by Stevens (1932, 1957) were followed. In most cases a single plant, judged to be of average size and growing with relatively little competition, was selected at a time when a maximum number of seeds could be secured. After harvesting, the plants were air-dried for 2 to 3 weeks, threshed and cleaned. In some cases (Capparidaceae, Leguminosae, Euphorbiaceae, Malvaceae), visual examination had to replace the usual cleaning. The methods of collecting and cleaning are well adapted to use with those species whose seeds are retained until all are mature. For plants in which ripening extends over a considerable period and seeds are released as soon as mature, only a portion of the total number can be procured at a single collection. In those cases, the number is given with remarks to show that more would have developed or that some had already dropped. In several of the families can be noticed species which do not drop their seeds or fruits readily and others which do.

In *Pistia stratiotes, Argemone mexicana* and *Chrozophora rottleri,* collections were made three times per week. In *Trianthema portulacastrum,* daily collections were made for a month. In some plants, seeds were damaged by insects and this is noted. "Immature seeds" indicate those that do not attain the same size, shape and colour as the mature ones; "infertile seeds" are those that failed to germinate under field conditions; and "abortive seeds" are those that did not develop at all. In most cases, the total number listed is that of plump and well-developed seeds for only one plant. In those plants where seeds cannot be separated readily from fruits, the weights are generally of the fruit or parts thereof, such as caryopsis with palea and lemma, achenes, mericarps or nutlets.

In cases of plants with many spreading branches, a square area or a single branch was used. For perennials which grow in clumps, the writers have tried to show the number of branches or tillers present.

RESULTS AND DISCUSSION

Seed production of several of the weeds which have been obtained are not quite as desired. Insects reduce seed production in *Phyllanthus fraternus, Hygrophila auriculata, H. difformis, Dentella repens* and *Xanthium strumarium,* although few seeds are involved. Those plants where seeds or spikelets are dropped include *Alloteropsis cimicina, Coix lachryma-jobi, Setaria glauca, Sporobolus diander, Oryza sativa* var. *fatua, Panicum psilopodium, Cyperus haspan, Pistia stratiotes, Celosia argentea, Argemone mexicana, Sida rhomboidea, Rotala densiflora, Heliotropium indi-*

cum, H. ovalifolium, Limnophila sessiliflora, Lindernia crustacea, Scoparia dulcis, Hygrophila polysperma and *Oldenlandia corymbosa*. Abortive seeds are observed in *Eriocaulon odoratum, Leucas cephalotes, Gnaphalium indicum* and *Xanthium strumarium. Aeschynomene indica* and *Scoparia dulcis* are found to have many undeveloped seeds. Dicotyledonous species produce more immature fruits and seeds than monocotyledons. On the other hand, monocotyledonous weeds form more infertile seeds than the dicotyledonous weeds.

The numbers of seeds produced by different groups of plants are shown in Table 1. These figures show a diversity for the two growth groups and most of the 24 main families. This is not in agreement with the observations of Stevens (1932), who found a close correlation for three growth groups (annuals, biennials and perennials) and 5 chief families (Poaceae, Polygonaceae, Chenopodiaceae, Brassicae and Asteraceae). However, in the Cyperaceae, Commelinaceae, Aizoaceae, Lythraceae, Onagraceae,

TABLE 1: NUMBERS OF SEEDS PRODUCED BY ANNUAL AND PERENNIAL SPECIES OF 24 FAMILIES

	Annuals		*Perennials*	
Family	*No. spp.*	*No. Seeds*	*No. spp.*	*No. Seeds*
Hydrocharitaceae	1	95	1	7,485
Gramineae	27	2,140	12	4,042
Cyperaceae	18	8,296	3	17,818
Eriocaulaceae	2	27,971	—	
Commelinaceae	3	1,246	—	
Polygonaceae	1	1,367	1	2,260
Amaranthaceae	3	4,048	2	21,481
Aizoaceae	3	20,027	—	
Leguminosae	5	3,439	1	5,340
Euphorbiaceae	7	4,562	1	3,258
Malvaceae	—		2	4,945
Lythraceae	4	85,909	—	
Onagraceae	1	7,500	1	468
Haloragaceae	—		2	3,658
Umbelliferae	1	4,320	1	42
Gentianaceae	1	54,184	1	256
Convolvulaceae	1	333	2	544
Boraginaceae	3	3,435	—	
Scrophulariaceae	6	13,853	2	76,232
Lentibulariaceae	2	4,472	—	
Acanthaceae	4	5,569	2	4,584
Rubiaceae	4	32,311	1	1,220
Campanulaceae	2	21,887	—	
Compositae	4	7,657	2	928

Umbelliferae, Gentianaceae, Boraginaceae and Compositae in the present study, the numbers of seeds produced are distinctly higher in annuals than in perennials. On the other hand, the perennials are distinctly ahead of the annuals in seed production in families like Hydrocharitaceae, Gramineae, Polygonaceae, Leguminosae and Scrophulariaceae.

Perhaps it would be more convenient to assign all weed species to a few groups: 1000 seeds or fewer, 9 species; 1000 to 10,000, 102 species; 10,000 to 50,000, 22 species; 50,000 to 100,000, 7 species. *Ammannia multiflora* and *Scoparia dulcis* are examples of the last group.

Weight of seeds seems to be more variable within families than might have been expected. The Gramineae, Leguminosae, Euphorbiaceae, Convolvulaceae and Compositae exhibit much diversity. The Polygonaceae, Onagraceae and Scrophulariaceae have uniformity of seed weight. The Elatinaceae and Hydrophyllaceae are noted for their minute seeds. The highest total weight per plant is found in *Coix lachryma-jobi* with 129.320 g.

It is of interest to compare the seed weights and seed numbers recorded in this study with those published by Pammel and King (1910), Ottawa Laboratory (1929), Korsmo (1930), and Stevens (1932, 57). There appear to be only three species reported in all the listings (Tables 2 and 3). For *Polygonum hydropiper,* the

TABLE 2: WEIGHT IN GRAMS OF 1000 SEEDS OF TWO SPECIES AS FOUND BY FIVE WORKERS

Worker	*Polygonum hydropiper*	*Portulaca oleracea*
Korsmo (1930)	2.500	—
Pammel and King (1910)	1.100	—
Ottawa Laboratory (1929)	2.250	—
Stevens (1932, 1957)	1.650	0.130
Datta and Banerjee	1.700	0.870

TABLE 3: NUMBER OF SEEDS PER PLANT IN THREE SPECIES FOUND BY THREE WORKERS

Worker	*Polygonum hydropiper*	*Portulaca oleracea*	*Setaria glauca*
Korsmo (1930)	385	—	850
Stevens (1932, 1957)	3,300	52,300	6,420
Datta and Banerjee	2,260	2,613	896

seed weight and seed number agree in the main with those given by Stevens. Korsmo's figure for seed number of *Setaria glauca* agrees with the present finding. The figures obtained by other workers are either higher or lower for *Portulaca oleracea*. This indicates the need for comprehensive studies of the seed habits of both temperate and tropical weeds. Pending such work, it will not be worth while to speculate further on this point.

Seed weight and seed number are two factors in the success of a weed species, and the length of time needed to complete growth is also important. Survival of annuals and perennials in a field will depend upon cultivation, and a few species may often remain in a field that has been tilled to exterminate weeds. In these circumstances, the degree of success of the cultivation is determined mostly by the seed production of those plants which survive.

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WEED MOVEMENT AND DISTRIBUTION IN A GRAZED TROPICAL PASTURE[1]

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Summary

The importance of the ecological approach to pasture research was illustrated by data relating environmental parameters to weed species distribution patterns and by the recognition of certain species as reliable indicators of sward condition. Of the more dominant weed species studied, the *Paspalum conjugatum* - *Setaria geniculata* association showed a very marked adaptation to the tops of the slopes. This corresponded closely with the gradient of soil depth going down the slope. *Commelina diffusa,* located toward the valley bottom, was closely related to soil pH. The other annual weed, *Erechtites hieracifolia,* exhibited a more varied distribution pattern which was related closely to total soil nitrogen and soil moisture. The more woody perennials, *Lantana camara, Melastoma malabathricum, Stachytarpheta urticaefolia* and *Elephantopus mollis,* all showed distribution patterns closely related to water extractable soil silica, among other environmental parameters. The weed species that appeared to be more sensitive to sward condition were: *Elephantopus mollis, Cuphea carthagenensis, Psidium guajava, Lantana camara* and the *Paspalum conjugatum* - *Setaria geniculata* association.

INTRODUCTION

Ecological techniques to aid in species evaluation and management can be important tools in pasture research. New or improved pasture species have been moved from sites of origin to regions and areas of superficially similar conditions, sometimes resulting in failure and losses of valuable plant materials. Detailed knowledge of some of the more important environmental factors which influence adaptation of species could help in finding particular niches where these species could be successful. At the same time, however, it is important to know those factors which influence weed distribution and movement in improved pastures, and to determine how these weeds influence improved pasture plants.

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[1] Jour. Series No. *1589* of the Hawaii Agricultural Experiment Station. Part of a thesis presented by the senior author in partial fulfilment of the Ph.D. degree in Agronomy at the University of Hawaii.

This paper reports on an approach to measurement of factors which influence weed competition in grazed, aerially-sown pastures on steep wetlands in Hawaii.

MATERIALS AND METHODS

A detailed study of the effects of environmental factors on species distribution patterns and seasonal fluctuations in sward dominance of species revealed some interesting relationships between such factors, certain weed distribution patterns, and the value of certain species as indicators of sward condition. This study took place on the island of Kauai, Hawaii, at an elevation of 180 m, with an annual rainfall of 2300 mm. The site is a steep-sided, 16 ha valley which was previously secondary forest. The valley runs approximately east and west; consequently, the slopes are oriented facing north and south, respectively. The original jungle vegetation was described by Motooka, Saiki *et al.* (1967). The area was treated with two separate applications of 4.48 kg/ha of fenoprop at a six-month interval. After sufficient time for kill or desiccation, a series of fires were used to prepare a suitable seedbed for aerial sowing of improved pasture species (Motooka, Plucknett *et al.,* 1967). The most important pasture species present were green panic (*Panicum maximum* var. *trichoglume*), pangolagrass (*Digitaria decumbens*), greenleaf desmodium (*Desmodium intortum*) and stylo (*Stylosanthes guyanensis*). Following a nine-month establishment period, grazing began; subsequently, vegetation and environmental data were collected along valley transects.

Environmental data collected included: soil moisture, pH, soil nutrients, temperature at the soil surface, vertical slope (down the slope) and horizontal slope (across the slope). Vegetation data included estimates of contribution to total dry matter production of improved species ('t Mannetje and Haydock, 1963) and dominance of weed species along belt transects across the valley profile. Dominance was measured by presence or absence of a particular species, expressed as presence within a given number of quadrats at each sampling date. These vegetation samples were taken over three years before and after each grazing period. The weed species studied were: sour paspalum (*Paspalum conjugatum*), knotroot foxtail (*Setaria geniculata*), spreading dayflower (*Commelina diffusa*), American burnweed, also called fireweed in Hawaii (*Erechtites hieracifolia*), Hawaiian elephantfoot (*Elephantopus mollis*), nettleleaf vervain (*Stachytarpheta urticaefolia*), lantana

(*Lantana camara*), Banks melastoma (*Melastoma malabathricum*), tarweed cuphea (*Cuphea carthagenensis*), and guava (*Psidium guajava*) (Anon., 1971).

Data collected were analysed using multiple regression techniques.

RESULTS AND DISCUSSION

SPECIES-ENVIRONMENTAL FACTOR RELATIONSHIPS

Multiple regression analyses enabled sorting of complex data on environmental and vegetation components. Environmental

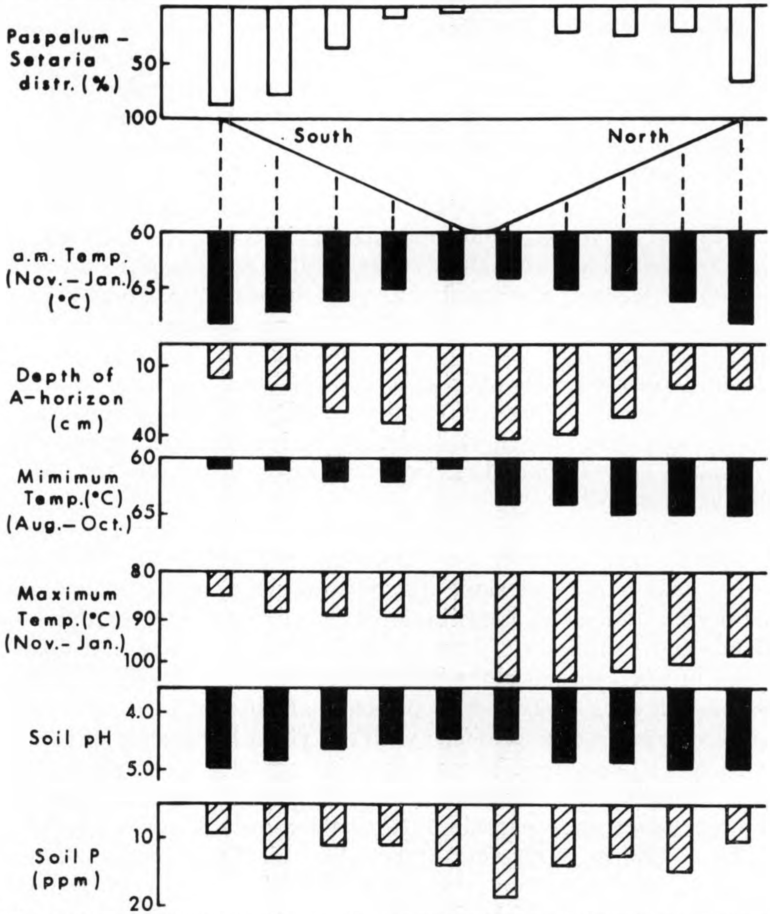

Fig. 1: The distribution of Paspalum conjugatum *and* Setaria geniculata *on north and south slopes, as influenced by environmental factors.*

factors were placed in order of importance in determining a particular species distribution pattern. It must be explained before further discussion that, owing to the lower degree of reliability and consistency of the data involving the temperature at the ground surface, the importance of this parameter, even though evident from the analysis, will not be over-emphasized. More credit will be given to soil parameters whose properties were studied in more detail and are considered statistically more reliable.

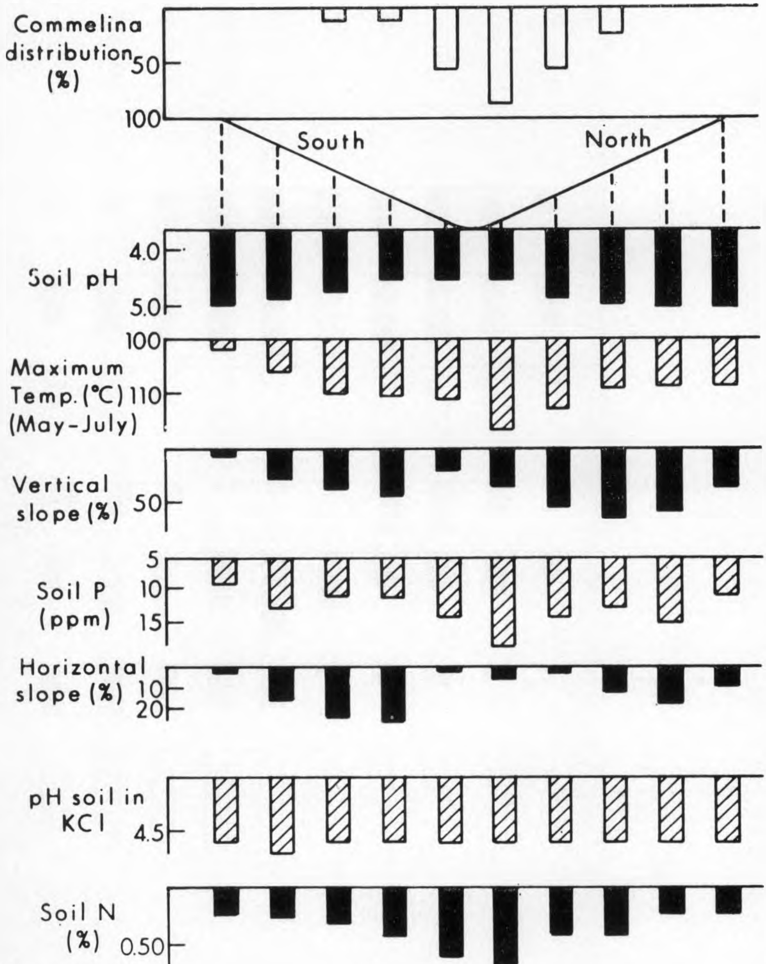

Fig. 2: The distribution of Commelina diffusa *as influenced by environmental factors.*

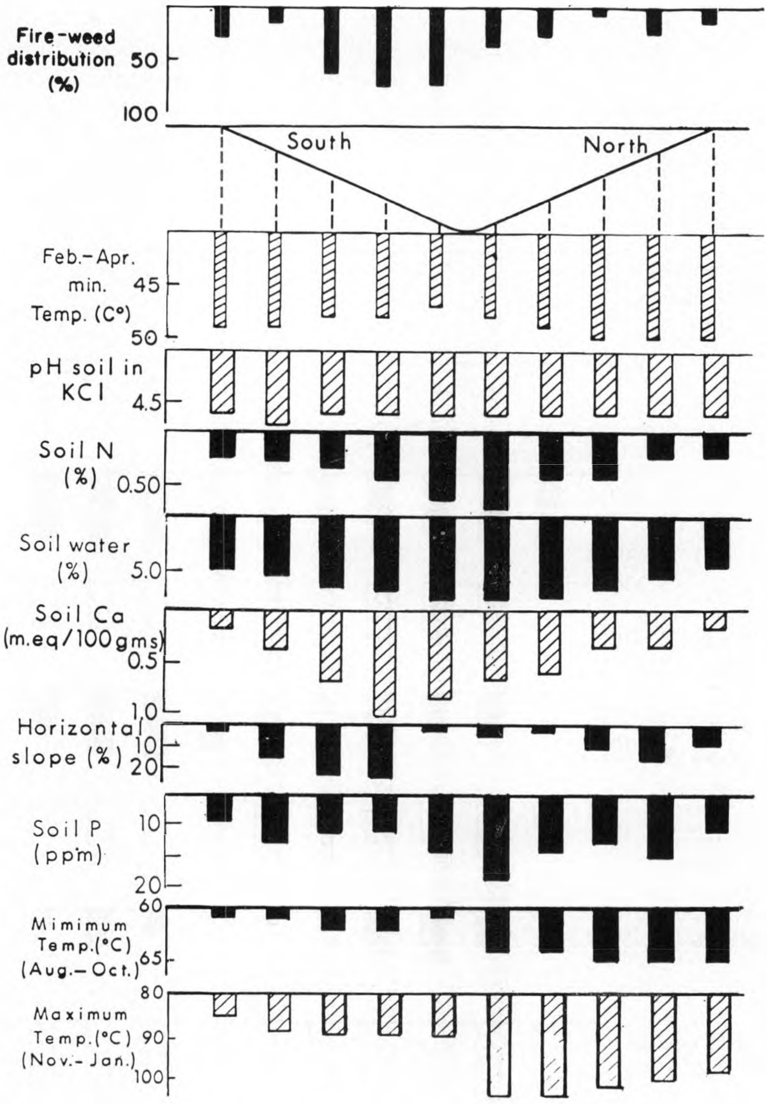

Fig. 3: Distribution of fireweed (Erechtites hieracifolia) *as influenced by environmental factors.*

Paspalum-Setaria Association: This particular weedy grass association exhibited a marked pattern. It was found predominantly at the top of the slopes and ridges where the moisture and nutrient status was low (Fig. 1). From the regression analysis it appears that the environmental factor most influencing such a distribution pattern was the morning temperature at ground surface during the winter months. Such regression analysis removes much of the variation with the extraction of the first factor and leaves the remaining factors contributing very little to the overall variance. It is felt that, from Fig. 1, a factor like soil depth more reliably relates to the distribution pattern for this particular species association.

Commelina diffusa. Figure 2 shows the typical distribution pattern across a valley transect. This weed is found in association with such improved forage species as green panic and greenleaf desmodium toward the valley bottom. In this environment soil pH, phosphorus and total nitrogen seem to best relate to this pattern of distribution. It should also be pointed out that valley bottoms were high moisture areas, a factor which would favour this plant.

Erechtites hieracifolia. This short-lived annual which appears after land clearing or overgrazing is inclined to grow in the more favourable situations of the lower slopes. After the variance explained by the minimum daily temperature at the ground surface during the February-April period is removed, such soil parameters as pH in potassium chloride, soil nitrogen, soil moisture and soil calcium influence the species distribution pattern significantly (Fig. 3).

Elephantopus mollis. From Fig. 4 it is evident that this perennial weed is located toward the top of the slopes and on ridge tops. In the valley it appeared to be more adapted to the south slope. Apart from the strong correlation between the distribution pattern and daily maximum May-July and daily minimum November-January temperatures at ground surface, there is an inverse correlation with vertical slope, soil moisture and depth of the soil A-horizon, and a positive correlation with soil pH.

Stachytarpheta urticaefolia seems to be more adapted to the poorer soils of the upper slopes and ridge tops (Fig. 5). It seems that, apart from the February-April daily afternoon temperature at the ground surface, the horizontal slope, water extractable soil silica and soil pH have most influence on the distribution pattern of this weed species.

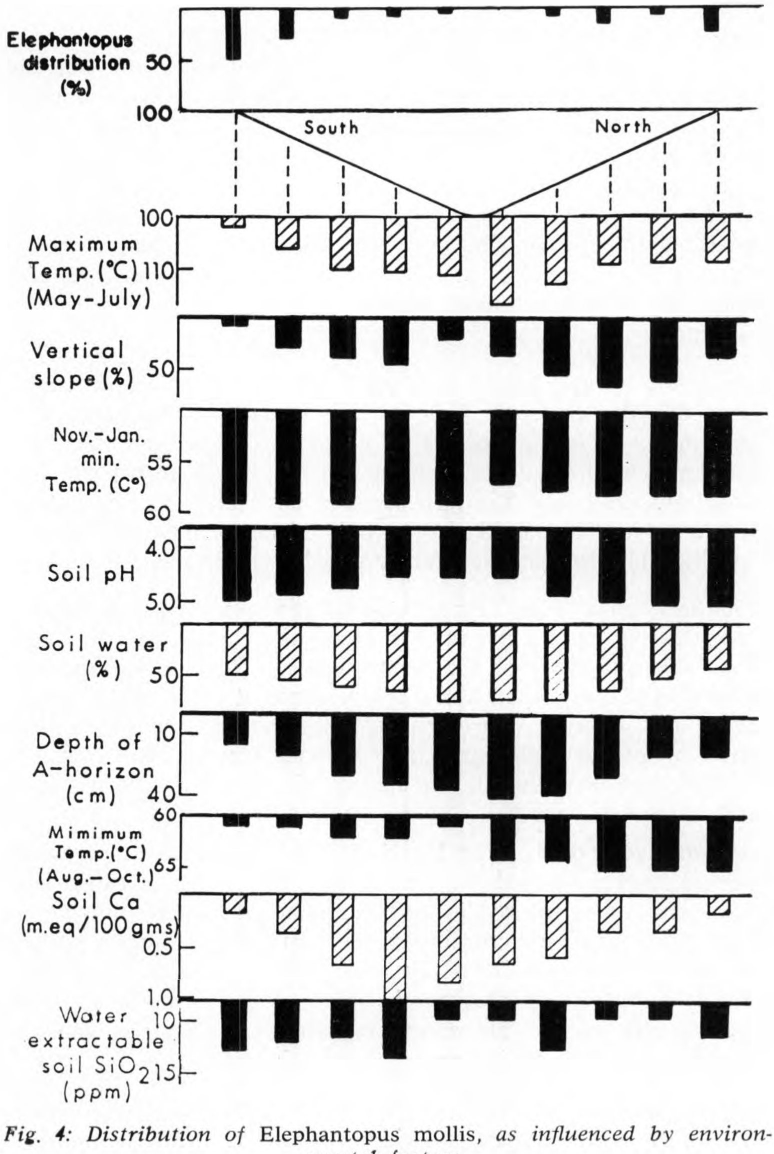

Fig. 4: Distribution of Elephantopus mollis, *as influenced by environmental factors.*

Lantana camara. Even though from Fig. 6 it is evident that there is no marked pattern of distribution of this species, it seems that lantana was more dependent on soil nutrient factors than the other weed species.

Melastoma malabathricum. From Fig. 7 it is evident that this brushy weed species is more adapted to conditions on the south slopes. The particular analysis used in this study shows Banks

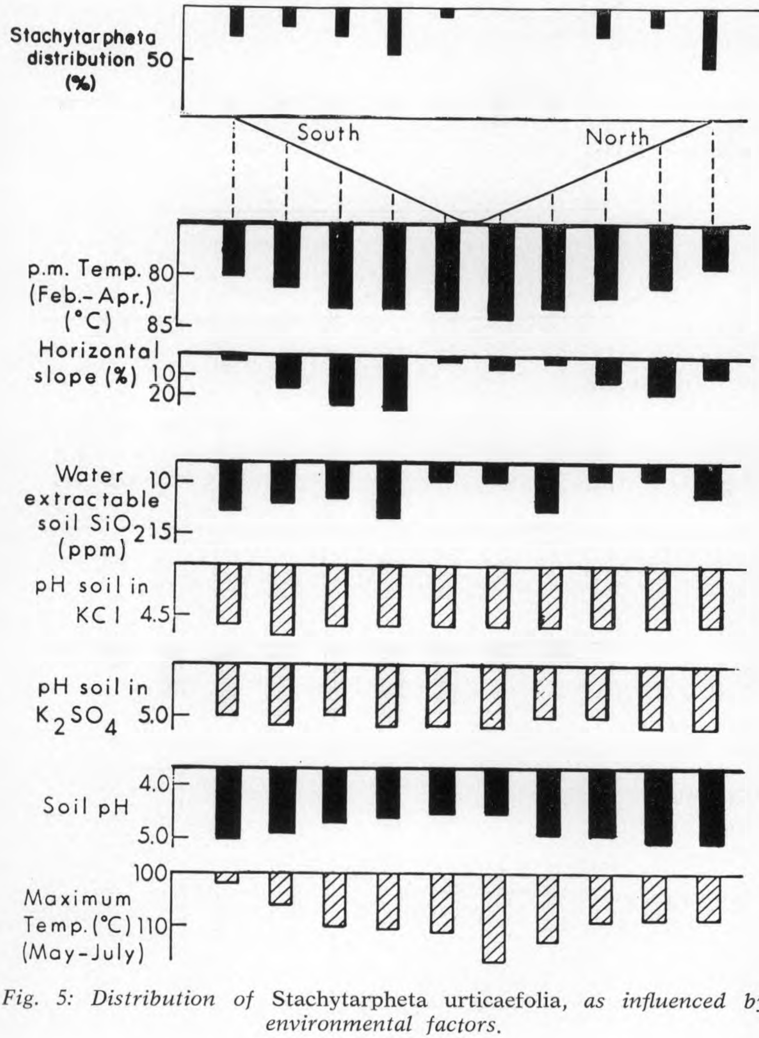

Fig. 5: Distribution of Stachytarpheta urticaefolia, *as influenced by environmental factors.*

melastoma to be influenced strongly by seasonal daily temperature variations at the ground surface. It is interesting to note that, in the case of the woody or semi-woody weed species (Hawaiian elephantfoot, lantana, nettleleaf vervain and Banks melastoma), the one environmental factor commonly influencing distribution patterns is the water extractable soil silica component. All of these species except the less woody Hawaiian elephantfoot exhibit a direct relationship with this factor. These soils are known to be low in extractable silicon, and crop responses to silicon have been recorded (Plucknett, 1972).

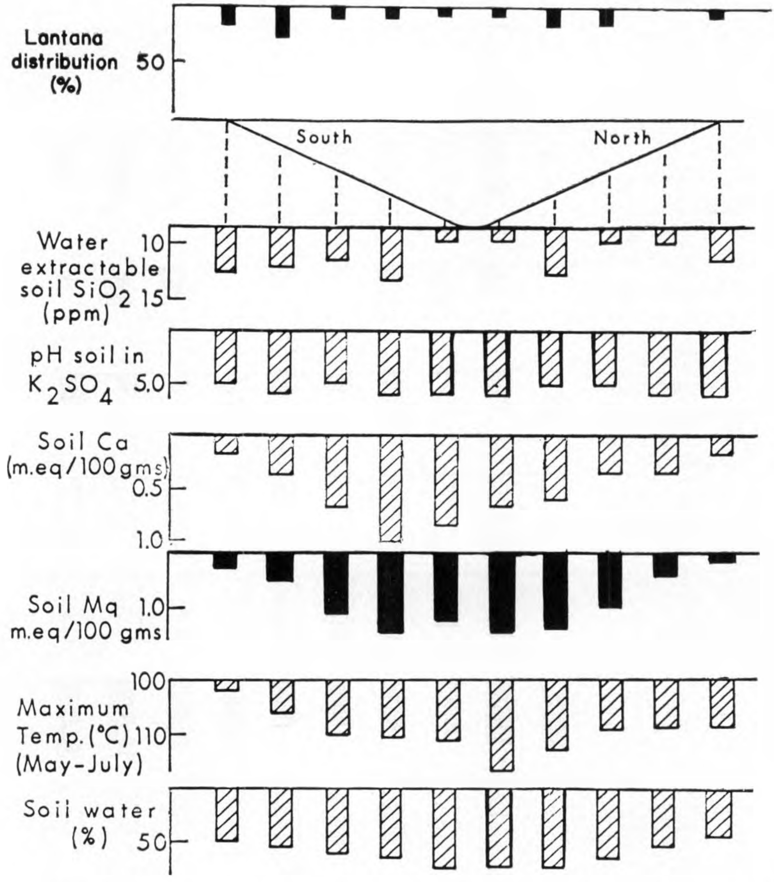

Fig. 6: Distribution of Lantana camara, *as influenced by environmental factors.*

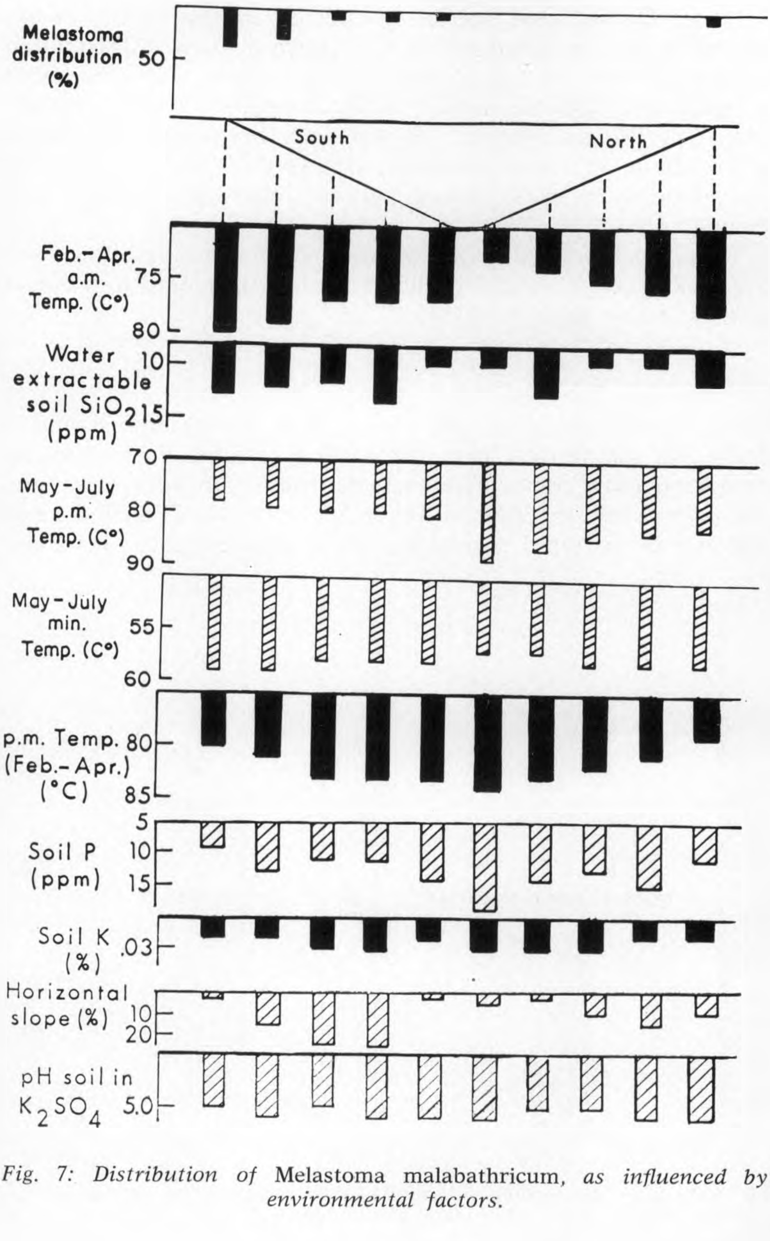

Fig. 7: Distribution of Melastoma malabathricum, *as influenced by environmental factors.*

Since all the weed species considered in this study, except spreading dayflower and American burnweed, show a distribution tendency toward the tops of the slopes and ridges, they were found in association with the similarly-adapted improved forage legume, stylo. Spreading dayflower and American burnweed were found where the more vigorous species such as green panic and green-leaf desmodium were heavily grazed, thereby exposing bare ground.

These dynamic aspects of the sward components, resulting from overgrazing and a natural decline in soil fertility, lead to the next section of this paper.

Sward Dynamics

By superimposing the influence of the grazing animal and a decline in soil fertility over the natural seasonal fluctuations in productivity and competitive characteristics of certain species, one can detect rapid successional trends within a sward. Such a trend will not be so rapid in regions where conditions for perennial

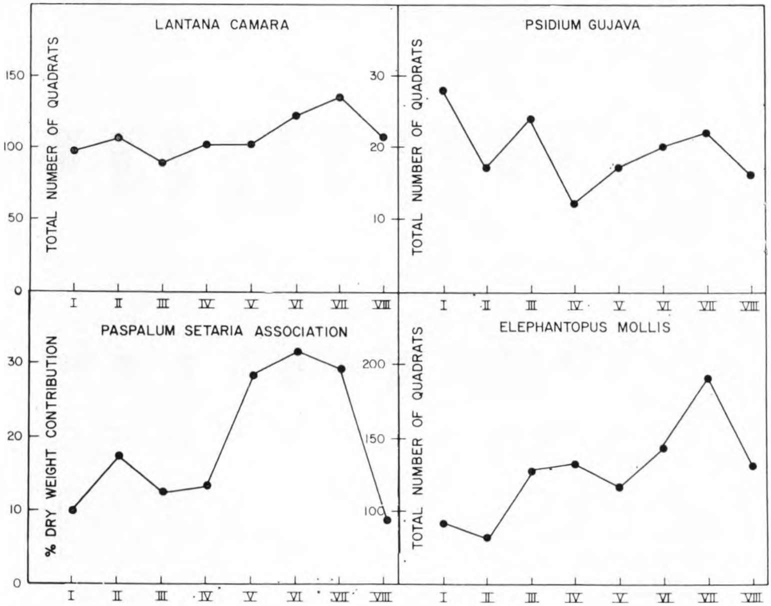

Fig. 8: Periodic fluctuations in dominance of weed species. Dominance of the Paspalum-Setaria *association is measured as estimated dry weight contribution. Dominance of the remaining species is measured directly in terms of presence in total quadrats sampled.*

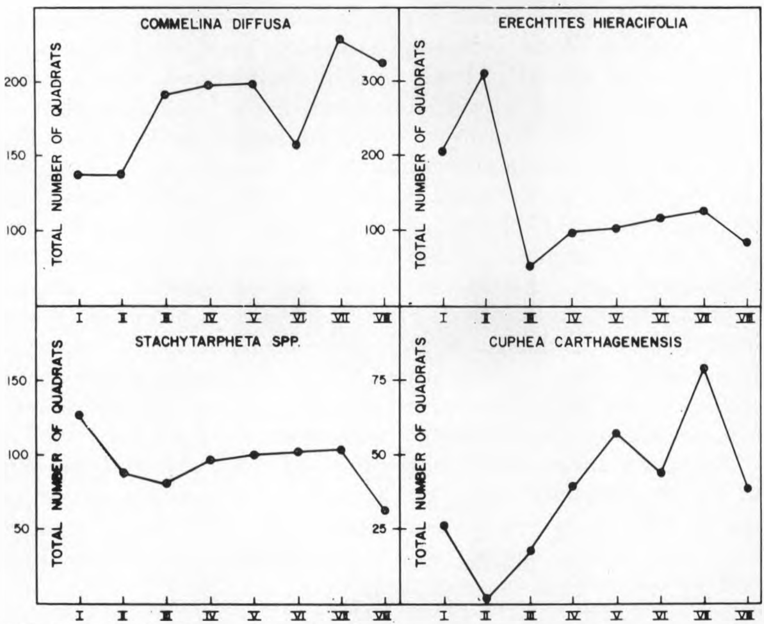

Fig. 9: Periodic fluctuations in dominance of weed species measured by the number of quadrats in which the species occur.

plant growth are not as conducive as those in the tropics. This is especially so in improved pastures. If a pasture is overgrazed or heavily trampled, exposing bare ground, and soil fertility is allowed to decline, weed species will quickly spread. Unless control measures are taken, the dominant components of a community will change rapidly. The recognition of this replacement of one type of plant cover by another is a necessary requirement in good range and pasture management.

Figures 8 and 9 show the fluctuation of the dominance of weed species from one sampling period to the next throughout the year. Samplings I, III, V and VII were taken before grazing, and II, IV, VI and VIII were after the grazing period. The corresponding dates for samplings I through VIII were as follows: March 1970, July 1970, September 1970, January 1971, April 1971, July 1971, December 1971 and July 1972. It can be seen from these figures that, as a general rule, there was an increase in dominance of the weed species from one sampling to the next up until sampling VII. This resulted from a natural decline in soil fertility because the pasture was not fertilized after sampling II. This also coincided with an increased overall grazing pressure under a rotational system. With increasing stress on the improved pasture species, weed species of lower fertility requirements and of lower acceptability to cattle were favoured in the ecological shift of dominant species. However, following sampling VII, the area was rested for four months through the wet season. This allowed the improved forage species to regain vigour and to force the less vigorous weed species out of the sward (Figs. 8 and 9). The reversal in dominance is especially evident in the case of the *Paspalum-Setaria* association, Hawaiian elephantfoot, tarwood cuphea, guava and lantana. Such weed species acted as reliable indications of a change in management favouring the improved forage species. As a practical tool a manager should look for such species to tell him of the sward condition before the successional process becomes economically irreversible.

An ecological approach to pasture and range research can help in the recognition of some of the more important environmental factors influencing species adaptations, as well as the realization that weed species can act as reliable indicators of the condition and productivity of a range or pasture.

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WEEDS IN NEW ZEALAND

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After scarcely 130 years of organized settlement, but with a range in latitude, diversity in topography, climate, and land use, and widespread modification or elimination of primitive vegetation and habitats, the weed flora in New Zealand is appreciable, varied in plant form, botanical affinities, and geographical origins.

Weedy indigenous species are few, mainly significant in sown grassland under high rainfall, but with some in indigenous tussock grassland, and aquatic habitats.

The adventive element is large, mainly European in origin, but with significant contributions from North, South and Central America, Australia, North and South Africa, eastern Asia, and tropical regions. Adventive weeds are troublesome in all modified or deliberately established plant communities and habitats.

The weed problem is dynamic, weeds which were significant (*e.g., Mentha pulegium*) are now of minor importance, while new weeds (*e.g., Nassella trichotoma*) have assumed importance with time.

New agricultural management and techniques, an increasing range of herbicides, aerial topdressing and herbicide application, and changing agricultural policies, all make for continuing change in the rural environment.

Increasing trade with a greater range of countries overseas allows more opportunity for accidental introduction of new weeds, and an increasing number of plant introductions for diverse purposes adds inevitably to the number of troublesome escapes from cultivation.

WEEDS OF CULTIVATED LAND

On fertile flats and ploughable rolling country under cash crops (cereals, process vegetables, tobacco, potatoes, linseed, etc.) and forage crops (brassicas, mangolds, etc.), free-seeding annuals and vegetatively-reproducing perennials are troublesome.

Widespread important annuals are *Amaranthus hybridus, Brassica campestris, Capsella bursa-pastoris, Chenopodium album, Coronopus didymus, Fumaria muralis, Galium aparine, Juncus bufonius, Poa annua, Polygonum aviculare, P. convolvulus, P.*

persicaria, Senecio vulgaris, Sisymbrium officinale, Solanum nigrum, Sonchus oleraceus, Spergula arvensis, Stachys arvensis, Stellaria media, Urtica urens, Veronica persica.

Widely occurring but more locally troublesome annuals include *Anagallis arvensis, Anthemis arvensis, A. cotula, Aphanes arvensis, A. microcarpa, Atriplex hastata, A. patula, Cerastium glomeratum, Chenopodium murale, Crepis capillaris, Erigeron canadensis, E. floribundus, Erodium moschatum, Euphorbia helioscopica, E. peplus, Lapsana communis, Malva neglecta, M. parviflora, Matricaria inodora, M. matricarioides, M. recutita, Polygonum hydropiper, P. lapathifolium, Ranunculus parviflorus, Sisymbrium orientale, Taraxacum officinale, Veronica arvensis, Vulpia bromoides,* and *V. myuros.*

In drier eastern South Island districts, a further group of annuals are troublesome, including *Amsinckia calycina, Avena fatua, A. persica* (Canterbury), *Calandrinia compressa* (Marlborough), *C. menziesii, Erodium cicutarium, Fumaria officinalis, Lactuca serriola, L. serriola* var. *integrata, Lamium amplexicaule, Lithospermum arvense, Myosotis arvensis, Navarettia squarrosa, Phalaris minor, Poa infirma, Silene gallica, Solanum sarrachoides, Thlaspi arvense,* and *Viola arvensis.*

Widespread troublesome perennials are *Agropyron repens, Cirsium arvense, Rumex acetosella, R. crispus, R. obtusifolius,* and *Trifolium repens.* In low rainfall South Island localities, the rhizomatous grasses, *Agropyron repens, Agrostis gigantea, A. tenuis, Arrhenatherum elatius* var. *bulbosum, Festuca rubra* ssp. *commutata, Hocus mollis* and *Poa pratensis,* with *Achillea millefolium,* constitute a major problem; locally troublesome are *Convolvulus arvensis, Cardaria draba, Linaria vulgaris, Silene vulgaris,* and *Sonchus arvensis.*

In northern North Island and Nelson district, additional species, including warm region grasses, are characteristic and troublesome. These include *Amaranthus lividus* (Waikato), *A. retroflexus* (occasional), *Antirrhinum orontium* (Nelson and Marlborough), *Calandrinia compressa* (Nelson), *C. menziesii* (Nelson), *Chenopodium ambrosioides* (North Island), *C. pumilio, Datura stramonium, Digitaria sanguinalis, Echinochloa crus-galli* and allies, *Eleusine indica* (North Island), *Galinsoga parviflora, Kickxia elatine* (Nelson), *Modiola caroliniana, Panicum capillare, P. dichotomiflorum, Paspalum dilatatum, P. paspaloides* (North Island), *P. vaginatum* (North Island), *Portulaca oleracea, Setaria lutescens, S. verticillata,* and *S. viridis.*

Nurseries and domestic gardens have the weeds typical of their districts, sometimes with additional species, including *Aegopodium podagraria, Allium triquetrum, Amaranthus deflexus, Calystegia sepium* agg., *Campanula rapunculoides, Cyperus rotundus* (North Island, Nelson), *Oxalis latifolia* (North Island, n. South Island), *O. pes-caprae* (North Island, Nelson), *Rorippa sylvestris, Symphytum* × *uplandicum, Ranunculus ficaria,* and *Salpichroa origanifolia* (North Island, Canterbury-local).

WEEDS OF SOWN GRASSLAND

Sown originally with *Dactylis glomerata, Lolium perenne,* and *Trifolium repens,* with ancillary pasture species, these grasslands have replaced extensive areas of indigenous forest and tussock grassland; they occur over a range of topography and fertility, from rich river flats to poor third-class hill country.

INDIGENOUS WEEDS

The ferns, *Pteridium aquilinum* var. *esculentum* and *Paesia scaberula,* with the woody *Leptospermum ericoides* and *L. scoparium* are widely occurring and major problems; alone, or in combination, or with indigenous shrubs (secondary or reversion growth), or with woody adventive weeds, they compete with, and over extensive areas of poor hill country under high rainfall, have replaced sown grassland.

Species of *Coprosma, Cyathodes,* the toxic *Coriaria arborea* and *C. sarmentosa,* and *Helichrysum aggregatum,* are widely occurring and locally troublesome shrubby weeds on hill country. *Pomaderris phylicifolia* var. *ericifolia* forms heath-like communities on dry North Island hills, and *Cassinia fulvida, C. leptophylla,* and *Olearia solandri* are troublesome on dry coastal hills in lower North Island and Marlborough.

The sprawling, semi-woody, bur-fruited *Acaena anserinifolia* and *A. novae-zelandiae* are troublesome locally on hill country, as also is the stinging *Urtica ferox.*

The robust *Cyperus ustulatus* and strongly rhizomatous *Carex coriacea, C. geminata,* and *C. lessoniana* are persistent in wetter pasture, as also the tufted sedges, *Carex comans, C. dipsacea, C. flagellifera,* and *C. testacea;* the leafless rushes, *Juncus australis, J. gregiflorus, J. pallidus,* and *J. sarophorus,* are widespread and troublesome in damp grassland.

ADVENTIVE WEEDS

Although dense swards on high-fertility land resist weed invasion, both poaching and hard grazing with drought allow weeds entry, including *Anthoxanthum odoratum, Bromus mollis, Carduus nutans, C. tenuiflorus, Cerastium holosteoides, Cirsium vulgare, Coronopus didymus* (causes feed flavours in dairy produce), *Crepis capillaris, C. taraxacifolia, Holcus lanatus, Hordeum murinum, Hypochaeris radicata, Juncus effusus* (often with indigenous leafless species), *Leontodon taraxacoides, Orobanche minor* (parasitic on a range of non-grassy species), *Plantago lanceolata, Ranunculus acris, R. sardous, Rumex crispus, R. obtusifolius, Senecio jacobaea,* and *Taraxacum officinale.* Locally, species as *Cryptostemma calendula* (North Island), *Juncus tenuis, Mentha pulegium* (decreasing), *Oenanthe pimpinelloides* (North Auckland), and *Ranunculus flammula* (Auckland Province), are troublesome.

Decreasing sward density, due to lower fertility on hill country, or to a low rainfall regime, often with poor management, allows entry of a range of herbaceous and woody weeds.

In drier South Island districts, sown grassland is commonly invaded by, and replaced with swards dominated by less desirable, weedy species — *Agrostis tenuis, Anthoxanthum odoratum, Festuca rubra* ssp. *commutata, Notodanthonia* spp., *Poa pratensis,* with *Achillea millefolium* and *Rumex acetosella.* Associated are many annuals, including *Aira caryophyllea, Aphanes arvensis, A. microcarpa, Bromus diandrus* (fruits cause pelt damage), *B. mollis, B. tectorum, Cerastium glomeratum, Crepis capillaris, Hordeum murinum* (fruits cause pelt damage), *Hypochaeris glabra, Myosotis arvensis, M. discolor, Trifolium arvense, T. dubium, T. glomeratum, T. striatum, Veronica arvensis,* and *Vulpia* spp. Longer lived weeds include *Acaena ovina, A. ovina* × *anserinifolia, Carduus nutans, C. pycnocephalus* (local), *C. tenuiflorus, Cirsium arvense, C. vulgare, Echium vulgare, Erodium cicutarium, Hieracium pilosella, H. praealtum, Hypochaeris radicata, Hypericum perforatum, Marrubium vulgare, Nassella trichotoma, Orobanche minor,* and *Stipa variabilis* (local — fruits cause pelt damage), with the shrubby *Cytisus scoparius, Rosa rubiginosa,* and *Ulex europaeus.*

In parts of North Island, swards are invaded, and sometimes largely replaced by grasses which could be considered weeds, including *Agrostis tenuis, Axonopus affinis, Cynodon dactylon, Dicanthium annulatum, Eragrostis elongata, Notodanthonia* spp.

(often fire-induced), *Pennisetum clandestinum, Sporobolus africanus, Stenotaphrum secundatum,* and *Themeda triandra.*

Additional to the indigenous ferns, *Paesia* and *Pteridium,* and woody weeds, important herbaceous weeds of hill country grassland in higher rainfall districts include *Carduus acanthoides, C. nutans, C. tenuiflorus, Carex longebrachiata* (Auckland Province, near Wellington), *Cirsium arvense, C. palustre, C. vulgare, Chrysanthemum leucanthemum, Digitalis purpurea, Erechtites atkinsoniae* (n. North Island, increasing in s. North Island), *Eupatorium adenophorum* (Auckland Province — gall insect introduced for control), *Phytolacca octandra* (North Island, Banks Peninsula), *Senecio jacobaea,* and *Silybum marianum.* The rhizomatous *Pennisetum macrourum* and toxic *Homeria breyniana* are significant, but localized.

Under higher rainfall (> 100 cm), adventive woody weeds are significant, either alone or with indigenous weeds. Widely occurring and common species are *Cytisus scoparius, Erica lusitanica, Hypericum androsaemum, Leycesteria formosa, Rosa rubiginosa, Rubus fruticosus* agg., *R. laciniatus, Sambucus nigra,* and *Ulex europaeus.* Throughout, but more localized, are *Berberis glaucocarpa* (*B. vulgaris* auct. N.Z.), *Buddleia variabilis, Crataegus monogyna, Cytisus monspessulanus, Lupinus arboreus* (coastal), and *Lycium ferocissimum* (coastal).

Significant, but more locally distributed woody weeds include *Acacia armata* (Auckland Province), *A. dealbata, Berberis darwinii, Erica arborea* (North Island), *E. baccans* (North Auckland), *E. caffra* (North Island), *Hakea gibbosa* (Auckland Province), *H. salicifolia* (Auckland Province, Nelson district), *H. sericea* (Auckland Province, Nelson district), *H. suaveolens* (Auckland Province), *Lantana camara* (North Auckland), *Osteospermum moniliferum* (North Auckland, Banks Peninsula), *Oxylobium callistachys* (North Auckland), *Pinus radiata* (pumice land, central North Island), *Psoralea pinnata* (Auckland Province), *Pultenaea daphnoides* (North Auckland), *Ribes glutinosum* (Marlborough, Canterbury), *Robinia pseudoacacia* (Auckland Province), *Rubus illecebrosus* (North Auckland, Coromandel), *Solanum marginatum* (North Island, n. S. Island), *S. mauritianum* (Auckland Province, Taranaki, Nelson), *S. sodomaeum* (coastal, n. North Island), and *Thymus vulgaris* (Central Otago).

Lucerne (*Medicago sativa*) crops of drier South Island districts are treated as a type of sown grassland; the troublesome weeds include *Achillea millefolium. Agrostis tenuis, Aphanes* spp., *Bromus diandrus, B. mollis, B. tectorum, B. unioloides, Capsella* *bursa-pastoris, Chenopodium pumilio* (increasing, Canterbury, Marlborough), *Cerastium glomeratum, Crepis capillaris, C. taraxacifolia, C. setosa* (Marlborough), *Erodium cicutarium, E. moschatum, Hordeum jubatum* (Central Otago), *H. murinum, Lolium perenne, Malva neglecta, Myosotis arvensis, M. discolor, Poa annua, P. infirma, P. pratensis, Silene gallica, Taraxacum officinale,* and *Trifolium repens.*

WEEDS IN MODIFIED INDIGENOUS TUSSOCK GRASSLAND

Significant weeds in modified tussock grassland are fewer, as compared with sown grassland, especially so in higher altitude *Chionochloa* communities. Many weedy species, especially annuals, are in fact useful components in the inter-tussock sward of lower altitude *Poa laevis/Festuca novae-zelandiae* grassland — examples include *Agrostis tenuis, Aphanes* spp., *Bromus* spp., *Cerastium* spp., *Erodium* spp., *Myosotis* spp., *Notodanthonia* spp., *Poa annua, Trifolium* spp., *Veronica verna,* and *Vulpia* spp.

Indigenous Weeds

The spiny, nodulated *Discaria toumatou,* as scattered shrubs or impenetrable communities, is regarded by some as troublesome, as also are several species of the spiny-leaved, herbaceous umbelliferous genus, *Aciphylla.*

Pteridium aquilinum var. *esculentum* and *Leptospermum* spp. invade locally, while fire-induced communities of *Celmisia coriacea* and *C. spectabilis* are a nuisance.

Adventive Weeds

On the central Volcanic Plateau, North Island, *Erica cinerea, E. tetralix,* and *Calluna vulgaris* (sown originally as bird cover), are widespread, and the silvicultural escape *Pinus contorta* var. *latifolia* (syn. *P. murrayana*) has established, forming forest-like communities in parts.

In South Island low tussock grassland, a greater range of significant weeds occurs. Herbaceous weeds include *Chamaepeuce afra* (North Canterbury), *Cuscuta epithymum* (parasitic on a range of indigenous species), *Hieracium aurantiacum* (spreading), *H. lachenalii* (spreading), *H. pilosella* (spreading; forms extensive patches, suppressing all inter-tussock species), *H. praealtum* (spreading; patch-forming), *Hypericum perforatum* (several insects introduced for control), *Nardus stricta* (Mackenzie country), *Nassella trichotoma* (Marlborough, Canterbury, Otago; only weed with its own Act of Parliament — Nassella Tussock Act 1946), *Potentilla recta* (Marlborough), *Senecio jacobaea* (Marlborough, Canterbury), *Stipa variabilis* (Canterbury, Marlborough, North Otago), and *Themeda triandra* (Marlborough).

Of the woody weeds, *Rosa rubiginosa* is most widespread, very apparent following control of the rabbit pest. *Ulex europaeus* is scattered, but becomes less aggressive with increasing altitude above 550 m, while *Cytisus scoparius,* established locally, is showing ability to prove aggressive at higher altitudes, and will be increasingly troublesome in the future. *Larix decidua* has established locally, as has *Pinus sylvestris; P. contorta* var. *latifolia* is spreading locally, and causing concern. The culinary *Thymus vulgaris,* escaped from miners' camps, is increasing and troublesome in parts of Central Otago.

WEEDS OF AQUATIC HABITATS

Herbaceous aquatic weeds are causing increasing inconvenience and economic loss — stoppages of electric-power generating plants, impeding drains and water races, and retarding boating and other recreational activities. As overseas, the most serious weeds, with minor exceptions, are escapes from pond or aquarium culture.

Indigenous Weeds

The free-floating *Azolla rubra, Lemna minor,* and *Spirodela punctata,* are widespread nuisances on stock-water drains and slow-moving drainage channels.

The tuberous-rooted *Scirpus caldwellii, S. fluviatilis,* and *S. medianus,* and *S. lacustris* and *Typha orientalis* impede flow in water-races, drainage channels, and slow-moving streams, while species of *Myriophyllum* and *Potamogeton* are troublesome in some localities.

The toxic *Ranunculus rivularis,* responsible for stock losses, grows about swamps and streams.

Adventive Weeds

A woody element proves troublesome along streams and rivers, impeding water-flow and causing stream diversion; originally planted, several of the species concerned are used by catchment authorities for river control work, under an amendment to the Noxious Weeds Act 1950. *Salix fragilis* is widespread, with *S.*

atrocinerea and *S. cinerea* a problem in swamps and slow-moving streams. *S. babylonica* is a nuisance locally, with *Alnus glutinosa* more frequent in n. North Island but increasing in South Island localities.

The submerged weed group presents a major problem: *Ceratophyllum demersum* is the most troublesome in the Waikato hydro-electric lakes, causing power generation stoppages; *Egeria densa* is established in the Waikato, and locally elsewhere in the North Island; *Elodea canadensis* is widely established, troublesome in the Nelson lakes; *Lagarosiphon major* is especially troublesome in the Rotorua lakes, and a nuisance elsewhere in North Island and n. South Island; *Potamogeton crispus* is established in North Island and n. South Island, with *Ranunuculus fluitans* occurring throughout.

Eichhornia crassipes, setting seed in some infestations, is still persistent and troublesome in n. North Island after two decades of organized control, while *Salvinia hertzogii* is troublesome at Western Springs, Auckland, and appearing elsewhere.

Along streams, drains, and in shallow waters, significant weeds include *Alternanthera philoxeroides* (North Auckland), *Alisma plantago-aquatica, Apium nodiflorum* (North Island), *Aster subulatus* (n. North Island, increasing s. North Island), *Callitriche* spp., *Festuca arundinacea, Glyceria fluitans* agg., *G. maxima, Iris pseudacorus, Juncus articulatus, Ludwigia palustris* (North Island), *L. peploides* ssp. *montevidensis* (Auckland Province), *Myosotis caespitosa, Mimulus guttatus, Nasturtium microphyllum, N. officinale, Oeanthe aquatica* (Marlborough, Westland), *Phalaris arundinacea, Polygonum hydropiper, Ranunculus sceleratus* (toxic to livestock), and *Zizania latifolia* (North Auckland).

In deeper waters, other weeds are locally troublesome, including *Aponogeton distachyus* (both islands, nuisance in Lake Mahinapua), *Hydrocelis nymphaeoides* (Auckland Province), *Myriophyllum brasiliense* (Manawatu, Waikato; spreading), *Ottelia ovalifolia* (North Island).

Spartina alterniflora, deliberately planted in estuarine places from Auckland northwards, is spreading and considered a threat to wading bird habitats.

WEEDS OF INDIGENOUS AND ARTIFICIAL FOREST

The troublesome weeds of indigenous forest margins, clearings, and damaged remnants are mainly hedge or garden escapes, and include some weeds of high rainfall, hill country sown grassland.

Herbs are few, lianes and woody species the majority; fruits are dry and wind-dispersed, or succulent and bird-dispersed.

Widely occurring and troublesome species are *Acer pseudoplatanus, Berberis glaucocarpa, Buddleia variabilis, Crataegus monogyna, Hypericum androsaemum, Leycesteria formosa, Prunus avium, Rubus fruitcosus* agg., *R. laciniatus, R. phoenicolasius,* and *Sambucus nigra.*

The lianoid weeds, rampant, and capable of reaching the canopy and smothering marginal trees or occupying clearings include *Boussingaultia cordiflora* (n. North Island), *Clematis vitalba, Hedera helix, Ipomoea congesta* (n. North Island), *Lonicera japonica, Passiflora mollissima* (North Island, n. of South Island), *Senecio mikanioides, Solanum jasminoides,* and *Tropaeolum speciosum.*

In damaged North Island forest, especially where the shrub and ground layer has been modified or eliminated by cattle, dense communities of *Berberis darwinii, Solanum diflorum,* or *S. pseudocapsicum* dominate the shrub layer. The ground layer is sometimes invaded by *Iris foetidissima,* forms of *Solanum nigrum* or *S. nodiflorum,* or covered by mats of *Selaginella kraussiana* or the succulent *Tradescantia fluminensis.*

Depending on location, the weed problem of artificial conifer forests may be indigenous *Pteridium* and woody species, or adventive woody species, especially *Cytisus scoparius* and *Ulex europaeus,* or a combination of both (see under "sown grassland"). After establishment, marginal, or in clearings, windthrow or burned-over areas, and unplantable places, a range of bird- or wind-dispersed herbaceous weeds, indigenous and adventive, prove troublesome.

WEEDS OF WASTE AND UNTENDED LAND

Throughout, an appreciable area of such land exists — roadsides, riverbeds, railway reserves, vacant urban and suburban sections, etc.

Herbaceous and woody weeds, mostly adventive and characteristic of sown grassland are troublesome, and spread to adjacent occupied country.

Some species are more significant on roadsides than in other habitats, reducing visibility and creating a traffic hazard, these including *Cortaderia atacamensis* and *C. selloana* (Auckland district, Whangarei), *Foeniculum vulgare, Melianthus major* (North Island), and *Populus alba* var. *nivea* (originally planted for bank stabilization). Troublesome also on roadsides and in vacant sections about towns are garden escapes, as *Polygonum cuspidatum, P. polystachyum, P. sachalinense, Rumex sagittatus* (North Island, spreading n. South Island), and *Salpichroa origanifolia* (North Island); the colourful *Crocosmia* × *crocosmiflora, Gladiolus cuspidatus* (Auckland Province), and *Watsonia bulbillifera* (Auckland Province), are a nuisance, the corms and cormils dispersed by water in drains.

Widespread and toxic to humans and livestock is *Conium maculatum,* troublesome on roadsides, riverbeds, in vacant sections, about hedgerows and plantations and yards, and unfortunately confused with *Foeniculum vulgare* (non-toxic).

NEW HERBICIDES FOR WEED CONTROL IN DIRECT-SOWN AND TRANSPLANTED RICE[1]

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Summary

An advanced yield test, conducted from January to June 1971, showed that six new herbicides were adequately selective on direct-sown rice *(Oryza sativa* var. IR8). Five herbicides (6 treatments) applied 3 days after sowing presoaked seeds, and another compound applied at the early 2-leaf stage of barnyard grass *(Echinochloa crus-galli)* gave excellent control of barnyard grass and, except for CP-27502, provided adequate control of smallflower umbrella plant *(Cyperus difformis)*. The herbicide treatments resulted in an increase in rice grain yields (2932 to 4493 kg/ha), significantly higher than the untreated check. The herbicides, arranged in order of decreasing effects on grain yields, are as follows: CP-27502 (4.48 kg/ha) ⩾ AN-1232 (6.72 kg/ha) ⩾ MON-0843 (3.36 kg/ha) ⩾ Amchem 70-25 (2.24 kg/ha) ⩾ CP-27502 (6.72 kg/ha) ⩾ S-18797 (4.48 kg/ha) > S-18507 (4.48 kg/ha). There was no significant difference in the grain yields among the herbicide treatments, except that of S-18507 which gave significantly lower yield than the other herbicide treatments.

In another test, five herbicides (EMD 7060H at 3 kg/ha, U-27,267 at 2 and 3 kg/ha, BAY NTN 5006 at 2 kg/ha, S-18797 at 4 kg/ha, MBR 8251 at 2 kg/ha) were compared with a standard compound (benthiocarb at 3 kg/ha), on their effects as pre-emergence treatments in transplanted rice. All herbicide treatments increased grain yields (2.87 to 4.0 MT/ha) significantly over the control as a result of adequate control of barnyard grass and smallflower umbrella plant. Grain yields from treated plots were comparable with the yield from the weeded control. S-18797 at 4 kg/ha was rather toxic to rice, and the yield was significantly less than those from the other herbicides.

INTRODUCTION

The performance of a compound must be thoroughly investigated before it is recommended for use by farmers. Tests are conducted that include the following:

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[1] Jour. Ser. No. *1553* of the Hawaii Agric. Exp. Sta., Univ. of Hawaii, Honolulu, Hawaii 96822.

(a) Laboratory and greenhouse screening trials by chemical companies to determine if a compound can be "released" for further investigation by other research organizations.

(b) Field screening evaluations by university, government, and private research institutions to determine if the compound can be developed for certain specific crops.

(c) Preliminary and advanced yield tests on specific crops.

(d) Persistence and residue analyses.

The main objective in these studies is to find the best possible use of a compound on a particular crop for a given region and type of weed problem. Thus, field evaluations (steps b and c) are critical since the data obtained from these studies are used by the chemical companies in deciding future tests on a compound. Factors such as production costs, high toxicity to animals, and long residue persistence in soils or in plant and animal tissues are also emphasized in development programmes for all pesticidal compounds.

A co-operative research project between the International Plant Protection Center of Oregon State University and the University of Hawaii at the Kauai Branch Station includes field screening of compounds newly released by chemical companies (step b). Consequently, it is possible to conduct early and advanced yield tests (step c) on selective compounds chosen from the screening tests. Field screening for rice herbicides was first started during the later part of 1969. Since then several compounds have proven to be effective for pre-emergence weed control in transplanted and direct-sown rice. In these studies, the pre-emergence herbicides found selective on transplanted rice were the following: chloramben, delachlor, pronamide, and oxadiazon (Obien *et al.*, 1970), a granular formulation of the isopropyl ester of 2,4-D + urea and granular mixtures of 2,4-D and trifluralin or TCE-styrene (Obien *et al.*, 1971a). The compounds found selective on direct-sown rice were oxadiazon, benthiocarb, and MBR 8050 (Obien *et al.*, 1971b).

The results of experiments discussed here show the early performance of new herbicides for direct-sown and transplanted rice.

MATERIALS AND METHODS

In the screening tests a compound is usually applied at three stages of growth — preplant-incorporated, pre-emergence, and post-emergence — at 2 to 4 rates on direct-sown and transplanted rice (Obien *et al.,* 1973). This method allows accurate evaluation of the field performance of a compound. Based on weed control and crop safety, effective compounds were selected from the screening tests for use in replicated early advanced yield trials.

The experiments were conducted in a Hauula paddy soil (pH = 4.9 to 5.5; organic matter = 11 to 14%) at the Wailua Paddy Crop Experiment Station of the Kauai Branch Station. The field was prepared with a small hand tractor, and fertilized with urea (50 kg N/ha) just before the final harrowing. The plots were again fertilized with N, P and K (500 kg/ha of 7:30:20 mixture) at 50 to 60 days after planting. Plots were 2 by 3 m, and rice seeds or seedlings were planted 25 by 25 cm apart in seven rows. Barnyard grass (*Echinochloa crus-galli*) seeds (6 kg/ha) were broadcast uniformly over the plots just before sowing direct-sown rice and after planting transplanted rice seedlings. Herbicide treatments were applied in water spray solution of 200 l/ha with a CO_2-pressured hand spray boom. Granular herbicides were broadcast by hand. Diazinon was applied occasionally to control rice stem borers and grasshoppers.

Direct-sown Rice

Rice seeds (var. IR8) were presoaked for three days and planted on puddled soil. The seeds were dropped on the mud and not covered, to simulate broadcasting or aerial seeding in commercial planting. The field was drained but the soil was wet. Deep standing water was avoided because it affected germination of direct-sown rice and barnyard grass. Herbicide treatments (Table 1) were applied three days after sowing. The plots were irrigated (3 to 5 cm in depth) 2 days after application of herbicides. At two weeks the water level was increased (5 to 8 cm) and maintained throughout the growing season.

Transplanted Rice

Rice seedlings, 20 days old in dapog (soil-less) culture, were planted at 3 to 4 seedlings per hill. The plots were wet and flooding was avoided to allow good germination of barnyard grass. Herbicide treatments were applied five days after planting, when barnyard grass was at initial emergence. The field was flooded to 3 to 5 cm depth one day after treatment application; subsequent water management was the same as in direct-sown rice.

TABLE 1: EFFECTS OF SIX NEW HERBICIDES ON RICE AND BARNYARD GRASS

Wailua, Kauai. Spring 1971

Treatment[1] *(kg/ha)*	*Reduction in: (%)*	*Time of Rating (days after sowing)* Rice 13	Rice 20	Rice 50	Barnyard grass 13	Barnyard grass 20	Barnyard grass 50	*Grain Yield of Rice (kg/ha)*[2]
S-18507 (EC) 4.48	Stand	0	0	0	60	93	98	7135b*
	Growth	15	13	0	75	93	85	
S-18797 (EC) 4.48	Stand	0	0	0	100	100	100	7902ab
	Growth	15	13	0	100	100	100	
MON-0843 (EC) 3.36	Stand	0	8	0	100	100	99	8585a*
	Growth	30	15	0	100	100	85	
CP-27502 (EC) 4.48	Stand	0	0	0	80	85	93	8696a*
	Growth	0	0	0	80	50	45	
CP-27502 (EC) 6.72	Stand	0	0	0	90	95	93	8060a
	Growth	0	0	0	85	80	55	
Amchem 70-25 (EC) 2.24	Stand	0	5	0	98	98	98	8076a
	Growth	0	15	0	95	95	80	
AN-1232 (EC) 6.72	Stand	0	0	0	98	93	99	8628a*
	Growth	0	0	0	95	90	80	
Unweeded control	Stand	—	—	—	—	—	—	4203c
	Growth	—	—	40	—	—	—	

[1] EC = emulsifiable concentrate. All treatments were applied 3 days after sowing, except S-18507 which was sprayed at early 2-leaf stage of barnyard grass (9 days after sowing).

[2] Mean values followed by different letters are based on Duncan's multiple range test. Letters with an asterisk (*) indicate significance at the 1% level, otherwise the significance was at the 5% level. All herbicide treatments gave significantly higher yields (1% level) over the check. Grain yields were calculated at 14% moisture content.

Evaluation

Herbicidal effects on rice and weeds in both direct-sown and transplanted rice tests were evaluated at time intervals in order to identify the slow and fast acting compounds, the rate of recovery of rice and weeds, and residual activity of the herbicides. The rice plants which appeared vigorous or "normal" in growth at a specific observation time were rated subjectively as zero reduction in stand and growth; all other ratings were then based on such normal plants. In the transplanted rice test, evaluation was based on a weeded control treatment. The unweeded control was rated as zero reduction in weed stand and growth. Grain yields of rice, taken from five centre rows of each plot, were statistically analysed for significant variations based on Duncan's multiple range test.

RESULTS AND DISCUSSION

Direct-sown Rice

Weed Control

In general, the degree of weed control closely followed the trend observed in the screening tests. Control of barnyard grass by the six herbicides was excellent (Table 1); the number of weeds in the plots at harvest time was negligible. The relatively better weed control in this early advanced test compared with the screening tests may be accounted for by the earlier application of the treatments in the former (3 days after sowing) than in the latter (5 days after sowing).

S-18507 and S-18797 gave complete control of sedges and broadleaf weeds. MON-0843 also gave complete control of broadleaf weeds; the sedges were likewise controlled but few bulrush (*Scirpus juncoides*) were noted at 50 days after sowing, and these slightly increased at harvest time. However, the general weed population was too low to produce any detrimental effects on the yield. Barnyard grass plants treated with MON-0843 were short, purplish at the base, chlorotic, causing general weakness and death of the plant.

CP-27502 (4.48 and 6.72 kg/ha) was weak on the sedges; also, the residual activity was short since the sedge population increased rapidly after control of the barnyard grass. For example, control at 13 days after sowing was 85% while that at 50 days after sowing was only 35%. CP-27502 caused some twisting of the barnyard grass shoot and reduced root development, resulting in general weakness and death of the plant.

TABLE 2: EFFECTS OF NEW HERBICIDES ON TRANSPLANTED RICE AND WEEDS

Wailua, Kauai. Spring 1972.

Treatment[1] *(kg/ha)*	*Reduction in: (%)*	*Time of Rating (days after planting)* 22 *Rice*	22 *Barnyard grass*	90 *Barnyard grass*	22 *Sedge*	*Grain Yield of Rice (MT/ha)*[2]
Benthiocarb (G) 3	Stand	0	98	98	100	6.30ab
	Growth	0	50	—	100	
EMD 7060H (G) 3	Stand	0	95	100	100	6.76a
	Growth	6	90	—	100	
U-27,267 (WP) 2	Stand	0	98	100	100	6.50a
	Growth	0	95	—	100	
U-27,267 (WP) 3	Stand	0	100	100	100	6.53a
	Growth	4	100	—	100	
S-18797 (EC) 4	Stand	0	95	98	100	5.63b
	Growth	10	80	—	100	
BAY NTN 5006 (EC) 2	Stand	0	100	100	100	6.66a
	Growth	0	100	—	100	
MBR 8251 (WP) 2	Stand	0	100	100	100	6.63a
	Growth	0	100	—	100	
Control — Weeded	Stand	0	100	100	100	6.63a
	Growth	0	100	—	100	
Control — Unweeded	Stand	0	0	0	0	2.76c
	Growth	10	0	—	0	

[1] G = granular, EC = emulsifiable concentrate, WP = wettable powder.

[2] Values followed by different letters are significantly (1% level) different based on Duncan's multiple range test.

At the rates used, Amchem 70-25 (2.24 kg/ha) and AN-1232 (6.72 kg/ha) showed comparable activity on the sedges and broadleaf weeds. Smallflower umbrella plant (*Cyperus difformis*) was controlled, but bulrush was present in the plots at 50 days after sowing and slightly increased in number at harvest time. At rates lower than the above treatments, AN-1232 appeared to be less active than Amchem 70-25, particularly with respect to broadleaf weeds. Amchem 70-25 inhibited root development of barnyard grass.

Effect on Rice

Of the six compounds, only MON-0843 and Amchem 70-25 caused slight stand reduction (8 to 5%) of rice seedlings (Table 1). Two compounds, CP-27502 and AN-1232, did not cause any measurable toxicity to rice during the period from 13 to 50 days after sowing. However, based on visual observations, both these compounds caused slight reduction in root growth, but there was no pronounced yellowing, curling, or other visible injury to the leaves. Amchem 70-25 inhibited root development of rice which resulted in lodging of a few plants, some of which floated on the water at 10 to 15 days after treatment. This root injury must have contributed in 15% growth reduction; however, the seedlings recovered rapidly and normal growth was noted at 30 to 40 days.

MON-0843 caused slight leaf chlorosis, and early growth was reduced temporarily by about 30%. S-18507, applied at the early 2-leaf stage of barnyard grass, reduced rice growth by 15 to 13% during the first 2 weeks after treatment. The toxicity was manifested as leaf chlorosis, the old leaves and leaf tips showing the greatest injury. S-18797 (4.48 kg/ha) caused pronounced chlorosis of the lower portion of the seedlings; the chlorosis progressed upwards to the young leaves. If total loss of chlorophyll occurred, the seedling dried up and died. However, at the above rate of S-18797, only the lower third or half of the seedling exhibited this symptom; the upper portion appeared green and "normal". On the other hand, the barnyard grass seedlings emerged slightly yellowish and rapidly turned completely chlorotic at the early 1- to 2-leaf stage. This symptom and type of selectivity were very similar to those exhibited by MBR 8050 on rice and barnyard grass (Obien *et al.*, 1971b).

As far as could be ascertained visually, there was complete recovery of the rice plants at 50 days after sowing. Nevertheless, grain yields varied among a few of the seven treated plots; this suggested that certain yield components, possibly panicle size and grain weight, were affected by the herbicides. Among the herbicide treatments, only S-18507 gave yields significantly lower than the other six treatments; however, all the herbicide treatments yielded significantly higher than the untreated check. A thick stand of barnyard grass resulted in yield reduction of 41 to 51% in the untreated check, or a yield increase of 2932 to 4493 kg/ha owing to adequate weed control with the application of herbicides.

Transplanted Rice

Weed Control

The compounds used in the early advanced test were chosen for their effectiveness against barnyard grass and safety on transplanted rice. The two dominant weed species were barnyard grass and smallflower umbrella plant; other species present were bulrush, purple ammania (*Ammania coccinea*), and primrose willow (*Ludwigia octovalvis*). Evaluations at 22 and 90 days after planting showed that all the herbicides gave excellent weed control (Table 2). The six herbicides inhibited weed seed germination and emergence. The few weeds which had emerged at the time of treatment showed varying susceptibility symptoms. The effect of S-18797 was described earlier in the section on direct-sown rice. EMD 7060H caused extensive chlorosis of barnyard grass, which resulted in death of the plant when the leaf chlorophyll disappeared. Benthiocarb reduced root growth and caused slow drying of the leaves. BAY NTN 5006 and MBR 8251 caused rapid drying of leaves; young emerging seedlings were killed a day after treatment. U-27,267 had little post-emergence activity, but emerging seedlings showed poor root development and drying of shoots. It was clear from this experiment that the six herbicides applied pre-emergence or to emerging weeds resulted in excellent control of barnyard grass and sedges in transplanted rice.

Effect on Rice

The general toxicity symptoms on rice were similar to those exhibited by barnyard grass; however, all the six compounds caused no major toxicity to rice (Table 2). EMD 7060H and S-18797 caused slight temporary chlorosis of the lower leaves of rice seedlings. Early rice growth was slightly inhibited by these two compounds and by U-27,267 at 3 kg/ha. S-18797 was the most toxic; the rate used could be lowered to reduce toxicity to rice and would probably give sufficient weed control. On the other hand, U-27,267 at 2 kg/ha, benthiocarb, BAY NTN 5006, and MBR 8251 had no significant effect on rice growth.

Grain yield of rice was used as the principal measure of weed control and herbicide toxicity to rice. All of the herbicide treatments and the weeded control gave grain yields significantly higher than the unweeded control. Of the herbicide treatments, S-18797 gave significantly less yield than benthiocarb, EMD 7060H, U-27,267, BAY NTN 5006, and MBR 8251. This effect of S-18797 may be attributed to its inherent toxicity to rice, since this compound provided adequate weed control.

ACKNOWLEDGEMENTS

We gratefully acknowledge the financial support of the International Plant Protection Center (IPPC) of Oregon State University and the technical help of Larry C. Burrill, new product evaluation leader, of the same institution. We are also thankful for the financial support and/or free supply of herbicides from the following companies: Gulf Research and Development Company for S-18507 and S-18797; Monsanto Company for CP-27502 and MON-0843; Amchem Products for Amchem 70-25, Ansul Company for AN-1232, Kumiai Chemical Co. for benthiocarb, E. Merck for EMD 7060H, Upjohn Chemical for U-27,267, Chemagro for BAY NTN 5006, and 3M Company for MBR 8251. The assistance of Dimyati Nangju of the Kauai Branch Station is also sincerely acknowledged.

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THE USE OF BENTHIOCARB IN RICE CULTIVATION

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Summary

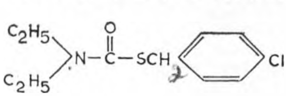
Benthiocarb is a highly valuable herbicide for rice. The application methods and present situation of its use in direct-sown and transplanted rice in Japan, Southeast Asia, Europe, Africa, U.S.A., Middle and South America are outlined. Application of 2 to 4 kg/ha benthiocarb at the 1- to 2-leaf stages and 3 to 5 days before sowing in water-sown rice, and application of 4 to 5 kg/ha benthiocarb immediately after sowing and of 4 kg benthiocarb + 2 kg/ha propanil at the 1- to 2-leaf stage in dry-sown rice, show excellent weed control without injuries to rice. In transplanted rice, both incorporation in soil of 4 to 6 kg/ha benthiocarb before transplanting and application of 3 to 4 kg/ha under flooded condition before or after transplanting give excellent weed control. In 1972 benthiocarb was applied to 45% of the total rice acreage in Japan.

INTRODUCTION

Benthiocarb has been produced by the Kumiai Chemical Industry Co. Ltd since 1965. In Japan it is used as a herbicide in rice and was applied to 45% of the total acreage of the rice fields in 1972. Benthiocarb has been developed as a herbicide to be used for dry-sown and water-sown rice, transplanted rice and upland crops in Japan, Korea, Southeast Asia, U.S.A., Middle and South America, Europe, Africa and other countries. The biological effects of benthiocarb have been reported on by Kimura (1971). The present report gives an outline of application methods.

CHEMICAL AND PHYSICAL PROPERTIES

Benthiocarb is a colourless, clear liquid, with a molecular weight of 257.8, soluble in organic solvents, and slightly soluble in water. Its chemical structure is as follows:



Acute oral toxicity (LD_{50}) is 560 mg/kg (mice), 1300 mg/kg (rats); acute dermal toxicity (LD_{50}) is 2900 mg/kg (rats); and subacute toxicity for 90 days maximum non-effect level is 240 ppm (rats), 600 ppm (dog).

APPLICATION METHODS

DRY-SOWN RICE

Japan

In Japan two methods of sowing dry-sown rice are used — strip sowing and broadcast sowing. From 30 to 40 days after sowing, the field is continuously conditioned to simulate the effect of rain on dry fields, and then irrigated.

(a) An overall application of 4 to 5 kg/ha benthiocarb emulsifiable concentrate (EC) is made just after sowing and up to the 1½-leaf stage of the grasses. In addition, it is recommended that 3 kg/ha of propanil be sprayed in anticipation of weed regrowth caused by the long dry period or abundance of the weeds themselves. This method inhibits, for about 30 days, the growth of barnyard grass (*Echinochloa crus-galli*), umbrella plant (*Cyperus difformis*), and finger grass (*Digitaria adsendens*).

(b) Application of a mixture of 4 kg/ha benthiocarb EC and 2 kg/ha propanil EC at the 1- to 2-leaf stage of rice (2- to 3-leaf stage of barnyard grass). Features of this method are high effectiveness to broadleaved weeds and barnyard grass in the 3- to 4-leaf stage development, and extension of the period of the residual effect. Occasionally, leaf scorching is caused when applied at the 3- to 4-leaf stage of rice, so it is recommended that application be carried out at the 1- to 2-leaf stage, or the 4- to 5-leaf stage of rice.

(c) Benthiocarb granule (3 to 4 kg/ha) is applied under flooded conditions within 10 days after the start of irrigation.

U.S.A.

In the south, an application of 3 to 4 kg/ha benthiocarb is made within 1 or 2 days after the first flush (before emergence). Benthiocarb shows conspicuous effectiveness on barnyard grass and sprangle top (*Leptochloa filiformis*).

Brazil

An overall treatment of 4 to 5 kg/ha is applied by tractor immediately after sowing.

Water-sown Rice

Japan

In Japan, pre-germinated seeds are broadcast under flooded conditions. It is necessary to drain the rice nursery for fixing roots on the third day and again three weeks after emergence.

(a) Three to five days before sowing, benthiocarb granule or EC (3 kg/ha) is applied to the soil under flooded conditions. The aim of this method is to inhibit weed emergence and to avoid damage to rice during emergence; treatment within 2 days before sowing is dangerous to rice.

(b) Application of benthiocarb granule or EC under flooded conditions at the 1- to 2-leaf stage of rice (the 2-leaf stage of barnyard grass). Benthiocarb is more selective between rice and barnyard grass when both are at the 1- to 2-leaf stage. Application of benthiocarb applied at or before the 2-leaf stage of barnyard grass gives successful control, and phytotoxicity to rice is avoided if applied after its 1-leaf stage. The feature of this method is that it kills the weeds at the early developing stage and controls successive weed emergence. In Japan, used 10 to 20 days after sowing, it is effective in controlling weeds for a sufficiently long period that a second application can be omitted.

(c) With treatment (a) above, to control weeds after a month's growth (corresponding to the 3- to 4-leaf stage of rice), an additional application of 3 to 4 kg/ha of benthiocarb granule is applied under flooded conditions.

Philippines

De Datta and Bernasor (1970) reported that treatment with 1.5 kg/ha of benthiocarb granule 6 to 8 days after sowing gave a completely selective control of weeds (barnyard grass and *Monochoria vaginalis*) in rice (variety IR-22) and increased yields to 6278 or 6192 kg/ha, as compared with 3024 kg/ha from untreated fields.

India

Have H. ten (1970) reported that treatment with 2 kg/ha benthiocarb 6 days after sowing resulted in a yield increase of 370 kg/ha more than from an untreated area.

Ceylon

S.D.I.D. Gunawardera (pers. comm.) states that treatment with 2 kg/ha of benthiocarb granule 6 days after sowing yielded 8625 kg/ha compared with 5718 kg/ha for untreated fields. This approximates a yield of 8743 kg/ha resulting from hand-weeding (twice).

Spain

Treatment with benthiocarb granule at the 1- to 2-leaf stage (11 days after sowing) in rice gave 98% control of barnyard grass and no crop injury was found; treatment with 1.5 to 4 kg/ha 3 days before sowing or 2 days after sowing decreased somewhat the number of rice seedlings, but gave no reduction in growth (Anon., 1972).

Colombia and Peru

The method adopted is application of 3 to 4 kg/ha benthiocarb EC 7 days after sowing under flooded conditions.

Transplanted Rice

Japan

In Japan there are two ways of transplanting rice. One method is to plant seedlings with 5 to 6 leaves by hand, and the other is to plant seedlings with 2½ to 3 leaves by machine 7 to 10 days before transplanting by hand. Where herbicidal control of weeds is involved, machinery planting is inferior to hand planting, because of the longer period of weed growth resulting from the comparatively shallow flooding and early planting; also, destruction of the treated soil layer by the machine is likely to result in crop injury. Consequently, to provide longer effectiveness and more safety to rice, better methods of treatment both before and after planting are proposed. Benthiocarb is applicable to these methods both for hand planted and machine planted rice.

(a) Soil incorporation before transplanting. This is done at final puddling; 4 to 6 kg/ha of benthiocarb granule or EC is spread under flooded conditions (water depth 3 to 5 cm) and then incorporated into the soil layer below 5 cm. It is important with this method not to miss the application time, and no reliable effect can be expected if there is surface drainage or overflow. This method is effective in controlling deep-rooted weeds.

(b) Soil surface treatment before planting. 3 to 4 kg/ha of benthiocarb granule is spread under flooded conditions after final puddling. It is again important with this method not to miss the time for treatment. Benthiocarb can be used on the day of transplanting rice.

(c) Soil surface treatment after planting. 3 to 4 kg/ha benthiocarb is applied from the day of transplanting up to the 1½-leaf stage of barnyard grass under flooded conditions. This method is used widely in Japan and gives good results in killing young weeds, and inhibiting the emergence of further weeds. Treatment later than the 2-leaf stage of barnyard grass is less effective.

(d) In the northern part of Japan, where weed growth continues much longer because of low temperatures, a second application 15 to 20 days after transplanting is necessary. However, for this second application, benthiocarb/simetryn granules are recommended.

Korea

Benthiocarb/simetryn granules have been commercially available since 1971. Treatment with this product is at the rate of 30 kg/ha 10 to 15 days after transplanting under flooded conditions.

Taiwan

Benthiocarb granule has been commercially available since 1972. The method is to apply 3 to 4 kg/ha 7 to 10 days after transplanting at the first cropping, and 5 to 7 days after transplanting at the second cropping.

Philippines

Several experiments at I.R.R.I. and B.P.I. have shown good results from the application of 1 to 3 kg/ha (as benthiocarb) of benthiocarb granule 10% and a mixture of benthiocarb 4% plus 2,4-D IPE 2% 4 to 10 days after transplanting. This method showed high herbicidal effectiveness and resulted in good yields (De Datta and Bernasor, 1970).

Indonesia

In 1970, application of 3 kg/ha to rice (variety IR-22) in the dry season 4 days after transplanting and at the 2- to 3-leaf stage in barnyard grass resulted in yields of 6100 and 6400 kg/ha compared with 3700 kg/ha from untreated areas (Lacsina, 1971).

India

Have H. ten (1970) reported yields of 4838 and 4556 kg/ha in experiments using 3 kg/ha benthiocarb 4 days after transplanting and at the 2- to 3-leaf stage of barnyard grass.

Spain

Application of 4 kg/ha benthiocarb granule 3 days after transplanting gave 95% control of weeds compared with untreated areas (Anon., 1972). No crop injury was found in 12 cm water depth 6 days after transplanting. The recommended method is to apply 4 kg/ha granule 7 days after transplanting.

PRESENT USE OF BENTHIOCARB

In Japan the rice field area in 1972 was about 2,560,000 ha. Of this 98% was transplanted (20% by machine) and the remaining was direct-sown. Benthiocarb was registered in 1969, and in 1972 it treated 45% of the area of transplanted rice and 37% of direct-sown rice. Four formulations of benthiocarb were used — *i.e.*, 10% granule, 50% EC, a 7% benthiocarb/6% chlornitrofen granule, and a 7% benthiocarb/1.5% simetryn granule.

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EFFICACY OF CHLOMETHOXYNIL IN RICE

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Summary

Chlomethoxynil was discovered and developed by Nihon Nohyaku Co. Ltd. and Ishihara Sangyo Kaisha Ltd., and evaluated at the experiment stations of the two companies in Japan in 1969-1972 for weed control in paddy rice. Chlomethoxynil applied 1 to 3 days before or 3 to 8 days after transplanting at rates of 2.1 to 2.8 kg/ha produced excellent weed control with good selectivity in transplanted paddy rice. Chlomethoxynil controlled a wide spectrum of weeds: barnyard grass, monochoria, false pimpernel, waterwort, toothcup, umbrella plant, narrowleaf waterplantain, slender spikerush and arrowhead. It caused occasional brownish discoloration of the leaf sheath of rice with no reduction in rice growth.

INTRODUCTION

Diphenylether herbicides such as chlornitrofen and nitrofen are the most commonly used for weed control in transplanted paddy rice in Japan, although the writers consider from their observations their level of herbicidal activity is inadequate. Chlomethoxynil, a new diphenylether herbicide, gives excellent weed control in transplanted paddy rice, having a broader spectrum of control, strong residual activity, an extended application period, and good selectivity. Chlomethoxynil also has the advantage of a low mammalian and fish toxicity. Its acute oral toxicity (LD_{50}) to mice is 33,000 mg/kg, and its sub-acute (90 days) oral toxicity to rats, maximum no-effect level, is 1,900 to 2,300 mg/kg. Fish toxicity with carps, TLM 48 hr is 1.2 ppm.

MATERIALS AND METHODS

The standard chlomethoxynil formulation, 7% granule, was used for evaluating its herbicidal efficacy in paddy rice. Wettable powder and emulsifiable concentrate were used for primary tests. Greenhouse studies to evaluate herbicidal characteristics were conducted at research laboratories. Field tests were conducted at research farms in Akita, Shiga and Fukuoka prefectures to evaluate the rate of chlomethoxynil required for weed control, the application period, the weed spectrum, and the selectivity to rice. The trials were generally carried out in two replications using 12 m^2 plots. The granular chlomethoxynil was applied by hand to the flooded field before or after transplanting of rice. The transplantings were carried out using 5- to 6-leaf stage seedlings in one series of tests (Table 1) and 2- to 3-leaf stage in other series (Table 2). Observations of weed control were made approximately 40 days after transplanting.

TABLE 1: WEED CONTROL WITH CHLOMETHOXYNIL APPLIED TO TRANSPLANTED PADDY RICE AT THREE LOCATIONS, 1970

(1 = no control, 10 = complete control)

*Location and Treatment**	*Rate (kg/ha)*	*Weed Control†* BY	*MO*	*BR*	*SP*	*AR*	*UM*
Shiga:							
chlomethoxynil —2	1.4	10	10	10	10	8	—
	2.1	10	10	10	10	8	—
3	1.4	10	10	10	10	8	—
	2.1	10	10	10	10	10	—
6	1.4	10	10	10	10	8	—
	2.1	10	10	10	10	10	—
10	2.1	8	4	10	10	8	—
	2.8	10	6	10	10	8	—
chlornitrofen 3	2.7	10	8	10	10	4	—
6	2.7	8	6	10	10	4	—
Akita:							
chlomethoxynil —3	1.4	10	10	10	10	—	10
	2.1	10	10	10	10	—	10
5	1.4	10	9	10	10	—	10
	2.1	10	10	10	10	—	10
10	2.1	9	9	10	10	—	9
	2.8	9	9	10	10	—	10
chlornitrofen 5	2.7	9	8	8	8	—	8
Fukuoka:							
chlomethoxynil —2	1.4	10	10	10	8	8	—
	2.1	10	10	10	10	10	—
4	1.4	8	8	10	10	10	—
	2.1	10	10	10	10	10	—
chlornitrofen 4	2.7	6	10	4	10	8	—

* —2 = applied 2 days before transplanting.
3 = applied 3 days after transplanting.

† BY = barnyard grass, MO = monochoria, BR = broadleaf weeds, SP = slender spikerush, AR = arrowhead, UM = umbrella plant.

RESULTS AND DISCUSSION

The herbicidal characteristics derived from the greenhouse studies are as follows. Chlomethoxynil is absorbed through the plumules, stems and leaves of weeds and not through their roots, and becomes active in a treated plant only when the plant is in light. Chlornitrofen and nitrofen also have these characteristics. In flooding application, chlomethoxynil has pre-emergence and delayed pre-emergence activities with a broad spectrum of control and strong residual activity, and it has good selectivity on transplanted rice. Chlomethoxynil may cause occasional brownish discoloration of the leaf sheath of rice with no reduction in rice growth. This discoloration is influenced by sunlight intensity and irrigation depth. In upland conditions, herbicidal activity of chlomethoxynil is susceptible to environmental conditions, especially soil humidity. In conclusion, it appears that chlomethoxynil possesses good characteristics for weed control in paddy rice.

Typical results of field tests are shown in Tables 1 and 2. The following conclusions could be drawn. Chlomethoxynil applied 1 to 3 days before or 3 to 8 days after transplanting at 2.1 to 2.8 kg/ha gives the best weed control in paddy fields with good selectivity. Weed species controlled with chlomethoxynil include

TABLE 2: WEED CONTROL WITH CHLOMETHOXYNIL APPLIED TO TRANSPLANTED PADDY RICE (2½-LEAF STAGE AT TRANSPLANTING) AT ISHIHARA RESEARCH FARM, SHIGA PREFECTURE, 1972
(1 = no control, 10 = complete control)

*Treatment**	*Rate (kg/ha)*	*Weed Control†* BY	*MO*	*BR*	*SP*	*AR*	*Rice Injury‡*
chlomethoxynil:							
—2	2.1	10	10	10	10	8	1
3	2.1	10	10	10	8	8	1
6	2.1	10	10	10	10	8	1
	4.2	10	10	10	10	8	2§
12	2.1	8	8	8	10	8	1
chlornitrofen:							
—2	2.7	8	10	6	10	8	1
3	2.7	6	8	8	8	6	1
6	2.7	6	8	10	10	4	1
12	2.7	4	8	8	8	4	1

* —2 = applied 2 days before transplanting.
3 = applied 3 days after transplanting.
† BY = barnyard grass, MO = monochoria, BR = broadleaf weeds, SP = slender spikerush, AR = arrowhead.
‡ 1 = no effect in rice, 10 = death of rice.
§ Only brownish discoloration of leaf sheath.

monochoria (*Monochoria vaginalis*), false pimpernel (*Lindernia pyxidaria*), waterwort (*Elatine triandra*), tooothcup (*Rotala indica*), chufa (*Cyperus microiria*), slender spikerush (*Eleocharis acicularis*), arrowhead (*Sagittaria pygmaea*), giant duckweed (*Spirodela polyrhiza*), barnyard grass (*Panicum crus-galli*), umbrella plant (*Cyperus difformis*), abunome (*Dopatrium junceum*) and narrowleaf water plaintain (*Alisma canaliculatum*).

Chlomethoxynil was also evaluated at many official experiment stations in 1970 and 1971 in Japan, and has been officially recognized as a promising herbicide for use with transplanted paddy rice.

WEEDS AND WEED CONTROL IN RICE IN NEW SOUTH WALES, AUSTRALIA

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Summary

The southern irrigation areas of New South Wales are the major rice-producing areas of Australia. Where crops are sown into a dry seedbed with a seed drill, barnyard grass *(Echinochloa* spp.) is the predominant weed. Heavy infestations may reduce yields by as much as 90%. Where rice is sown from the air into previously flooded bays, *Echinochloa* is rarely a problem. The most serious weeds in this situation are *Cyperus difformis* and *Damasonium minus*. Severe infestations of *C. difformis* may reduce yields by 44%. *Echinochloa* is controlled by post-emergence applications of either propanil or molinate, while *C. difformis* and *D. minus* are controlled with MCPA. Weeds at present of minor importance include *Diplachne fusca* in drill-sown rice, and *Typha* spp. in aerially-sown rice.

The southern irrigation areas of New South Wales, lying between 34 and 36° S latitudes, and watered from the Murrumbidgee and Murray Rivers, are the major rice-producing areas of Australia. In the 1970-1 season, these areas produced over 287,-500 tonnes of paddy rice, the average yield being approximately 7.4 tonnes/ha. The only other area of commercial rice production in Australia is on the Burdekin River in Queensland where a total of 15,500 tonnes of paddy rice was harvested from the summer and winter crops in 1970 (A. Greasley, pers. comm.).

Only one rice crop per year is possible in New South Wales, as low temperatures prevent sowing before mid-September. Crops sown later than mid-October are prone to low temperature injury at flowering.

This paper aims to describe the current incidence of weed species in the New South Wales rice crop, and the methods used to control them.

RICE ESTABLISHMENT METHODS

Australian methods of rice culture have been described by McDonald (1963a, b).

Two methods of rice establishment are used, and these greatly influence the weed populations which develop. Much of the rice is sown into a dry prepared seedbed with a seed drill. Immediately after sowing, the field is flooded for 12 to 24 hours and then drained. This "flushing" process is repeated as necessary to provide the germinating rice with a moist but aerobic environment. When the young plants are 7 to 10 cm high, permanent water is applied, and the fields remain flooded until the rice is mature.

Some crops, particularly in the Murray irrigation areas, are sown from the air. Pre-germinated seed is broadcast on to flooded fields which remain permanently covered with water until rice maturity.

THE WEED PROBLEM

Echinochloa spp. (barnyard grass) is the major weed under drill-sown conditions. Four species of this genus are of importance in rice in New South Wales (P. Michael, pers. comm.). The most common is *E. crus-galli,* a species which contains many forms varying in morphology and in physiological characteristics. *Echinochloa colonum* occurs frequently, but is of less importance than *E. crus-galli,* partly because of its shorter habit of growth and, presumably, reduced competitive ability late in the season. *Echinochloa microstachya* is a larger growing species and occurs in very dense but scattered infestations. *Echinochloa oryzoides* is a tall-growing species of limited distribution. It is of considerable importance where it occurs, however, as its spikelets are large and difficult to separate from the rice grain. The presence of any *E. oryzoides* in a seed crop leads to the rejection of that crop from the pure seed scheme.

All species germinate with the rice during the "flushing" period, and may compete strongly. Boerema (1963) found that where *Echinochloa* tiller numbers were reduced by herbicide treatment from 860 to 53/m^2, rice yield increased from 4,660 to 10,150 kg/ha. Nitrogen taken up by *Echinochloa* decreased from 94.2 to 1.1 kg/ha, while that taken up by rice increased from 15.5 to 112 kg/ha. In other experiments, competition from a population of 4,390 *Echinochloa* plants/m^2 reduced yields from 10,330 to 1,170 kg paddy per ha (Fischer *et al.,* 1966). Kleinig and Noble (1968) have shown that competitive effects are accentuated at higher levels of soil nitrogen and phosphorus.

Echinochloa population increases with years of irrigated cropping. Older rice land is heavily infested, while recently developed land is at present relatively free of the weed. Even in heavily infested crops, the distribution of *Echinochloa* often is variable, ranging from dense infestation to practically weed-free conditions within a few metres. The only other weed of economic importance in drill-sown rice is *Diplachne fusca,* known as silver grass or silver-top grass. This grass can heavily infest rice crops, but has occurred only in limited areas, and no studies of its competitive effects have been carried out. There is evidence, however, that the area affected by this weed has increased in recent years.

Under aerial sowing establishment, the germination of grass species is prevented by the anaerobic soil conditions. Provided that the soil is continually covered with water during the establishment period, these weeds do not usually present a problem.

The two principal weeds of aerial sown rice are the annual sedge *Cyperus difformis,* known locally as "Dirty Dora" and the broadleaved emergent aquatic *Damasonium minus* (starfruit). The sedge, which has been reported as a significant weed from many rice-growing areas of the world, is widespread throughout the New South Wales irrigation areas. *Damasonium minus,* although endemic throughout Australia (Burbidge, 1963), has been reported as a serious weed in rice only in the last six to eight years. During this time it has spread considerably.

Field experiments in which *C. difformis* was removed by hand demonstrated that at high populations (750 to 4,300 *C. difformis* plants/m^2) competition with rice was sufficiently severe to reduce yields by 33 to 44%. An important amount of this competition took place during the pre-tillering and early-tillering phases of rice growth (M. Nott and R. Trounce, pers. comm.).

An experiment with *D. minus* indicated that controlling the weed with MCPA at the early tillering stage of the rice increased rice tiller numbers by 63% (Anon., 1967). No data are available on the effects of *D. minus* on rice yield.

Typha orientalis and *Typha domingensis,* both known as "cumbungi", occur commonly in aerially sown rice. Their density is usually low, and significant yield reduction is probably limited to small sporadic areas of crop. These weeds are kept from becoming more serious by the rotational cropping system, which includes three to five years of pasture or other crops between rice crops.

WEED CONTROL

The earliest methods used to control *Echinochloa* in rice were harrowing and strategic water management which attempted to drown the grass (Anon., 1953). These methods were often unsuccessful and at times led to crop damage. Chemical weed control has now superseded mechanical methods, with propanil and molinate being widely used.

The first research with propanil in New South Wales was carried out in the 1960-1 season (Boerema and McDonald, 1962). More detailed studies were made by Boerema (1963). He found that this herbicide at 4.5 kg/ha gave excellent control of *Echinochloa* seedlings in the 1- to 3-leaf stage if irrigation water was re-applied to the field two to four days after spraying. Poorer weed control was obtained if water was applied immediately after spraying, or if grass plants had reached the 4- to 7-leaf stage.

Propanil is a contact-acting herbicide with no soil activity. As a result there is danger of a second germination of *Echinochloa* unless permanent flood can be applied soon after spraying. This herbicide is less effective if temperatures are low at, or immediately after, the time of application. Spring weather conditions in southern New South Wales are characterized by a progression of frontal systems which result in sudden changes of as much as 15° C in mean daily temperatures (Fig. 1). Under these conditions, weed control with propanil is not always dependable. Efficiency of this herbicide can also be reduced by dry soil conditions restricting *Echinochloa* growth.

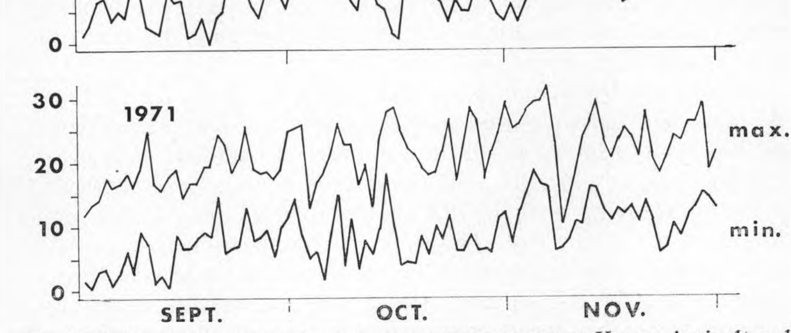

Fig. 1: Daily maximum and minimum temperatures at Yanco Agricultural College and Research Station for the spring periods of 1970 and 1971.

Propanil is applied to actively growing grass plants in the 1- to 3-leaf stage at 3.4 kg in at least 170 litres of water per hectare, and the field flooded 24 to 48 hours after spraying. Aerial application is effective provided the total volume applied is not less than 90 l/ha.

Molinate was first used experimentally in Australia by Fischer *et al.* (1966). They found it very effective, either pre- or post-emergence, at 3.4 to 6.7 kg/ha. Molinate has the advantage of providing a residual activity in the soil for at least three weeks. This prevents the establishment of any *Echinochloa* seedlings which may germinate after spraying. This herbicide will also control grass up to the tillering stage if necessary, but early spraying is advised to minimize the period of competition between weed and crop. Molinate tends to volatilize from the soil surface, but losses are not serious if the material is sprayed on to a dry soil surface and the field is flooded within three days. This flooding appears to fix the herbicide on the soil and greatly reduce further losses by volatilization.

If weather conditions preclude application to dry soil, molinate may be applied from the air after permanent water has been applied to the bays. This method is widely used in the U.S.A. (Smith, 1966, 1967) but, under rice establishment conditions in southern New South Wales, *Echinochloa* has often reached the 5-leaf stage by the time drill-sown rice is sufficiently advanced to withstand permanent flood. Under these conditions, considerable competition may have taken place before the grass is controlled (Smith, 1968).

Molinate, therefore, should be applied to a dry soil surface when *Echinochloa* plants are in the 1- to 3-leaf stage, at 3.4 kg/ha, and the field should be flooded as soon as possible after spraying. If spraying on to dry soil is not possible, satisfactory weed control can usually be achieved by applying the herbicide into flooded bays at the same rate.

Control of *Diplachne fusca* has not been fully investigated. Molinate had been reported to give control in some experiments, but has been observed to fail in a number of commercial crops.

Both *Cyperus difformis* and *Damasonium minus* are controlled by aerial spraying with MCPA at 0.6 to 0.9 kg/ha at the mid-tillering stage of the rice. The timing of application is essentially a compromise between minimizing the period of weed competition and reducing the risk of crop damage. By the mid-tillering stage, it is probable that weed competition will have already reduced rice tillering and yield. However, local research has confirmed earlier findings that application of phenoxy herbicides to rice prior to tillering may cause significant crop damage.

No selective chemical control for *Typha* spp. in the growing crop is known. If these species become more serious as weeds, control by either cultural or chemical methods may have to be carried out during the non-rice phase of the rotation. Such measures should prevent infestation from rhizomes in the soil. It seems doubtful if infestations will increase if they are restricted to plants originating from seed.

New South Wales rice growers are fortunate in that only a small number of species occur as significant weeds in rice. All are annuals with the exception of *Typha* spp. which are forced to behave as annuals by the current system of crop rotation. These factors facilitate weed control, and lead to the expectation that complete control of weeds in the rice crop will be technically possible in the foreseeable future.

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TRIALS WITH BENTAZON IN RICE

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Summary

Trials conducted in Asia, Africa, America and southern Europe indicated that, besides being highly compatible in rice, bentazon possesses a very broad spectrum of efficacy which includes nearly all broad-leaved weeds and Cyperaceae found in rice. It has, however, hardly any effect on Gramineae. Herbicides effective against grasses in rice often have little effect on Cyperaceae and other weeds. A combination with bentazon is promising. Bentazon may be applied either in spray form after, or as a granule during weed emergence.

INTRODUCTION

Various authors (Fischer, 1968; Behrendt and Sipos, 1969, 1970; Luib *et al.*, 1971; Luib and van de Weerd, 1972; Menck and Behrendt, 1972) have already reported on the compatibility of bentazon in cereal and soya beans, and on its efficacy against broad-leaved weeds and sedges.

The present report gives more detailed results obtained in trials carried out in rice-fields in Asia, Africa, America and southern Europe during 1970-72.

MATERIALS AND METHODS

The first formulation of bentazon, available for post-emergence application, was a wettable powder containing 50% active ingredient. This has now been replaced by a liquid formulation containing 480 g/l and a granule containing 5% a.i. Toxicity of this herbicide to fish is low; 500 ppm produced no reaction on guppies (*Lebistes reticulatus*) after 4 days.

Each plot in the field trials was 10 to 20 m^2 in area, with three or four replications. Crop compatibility and herbicidal efficacy were assessed according to a 1 to 10 scale (1 = no damage; 10 = total loss).

Both the wettable powder and liquid formulations were applied post-emergence to the weeds at various stages of growth. The water level was lowered each time so that the weeds were thoroughly drenched with spray mixture. Rates of 1.5, 2.0 and 3.0 kg (all rates in kg a.i./ha) were applied. The granule was applied in stagnant irrigation water at a rate of 2.0 kg.

TABLE 1: CROP COMPATABILITY OF BENTAZON IN RICE (4 WEEKS AFTER TREATMENT)

Assessment scale 1-10 (1 = no damage; 10 = total loss)
No. of trials in parentheses

Treatment	*Transplanted Rice*			*Sown Rice*			
(kg)	*a*	*b*	*c*	*a*	*b*	*c*	*d*
Wettable powder 1.5	—	1.0(8)	1.0(15)	—	1.0(1)	1.2(13)	1.5(3)
Liquid 2.0	—	1.0(7)	1.0(12)	—	1 1(5)	1.2(30)	1.1(27)
Liquid 3.0	—	1.1(2)	1.1(8)	—	1.0(2)	1.3(14)	1.2(7)
Granule 1.5	1.0(3)	—	—	1.0(2)	1.0(3)	—	—
Granule 2.0	1.0(6)	1.0(1)	—	1.0(2)	1.0(2)	—	—

a = emergence of weeds
b = 1- to 2-leaf stage of weeds
c = 3- to 5-leaf stage of weeds
d = start of flowering of weeds

TABLE 2: EFFICACY OF BENTAZON IN % AGAINST INDIVIDUAL WEED SPECIES IN RICE (4 WEEKS AFTER TREATMENT)

No. of trials in parentheses

Weed Species	Wettable Powder and Liquid									Granule
	1.5 kg			*2.0 kg*			*3.0 kg*			*2.0 kg*
	a	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*	*d*
Alisma spp.	—	98(8)	95(3)	—	98(12)	96(16)	—	99(8)	96(6)	—
Ammania spp.	—	93(3)	—	—	100(1)	97(1)	—	99(3)	97(1)	—
Butomus umbellatus	—	88(3)	95(2)	—	92(6)	92(11)	—	92(3)	93(2)	—
Commelina communis	—	100(1)	—	—	98(8)	—	—	100(6)	—	—
Cyperus spp.	75(8)	93(7)	—	81(7)	94(18)	90(2)	90(2)	92(8)	—	83(6)
Eleocharis spp.	71(8)	84(9)	—	71(7)	75(5)	80(1)	86(2)	96(6)	—	67(6)
Monochoria vaginalis	77(8)	94(7)	—	81(7)	91(4)	—	85(2)	96(4)	—	72(9)
Rotala indica	68(2)	92(1)	—	78(2)	94(1)	—	—	—	—	89(2)
Sagittaria spp.	63(2)	89(3)	—	69(2)	95(3)	—	—	100(1)	—	69(4)
Scirpus maritimus	—	92(7)	94(3)	—	93(13)	93(24)	—	98(7)	96(6)	—
Scirpus mucronatus	—	97(7)	94(3)	—	97(12)	95(15)	—	98(5)	95(5)	—
Scirpus spp.	86(2)	93(16)	94(6)	84(2)	95(28)	94(39)	—	98(12)	95(11)	85(2)
Sesbania exaltata	—	—	—	—	98(9)	—	—	98(6)	—	—

a = 1- to 2-leaf stage of weeds
b = 3- to 5-leaf stage of weeds
c = Start of flowering of weeds
d = On emergence of weeds

At the time of application, the weeds had reached the following stages of development: Spray mixture — 1- to 2-leaf stage, 3- to 5-leaf stage; granule — during emergence.

RESULTS

The crop compatibility of both wettable powder and liquid was good at all growth stages (Table 1). Slight leaf chlorosis caused by an excessive application rate quickly vanished and did not affect the further development or the yield. The granule has also proved highly compatible in rice in all trials carried out so far.

The herbicidal efficacy (Table 2) of powder and spray, when applied post-emergence, is excellent against the most important weeds found in rice — *e.g.,* water plantain (*Alisma* spp.), redstem (*Ammania* spp.), flowering rush (*Butomus umbellatus*), dayflower (*Commelina communis*), sedges (*Cyperus* spp.), water lily (*Monochoria vaginalis*), toothcup (*Rotala indica*), arrowhead (*Sagittaria* spp.), bulrushes (*Scirpus* spp.) and hemp sesbania (*Sesbania exaltata*). Efficacy against spike-rush (*Eleocharis* spp.) varies. An application of 1.5 kg at the 3- to 5-leaf stage is usually sufficient. The 3- to 5-leaf stage is the most effective time for post-emergence treatment.

A rate of 2 kg of the granule applied during emergence of the weeds was not adequate in all cases, but 3 kg should prove satisfactory.

DISCUSSION

The large number of trials carried out shows that bentazon is effective against all weeds found in rice, except the Gramineae. Compatibility is very good at all growth stages of development both in sown and transplanted rice, a feature which, with its range of efficacy, helps to distinguish bentazon from the hormone-type herbicides.

The limited number of trials with the granular formulation shows that bentazon is just as compatible when applied to the soil. However, more active ingredient must be applied per unit of area to obtain similar results.

The granular formulation, applied shortly after transplantation, is preferred for transplanted rice, and sprays for sown rice. No side-effects on neighbouring crops sensitive to hormones were observed.

Changes in the methods of cultivation and the repeated use of herbicides to control barnyard grass (*Echinochloa* sp.) have encouraged the growth of annual and perennial broad-leaved weeds and Cyperaceae. In Japan, for example, these are *Sagittaria pygmaea, Sagittaria trifolia, Cyperus serotinus* and *Scirpus hotarui.* As herbicides at present on the market have little or no effect on these weeds, combinations of bentazon and these herbicides have been tested. Results obtained are very promising and further work is in progress.

To gain the combined benefit of bentazon with a product effective against grasses, another effective application method is to apply the grass herbicide first and then treat the remaining weeds with bentazon.

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COMPETITIVE EFFECTS OF BARNYARD GRASS (*ECHINOCHLOA CRUS-GALLI*) ON RICE

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Summary

The competitive effects of barnyard grass on transplanted rice were studied during the period 1965 to 1968. Barnyard grass densities of 0 to 320/m^2 or its weight produced were an inverse function of rice yield. A regression of the logarithm of rice yield as a percentage of weed-free rice against barnyard grass weight was expressed by a straight line. Two critical periods of rice occurred when barnyard grass was allowed to compete with rice until harvest. Barnyard grass competition seriously reduced the number of effective tillers, and affected several eco-physiological aspects of rice such as leaf area index, productive structure, nitrogen content of leaves, nitrogen uptake pattern, solar radiation into the community of rice and barnyard grass, and rooting system.

INTRODUCTION

The most important and basic requirement for developing an effective weed control method on arable lands is to establish the degree and pattern of weed competition to crops when crop and weed are grown together. Ennis' report (1967) showed that weeds reduce rice yield by 20 to 70% — 34% on the average (Noda, 1970). Of the weeds in rice, barnyard grass (*Echinochloa crus-galli*) has become a serious problem which is difficult to control completely since it produces abundant seeds and is similar to rice in its growing behaviour. Holm (1969) has called it one of the world's worst weeds. A considerable number of papers on rice-barnyard grass competition have been published (for example, Arai and Kawashima, 1956; Kasahara, 1961; Chisaka, 1966; Smith, 1966), but they are not all in agreement. To further understanding of this problem, several experiments were conducted during the period 1965 to 1968. This paper reviews the results. The detailed data and discussion refer to previous reports (Noda *et al.*, 1968, 1971).

COMPETITIVE EFFECTS ON RICE YIELD AND ITS COMPONENTS

The relation between rice yields and barnyard grass densities at the nine stands of 0, 2, 5, 10, 20, 40, 80, 160, and 320 plants per square metre was studied under high and low fertility levels, and on three rice stands of 25, 16, and 11 per square metre. Barnyard grass density was a function of rice yield. However, percentage loss of rice yield varied to some extent according to fertility levels or rice stands; it was higher in sparse stands of rice than in dense ones, and under high levels of fertility than under low ones at every density of barnyard grass. Further, barnyard grass weight was also a function of rice yield, and a regression of the logarithm of rice yield as a percentage of yield from weed-free rice against barnyard grass dry weight produced was expressed by a straight line, regardless of conditions such as rice stands and fertility levels. This relation is shown as follows:

$$\log Y = a - bX \text{ or } Y = c/d^X$$

where the X and Y co-ordinates are the weight of barnyard grass in grams and rice yield as a percentage of that from weed-free rice, respectively; a, b, c and d are all constants. As this relationship was obtained every year, regardless of fertility levels or rice stands, it seems clear that the weight of barnyard grass is a more precise indicator of rice yield than is the number of barnyard grass plants present per unit area. The equation means that the rate of decrease in rice yield is high when the barnyard grass co-exists in small quantity. As the weight of barnyard grass increases, the rate of decrease lowers, and eventually there is no appreciable decrease of rice yield in spite of an increase in the weight of barnyard grass.

As one test of the validity of the equation, the figures for competing barnyard grass equivalent to 500 g/m^2 were substituted as indicated in Table 1.

TABLE 1: AN ESTIMATE OF PERCENTAGE LOSS OF RICE YIELD DUE TO BARNYARD GRASS COMPETITION

Year	*Percentage Loss*	*Range of Barnyard Grass Stands*
1965	45.6	7.1 to 50.1
1966	25.7	5.6 to 79.5

Generally, rice yield is given by the product of the number of panicles (Pn), the fertilization percentage of spikelets (F), the number of spikelets in a panicle (S), and the weight of grain (G). The proportions in which these four components contributed to the assessment of yield loss due to barnyard grass competition were measured in the 1965 experiment for each fertility level, as indicated in Table 2. The most important was found to be the

TABLE 2: PROPORTIONS IN WHICH FOUR RICE YIELD COMPONENTS CONTRIBUTED TO YIELD LOSS DUE TO BARNYARD GRASS COMPETITION

Fertility	*Pn* %	*S* %	*F* %	*G* %
Low	54.9	14.3	8.1	22.6
High	41.6	19.4	11.1	27.6
Mean	48.3	16.8	9.6	25.3

number of panicles and the second was the weight of grain. No substantial difference between low and high fertility seems to exist.

CRITICAL PERIOD OF COMPETITION ON RICE

In the 1966 to 1968 experiments, barnyard grass coexisting with rice was removed at one-week (1966 and 1967) or two-week (1968) intervals after planting, and the rice maintained weed-free for the rest of the growing season. Thus, rice competed with barnyard grass for various lengths of time up until harvest. Rice yield differed according to the term of competition. Yield loss for

TABLE 3: DIFFERENCE OF RICE YIELD LOSS DUE TO BARNYARD GRASS COMPETITION AT SUCCESSIVE STAGES OF RICE GROWTH

Season	*Sum of Rating**	*Growing Stage*
July:		
Early	0.5	
Middle	3.0	
Late	3.5	Maximum tillering
August:		
Early	1.0	Ear differentiation
Middle	0.5	
Late	1.5	
September:		
Early	3.0	Heading
Middle	3.0	
Late	1.0	
October:		
Early	0.5	
Middle	0	
Late	0	
November:		
Early	0	Harvesting

*From four experiments, 1966 to 1968. No, moderate, and heavy losses are rated 0, 0.5, and 1.0, respectively.

every week at successive stages of rice was obtained by subtracting "Rice yield competed for $(n + 1)$ weeks" from "Rice yield competed for n weeks". When the results of the experiments were summarized, it was found that there were two critical periods when rice was adversely and dramatically affected by barnyard grass competition as shown in Table 3.

These two periods were around the maximum tillering stage and around the early ripening stage just after heading. Competition during the first period caused a reduction in the number of panicles, and its effect became more serious under basal fertility conditions. Competition during the second period caused a reduction in grain weight as well as a decrease in the number of perfect kernels; these effects seem to be encouraged by fine climates under a slow-acting fertility condition.

EFFECTS OF BARNYARD GRASS COMPETITION ON RICE GROWTH

The height of rice plants was little affected by barnyard grass coexistence during the early stages, but became increasingly affected as growth progressed. Rice tended to be taller with high density barnyard grass competition, and this trend was more apparent in a sparse stand of rice and/or a heavy fertility level than in a compact stand and/or a light fertility level. On the other hand, an increase in plant height was also found in barnyard grass. These phenomena are probably due to a temporary enhancement of growing conditions as a result of the reduction in sunlight intensity.

The number of tillers in rice was greatly influenced by coexistence with barnyard grass. In the 1965 experiment, tillering was eventually reduced by as much as 50% at barnyard grass densities of 160 and 320/m^2, becoming more serious as the rice developed, especially after early August. Percentage reduction in tiller numbers was nearly always higher in low densities of rice than in high ones and under conditions of high than of low fertility.

Heading time of rice was little affected, though rice suffering heavy competition from barnyard grass at densities of more than 80/m^2 tended to be delayed in heading by one or two days. In addition, strong competition caused incomplete heading in a few rice plants in 1965, probably caused by severe physiological disturbance resulting from a reduction of sunlight intensity and a decrease of nutrient uptake during the stages from panicle formation to heading.

EFFECTS ON ECO-PHYSIOLOGICAL ASPECTS OF RICE

The productive structure of the rice and barnyard grass community at barnyard-grass densities of 0, 5, 20, 80, and 320 plants/m^2 was investigated at four successive stages of rice growth in 1966. Degeneration of the productive structure due to competition was not so serious on 27 July, but became increasingly serious after 22 August. Distribution of the height of the assimilatory organ of rice could be plotted as a normal curve with a peak 40 to 60 cm above the ground surface; the non-assimilatory organ distributed along a downward sloping straight line on the graph. Both organs were less in total amount as densities of barnyard grass increased. Vertical variation of sunlight intensity above the ground surface was measured for different populations at several stages of rice. The reduction became distinct on 22 August, when barnyard grass height exceeded that of rice, and increased still further with the advance of time. For instance, the intensity at a density of 320/m^2 on 27 September was reduced by as much as about 70% in a central portion of the population. Development of the dry weight of rice leaves was influenced by competition; that in the rice with most severe competition was greatly reduced at the peak of leaf growth, being only about one-half or one-third of that of the weed-free rice.

The leaf area index of weed-free rice generally started at a value of 2 or 3 around late July and afterwards increased rapidly, showing a peak of about 6 in late August, then declined again to 1 or 2. The leaf area index of rice with competition was rather lower, with a peak of only about 2 in that with the most severe level of competition. The nitrogen content of the leaf-blade in the portion 40 to 80 cm above ground surface was significantly lower in rice with competition than it was in weed-free rice on 22 August, though this difference ceased to exist by 12 September. This probably indicates that barnyard grass competition at the middle stages of rice growth also lowers the assimilatory activity of rice leaves. Total nitrogen absorbed by rice was at a maximum on 22 August, whereas that of barnyard grass continued to increase until 12 September. The pattern of nitrogen uptake by rice and barnyard grass differed considerably, and it is therefore probable that competition for nutrients, mainly nitrogen, is more severe during the first half of the rice growing season.

The root system of rice coexisting with barnyard grass was investigated at several stages, and compared with that of weed-free rice. The roots of rice appeared to be prevented from spreading into the tillaged layer of soil.

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PRELIMINARY STUDIES ON PICLORAM IN MIXTURE FOR GENERAL WEED CONTROL

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Summary

Studies on picloram, methylarsinic acid and sodium chlorate were aimed at the possibility of developing a premix compound suitable for general weed control. It was the intention that the mixture would be used as a single application to provide for a minimum of 10 to 12 weeks' control. Results so far indicate that the desired mixture is effective against at least 12 species, including the important grasses *Paspalum conjugatum* and *Ottochloa nodosa* and the broadleaved weed *Mikania cordata*. None of the treatments which included individual herbicides and their factorial combinations gave the required period of control except for the triple-mixture against the broadleaved weeds tested. Changes in the composition of herbicidal components are suggested to lengthen the period of control of the grasses. Further screening trials to cover a wider range of soil types and comparative trials with commonly used mixtures are considered necessary. Phytotoxicity studies are being maintained to study possible long-term effects on yield of the crops under investigation.

INTRODUCTION

The use of chemicals for weed control is a common practice in estate management of many rubber and oil palm plantations in Malaysia. They are used on a very large scale mainly for eradicating or controlling troublesome weeds during the early years following transplanting and for general maintenance when the crops come into bearing. The general acceptance of the use of weedkillers in the plantation industry has resulted in the importation or local production of a wide range. Among these are sodium arsenite, sodium chlorate, TCA, 2,2-DPA, amitrole, 2,4-D, 2,4,5-T, and paraquat which have been tested and well reported in the *Planters' Bulletins* of the Rubber Research Institute of Malaya (Anon., 1954, 1956a, b, 1959, 1961, 1967, 1971). Pre-emergence herbicides entered the scene at a much later date (Riepma, 1965; Pushparajah, 1971). These weedkillers vary in their effectiveness, selectivity, duration of control and persistence in the soil.

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It is well known that persistent use of a particular weedkiller may lead to changes in plant succession or weed composition (Riepma, 1963; Pushparajah and Woo, 1971). It is also well known that no weedkiller by itself is adequate at economic rates (Shepherd *et al.*, 1971). A weedkiller which eradicates grassy weeds may not affect or efficiently kill broadleaved species nor prevent their regeneration, colonization or encroachment and vice versa. These problems have been recognized early and subsequently mixtures of different weedkillers were developed. These herbicidal mixtures were either synergistic in their effects, complementary in action, or produced more persistent effects or a much wider spectrum of activity (Wong, 1966a, b; Shenk, 1971; Seth, 1971a, b). Sequential applications with different herbicides were also tested and reported (Wong, 1966a, b; Smith, 1966).

This paper reports on the feasibility of developing a mixture for general weed control based on picloram, methylarsinic acid and sodium chlorate. The persistence of picloram is a decided advantage and it was felt that this persistence could be adjusted by careful selection of appropriate dosage. Further, it has been shown that picloram has a wide spectrum of activity against broadleaved weeds (creepers as well as soft and shrubby weeds). A comprehensive review of picloram and a list of references are given by Goring and Hamaker (1971). The results of preliminary trials against major weeds of plantation crops are presented together with some studies on the effects of the mixture on immature rubber and oil palm.

MATERIALS AND METHODS

EFFICACY AND SPECTRUM OF ACTIVITY

In studies on the efficacy of the mixture, subplots (3.6 m × 3.6 m) were set up in the inter-rows of immature rubber and oil palm in areas where the weed vegetation was dense and actively growing. The experimental sites were selected to include, where possible, different soil types on which the major plantation weeds for evaluation were present. The principal weeds included in the screening were almost pure stands of *Paspalum conjugatum, Ottochloa nodosa, Ischaemum muticum, Mikania cordata* and *Gleichenia linearis*. Other main weed species tested were *Borreria latifolia, Axonopus compressus, Fimbrystylis acuminata, Lygodium microphyllum* and *Passiflora foetida*. The weed composition was noted before treatment and weed control ratings were taken at regular intervals after spraying. Rating was done visually by comparing with the untreated control and using indices 0 to 10 to indicate percentage control, 0 indicating no effect, 10 complete kill.

The design of all experiments was factorial, arranged in randomized blocks, replicated 3 times.

Treatments were:

Picloram at 70.02 g/ha.
Methylarsinic acid at 2.24 kg/ha.
Sodium chlorate at 5.60 kg/ha.
Control.
Picloram + methylarsinic acid as tank mix at above rates.
Picloram + sodium chlorate as tank mix at above rates.
Methylarsinic acid + sodium chlorate as tank mix at above rates.
Picloram + methylarsinic acid + sodium chlorate as tank mix at above rates.

The treatments were applied with a hand-operated knapsack pneumatic sprayer. Volume of application varied between 449 and 1123 l/ha according to weed density and height of the weeds.

Effects of Picloram/Methylarsinic Acid/Sodium Chlorate on Immature Rubber

The experimental site was a sandy area where mixed weeds have invaded strips of 1- to 1½-year-old rubber (RRI 600, clonal type), planted 6.71 m between rows and 3.35 m within rows. Weeds present were mainly *Ischaemum muticum, Paspalum conjugatum, Brachiara* sp., *Mikania cordata, Digitaria marginata, Eragrostis elegantula* and *Tricholaena rosea.* Visual estimates of density of each weed were recorded.

The design was a simple randomized block, with 4 replicates. The rate of application was as detailed above. Plots were 30 m × 1.83 m strips containing 9 trees. Volume of spray was calculated as 449 l/ha.

Growth measurements were recorded before spraying and at 3-monthly intervals and applications were repeated at 2-monthly intervals, irrespective of whether weeds were present.

Effects of Picloram/Methylarsinic Acid/Sodium Chlorate on Immature Oil Palm

Oil palms of various field ages, namely, 9 months, 12 months and 30 months, were evaluated in separate experiments. The experimental sites were coastal clay soils (Selangor series) for 9- and 12-month palms and Briah series for the 30-month palms. Experimental designs were complete randomized blocks with 4 palms per plot replicated 4 times. In the 9- and 12-months-old palms, the mixture at the dosages given above was compared with a standard mixture of methylarsinic acid 1.68 kg/ha and sodium chlorate 11.21 kg/ha with untreated palms as the control. All palms were circle-sprayed, the weeding circle being bare except for a few shoots of legume cover crop at the periphery.

In the 30-months-old palms, only the picloram/methylarsinic acid/sodium chlorate mixture was used. Treatments were the different methods of weed control normally practised in oil palms — *i.e.*, circle-spraying, strip-spraying, and spraying of the harvester's path. The circles were almost bare except for *Ottochloa nodosa* towards the periphery while the strips and harvester's path were mainly *Ottochloa nodosa* and *Paspalum conjugatum*. All sprays were applied with a knapsack sprayer at a rate of 499 l/ha.

TABLE 1: COMPARATIVE PERFORMANCE OF PICLORAM, METHYLARSINIC ACID AND SODIUM CHLORATE AND THEIR COMBINATIONS AGAINST SELECTED WEEDS OF PLANTATION CROPS

Treatment (per ha)	*Paspalum conjugatum*	*Ottochloa nodosa*	*Mikania cordata*	*Ischaemum muticum*	*Gleichenia linearis*	*Borreria latifolia*
picloram 70.02 g	U	U	G	U	U	U
methylarsinic acid 2.24 kg	U	S	U	U	U	U
sodium chlorate 5.60 kg	U	U	U	U	U	U
picloram 70.02 g/methylarsinic acid 2.24 kg	G	S	G	U	U	S
picloram 70.02 g/sodium chlorate 5.60 kg	U	S	E	U	U	S
methylarsinic acid 2.24 kg/sodium chlorate 5.60 kg	G	G	E	S	U	G
picloram 70.02 g/methylarsinic acid 2.24 kg/sodium chlorate 5.60 kg	G	E	E	U	S	G
Control	—	—	—	—	—	—

Ratings according to Rubber Research Institute (RRI) Classification (*Plrs' Bull. No. 91,* 1967).

E = Excellent control (kill 90% and above).

G = Good control (80% - 90% kill).

S = Satisfactory control (70%-80% kill).

U = Unsatisfactory control (less than 70% kill).

RESULTS

Efficacy and Spectrum of Activity

Results of screening trials to determine efficacy and spectrum of activity of the triple mixture are summarized in Table 1. It is concluded from the various trials that:

(1) Picloram at 70.02 g/ha has virtually no effect on grasses. This was expected since picloram is a broadleaved weedkiller. It is not effective against ferns at this rate while control of broadleaved weeds tested (*Borreria latifolia* and *Mikania cordata*) is good to excellent.

(2) Methylarsinic acid at 2.24 kg/ha is satisfactory only against *Paspalum conjugatum* and *Ottochloa nodosa.*

(3) Sodium chlorate at 5.60 kg/ha is not effective against any of the weed species tested.

(4) The combination picloram/methylarsinic acid gives satisfactory control of *Ottochloa nodosa* and satisfactory to good control of *Paspalum conjugatum, Mikania cordata* and *Borreria latifolia.*

(5) Picloram/sodium chlorate gives satisfactory control of *Ottochloa nodosa* and *Borreria latifolia* and excellent control of *Mikania cordata.*

(6) Methylarsinic acid/sodium chlorate gives excellent control of *Mikania cordata,* but regeneration is rapid. Satisfactory to good control is also achieved against the grasses *Ischaemum muticum, Paspalum conjugatum* and *Ottochloa nodosa* and good control against another broadleaved species, *Borreria latifolia.* The two weedkillers appear to be synergistic in their effects.

(7) Picloram/methylarsinic acid/sodium chlorate gives as good results as methylarsinic acid/sodium chlorate. However, the triple mixture is particularly effective against *Mikania cordata* and *Borreria latifolia* and remains effective for a much longer period than the double mixture.

(8) Various other weed species present in the treated plots were kept under observation following the application of treatments. Weeds which were killed in the triple mixture plots were the cover crops (*Pueraria phaseoloides, Centrosema pubescens*), *Axonopus compressus, Mimosa pudica,* young

Clidemia hirta, Melastoma malabathricum and *Cleome ciliata.* Older *Melastoma* plants were only defoliated while *Lygodium microphyllum* was partially scorched.

(9) With the exception of the triple mixture against *Mikania* and *Borreria,* where the control obtained is a minimum of 10 to 12 weeks, the duration of control on other weed species needs lengthening.

EFFECTS OF PICLORAM/METHYLARSINIC ACID/SODIUM CHLORATE ON IMMATURE RUBBER

Strip-spraying of 1- to 1½-year-old rubber trees at 2-monthly intervals have not produced any defoliation, dieback or any unusual symptoms. Girth measurements recorded prior to spraying and at the end of 3 months (following two rounds of spray) are summarized in Table 2. There is no significant difference in growth between trees which have been strip-sprayed and those in hand-weeded plots.

TABLE 2: GIRTH MEASUREMENTS OF 1- TO 1½-YEAR-OLD RUBBER TREES STRIP-SPRAYED WITH TRIPLE MIXTURE
(Locality: Batu Pahat, Johore)

Treatment (per ha)	*Before Spray (cm)*	*3 months after Spray (cm)*
picloram 70.02 g/methylarsinic acid 2.24 kg/ sodium chlorate 5.60 kg	16.3	18.5
Hand-weeded control	16.7	18.9
SE	±0.69	±0.83

EFFECTS OF PICLORAM/METHYLARSINIC ACID/SODIUM CHLORATE ON IMMATURE OIL PALM

Circle-spraying of the triple mixture has been demonstrated to affect 9-months-old palms (see Table 3). Effects were observed in the form of bending from the vertical position with slight twisting of some of the fronds. Such effects were noticeable only after one month and more than half the number of palms were affected. There was no bending in palms circle-sprayed with methylarsinic acid/sodium chlorate mixture, nor in the palms hand-weeded.

TABLE 3: VISUAL ASSESSMENT OF PHYTOTOXICITY TO 9-MONTHS-OLD OIL PALM TAKEN AT MONTHLY INTERVALS AFTER SPRAYING

Treatment (per ha)	No. of Palms Affected*/Total Palms 1 mon	2 mon	3 mon
picloram 70.02 g/methylarsinic acid 2.24 kg/ sodium chlorate 5.60 kg	0/16	9/16	10/16
methylarsinic acid 1.68 kg/sodium chlorate 11.20 kg	0/16	0/16	0/16
Hand-weeded control	0/16	0/16	0/16

*Palms bending with noticeable twisting.

With 12-months-old palms, slight bending was observed in only 2 palms circle-sprayed with the triple mixture. All other palms, including those circle-sprayed with methylarsinic acid/sodium chlorate, appeared normal. There was no difference in growth as determined by frond length measurements (Table 4) between treated and non-treated palms.

TABLE 4: FROND LENGTHS (cm) OF 12-MONTHS-OLD OIL PALM TAKEN BEFORE AND AT MONTHLY INTERVALS AFTER CIRCLE-SPRAYING

Treatment (per ha)	Before Spray	After Spray 1 mon	2 mon	3 mon
picloram 70.02 g/methylarsinic acid 2.24 kg/ sodium chlorate 5.60 kg	205.82	212.55	222.90	240.59
methylarsinic acid 1.68 kg/sodium chlorate 11.20 kg	208.80	218.76	226.88	241.95
Hand-weeded control	212.07	216.17	227.59	243.81
SE	± 4.62	± 4.09	± 5.90	± 5.81

The various chemical weeding methods tested on the 30-months-old palms using the triple mixture did not have any adverse effects on the palms. There was no bending of palms or twisting of fronds and growth rates were not significantly different between the treatments including the control (inter-row hand-weeded, circle hand-weeded). The frond measurements are indicated in Table 5. Harvesting records to date have also shown that yield has not been affected by the treatments.

TABLE 5: FROND LENGTHS (cm) OF 30-MONTHS-OLD OIL PALM TAKEN BEFORE AND AT 3 MONTHS AFTER CIRCLE-SPRAYING WITH TRIPLE MIXTURE

Treatment	*Before Spray*	*3 months after Spray*
Circle-spraying (harvester's path hand-weeded)	398.86	404.34
Spraying of harvester's path (circle hand-weeded)	376.26	402.99
Inter-row or strip-spraying (circle hand-weeded)	387.97	399.10
Circle hand-weeded (harvester's path hand-weeded)	382.72	396.58
Inter-row hand-weeded (circle hand-weeded)	401.52	409.53
SE	±7.54	±8.34

DISCUSSION

Results of completed trials indicate that a tank mix combination of picloram 70.02 g/ha + methylarsinic acid 2.24 kg/ha + sodium chlorate 5.60 kg/ha is effective against some of the major weed species of plantation crops. One of these is *Mikania cordata* which has been demonstrated to depress yield of rubber (Mainstone and Wong, 1966) and oil palm (Gray and Hew, 1968). Screening trials are still in progress to determine the spectrum of activity and to maximize the period of control.

Safety and selectivity in favour of crop plants is a primary concern in the use of herbicides in plantation crops and many researchers have emphasized this in the past (Palmer, 1968; Riepma, 1968; Barnes and Tan, 1969; Seth, 1969). Ramachandran *et al.* (1969) point to the danger of spray-drift and the hazards of root absorption in immature oil palms. A case of volatility affecting yield was also cited. Brown (1969) reported on the risks of using translocated herbicides in young palms, but was unable to state to what age these risks extend. Turner and Bull (1967) decribe the symptoms of damage to immature oil palms as a result of translocated herbicides such as 2,4-D and picloram without reporting on the rates used. Seth (1969) reported on the phytotoxic symptoms (bending) of 12-months-old oil palms which were sprayed overhead with 4.05 g 2,4-D contained in 2.5 l water per palm. There is lack of local data on rate of breakdown of translocated herbicides and cumulative effects. Such data are essential in the understanding of phytotoxicity problems and the ultimate fate of the herbicides. Cases of indiscriminate or accidental use of translocated herbicides are not too uncommon and this has contributed to some concern. The excessive use of

2,2-DPA resulting in typical injury to oil palm fronds has been recently reported by Piggot (1972).

The herbicide picloram in the triple mixture is a translocated herbicide. Any possible risks of injury to crop plants are likely to be attributed to this component as the rates of the other two components are low compared with nominal rates currently in use. Presently available data seem to indicate that the mixture at the rates used has no deleterious effects on immature rubber 1 to 1½ years field age and immature oil palms 2 years and older. Field experiments have not been concluded yet and some vital data are being recorded. There is no indication to date of depressed yield in oil palm as a result of using the mixture. Weeding circles have been kept bare and lower fronds deliberately touched with spray solution to provide for stringent field conditions. Where vegetation is present, the underlying soil receives very little of the sprayed chemical (Lowe, 1971) and injury through root absorption is minimized. There is every indication that age and size of palms and dosages applied are critically important, apart from the various soil factors that affect persistency and availability of herbicides.

CONCLUSIONS

Preliminary field trials on picloram 70.02 g/ha, methylarsinic acid 2.24 kg/ha, and sodium chlorate 5.60 kg/ha and their factorial combinations have indicated that a triple mixture at these rates can control important weed species of plantation crops, such as *Paspalum conjugatum, Ottochloa nodosa* and *Mikania cordata*. Studies have been extended to other weed situations to determine the range of species susceptible to the mixture. There is some evidence to indicate that the mixture is particularly promising where broadleaved weeds are dominant. The duration of control is not yet within the desired period of 10 to 12 weeds for grasses and some alterations in composition of the mixture may be necessary as soon as the complete spectrum of activity is known. Against the two broadleaved species tested (*Mikania cordata* and *Borreria latifolia*) a control period of at least 10 weeks may reasonably be expected.

On crop tolerance, available data indicate that the triple mixture has no deleterious effects on immature rubber 1- to 1½-years-old grown in sandy soil (riverine alluvium). Studies on other soil types are currently in progress. Data to date have also shown that 30-months-old palms are not affected by circle-spraying and that 12-months-old palms may be the critical age. Field experiments on phytotoxicity are being maintained to enable other vital data such as cumulative effects (if any) to be studied.

ACKNOWLEDGEMENTS

The authors wish to acknowledge with thanks the co-operation of the H&C Oil Palm Research Station, Banting, for all field data recorded and to W. M. Reid (Manager, Telok Datok Estate), C. Cunningham (Manager, Highlands Estate), Tan Wah Boon (Manager, Tai Tak Estate) and Foo Chow Len (Manager, Sri Gading Estate) for making available trial sites.

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THE ELEVENTH BRITISH WEED CONTROL CONFERENCE, NOVEMBER, 1972

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The largest gathering of weed scientists in Europe occurs biennially at the British Weed Control Conference. Held at Brighton, England, from 13 to 16 November 1972, the eleventh conference attracted over 1200 delegates. About 700 people were from the United Kingdom and about 300 from other West European countries. The Scandinavian and Mediterranean countries were well represented and delegates also attended from Eastern Europe, Africa, North America, Japan and Australasia.

To accommodate the far-reaching interests of its contributors, the conference contained 18 sessions, six of which were plenary and the others grouped and held concurrently. A total of 40 invited papers were presented and nearly 150 research reports were introduced or summarized by sessional chairmen.

HERBICIDES IN PERSPECTIVE

This opening theme, organized by J. D. Fryer (Director, WRO), was introduced by Sir Emrys Jones (Director-General, ADAS) and Dr D. Rudd Jones (Director, GCRI). Two speakers, Dr F. H. Tschirley (Pesticides Co-ordinator, USDA) and Dr R. F. Glasser (Shell International Chemical Co. Ltd), alternated on several themes as applied respectively to the U.S.A. and to the world situation. They discussed the growth of herbicide use, the problems encountered, reasons for regulation, and the job of the regulatory authority. The need for an awareness of potential environmental and human health problems was stressed. A multidisciplinary approach to crop protection to bring together the talents of entomologists, weed scientists, plant pathologists and others was seen as a necessary future development.

OBJECTIVES OF WEED CONTROL

An integrated approach to crop rotations was considered to be important by several speakers. Today's weed control objectives were analysed under two headings, grain and vegetable crops.

*Submitted from IBS, Wageningen, Netherlands.

There are clearly still many unsolved problems, for example, *Agropyron repens* in cereals, weed seed contamination of cereal seed, the costly cleaning operation in harvested process crops, and the continuing unreliability of many soil herbicide treatments for vegetable crops. However, the feeling emerged that, too often, weed control needs are considered individually and not in terms of the whole rotational system. In general, the vegetable grower asks for more complete weed suppression than does the cereal farmer and when the two types of crop come together in one rotation there is often a carry-over of problems from the grain to the vegetable crop.

The requirement for more information on weed-crop relationships in vegetable crops is made more complex by the tendency for more specialized cropping systems which control the size of the product and facilitate mechanical harvesting.

As the availability of new herbicides occurs primarily in relation to the world's major crops, it was considered that progress in less extensively grown crops will be made by developing uses of existing materials in programmes and mixtures.

BRITAIN AND THE EEC

Not surprisingly, the consequences of Britain's entry into EEC in January 1973 formed a major background theme of the conference. Two plenary sessions were addressed directly to this topic.

In the first, influences of changing agricultural policies on U.K. cropping systems in the next decade were discussed. B. H. Davey (Newcastle University) foresaw a small rise in cereal and sugar beet acreages with grain maize and oil seed rape becoming more attractive, but concluded that the present systems are robust and unlikely to change much. The same broad conclusions were reached by R. Gardner (MAFF) speaking for the conglomerate horticultural industry. He especially stressed the need for Britain to take advantage of its climate-favoured crops, like brassicas, leaf salads and daffodils, and also made the point to British herbicide manufacturers that some of the minor crops may be worth more serious attention when viewed Europe-wide.

In the second session, the already complex regulatory schemes of current and prospective EEC members were reviewed and the prospects of harmonization discussed, particularly with the co-ordinating efforts of the Council of Europe, the European Weed Research Council (EWRC), and the European and Mediterranean Plant Protection Organization (EPPO). Dr S. Hahn (BASF AG) described the stages in the Federal Republic of Germany which led to the clearance of a herbicide and full commercial use after about seven years and compared this with the procedures in the other five member countries (Benelux, France, Italy). R. J. Makepeace (MAFF) considered the schemes in the applicant countries (Britain, Denmark, Eire) and pointed particularly to the advantages of a procedure which incorporates the requirement to clear a chemical for safe use but then leaves the proprietor some freedom to develop herbicidal efficacy.

In a description of the activities of the Council of Europe, which consists of the EEC countries together with eight other constitutionally democratic countries, J. A. R. Bates (MAFF) indicated that its publication *Agricultural Pesticides* is likely to be adopted as a guideline by EEC.

The contribution of the EPPO and EWRC organizations was described by Dr W. van der Zweep (IBS, Wageningen, Netherlands). EPPO is governmental, but non-political, and co-ordinates the efforts of its 32 member countries with respect to plant disease and pest legislation and documentation. EWRC has 28 member countries and is a professional body which promotes weed research, the exchange of information on weed problems, and practical control measures. It was clear that in a wide geographical sense both organizations have already anticipated the need for international harmony in the use of herbicides.

* * *

In the remainder of this report those aspects of the research sessions likely to be of most interest are summarized.

HERBICIDES IN SOIL

The present state of knowledge on root function was outlined by Scott-Russell and Shone (Letcombe Laboratory) with the whole root system considered as an absorbing organ. The thickened cell walls of older roots do not provide the barrier to chemical uptake which was previously envisaged. In the context of no-cultivation, continuity of pore space is important in allowing root development. This may improve over the years and result in better crop growth with time.

Factors affecting pesticide availability in soil were outlined by Graham-Bryce (Rothamsted), who stressed that there is no simple relationship between adsorption and activity.

Several papers were concerned with the prediction of herbicide performance in soil and a fresh look was taken at current recommendations for soil-applied herbicides by Holly (WRO).

He wondered whether some of the earliest recommendations which still stand have become unduly sanctified by time. Many are qualified on the basis of soil texture but research has shown that the most important performance factor is usually soil organic matter content. There is still a dearth of guidance on how to hasten the disappearance of unwanted herbicide.

EFFICIENCY OF FOLIAGE-APPLIED HERBICIDES

Kirkwood (Strathclyde University) discussed leaf penetration by chemicals, the importance of wax and possible favoured cuticular entry points, especially the lower leaf surface. In this respect, stomatal penetration is not so important.

The effect of environmental factors on the performance of glyphosate against *Agropyron repens* was considered by Caseley (WRO). Glyphosate activity was greatest at lower temperatures and higher humidity. Low light intensity delayed the phytotoxic effect.

From work with ioxynil and bromoxynil, Savory and Hibbitt (May and Baker Ltd) suggested that reduced herbicidal activity could be connected with high wind speed.

Turner and Loader (WRO) reported synergistic effects when ammonium salts were added to picloram, MCPA and mecoprop. This work suggests interesting possibilities of reducing herbicide dosages and also points to the possible dangers of combining certain fertilizers with growth regulators.

PERENNIAL WEEDS

Two-thirds of the reports in this session concerned *Agropyron repens*. Several papers were devoted to biological studies, including the growth of seedlings of the weed sown in field crops (Williams, Rothamsted), differences in growth patterns between clones (Pooswang *et al.*, Reading University), and the occurrence of innate dormancy in rhizome fragments (Leakey and Chancellor, WRO, and Vince, Reading University). The latter authors also reported temperature and orientation effects on the growth pattern of rhizomes.

Evans (Monsanto) concluded that glyphosate at rates above 1.5 kg/ha could be completely effective against the weed and other workers reported good results with TFP alone (Blair, WRO) and as a follow-up to paraquat (van Hiele and de Boer, Wageningen University).

A range of other perennial weeds were shown to be sensitive to glyphosate, particularly *Cynodon dactylon, Pennisetum clandestinum* and *Cyperus rotundus* (Evans), and *Dactylis glomerata, Mercurialis perennis, Poa pratensis, Ranunculus repens, Rumex obtusifolius, Taraxacum officinale* and *Potentilla anserina* (Davison, WRO). The latter author also found oxadiazon promising for the control of *Convolvulus arvensis.*

Promising control of *Pteridium aquilinum* was obtained with summer applications of asulam (Soper, May and Baker Ltd). Work by Veerasekaran and Kirkwood (Strathclyde University) suggests that this plant is most susceptible after the fronds have unfurled.

BEET, POTATOES AND ARABLE LEGUMES

Five papers concerned sugar beets and two new herbicides were discussed. Hack and Schmidt (Bayer AG) claimed that the combination of azolamid and lenacil gave a safe, wide-spectrum mixture which was relatively insensitive to soil moisture status. A grass and broadleaf weedkiller, NC 8438, was reported by Pfeiffer and Holmes (Fisons Ltd) and Sullivan *et al.* (Great Western Sugar Co.) persistent enough to control late emerging weeds in warm climates.

In potatoes, interest in trietazine has revived, now in combination with linuron. Work was reported by Mannall *et al.* (Bayer Agrochem Ltd) on the post-crop-emergence use of metribuzin which may, however, be too persistent.

The arable legume session was dominated by the pea crop. The most important pre-emergence development was a mixture of trietazine and simazine reported in Fisons Ltd trials and in post-emergence applications bentazon (May and Taylor, BASF UK Ltd) and cyanazine (Morris, Shellstar Ltd) show some promise although some deficiencies and dangers to the crop were apparent (King and Handley, PGRO). Bentazon was also seen as a possible post-emergence treatment in dwarf beans by the latter authors and in soya beans (Luib and van de Weerd, BASF).

VEGETABLES

Half of the twelve papers in this session concerned brassicas and often the information presented was confirmation of previous knowledge. Peat soils still present a problem in brassica weed control in spite of the number of safe herbicides available, but the situation in onions is more satisfactory (MacNaiedhe, Lullymore, Eire). Prynachlor was found to be particularly useful on peat soils. Several authors reported the usefulness of bioxone in onion crops after the two-leaf stage.

Activated charcoal was re-examined as a powder dip to increase the tolerance of transplanted brassicas, lettuce and tomatoes to herbicides (Allott and Uprichard, Loughgall).

FRUIT

Ten papers dealing with herbicides in strawberries were summarized by Robinson (Kinsealy, Eire). Phenmedipham was shown to be particularly useful against *Veronica* spp. (Uprichard Loughall; Jefferies and Scott, Long Ashton). Other treatments considered worthy of further trials are MO 338, pentanochlor and pyrazon (Clay, WRO), and 2,4-D (Davison, WRO).

Several authors put the tolerance of strawberries to pronamide in doubt and there is still disagreement on its safety in the raspberry crop. In raspberries no cumulative harm seems likely from chlorthiamid, dichlobenil, bromacil, terbacil or atrazine treatment when grown on the stool system (Lawson *et al.*, SHRI) though this may not be true of row systems (O'Callaghan and Rath Co., Wexford, Eire).

Preliminary results were presented of tests with early spring glyphosate applications on apples, blackcurrants and raspberries and interesting comparisons were made with the present paraquat recommendations in these crops (Clay, WRO).

A practical approach to orchard management was described by Banwell (Canterbury) in which the most successful maintenance treatment was 2,4,5-T in diesel oil, carefully applied.

In three papers, longer term effects of repeated applications of maleic hydrazide and 2,4-D were described, with general agreement that the resulting low-growing grass-dominated sward was easily managed.

AMENITY HORTICULTURE

Contributions to this session ranged from the use of granular dichlobenil, chlorthiamid and atrazine among forest trees to a simple system of garden maintenance based on paraquat and simazine.

Several papers gave useful information on the tolerance of a wide range of herbaceous and woody ornamental species to residual herbicides, particularly terbacil and lenacil.

TROPICAL FARMING

A welcome awareness of weed control problems in smaller scale tropical agriculture was shown by the inclusion of a small session containing papers describing various extension projects or dealing with more specific topics. Cocoa and flooded rice were discussed and a paper was given on the control of *Striga hermonthica.*

EXPERIMENTAL TECHNIQUES

Field experimentation was discussed from widely different viewpoints in this session. The highly organized system of a large research station was described by Elliott *et al.* This has evolved over the years in order to provide for the proper planning, execution and interpretation of up to 300 field experiments per annum which are based at WRO, Oxford.

In the completely different sphere of unsophisticated, developing tropical agriculture, Kasasian (WRO) clearly stated the problems of the lonely weed specialist whose work is often less concerned with technology than with economic and sociological factors. Here simplicity of methods and equipment usually still give the best chance of success.

Other reports described equipment and methods developed for specialized purposes, such as sprayers for herbicide evaluation and sugar beet experimentation, an automatic punching counter for recording plant parameters, and techniques for *Avena* spp. assessment in the field.

The specialized problems of aquatic weed experimentation, where a treatment often affects not only the target but the whole environment, were defined by Robson and Barratt (WRO). They also suggested ways of overcoming some of the difficulties.

Highlights of the 1972 Conference of the International Association on Mechanization of Field Experiments, held at Brno, Czechoslovakia, were presented.

PLANT GROWTH REGULATORS

Diverse uses of plant growth regulators were explored by a number of workers.

Altering the growth of the crop was considered by Osborne (Cambridge University), particularly the possibilities of enhancing cereal germination. A paper from Nottingham University described a germination response in sugar beet when the seed was steeped in water and in solutions of gibberellic acid, kinetin or 6-benzylaminopurine and, from NVRS, it was shown that celery seed germination could be stimulated with a gibberellin-Alar mixture.

Dormancy in weed seeds was discussed in a paper from Aberystwyth University College, and work at WRO with a range of chemicals pointed to particular weed sensitivities.

Various growth regulators altered the dominance system in *Agropyron repens*, increased sprouting of *Cyperus rotundus* tubers and inhibited the growth of *Myriophyllum verticillatum*, but attempts to use these effects to enhance herbicidal effects were generally disappointing.

NEW CHEMICALS

Invitations were extended world-wide but only a few announcements of new chemicals were made.

Ciba-Geigy's herbicide for rice, C 19490, was claimed to give good grass weed control and in mixture with a triazine, coded C 288, may have advantages over the existing herbicides in the crop.

Hoechst announced Hoe 2991, a substituted urea, proposed common name fluoretoxuron, which is selective in cotton.

Two new uracils were described by Roussel-Uclaf and Procida. RU 12068 has similarities with lenacil, but is more soluble. RU 12709 is similar to terbacil but more soluble and less persistent.

A material from Upjohn, U 27267, was being considered as a pre-emergence herbicide in beet, potatoes and tomatoes.

The use of new sulphones, related to ioxynil and bromoxynil was suggested by Wain, University of London, with the particular advantages of activity against *Agropyron repens* and *Avena fatua*.

A plant growth regulator, *N,N-bis* (phosphonomethyl) glycine, proposed common name glyphosine, from Monsanto is being considered for the acceleration of sugar cane, and perhaps sugar beet, ripening.

* * *

The Conference *Proceedings* are published in three volumes obtainable from the Technical Secretary, 11th BWCC, Clacks Farm, Boreley, Ombersley, Droitwich, Worcestershire, England.

SOME PROBLEMS AND PROGRESS OF WEED CONTROL IN INDIA, 1948-1972

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INTRODUCTION

Weeds are now widely regarded as pests of great agricultural menace because they lower agricultural production, or increase its cost, or impair the quality of produce in various ways. A review of the losses caused through weeds in India published by Mitra (1962) clearly reveals that losses due to weeds in India are sufficiently alarming to warrant urgent attention. Mehta and Joshi (1965) reported that, on a very conservative estimate, losses of about 10% caused by weeds to the principal agricultural products amount to approximately Rs.4200 million per annum.

In Uttar Pradesh alone, about 400,000 ha of cropped area are infested with the noxious weed known as baisure (*Pluchea lanceolata*). In Madhya Pradesh, large tracts are infested with kandiari (*Carthamus oxycantha*). In Rajasthan, weeds like cocklebur (*Xanthium strumarium*) seriously affect the quality of sheep wool. Another noxious weed, nutsedge (*Cyperus rotundus*), is extensively spread all over India and is consuming a good share of nutrition in vegetable and crop lands, though an elaborate study for eradication of this weed was made in India as early as 1925 by Ranade and Burns (1925). In Uttar Pradesh and Madhya Pradesh, kans (*Saccharum spontaneum*) occupies a very large area which could be profitably reclaimed for cropping. Another noxious weed, lantana (*Lantana camara*), has also infested vast areas in different parts of India.

With the introduction of the new high-yielding varieties programme in India, the wild oat (*Avena fatua*) problem in Punjab has recently become very acute. This weed has reduced the yield of new wheat varieties in very large areas. Another weed (*Phalaris minor*) is rapidly invading the wheat-growing areas in Haryana, Punjab and Uttar Pradesh. Similarly, pohli (*Carthamus oxycantha*) which was supposed to have been eradicated in Punjab, is again creating problems.

For the last few years, *Eupatorium odoratum* has spreau extensively in Assam, West Bengal, Kerala, Orissa and Tamil Nadu. In Assam, this weed forms dense strands as high as tea bushes or citrus trees. In Kerala, it is a serious weed in rubber plantations (Bennett and Rao, 1968). In Assam, *Imperata cylindrica* and in Nilgiris (Tamil Nadu), *Pennisetum clandestinum* and *Oxalis latifolia* are posing serious problems in plantation crops like tea thereby reducing the production of tea leaves considerably. Recently in Maharashtra, *Parthenium hysterophorus* has infected vast tracts of agricultural land and created serious problems. Similarly, in Tamil Nadu another weed, *Solanum elaegnifolium,* which has caused considerable loss to agricultural production, is spreading rapidly throughout the State.

The root parasite witch seed (*Striga* sp.) is another pest which causes considerable damage to crops like maize, sorghum, pearl millet (bajra) and sugar cane in many States like Rajasthan, Madhya Pradesh, Maharashtra, Mysore, Bihar and Uttar Pradesh. The damage caused by broom rape (*Orobanche* sp.) in tobacco is to the extent of 5 to 10% in West Bengal, 15 to 20% in Maharashtra and Gujarat, and 30 to 35% in Tamil Nadu State.

Apart from the weeds of arable land, aquatic weeds like water hyacinth (*Eichhornia crassipes*) is also a serious problem in States like Assam, Bihar, West Bengal, Orissa, Andhra Pradesh and Uttar Pradesh. This weed is causing enormous damage to fishery tanks and canals and low-lying areas which were earlier used for rice and water chestnut cultivation. In West Bengal alone, the loss due to this weed amounts to about 100 million rupees annually. In low-lying paddy growing areas in West Bengal, the algal weeds like *Chara* sp. and *Nitella* sp. appear to be a great menace in hampering the full growth and yield of paddy.

For the last 5 years in Kerala State, the water fern (*Salvinia auriculata*) and two species of pond weeds (*Potomogeton pectinatus, P. perfoliotus*) in irrigation canals in some States (*i.e.,* Rajasthan, Kerala, Andhra Pradesh, Uttar Pradesh) have been posing serious problems. These pond weeds hinder the normal flow of water in irrigation channels.

Apart from this, weeds also harbour insect pests and diseases and provide ideal ecological conditions for their shelter and proliferation. In India, wheat rust spends a part of its life cycle on barberry plants. There are a number of insects which have weed plants as alternate hosts. For instance, *Leersia oryzoides* is an alternate host for bacterial blight of rice; weeds like *Echi-*

nochloa spp., *Panicum* spp., and *Zizania* spp., are alternate hosts to rice stem borer. In India, the weeds on levees in waste areas give protective cover for rats and aggravate the problems of these pests. The control of host plants and weed infestation in border areas may reduce problems caused by many pests.

For tackling weed problems, it is necessary to be armed with complete data about their distribution and economic importance in different States. With this end in view, a detailed list of "Weeds of Agricultural Importance of India" was published by Joshi and Sardar Singh (1965).

The detrimental effects of weeds necessitate their eradication in crop land and other locations. The control of weeds is one of the most important steps in crop production, though very little has been done in India in this respect so far. Mechanical (*i.e.*, hand-weeding, the hoe, use of other agricultural implements to physically remove weeds) and cultural operations (*i.e.*, crop rotation, crop competition, etc.) are traditional methods of weed management which are still in wide use in India.

CHEMICAL CONTROL

Integrated weed control which combines all the known methods (*i.e.*, mechanical, cultural, biological and chemical) is only now accepted in India as the effective approach to controlling weeds.

For various reasons, chemical weed control in India has not yet received much attention. First, the availability of agricultural labour at a comparatively cheap rate makes the farmer rely on traditional methods of hand-weeding for weed control. Secondly, as the cost of application is rather high, the farmer is reluctant to use it extensively. Finally, Indian farmers generally follow a mixed cropping pattern of both dicotyledons and monocotyledons in which herbicides cannot be conveniently adopted.

Despite all these difficulties, earnest efforts are being made to test and popularize herbicides. The first attempts to control weeds by means of chemicals were made as early as 1937 in Punjab with the use of a non-selective herbicide, sodium arsenite, to control *Carthamus oxycantha* (as reported by Chakravarti, 1963). The hormone type of herbicide, 2,4-D, was introduced in 1948. Since then, the importance of weed control through chemicals has been rightly appreciated by the Indian Council of Agricultural Research and 13 schemes on a co-ordinated basis were sanctioned as early as 1952. The work was started first in Tamil Nadu State (previously called Madras) and at the Bose Research Institute, Calcutta. Subsequently, similar schemes were sanctioned for the other States, Punjab, Maharashtra, Andhra Pradesh, Kerala, Rajasthan, Assam, Himachal Pradesh, Madhya Pradesh, Uttar Pradesh and Jammu and Kashmir. An important feature of the co-ordinated scheme was that the treatments at all the centres were standardized. The objective of the co-ordinated weed control scheme was to investigate the weed flora of the region in a major crop, the relative efficacy of the chemicals, the economics of their use in terms of resultant increase in yields, their superiority or otherwise over local methods (cultural and mechanical) of control and, finally, the effectiveness of pre- and post-emergence spraying either singly or in combination with mechanical control.

From 1948 to 1972, about 30 sophisticated herbicides belonging to different groups were imported into India in a limited quantity. The important herbicides imported were alachlor, atrazine, amitrole, butachlor, bromacil, barban, chloramben, fluometuron, chlorpropham, diquat, 2,2-DPA, diuron, DNOC, EPTC, maleic hydrazide, methylarsinic acid, mecoprop, MCPA, MCPB, monuron, nitralin, propanil, paraquat, pebulate, pentachlorophenol, simazine, sirmate, TCA, trifluralin, terbacil, tri-allate, 2,4-D, 2,4-DB, disul, and 2,4,5-T.

Some of these herbicides proved quite promising against noxious weeds in agricultural crops used at recommended dosages at the proper time under Indian conditions (Verma and Bhardwaj, 1963; Joshi and Paharia, 1969; Joshi and Kapoor, 1970). Usage during 1971-2 included methylarsinic acid (13 tonnes), triazine compounds like simazine and atrazine (5 tonnes), propanil (15 tonnes), and miscellaneous weedicides totalling 50 tonnes like alachlor, butachlor, nitralin, tri-allate and MCPA, amounting to 24.70 million rupees. In addition to this, 400 tonnes of indigenously manufactured weedicides worth 4.50 million rupees were also consumed. Thus, the total cost of weedicides used in this year was about Rs.30 million. The bulk of the herbicides used was in plantation crops (*i.e.*, tea, coffee and rubber).

During 1971-2 the main weedicides consumed were paraquat (125 tonnes), 2,2-DPA (250 tonnes), substituted ureas (20 tonnes).

Since 1965 India has been manufacturing three herbicides (2,4-D, 2,4,5-T, and ammonium sulphamate). An Indian Standard Specification for 2,4-D and its formulations has also been completed. The present licensed manufacturing capacity of herbicides is only about 2285 tonnes and the installed capacity is 1935 tonnes (see Table 1).

TABLE 1: MANUFACTURE OF HERBICIDES IN INDIA

Chemical and Location	*Capacity*		*Current*	*Under*
	Licensed	*Installed*	*Production*	*Implementation*
2,4-D, 2,4,5-T, etc.:				
Agromore Ltd., Bangalore	435	435	—	800
Atul Products, Bulsar	1200	1200	—	—
Bharat Pulverising Mills	300	300	—	—
MCPA, MCPB, TCA, 2,2-DPA				
Indian Organic Chemical Co., Bombay	350	—	—	—
Total	2285	1935	350	800

Some other firms are also proposing to manufacture promising sophisticated herbicides and the Central Government has issued 3 letters of intent. Details are given in Table 2.

TABLE 2: HERBICIDES TO BE MANUFACTURED IN INDIA FOR WHICH LETTERS OF INTENT ISSUED

Companies and Herbicides	*Quantity Proposed to be Manufactured (tonnes)*
Dow Chemical Co.:	
2,2-DPA (Dowpon)	1540
Indofil Chemical Co.:	
propanil (Stam F. 34) and ~~nitralin~~ nitrofen (Tok E-25)	1500
Monsanto Chemical Co:	
butachlor (Machete), alachlor (Lasso) and tri-allate (Avadex BW)	4400

The State governments are also seriously thinking of developing weed control work. The total area of 1.4 million hectares covered by weed control during 1969-70 as reported by States increased to 1.7 million hectares during 1971-2. The areas of weed control practised in each State and the targets fixed for 1972-3 and 1973-4 are given in Table 3.

Out of the total 80 million hectares fixed for plant protection measures, the Central Government proposes to apply weed control measures in 2 million hectares during the last year of IV Plan period (1973-4).

The Government of India has also introduced a pilot project, with an outlay of one million rupees, to demonstrate the use of herbicides in various crops in different locations in India. In the beginning, the weeds which are more widespread and obnoxious are being tackled on a priority basis, an area of 4000 hectares of infested land being involved.

In the V Plan, it is proposed to continue the weedicide scheme in an expanded form. With the implementation of this expanded scheme, it should be possible to demonstrate to farmers on a large scale the efficacy and economics of weed control with

TABLE 3: PRESENT AND TARGET AREAS OF WEED CONTROL, 1969-70 TO 1973-4, AS REPORTED BY THE STATES

	Area in '000 hectares				
State/Union Territory	*1969-70*	*1970-1*	*1971-2*	*1972-3 (Target)*	*1973-4 (Target)*
Andhra Pradesh	345	416	404	600	800
Assam	—	—	—	—	—
Bihar	—	20	—	50	60
Gujarat	—	10	10	10	10
Haryana	154	138	—	—	—
Himachal Pradesh	0.4	90.2	0.4	10.4	5
Jammu and Kashmir	—	0.045	0.018	4	10
Kerala	116	70	—	14	135
Madhya Pradesh	101	25	149	560	10
Maharashtra	6	2	1	—	5
Manipur	—	—	—	5	—
Meghalaya	—	—	5	—	—
Mysore	3	4	—	10	—
Nagaland	—	—	—	—	—
Orissa	20	60	64	60	—
Punjab	560	610	600	500	500
Rajasthan	20	19	32	35	150
Tamil Nadu	—	—	4.8	5	5
Tripura	—	—	0.08	0.17	—
Uttar Pradesh	120	146	429	435	430
West Bengal	37.6	40	45	120	130
Andaman and Nicobar Island	—	—	*	—	*
Arunachal Pradesh	—	—	*	—	*
Chandigarh	—	—	*	—	*
Dadra and Nagar Haveli	—	—	*	—	*
Delhi	0.7	0.8	*	2	*
Goa, Daman and Diu	—	0.008	*	0.2	*
Lacadiv and Minicoy	0.2	—	*	—	*
Pondicherry	—	38	*	—	*
	1483.9	1665.153	1744.298	2417.77	2300

*Not available.

herbicides, and to maintain the interest generated during IV Plan. Weed control with herbicides is definitely expected to assist the small farmers who are not financially in a position to employ labour to remove the weeds responsible for the low yields of most of their crops. Once the farmers become accustomed to herbicides and learn their efficacy and usefulness, it should be possible to accelerate the manufacture of most of the herbicides indigenously.

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NEW USES FOR NAPROPAMIDE IN ASIAN-PACIFIC COUNTRIES

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INTRODUCTION

Napropamide (formerly R-7465) is a pre-emergence or pre-plant incorporated herbicide under development by Stauffer Chemical Company. During the third Asian-Pacific Weed Science Society meeting at Kuala Lumpur, the senior author presented a paper on this herbicide. In the past two years, additional information was obtained from field tests carried out throughout the world, and this paper will discuss applications of napropamide to crops common in Asian-Pacific countries. Application methods, dosages used, crop tolerance and weeds controlled are discussed. The results of tests on vegetable crops, transplanted paddy rice, subtropical and tropical plantation crops, and many other crops are also included. Some information on fundamental biochemical studies with napropamide are also presented. These include the uptake and metabolism of napropamide in plants, behaviour and persistence in soils, and its degradation in soil by micro-organisms and by sunlight.

FIELD RESULTS WITH NAPROPAMIDE

In the past few years, many field tests were conducted in Japan, Korea, Malaysia, Philippines, Taiwan and Thailand by Stauffer personnel and by co-operators. Some of the results are reported below.

VEGETABLE CROPS

Napropamide applied to the soil surface at 1.5 to 3.0 kg/ha was safe to many vegetable crops including tomatoes, eggplant, peppers, potatoes, cabbage, Chinese cabbage and white radish. Data obtained from Kimhae Horticultural Experiment Station, Korea, in 1972, are given in Table 1.

TABLE 1: WEED CONTROL IN PEPPER

Treatment (kg/ha)	*Weed Control (%)**	*Pepper Germination (%)*	*Pepper Height (cm)*
napropamide 1	90	62	31.4
napropamide 2	100	43	34.8
nitrofen 1	90	32	13.1
alachlor 1.5	80	33	18.4
butachlor 1.8	80	8	14.9
linuron 0.75	50	20	7.0
chlorthal 4	60	60	14.9
noruron 1.6	80	18	23.5
Control	0	58	23.0

*Weed species found in untreated plots were *Echinochloa crus-galli, Digitaria sanguinalis, Portulaca oleracea, Chenopodium* sp. and *Amaranthus* sp.

For vegetable crops, napropamide is usually applied to the soil surface after seeding or transplanting. Another convenient application method was tried and found practical to Asian growers. The napropamide wettable powder was added to the water container used for irrigation at a dilution rate of 1:2000 or higher and the chemical was applied as the vegetable beds were sprinkled.

Transplanted Paddy Rice

Napropamide was quite phytotoxic to many small-seeded crops in the family Gramineae. It cannot be used for direct-sown rice. However, it was rather safe to transplanted rice under flooded conditions at a low dosage. Napropamide + simetryn in a granular formulation applied at 0.6 + 0.3 kg/ha was tested in Japan and Korea at many locations in 1972. Control of grass weeds, broadleaf weeds and sedges was good and no rice injury was reported. Napropamide + molinate at a rate of 0.6 + 2.1 kg/ha gave promising results in tests conducted in Korea and Taiwan. Napropamide applied alone in a granular formulation gave satisfactory weed control and was safe to rice. Table 2 shows the results obtained from a field trial conducted by W. L. Chang, Chia-I Agricultural Experiment Station, Taiwan Republic of China.

TABLE 2: WEED CONTROL IN RICE

(DAT = days after transplanting)

Treatment (kg/ha)	*Time of Application*	*Weed Control (%)* 20 DAT	*Weed Control (%)* 40 DAT	*Rice Injury (%)* 20 DAT	*Rice Injury (%)* 40 DAT	*Rice Plant Height (cm)*	*Panicles per Hill*
napropamide 0.625	4 DAT	90	82	0	0	84.1	14.4
butachlor 1.5	4 DAT	80	76	0	0	84.3	13.9
Control		0	0	0	0	84.4	14.5

Weed species found in the untreated plots included *Monochoria vaginalis, Echinochloa crus-galli, Cyperus difformis, Lindernia cordifolia, Eleocharis acicularis, Rotala indica* and *Fibristylis miliacea.*

SUBTROPICAL AND TROPICAL PLANTATION CROPS

Napropamide was tested on oil palm by soil surface application in Malaysia in 1971 and 1972. Oil palm showed high tolerance to napropamide. Rates as high as 16 kg/ha did not injure two-year-old oil palm trees. Weed control results are shown in Table 3.

TABLE 3: WEED CONTROL IN OIL PALM

Treatment (kg/ha)	*Weed Control (%)* Months after Application* 2	5
napropamide 4.0	85	90
napropamide 5.0	85	90
diuron 1.7	90	50
alachlor 1.8	50	30
Control	0	0

*The principal weed species were *Paspalum conjugatum, Panicum repens* and *Mikania cordata.*

It is interesting to note how long the weed control persisted with napropamide and the increased weed control five months after the soil-surface application compared with the two-month ratings. The perennial grass, *Paspalum,* was not killed but its growth was inhibited.

Dr J. K. Templeton of Rubber Research Center, Hat Yai, Thailand, tested napropamide for weed control on nursery rubber seedlings and obtained good results as shown in Table 4.

TABLE 4: WEED CONTROL IN RUBBER

Treatment and Dosage (kg/ha)	*Months after Spraying 1*	*2*	*3*	*% Seedling Establishment*	*% of Plants with Multiple Shoots*	*Ht (cm) at 2 mon.*
napropamide 0.938	70	50	53	84	7	26.8
napropamide 1.875	90	78	50	84	2	26.8
napropamide 3.75	78	75	58	83	4	29.8
diuron 1.7	83	60	53	90	5	31.9
Hand-weeding	38	55	48	87	7	30.1

Eleusine indica was very well controlled. The principal species to regenerate were the dicotyledons, *Calopogonium* and *Scoparia* species. At these rates, Dr Templeton observed that slight stunting to rubber seedlings was caused by napropamide. But it did not induce multiple stem formation in the young rubber seedlings as caused by certain other pre-emergence herbicides. He suggested that napropamide should be tested for grass control on one-month-old rubber seedlings.

Napropamide has been tested on sugarcane during the past few years in Taiwan. S. Y. Peng of the Weed Control Laboratory, Taiwan Sugar Research Institute, tested napropamide on autumn-planted sugarcane intercropped with peanuts. Both crops were tolerant to napropamide at 2 and 4 kg/ha when applied post-plant to the soil surface. The results are given in Table 5.

TABLE 5: WEED CONTROL IN PEANUTS

Treatment (kg/ha)	*% Weed Control after 2 months*	*Peanut Yield (kg/ha)*
napropamide 2.0	68	887.5
napropamide 4.0	82	950.0
linuron 1.5	54	787.5
Control	0	544.0

The principal weed species controlled were *Eleusine indica, Echinochloa crus-galli, Portulaca oleracea, Amaranthus viridis, Digitaria chinensis* and *Chenopodium* sp.

The senior author conducted preliminary tests with napropamide on tea and banana plantations. Established tea plants and newly transplanted banana seedlings were tolerant to napropamide at a rate of 3 kg/ha. Weeds controlled included most annual grass weeds, annual broadleaf weeds, and *Cyperus rotundus*.

Vineyards and Orchards

Grapes showed very high tolerance to napropamide applied to the soil surface at a high dosage of 10 kg/ha. Phytotoxicity studies in California showed that newly planted almonds, plums, apricots and peaches showed excellent tolerance to napropamide at rates up to 18 kg/ha applied pre-emergence to the soil surface followed by flood or basin irrigation. In one trial, a total of 15 standard and experimental compounds were compared. At a rate of 18 kg/ha, napropramide was the safest material in the group. Trials on citrus in Florida showed that five-year-old orange trees were tolerant to napropamide at rates up to 22.3 kg/ha applied to the soil surface followed by overhead irrigation.

Other Crops

Napropamide was tested at Gumma Sericultural Experiment Station in Japan, on six-year-old mulberry plants. At rates of 2.5 and 5 kg/ha applied to the soil surface, napropamide gave 96 and 98% control of weeds, respectively. The main weed species were *Digitaria sanguinalis, Chenopodium album* and *Stellaria media.* Mulberry trees were tolerant to both rates. At the same location, a repeat application of napropamide at 2.5 kg/ha applied in April, 1971, and 5 kg/ha applied in June, 1971, maintained 90% control of *Digitaria sanguinalis* through July of 1972.

In 1972, personnel at the Sosa Tobacco Experiment Station, Korea, tested napropamide along with other herbicides on tobacco. Napropamide was the only chemical which was safe on transplanted tobacco. The weed control ratings taken at 10-day intervals are presented in Table 6.

TABLE 6: WEED CONTROL IN TOBACCO

Treatment (kg/ha)	*% Weed Control Days after Treatment*			
	10 days	*20 days*	*30 days*	*40 days*
napropamide 1.5	91	93	93	94
linuron 0.5	80	84	83	80
alachlor 0.96	92	94	94	94
butachlor 1.8	93	95	95	96
nitrofen 2.0	52	84	35	25
Control	0	0	0	0

Weed species controlled included *Digitaria sanguinalis, Echinochloa crus-galli, Portulaca oleracea, Chenopodium album,* and *Equisetum* sp.

Besides these crops, other crops, including sweet potatoes and green beans, showed tolerance to napropamide at rates of 2 and 4 kg/ha.

GROWTH STIMULATION EFFECT

Chemically, napropamide is related to auxins of the naphthoxy type which cause malformation of dicotyledonous plant species. Napropamide does not show these hormonal-type symptoms. However, several reports received during the past few years indicated that napropamide caused stimulation of growth of tomato plants and other crops under certain conditions. The size of tomato plants treated with napropamide was often increased over that of the controls in greenhouse tests in California.

From Japan, one co-operator observed in laboratory evaluation tests that napropamide at 1 kg/ha applied to rice seedlings produced 80% more root growth than untreated plants. The height of pepper plants treated with napropamide at 1 and 2 kg/ha was increased 34 to 47% over the untreated plants in tests carried out in Korea.

The mechanism by which napropamide caused the stimulation of plant growth and the conditions which prevailed when the enhancement of growth occurred are not known. The writers wish to point out this interesting finding since other investigators may want to carry out further research on the subject.

FUNDAMENTAL STUDIES

Metabolism of Radioactive Napropamide in Plants

Murphy *et al.* (1972) reported on their laboratory study of the uptake and metabolism of napropamide by plants. Radioactive napropamide, ring-labelled with carbon-14, was rapidly taken up by the roots of tomato plants. Within one hour after treatment, the radioactivity had translocated from the roots upward throughout the tomato stems, and in eight hours the radioactive materials were distributed throughout the leaves.

Napropamide was rapidly converted in the roots and shoots of tomato plants into water-soluble metabolites. The main radioactive metabolite was identified as a water-soluble hexose conjugate of 2-(α-naphthoxy-4-hydroxy)-*N*, *N*-diethylpropionamide. This metabolite represented 47% of the soluble radioactivity in the plants. A second major water-soluble radioactive component which migrated as a single spot on thin-layer chromatographs represented 22% of the soluble radioactivity in the tomato seedlings. This component was found to be a mixture of hexose conjugates of 2-(α-naphthoxy-4-hydroxy)-*N*, *N*-diethylpropionamide and 2-(α-naphthoxy-4-hydroxy)-*N*-ethylpropionamide. Ring hydroxylation and dealkylation of the propionamide side chain of the napropamide appeared to be the initial steps in detoxification of the herbicide, followed by conjugation with sugar.

Behaviour and Persistence of Napropamide in Soils

Miller and Gray (1972) reported that laboratory studies on the behaviour and persistence of napropamide in soils showed that it was biodegraded in soils but at a relatively slow rate. After incorporation of radioactive napropamide (ring-labelled with carbon-14) 5 cm deep at a rate of 4 kg/ha in moist soils contained in open glass jars, the half-life at 21 to 32° C was 8 to 12 weeks. Microbial effects were important in the disappearance of napropamide in moist soil, since the chemical disappeared much more rapidly in non-autoclaved soil than in autoclaved soil. Radioactive breakdown products identified in moist loam soil, one year after incorporation of radioactive napropamide included 2-(α-naphthoxy)-*N*-ethylpropionamide, 2-(α-naphthoxy) propionamide, 2-(α-naphthoxy) propionic acid, 2-(α-naphthoxy)-*N*-ethyl-*N*-hydroxethyl propionamide, 2-hydroxyl-1, 4-naphthoquinone, 1, 4-naphthonquinone and *o*-phthalic acid. A large portion of the radioactive products became associated with high molecular weight humic acids of the soil.

Leaching studies with radioactive napropamide indicated that it was rather resistant to leaching in most mineral soils. In clay and silty clay soil, napropamide leached downwards only about 2.5 cm when leached with 20 cm of water. In a loam soil and in a loamy sand it moved downward approximately 5 cm and 20 cm, respectively, when leached with 20 cm of water.

Photodecomposition tests showed that approximately 50% loss of napropamide occurred in 4 days when the herbicide was applied to the soil surface and exposed to high-intensity sunlight during summer months. During winter months, under partly cloudy weather conditions, only 30% loss occurred in 8 days on the soil surface.

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PURPLE NUTSEDGE (*CYPERUS ROTUNDUS*): ITS BIOLOGY AND CONTROL[1]

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Summary

A new approach to purple nutsedge *(Cyperus rotundus)* control is suggested by inducing dormant buds on the tubers to sprout, after which a herbicide is used to destroy the foliage. Cytokinins enhanced sprouting of tubers when incorporated into the soil under greenhouse conditions. Paraquat at 2.2 kg/ha was used to kill top growth of 2- and 3-week-old plants. Paraquat did not affect the basal bulbs and the previously dormant buds on the tubers, consequently permitting their regrowth. With N-6 benzyl adenine pretreatment, little rejuvenation from the tubers resulted after the foliage was removed.

INTRODUCTION

Purple (*Cyperus rotundus*) and yellow (*C. esculentus*) nutsedge are perennial weeds that infest agricultural lands world wide. Purple nutsedge is distributed throughout the warm regions of the world (Holm and Herberger, 1969), while yellow nutsedge thrives in the cooler regions (Hauser, 1971). According to the survey by Holm and Herberger purple nutsedge is considered the world's worst weed.

BIOLOGY OF PURPLE NUTSEDGE

Since purple nutsedge produces few viable seeds (Justice and Whitehead, 1946), the principal method of propagation is through the basal bulb and tuber. The basal bulb is a swollen, corm structure which forms the base of the plant. Aerial leaves arise one-third phyllotaxy from the nodes of this corm. Buds are formed in the axils of the leaves. The tuber is an oval or spherical compressed stem structure with three to ten buds distributed spirally at the nodes. Deciduous scale leaves cover the buds. The exterior of the tuber is at first white, but it changes colour with age through brown to black (Ranade and Burns, 1925).

[1] Published as Journal Series No: 1551, Hawaii Agr. Exp. Sta. Research partially supported by Western Regional W-108 funds.

Both the basal bulb and tuber serve as food-storage organs. These structures originate from the meristematic cells of the rhizome apex (Wills and Briscoe, 1970). The writers observed that when tubers and basal bulbs were grown in complete darkness rhizomes formed, but in light a plantlet with a rudimentary rhizome resulted.

A young rhizome is at first white and succulent but with age it becomes black and wiry. Anatomical and translocation studies of the old rhizome showed that it is completely intact and has a functional vascular system (Holt *et al.*, 1967; Akobunda *et al.*, 1970; Wills and Briscoe, 1970; Ray *et al.*, 1971).

Under field conditions, early growth of purple nutsedge consists of rhizomes emerging from the tuber which terminate in above-ground foliar parts with a basal bulb below the soil surface (Hauser, 1962b). The new basal bulb gives rise to more rhizomes, which after elongating for varying distances terminate in more basal bulbs or tubers. Thus, in an established purple nutsedge stand, complex interconnected systems of plants, rhizomes, basal bulbs and tubers are present. In an experiment in Georgia, tubers planted at 1 m intervals produced 5.73 million plants and 6.82 million tubers and basal bulbs per hectare (Hauser, 1962a). These data clearly emphasize the reproduction capacity and seriousness of purple nutsedge as a weed.

Two types of dormancy have been described in purple nutsedge. Tuber apical dominance (Ranade and Burns, 1925; Smith and Fick, 1937) was observed in isolated tubers where the apical bud usually sprouted first while other buds remained inhibited. These inhibited buds resumed growth when the foliage of the existing plant was killed (Jangaard *et al.*, 1971). Dissection of tubers also caused sprouting of buds near the cut surface (Muzik and Cruzado, 1953). The interconnected tuber-rhizome system also exhibited apical dominance just as an individual tuber (Smith and Fick, 1937). When the intact tuber-rhizome chain was planted vertically, sprouting usually occurred only in the uppermost tuber. When the rhizomes were severed or killed with heat, all the tubers on the chain sprouted at equal rates (Muzik and Cruzado, 1953). The elimination of this type of apical dominance explains in part why cultivation frequently appears to increase nutsedge infestation of an area (Ranade and Burns, 1925; Smith and Fick, 1937).

The cause of dormancy in purple nutsedge has not been established. It may be due to the presence of growth inhibitors. Work in California indicated that ethephon stimulated sprouting of purple nutsedge tubers (Jackson *et al.*, 1971), but the writers were unable to obtain similar stimulation with tubers from Hawaii (Teo *et al.*, 1971). Instead cytokinins (Teo *et al.*, 1971; 1973; Teo and Nishimoto, 1972) were found to enhance sprouting of purple nutsedge.

CONTROL OF PURPLE NUTSEDGE

In 1925, Ranade and Burns reported that control of this weed in India could be achieved by two successive ploughings during the hot season. Similar success was later reported by Andrews (1940) and Smith and Mayton (1942). Deep ploughing of the soil to expose the tubers to the sun was essential to kill the propagative structures. Hollingsworth and Ennis (1956) noted that cultivation alone gave as good or better control than the use of herbicides. Thus, where practical, deep tillage seems to be an economical control method.

Herbicides like 2,4-D, amitrole, methylarsinic acid (MSMA), dichlobenil, the substituted uracils, and the thiocarbamates were reported to give varying degrees of control. Two applications of amtirole were effective on nutsedge clones from a single tuber, but for an established stand, owing to the varied growth stage, success was limited (Hauser, 1963a, b). Nutsedge was most susceptible to applied amitrole 4 weeks after initial emergence. Repeated applications (4 to 8 times year) at 5.6 to 16.8 kg/ha of methylarsinic acid destroyed most established space-planted purple nutsedge in Arizona (Hamilton, 1971). Dichlobenil and terbacil at 6.7 to 9 kg/ha when incorporated in the soil, gave excellent control for 12 to 18 months. But these herbicides were highly persistent in the soil and enough remained in the soil for as long as 24 months to be toxic for subsequent crop growth (Waters and Burgis, 1968). The thiocarbamates may be the most effective group of compounds for nutsedge control — these include herbicides such as EPTC, butylate and vernolate (Antognini *et al.*, 1959; Jordon *et al.*, 1960; Kasasian, 1971). Soil incorporation of EPTC (3.7 kg/ha) gave good seasonal control of purple nutsedge in western U.S.A. At such a rate EPTC was reported to cause bud inhibition of the tuber (Antognini *et al.*, 1959). However, the tubers were reported killed when exposed to soil-incorporated EPTC at 13.4 to 17.9 kg/ha (Holt *et al.*, 1962) for 8 to 12 weeks.

It is apparent from the various reports that no economical effective eradication method for this weed is yet available. It seems that the main cause of this failure is the inaccessibility of applied chemicals to the underground reproductive structures, which soon rejuvenate into shoots upon death of the existing foliage.

New shoots arise from the existing dormant buds on the tuber. The existing basal bulbs, like the tubers, also have viable buds that are capable of forming shoots. After reaching a certain stage of development, the newly-formed basal bulbs and tubers are capable of growth independent of the parental structures. Even if the parental structures are killed, the newly-formed basal bulbs and tubers may remain unaffected and will eventually develop into plants. Thus, for any eradication method to be effective, it should aim at destroying all these potential sites of regrowth.

An ideal approach to purple nutsedge control is to use a systemic herbicide which is capable of killing both the aerial and underground parts. At this time no herbicide has been reported to be effective in this manner without leaving harmful residues in the soil. An alternative method would be to induce all buds on the dormant tubers in the soil to sprout and subsequently use a herbicide to kill the newly-formed foliage. In this way, the tubers would be depleted of their viable buds. In a greenhouse experiment, the writers were able to cause 70 to 90% of the buds present on the tubers to sprout by treating the soil with either benzyl adenine or SD 8339 (a synthetic cytokinin produced by Shell), while in the control only 25% of the buds sprouted (Teo and Nishimoto, 1972). Cytokinin activity in the soil persisted for less than 1 week. This seemed to be a desirable characteristic. An earlier study (Teo *et al.*, 1973) showed that, when purple nutsedge plants were foliarly treated with N-6 benzyl adenine for an extended period of time (about 3 weeks), their growth habit was altered. There was an increase in the number of rhizomes and plants produced. However, if only the tubers were treated with benzyl adenine to induce sprouting, the subsequent growth of the plants was similiar to that of the control. The aim of this work was to develop the concept of using a cytokinin to enhance bud sprouting for subsequent herbicide treatments. Cytokinins are expensive and may not be of practical use in the field, but it is hoped that a cheaper chemical exhibiting cytokinin-like activity could be synthesized for economical use.

Materials and Methods

Tubers were dug from the fields at Waimanalo Experimental Farm, Hawaii. Six tubers were planted in soil in an aluminium foil tray (8 × 4 × 5 cm). Three hundred and fifty grams of soil was initially drenched with 100 ml of water or 50 ppm benzyl adenine solution. Two- and three-week-old plants were sprayed with paraquat (2.2 kg/ha). Four weeks after the herbicide treatment, fresh weights of the green leaves were taken. The original tubers were harvested and germinated in petri dishes treated with 100 ppm benzyl adenine to induce all buds on these tubers to sprout (Teo and Nishimoto, 1972). The numbers of shoots per tuber were counted after 10 days. Each treatment was replicated four times and the experiment was repeated.

Results and Discussion

Benzyl adenine-treated soil increased shoot production as a result of enhanced bud sprouting of the tubers, but such an increase would not be disadvantageous since the foliage could be treated with a herbicide. The use of a strictly contact herbicide like paraquat to kill the top growth of purple nutsedge was unsatisfactory in eventual eradication. Paraquat did not affect the basal bulbs and the new reproductive structures formed, thus allowing regrowth later. The fresh weight represented in Table 1 was derived from resprouting of the basal bulbs and the newly-formed reproductive structures.

There was minimal resprouting from the original tubers in benzyl adenine-treated soil as compared with the untreated soil (Table 2). This clearly indicated that benzyl adenine caused virtually all the buds on the tuber to sprout. Consequently little rejuvenation is expected from the tubers. Paraquat treatment did not affect tuber viability. This was expected, since paraquat is

TABLE 1: FRESH WEIGHT OF GREEN LEAVES FOUR WEEKS AFTER TREATMENT OF PURPLE NUTSEDGE FOLIAGE FROM TWO GROWTH STAGES (2 AND 3 WEEKS)

One set of plants at each growth stage derived from tubers treated with benzyl adenine.

Treatment (kg/ha)	*Fresh Weight of Leaves (g)* Growth Stage (2 wk)	Growth Stage (3 wk)
Control	3.18	2.99
Benzyl adenine + control	4.23	4.12
paraquat 2.2	1.50	2.01
Benzyl adenine + paraquat 2.2	2.98	1.95
LSD (5%)	1.69	1.69

TABLE 2: VIABILITY OF BUDS ON TUBERS ORIGINALLY PLANTED FOUR WEEKS AFTER TREATMENT OF PURPLE NUTSEDGE FOLIAGE FROM TWO GROWTH STAGES (2 AND 3 WEEKS)

One set of tubers originally treated with benzyl adenine.

Treatment *(kg/ha)*	*No. of Sprouts per Tuber* *Growth Stage* *(2 wk)*	*Growth Stage* *(3 wk)*
Control	2.29	2.00
Benzyl adenine + control	0.25	0.33
paraquat 2.2	2.50	2.33
Benzyl adenine + paraquat 2.2	0.38	0.21
LSD (5%)	1.05	1.05

not translocated to any extent. Also, there was no significant difference between treatments at the 2- or 3-week growth stages.

The idea of cytokinin-enhanced tuber sprouting for preconditioning of purple nutsedge for subsequent eradication may be useful. However, satisfactory results may be obtained by using a systemic herbicide instead of a contact one provided no harmful residues remain to injure subsequent crops.

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CONTROL OF PURPLE NUTSEDGE (*CYPERUS ROTUNDUS*) WITH GLYPHOSATE

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Summary

Glyphosate was tested against purple nutsedge *(Cyperus rotundus)* growing in a mature coffee plantation in Tanzania. Dosage rates of 2, 4 and 6 kg/ha and a split application of 2 + 2 kg/ha gave 95 to 100% control of nutsedge foliage within 4 to 6 weeks of application. All doses were still very effective 26 weeks after application. Excavations of tubers from treated areas revealed a possible reduction of numbers in the upper 10 cm of soil. Dry weights of tubers were unaffected by glyphosate but isolated tubers were inhibited from sprouting. Glyphosate appears to be a most promising product for the control of purple nutsedge.

INTRODUCTION

Purple nutsedge (*Cyperus rotundus*) is a serious weed in East Africa and has proved to be particularly troublesome in plantations where minimum cultivation systems have been practised. Of the available nutsedge herbicides, none has been found to be entirely satisfactory for economic use in the high altitude tropics of East Africa. The discovery of a new class of post-emergence herbicides, of which glyphosate is a member, for the control of perennial weeds (Baird *et al.*, 1971) was welcomed as a possible alternative to existing methods of control. The present study was undertaken to determine the effect of glyphosate on purple nutsedge in a coffee plantation.

MATERIALS AND METHODS

Glyphosate (formulated as MON-1139) at 2, 4 and 6 kg/ha in 350 l/ha water was applied to a dense stand of purple nutsedge 45 cm high with 95% ground cover. A split dose of 2 + 2 kg/ha with a 15-day interval between spraying was also applied. Treatments were applied with an Oxford Precision sprayer on 21 April 1972 to fourfold replicated plots of 16 m^2 in a mature, unshaded arabica coffee plantation situated 10 km west of Arusha, Tanzania, at an altitude of 1,400 m. The soil, a grey volcanic loam, had not been cultivated for 6 years, during which time a

TABLE 2: EFFECT OF GLYPHOSATE ON NUMBER, DRY WEIGHT AND SPROUTING OF NUTSEDGE TUBERS FROM 4 SOIL DEPTHS (CM)

		Tubers per m²				*100 Tuber Dry Wt.*			*% Sprouting of Tubers*			
Treatment	*(kg/ha)*	*0-10*	*10-20*	*20-40*	*40-60*	*0-10*	*10-20*	*20-40*	*0-10*	*10-20*	*20-40*	*40-60*
Glyphosate	2	1677	1609	405	61	7.4	13.7	13.4	11.7	24.8	34.6	28.6
Glyphosate	4	713	1541	572	108	6.8	10.3	11.5	5.3	10.9	21.4	14.1
Glyphosate	6	939	1565	576	49	6.3	10.0	10.9	2.9	13.0	16.2	25.5
Glyphosate	2 + 2	808	1733	564	70	7.1	10.9	11.5	12.5	28.4	30.4	19.4
Control		1438	1970	652	64	6.8	8.5	10.7	35.2	52.5	49.5	54.5

combination of rotary scything and repeated paraquat applications had been used to control weeds.

Measurements of nutsedge density were made 21 and 26 weeks after application by counting emerged shoots within 10 randomly placed quadrats of 0.1 m^2 on every plot. Areas of 1 m^2 were excavated at 21 to 24 weeks to a depth of 60 cm and tubers were extracted from the 0–10, 10–20, 20–40 and 40–60 cm levels. Approximately 200 tubers from each plot were incubated on moist filter paper in open plastic containers at room temperature (*c.* 20° C) for 5 days. Tubers were considered to have sprouted when one or more rhizome initials had emerged.

RESULTS AND DISCUSSION

Within two weeks of application, all nutsedge foilage had collapsed owing to weakness of the fascicle caused by all doses of glyphosate. At this time 50 to 60% of the foliage was green but by 4 to 6 weeks there was 95 to 100% desiccation. There was little regrowth during the subsequent dry season and no significant differences between plant densities on glyphosate treatments could be detected at 21 and 26 weeks after application. The difference between treated plots and the control was highly significant (Table 1).

TABLE 1: EFFECT OF GLYPHOSATE ON NUTSEDGE DENSITY

		21 weeks		*26 weeks*	
Treatment	*(kg/ha)*	*Shoots per m^2*	*% of Control*	*Shoots per m^2*	*% of Control*
glyphosate	2	129	32	48	17
glyphosate	4	70	17	43	15
glyphosate	6	99	24	41	14
glyphosate	2 + 2	83	21	40	14
Control		403	100	283	100
LSD ($P = < 0.05$)		79		79	

There was an indication that glyphosate may have reduced the number of tubers in the upper 10 cm of soil but differences in treatments were insignificant at the 5% level (Table 2).

There was no treatment effect on the dry weight of 100 tubers but it was observed that tuber weights in the upper 10 cm were significantly lower than those recovered from deeper levels.

Glyphosate had a marked effect on sprouting of incubated tubers, particularly at 4 and 6 kg/ha. Unsprouted tubers failed to grow when planted in potted soil but gave a positive response to the tetrazolium test for viability. It seems, therefore, that glyphosate had induced or prolonged tuber dormancy or inhibited normal sprouting mechanisms. Sprouting inhibition was most effective in the upper levels but was also apparent at 40–60 cm, thus providing strong evidence that translocation had taken place. Leaching and subsequent uptake of active material by the tubers was unlikely if the manufacturer's claim that glyphosate is inactivated by soil components is correct (Monsanto, 1971).

There was no observed deleterious effect of any treatment on the coffee but care was taken to avoid spraying the crop foliage. In normal farm practice this precaution would be difficult to maintain.

Preliminary results of glyphosate activity on purple nutsedge are very encouraging. Long-term studies are required to determine the effect of this herbicide on tuber populations and the capacity of tubers to survive periods of supressed sprouting.

ACKNOWLEDGEMENTS

E. von Roretz of Selian Coffee Estate kindly provided an experimental site and Monsanto donated samples of glyphosate.

This research was conducted under Research Scheme R.2557 financed by the Overseas Development Administration of the British Foreign and Commonwealth Office and by the East African Community. This paper is published with the approval of the Communications, Research and Social Services Secretariat of the East African Community and the Director, Tropical Pesticides Research Institute.

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NUTGRASS (*CYPERUS ROTUNDUS*) SUPPRESSION WITH POLYTHENE FILM

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The use of polythene and other plastic film to suppress the growth of nutgrass (*Cyperus rotundus*) has several horticultural applications, including forming an impenetrable base for pebble gardens, seedbeds and potted plants to prevent infestation from the underlying soil, suppressing weed growth around trees and shrubs and in other ornamental areas, and as a weed suppressant mulch in vegetable culture. Other areas of economic interest include the protection of the bases of home pools and water storages lined with plastic film against nutgrass penetration.

A trial was laid down at the Queensland Agricultural College (fifty miles west of Brisbane) to investigate the penetration by nutgrass shoots of standard black polythene film of different thicknesses. The soil was a moist, black clay loam with an estimated average density of nutgrass tubers of 0.75 million per hectare in the upper 20 cm, which was ploughed and rotary-hoed prior to laying the plastic film. Sheets of black polythene film* each 1.83 m square and of nominal thickness 0.05, 0.10, 0.15, 0.20 and 0.25 mm were laid over the freshly cultivated soil in a replicated randomized layout and buried around the edges. The sheets were covered with dry sand to prevent them from lifting as the nutgrass shoots emerged beneath.

Preliminary results are given in Table 1.

TABLE 1: AVERAGE NUTGRASS SHOOT EMERGENCE PER SQUARE METRE

	Film thickness (mm)				
	0.05	*0.10*	*0.15*	*0.20*	*0.25*
Days after laying:					
16	0.75	0.50	0.0	0.0	0.0
39	3.01	0.17	0.0	0.0	0.0
72	7.60	2.59	0.08	0.0	0.0

*Donated by Union Carbide Australia Ltd.

The polythene sheets were lifted from one replication 75 days after laying down. Numerous dead, and a smaller number of chlorotic living nutgrass shoots occurred around the inner edges of all sheets and throughout the entire area of the two thinnest sheets, both of which had been penetrated. It is suggested that the chlorotic shoots arose from tubers supplied with nutrients from green shoots either outside or penetrating the sheets.

An incidental observation was that shoots of Johnston grass (*Sorghum halepense*) failed to penetrate polythene film of nominal thickness 0.10 mm.

The results suggest that standard black polythene film of nominal thickness 0.20 mm is sufficient to prevent the penetration of nutgrass shoots arising from clean soil surfaces. Further observations will be made on this trial, whilst a trial to examine the penetration of buried polythene film by nutgrass rhizomes and the application of this technique to practical horticultural situations continues.

BIOCHEMICAL CHANGES IN NUTGRASS (*CYPERUS ROTUNDUS*) AS INFLUENCED BY HERBICIDES

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Summary

In nutgrass *(Cyperus rotundus)* plants, 2,4-D and "Bladex-P" (2,2-DPA/amitrole) treatments caused an initial decrease of protein percentage, which was followed by a sharp increase in shoots and gradual increase in roots. The proteins were slightly increased in "Bladex-P" treatments, while 2,4-D caused a very marked increase. The activity of peroxidase in roots is about double the activity in shoots in control plants. One day after spraying, the activity of enzymes increased in 2,4-D treatments and decreased in "Bladex-P" treatments. Almost all the reductions in enzyme activity were within 7 days of spray of the herbicides. But in the roots the reduction due to 2,4-D treatments was gradual and continued up to 14 days after spraying.

Treatment of plants with 2,4-D results in a reduction in carbohydrate content and an accumulation of nitrogen (Sell *et al.*, 1949; West *et al.*, 1960; Nooden and Thimann, 1966). The changes in carbohydrates, proteins, amino acids and respiratory rates of plants and plant parts treated with herbicides indicate an altered enzymatic action within the plant (Hand, 1939; Smith *et al.*, 1947). Some of these effects have been investigated (Freed *e al.*, 1961). The actual mechanism is still a matter of conjecture in spite of some excellent research and well-founded theorizing. A brief examination of proteins and enzyme action in the light of results obtained with 2,4-D and "Bladex-P" (2,2-DPA + amitrole) in nutgrass (an obnoxious and perennial weed) particularly, may suggest how these herbicides fit into the protein and enzymatic pattern.

EXPERIMENTAL

The experiment was conducted in the greenhouse of Haryana Agricultural University, Hissar. Earthen pots of 30 cm height and 22.5 cm diameter were filled with 5 kg of sandy loam soil. Ten healthy tubers of nutgrass (*Cyperus rotundus*) were sown in each pot on 6 March, 1969. Pots were watered frequently, to maintain a fairly high moisture level in the soil. The emergence of shoots was observed on 14 March, 1969. The plants were sprayed with ester formulation of 2,4-D (67.5% a.e.) at the concentrations of 1000, 2000, 3000, and 4000 ppm a.e.; and "Bladex-P" (2,2-DPA, 48% a.i. + amitrole, 32% a.i.) at concentrations of 16 000, 24 000, 32 000 ppm a.i.) on 30 March, 1969. 2.2 ml of fluid was sprayed uniformly over the foliage in each pot. Each treatment was replicated four times.

From each treatment, plants were randomly sampled 1, 7 and 14 days after spraying. Oven-dried shoots and roots were estimated by Hand's ferricyanide method (A.O.A.C., 1965). Protein was determined by the method of Lindner (1944). The enzyme activity was determined in fresh tissue. Catalase was assayed by following the method of Sumner and Somers (1953), where the technique of Ponting and Jeslyn (1948) was followed for the assay of peroxidase.

RESULTS AND DISCUSSION

Sugars and Proteins

Sugar content increased and protein content decreased over control, 24 hours after application of herbicides (Table 1). These changes were more marked in shoots and less in roots. 2,4-D was more effective than "Bladex-P".

The data in Table 2 indicate that the sugar content in shoots and roots decreased as the concentrations of the herbicides increased, but there was a steep fall in sugar percentage in the "Bladex-P"-treated plants. The "Bladex-P" caused more reduction in shoots and less in roots after 14 days of treatments.

TABLE 1: CHANGES IN SUGAR AND PROTEIN PERCENTAGES IN NUTGRASS

(One day after application of lethal doses of 2,4-D and "Bladex-P")

	Shoots	*Roots*
Sugar percentage:		
Control	5.65	7.90
2,4-D	6.90	8.40
"Bladex-P"	6.40	8.15
Protein percentage:		
Control	8.60	4.80
2,4-D	7.95	4.30
"Bladex-P"	7.80	4.70

TABLE 2: EFFECT OF HERBICIDES ON SUGAR PERCENTAGE IN NUTGRASS
(On dry weight basis)

Treatment (ppm)	*Shoots Days after Spraying* 7	*14*	*Roots Days after Spraying* 7	*14*
Control	6.10	6.60	7.80	8.25
2,4-D:				
1 000	5.45	3.36	7.71	6.13
2 000	4.80	2.30	6.15	3.55
3 000	3.95	2.55	4.80	2.75
4 000	3.90	2.61	4.90	2.80
"Bladex-P":				
16 000	4.00	3.20	7.40	5.30
24 000	3.55	2.55	6.00	4.69
32 000	3.15	1.97	5.85	4.10

Protein content increased both in shoots and roots with increased doses of herbicides. Most of the increase of protein in shoots was within seven days of the treatments, while in roots this increase was gradual and slowly continued up to 14 days after treatment. "Bladex-P" had a slight or negligible effect but 2,4-D caused a very marked increase.

Increase in protein concentration may be due either to the increased absorption of nitrogen compounds from the soil and biosynthesis of amino acids and proteins (Rasmussen, 1947) or merely an indication of depletion of sugars or their utilization in protein synthesis (Sell *et al.,* 1949). But in "Bladex-P"-treated

TABLE 3: EFFECT OF HERBICIDES ON PROTEIN PERCENTAGE IN NUTGRASS
(On dry weight basis)

Treatment (ppm)	*Shoots Days after Spraying* 7	*14*	*Roots Days after Spraying* 7	*14*
Control	8.90	9.05	5.20	5.50
2,4-D:				
1 000	9.35	9.45	5.75	6.35
2 000	9.85	10.05	6.35	7.05
3 000	10.45	10.85	7.00	7.10
4 000	10.75	10.90	6.95	7.00
"Bladex-P":				
16 000	9.10	9.05	5.25	5.30
24 000	9.10	9.15	5.45	5.50
32 000	9.15	9.15	5.50	5.50

plants, the increase in protein was very small and negligible while the depletion of sugars was very pronounced which contradicts the possibility given by Sell. Hence it may be confirmed that the increase in protein content of nutgrass treated with 2,4-D is due to an increased rate of absorption of nitrogenous compounds from the soil and the increased synthesis of amino acids and proteins.

ENZYMES

Catalase and peroxidase activities are presented in Tables 4 and 5.

TABLE 4: EFFECT OF HERBICIDES ON CATALASE ACTIVITY IN NUTGRASS

(Expressed in ml of KMO_4 used)

Treatment (ppm)	*Shoots* *Days after Spraying* 1	7	14	*Roots* *Days after Spraying* 1	7	14
Control	0.85	0.85	0.87	1.15	1.15	1.15
2,4-D:						
1 000	0.85	0.75	0.72	1.15	1.12	1.10
2 000	0.92	0.71	0.70	1.15	1.08	1.05
3 000	0.92	0.65	0.65	1.15	1.05	0.90
4 000	0.90	0.65	0.64	1.10	1.05	0.88
"Bladex-P":						
16 000	0.80	0.53	0.50	1.17	1.07	1.00
24 000	0.80	0.53	0.50	1.14	0.97	0.93
32 000	0.75	0.53	0.43	1.12	0.80	0.80

The data in Table 4 show that, one day after spraying, activity of the catalase increased up to 2000 ppm of 2,4-D in shoots but did not increase in roots; "Bladex-P" reduced the activity in both shoots and roots. Activity was decreased by all concentrations of both herbicides after 7 and 14 days of spray.

The data in Table 5 show that the activity of peroxidase in roots is about double the activity in shoots (in control plants). After one day of spray, the activity of peroxidase increased in shoots and roots with increased doses of 2,4-D, but all the concentrations of "Bladex-P" reduced the activity. After 7 and 14 days of spray, activity was decreased in shoots and roots with all the concentrations of herbicides tried. From the data presented here it is clear that most of the reduction in enzyme activity in shoots was within 7 days of the spray. But in roots

TABLE 5: EFFECT OF HERBICIDES ON PEROXIDASE ACTIVITY IN NUTGRASS
(Expressed in optical density units)

Treatment (ppm)	*Shoots*			*Roots*		
	Days after Spraying			*Days after Spraying*		
	1	7	*14*	*1*	7	*14*
Control	0.065	0.067	0.070	0.122	0.126	0.132
2,4-D:						
1 000	0.068	0.045	0.040	0.124	0.102	0.100
2 000	0.070	0.032	0.031	0.127	0.085	0.080
3 000	0.072	0.030	0.030	0.125	0.076	0.075
4 000	0.068	0.034	0.032	0.130	0.070	0.070
"Bladex-P":						
16 000	0.060	0.032	0.030	0.115	0.080	0.075
24 000	0.057	0.030	0.227	0.108	0.060	0.060
32 000	0.053	0.030	0.028	0.101	0.050	0.045

the reduction due to 2,4-D treatments was gradual and continued up to 14 days of spray.

The present results are in agreement with those of Wort and Cowie (1953), and Palmer and Porter (1959). Hand (1939) suggested that protein dissociation by auxins (2,4-D is a synthetic auxin) can sometimes activate enzymes. This may be the cause of the initial increased activity of catalase and peroxidase in shoots and roots of nutgrass treated with 2,4-D. If dissociation activities are carried to the extreme, there would be dissociation of essential constituents of enzymes which will result in the inhibition of enzyme activity (Northen, 1952) and that may be one of the reasons 2,4-D inhibits enzyme activity in prolonged treatments. Amitrole has a direct precipitation action on the proteins of cytoplasm (Crafts, 1965). As amitrole is one of the constituent of "Bladex-P", the inhibition of enzymic activities by "Bladex-P" may be because of this action.

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BIOLOGY AND CONTROL OF PERENNIAL CYPERACEAE IN JAPAN

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Summary

Cyperus serotinus, Eleocharis acicularis and *Eleocharis kuroguwai* are the important perennial weeds of rice fields in Japan. Tubers of *C. serotinus* brought to or near the soil surface by tillage were killed during winter, the number of tubers surviving winter damage being about 60% of those surviving in untreated plots. Puddling when the shoots of *C. serotinus* were about 10 cm high suppressed the number of shoots to 12 to 13%. *Cyperus serotinus* has also been controlled by forage treatment with paraquat or the sodium salt of 2,4-D after the rice harvest. This method is effective by the beginning of tuber formation. Control of *E. acicularis* has been obtained with a number of herbicides applied just after transplanting.

PERENNIAL CYPERACEAE IN PADDY FIELDS

Perennial Cyperaceae infesting paddy fields in Japan include *Cyperus serotinus, Eleocharis acicularis* (slender spikerush), *Eleocharis kuroguwai* (water chestnut), *Scirpus maritimus* (syn. *S. planiculmis*) (sea club-rush), and *Scirpus triangulatus* (roughseed bulrush).

Cyperus serotinus is most common in early-season or direct-sown rice fields. Its leaves grow to a height of 50 to 100 cm, and a dense stand can seriously reduce rice yields. *Eleocharis acicularis* is widely distributed throughout almost all the paddy fields of Japan, being especially dense in early transplanting rice fields. In spite of the short length of its stems and leaves, a dense carpet-like stand will reduce rice yields. The stems of *E. kuroguwai* grow to a height of 40 to 70 cm and this species also markedly reduces rice yields though it is not as widely distributed as the other two weeds.

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These three species are the important perennial weeds in rice fields. They have been spreading as a result of a reduction in hand-weeding, more mechanical cultivation with rotary tillers, and a decrease in the growing of winter crops. More recently, the trend toward greater control of annual weeds with herbicides may have contributed to their spread.

AUTO-ECOLOGY

The Japanese archipelago stretches from the 24th to 46th parallel, a distance of more than 3,000 km. The humid, tropical heat of the summer is followed in winter by very cold weather with extremely heavy snowfall in the north-west parts of the country. There is hardly a crop which could not be grown somewhere in Japan. Among those crops, rice exceeds all others in acreage and importance, accounting for 47% of the cultivated land.

Cyperus serotinus and *E. acicularis* emerge in late March or early April when the average daily maximum temperature is about 15° C, and the soil is not flooded. They grow until the tillage before rice transplanting. Plants buried in the soil by tillage are killed, but those left on or near the surface survive and grow well after rice transplanting.

Eleocharis kuroguwai sprouts only under flooded soil conditions and at a higher optimum temperature than for the other two. Tubers differ in degree of dormancy, and shoots appear one after another for one to two months following rice transplanting.

These weeds produce a few rhizomes from the base of the plant and propagate until September. *Cyperus serotinus* and *E. kuroguwai* form tubers at the tops of rhizomes, and *E. acicularis* forms bulbs at the base of the plant and at the tops of rhizomes from early or mid-September. The formation period of tuber or bulb is not influenced by the growth of the plant, but is affected mainly by shortening of day-length, as well as lack of nutrients and decrease in soil moisture.

The bulbs of *E. acicularis* occur mainly in the upper 2 to 3 cm of the soil, and most tubers of *C. serotinus* are produced in the upper 10 cm. Tubers of *E. kuroguwai* are found to the full depth of cultivation of the soil.

Several varieties of *C. serotinus,* which differ in the length and width of leaves or the period of tuber formation, have been observed.

CULTURAL CONTROL METHODS

CONTROL OF *Cyperus serotinus* WITH WINTER TILLAGE

The tuber of *C. serotinus* is killed by temperatures below 0° C or by desiccation. Experiments on the effect of bringing tubers to the soil surface by winter tillage were conducted and the results are given in Table 1.

TABLE 1: EFFECTS OF WINTER TILLAGE ON *CYPERUS SEROTINUS*
(Ratio of number of tubers which had survived winter damage until 25 March to total number of tubers produced in autumn — %)

Date and Method of Tillage	*Depth of Soil (cm)* 0-5	5-10	10-15	*Total*
4 Dec.: rotary tiller	24	29	24	77
4 Dec.: plough	10	23	22	55
4 Dec.: rotary tiller 22 Jan.: rotary tiller	21	27	20	68
4 Dec.: plough 22 Jan.: rotary tiller	14	26	15	55
No tillage	55	33	4	92

Tubers on or near the surface of the soil were killed by desiccation or freezing after tillage in early winter, and the number of tubers that survived winter damage was estimated at about 60% of those that survived in the untreated plot. The effect of freezing or desiccation on tubers was not very severe in plots cultivated with a rotary tiller, because the size of the soil clod was smaller than that resulting from ploughing. Effects of repeated tillage were almost the same as from a single tillage.

CONTROL OF *Cyperus serotinus* WITH PUDDLING

Not only are the shoots of *C. serotinus* killed, but many tubers are buried in the soil by puddling just prior to rice transplanting. Sprouting from tubers cannot occur under flooded soil conditions.

Puddling with rotary tillage or raking at time of emergence that did not bury the shoots and tubers completely was not very effective. Puddling about one month after tillage, when the shoots were about 10 cm in height, was very effective, the ratio of weed shoots establishing after this treatment to those in untreated plots being 12 to 13% (see Table 2).

Recently, almost all rice fields in Japan have been cultivated with rotary tiller just before transplanting, and it is assumed that this is one of the causes of the spread of *C. serotinus*.

TABLE 2: EFFECTS OF PUDDLING ON *CYPERUS SEROTINUS*
(Number of shoots which established after puddling)

	Puddling 14 days after Tillage		*Puddling 33 days after Tillage*	
	Rotary	*Rake*	*Rotary*	*Rake*
Sprout before puddling	9	—	55	68
Sprout after puddling	721	339	250	227
Floating shoots in water	49	62	—	—
Total shoots	779	401	305	295
Ratio of total number of shoots after puddling to total number of tubers (%)	38	19	13	13

CHEMICAL CONTROL METHODS

CONTROL OF *Eleocharis acicularis* WITH HERBICIDE APPLIED AFTER TRANSPLANTING OF RICE

Dichlobenil, 2,6-dichlorobenzamide, MCPA, etc., are effective on *E. acicularis*. Mixtures of these with other herbicides have given good control of *E. acicularis* and many annual weeds, but rice plants were occasionally also affected.

A new herbicide developed in Japan, *S*-(4-chlorobenzyl)-*N,N*-diethylthiol carbamate gives complete control of *E. acicularis* but does no injury to the rice plants. This chemical is applied to the surface just before or after transplanting at the rate of 3 to 4 kg/ha. The acreage of rice fields treated with this herbicide, including mixtures of it with simetryn or chlornitrofen, has been increasing rapidly.

CONTROL OF *Cyperus serotinus* WITH HERBICIDES

The response of *C. serotinus* to the sodium salt of MCPA, paraquat, amitrole, 2,2-DPA, prometryn and a mixture of MCPA and amitrole sprayed on to foliage, was compared at various growth stages. Leaves of *C. serotinus* were withered on the day after treatment with paraquat at the stage of shoot development. Withering resulting from treatment with MCPA was the same as with mixtures of MCPA and amitrole, tops being killed within 20 to 30 days after treatment. Withering of leaves treated with amitrole or 2,2-DPA was not so severe.

Plants treated with MCPA, both alone and with amitrole, and paraquat, at the stage of developing shoots, failed to produce tubers. However, some tubers were produced by the plants treated with 2,2-DPA or amitrole at the stage of increasing shoots, because the plots were not completely damaged. In the plots treated at an early stage of tuber formation, a considerable number of tubers were formed, and tuber formation was scarcely influenced by treatment at the late stage of tuber formation.

About half the tubers on the plot treated with MCPA sprouted normal shoots, while most of the tubers on the plot treated with amitrole did not sprout shoots. On the plots treated with mixtures of MCPA with amitrole, sprouts did not appear from one-third of the tubers, there being only 4% of normal shoots. On the

TABLE 3: INFLUENCE OF HERBICIDES APPLIED TO FOLIAGE OF *CYPERUS SEROTINUS* ON THE NUMBER OF TUBERS AND THEIR SPROUTING

(Figures are given as percentage of total number of tubers produced on untreated control plot)

Treatment (kg/ha)	*Date of Application**	*Normal Shoot*	*Abnormal Shoot*	*No. Sprouting*	*Total*
MCPA 40	3 Aug.	0	0	0	0
	18 Aug.	0	0	0	0
	15 Sep.	24	0	18	42
	26 Sep.	88	0	10	98
paraquat 9.8	3 Aug.	0	0	0	0
	18 Aug.	0	0	0	0
	15 Sep.	12	4	15	31
	26 Sep.	81	1	7	89
amitrole 40	3 Aug.	0	0	0	0
	18 Aug.	20	1	0	21
	15 Sep.	0	3	48	51
	26 Sep.	17	53	9	79
prometryn 20	3 Aug.	66	0	7	73
	18 Aug.	85	0	5	90
	15 Sep.	82	0	6	88
	26 Sep.	87	0	11	98

*Growth stage of *C. serotinus* at each application time:
3 Aug.: early stage of shoot increasing
18 Aug.: middle stage of shoot increasing
15 Sep.: early stage of tuber formation
26 Sep.: late stage of tuber formation.

paraquat plots more than one-third of tubers sprouted normally. Prometryn and 2,2-DPA were not so effective in controlling tuber formation or depressing emergence (Table 3).

Effects of herbicides on *C. serotinus* in withering foliage, suppressing tuber formation or causing the abnormal sprouting from tubers are markedly different with each kind of herbicide, and depend on the time of application. If treatment is before tuber formation, MCPA or paraquat may give a high level of control.

In rice fields harvested by early September, paraquat at 7 to 10 kg/ha, the sodium salt of 2,4-D at 3 to 4 kg/ha or sodium chlorate at 80 kg/ha have been applied to *C. serotinus*.

PRELIMINARY INVESTIGATIONS IN AUSTRALIA AND NEW ZEALAND WITH THE MONO(ISOPROPYLAMINE) SALT OF GLYPHOSATE

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Summary

Initial observations obtained from trials established in Australia and New Zealand with the mono(isopropylamine) salt of glyphosate indicate good total vegetation control in non-crop situations and orchards. In Australia, good control of Indian doab *(Cynodon dactylon)* has been obtained with 1 kg/ha whereas for nutgrass *(Cyperus rotundus)* control 2 kg/ha was required. New Zealand results indicate control of couch *(Agropyron repens)* and paspalum *(Paspalum dilatatum)* with rates as low as 1.1 kg/ha; whereas karbutilate at 12.6 kg/ha gave only moderate control of paspalum and no control of couch.

INTRODUCTION

Trials have been established with the mono(isopropylamine) salt of glyphosate (hereafter referred to as glyphosate) to evaluate its efficacy as a post-emergence herbicide for the control of annual and perennial grass and broadleaved weed species.

As glyphosate has the capacity to translocate readily from vegetative parts to underground root structures of perennial weed species, trial locations have been situated in areas containing such perennial weeds as nutgrass (*Cyperus rotundus*), paspalum (*Paspalum dilatatum*), Indian doab (*Cynodon dactylon*) and couch (*Agropyron repens*).

Owing to the limited crop selectivity of glyphosate, initial areas of evaluation have been confined to non-crop situations and orchards.

METHODS AND EXPERIMENTAL

Trial designs were randomized blocks with two to four replicates. Application was by a knapsack sprayer at volumes ranging from 227 to 1,680 l/ha. Plot size was from 1.0 to 3.6 m wide by 10.8 to 30.5 m long. Rates of glyphosate application ranged from 0.5 to 8.0 kg/ha. Weed species in each trial were identified and counted by means of a fixed quadrat prior to application and also at subsequent assessments. Visual estimates of control were also made at each assessment.

RESULTS

Fallow Application (Nutgrass/Indian Doab)

Glyphosate was applied to Indian doab and 12.7 cm high nutgrass shoots at rates varying from 0.5 to 8.0 kg/ha. Results 40 days after treatment showed good Indian doab control at 1.0 kg/ha.

Although full annual grass control was initially obtained, reinfestation occurred 20 days after treatment. A 70-day assessment after application showed good nutgrass control with glyphosate at 2 kg/ha when compared with the untreated control areas. Nutgrass dormancy then occurred.

Another assessment 189 days after application (see Table 1) was made when the nutgrass in the untreated areas measured 1.9 to 7.6 cm in height. Continued good control of nutgrass was obtained with glyphosate at 2 kg/ha; nutgrass shoots that did occur in these plots measured 0.63 to 1.9 cm high and were chlorotic.

TABLE 1: 1972 AUSTRALIAN NUTGRASS/INDIAN DOAB TRIAL

Percentage Knockdown/Control. Score 0 to 100 (100 = dead)

Treatment	*Nutgrass*					*Indian doab*				
	Days after Treatment					*Days after Treatment*				
(kg/ha)	*20*	*30*	*40*	*70*	*189*	*20*	*30*	*40*	*70*	*189*
glyphosate 0.5	16	36	42	60	43	67	63	70	100	80
glyphosate 1.0	15	39	50	87	50	95	96	100	100	95
glyphosate 2.0	32	63	68	93	75	100	100	100	100	90
glyphosate 4.0	56	81	88	94	70	100	100	100	100	84
glyphosate 8.0	78	94	98	98	94	100	100	100	100	90

In order to obtain an indication of the effectiveness of the translocation and herbicidal activity of glyphosate, the Queensland Lands Department were asked to incubate tubers from the trial area.

The procedure was to take a soil sample of approximately 20 × 20 cm and 15 cm deep from replication numbers 1 and 2. The samples were taken 73 days after herbicide application. The tubers were then removed from the soil and trimmed before being placed in a 1:1 sand-peat mix and incubated at 30 to 32° C in the dark for 20 days. The trays were kept moist. Results are given in Table 2.

TABLE 2: NUTGRASS TUBER 20 DAY INCUBATION TRIAL

Plot No.	*Glyphosate Appn. Rate kg/ha*	*No. of Tubers*	*No. of Shoots Visible Days of Incubation*				*No. of Tubers Regenerated*	*% of Tubers Regenerated per Plot per Treatment*
			0	*7*	*13*	*20*		
2	0	53	0	49	59	59	45	85 } 75
9	0	40	0	26	31	38	26	65 }
4	1	36	0	9	19	26	19	53 } 37
7	1	32	0	3	6	11	7	22 }
5	2	38	0	2	2	3	3	8 } 7
8	2	16	0	2	2	2	1	6 }
1	4	35	0	2	2	4	3	9 } 4
10	4	22	0	0	0	0	0	0 }
3	8	39	0	0	0	0	0	0 } 4
6	8	39	0	3	3	3	3	8 }

The above work was undertaken to give only a rough guide and the sampling and handling techniques are open to criticism.

The numbers of tubers regenerating after treatment with glyphosate decreased markedly for rates of 2 kg/ha and above. This indicates that the chemical has a herbicidal effect and is translocated in the plant.

Railways

Trials have been established with glyphosate plus standard railway herbicides for total vegetation control in both Australia and New Zealand. On the South Australian Railways, a high degree of knockdown of annual and perennial grass and broad-leaved weeds was obtained 20 to 45 days after application (see Table 3).

In New Zealand, glyphosate plus and minus simazine has been evaluated against karbutilate. Good control of couch, paspalum and several other grass and broadleaved weeds was obtained with glyphosate at 1.1 kg/ha 102 days after application (see Table 4).

TABLE 3: 1972 SOUTH AUSTRALIAN RAILWAY TRIAL
Percentage Knockdown/Control. Score 0 to 100 (100 = dead)

Treatment	*Days After Treatment*											
	10				*20*				*45*			
(kg/ha)	**a*	*b*	*c*	*d*	*a*	*b*	*c*	*d*	*a*	*b*	*c*	*d*
glyphosate 0.5	10	5	20	5	60	30	60	20	100	30	70	30
glyphosate 1.0	40	20	20	10	70	65	40	60	100	65	90	80
glyphosate 2.0	70	25	40	20	90	75	60	75	100	75	100	100
glyphosate 3.0	60	25	40	20	90	80	75	80	100	80	100	100
glyphosate 4.0	80	50	80	20	95	90	90	80	100	90	100	100
amitrole 1.6/ atrazine 1.6	10	5	5	5	60	40	30	50	100	30	70	30
amitrole 2.4/ atrazine 2.4	15	10	5	5	80	75	50	70	100	60	90	60

* a = Cape weed *(Cryptostemma calendula)*
b = Indian doab
c = Bermuda buttercup *(Oxalis pes-caprae)*
d = Fennel *(Foeniculum vulgare)*

TABLE 4: 1972 NEW ZEALAND RAILWAY TRIAL, AUCKLAND
Percentage Knockdown/Control. Score 0 to 100 (100 = dead)

Treatment (kg/ha)	*Days After Treatment*				
	21	*36*	*45*	*66*	*102*
glyphosate 1.1	52	82	62	90	92
glyphosate 2.2	70	92	82	97	98
glyphosate 4.4	89	95	89	99	98
karbutilate 12.6	37	62	42	57	52
glyphosate 4.4/simazine 3.6	55	92	82	98	98

Weed species present at time of application: Paspalum; Yorkshire fog *(Holcus lanatus)*; prairie grass *(Bromus unioloides)*; couch; creeping mallow *(Modiola caroliniana)*; celery-leaved buttercup *(Ranunculus sceleratus)*; Cape weed; oxtongue *(Picris echioides)*.

INDUSTRIAL

A trial was established at Hamilton, New Zealand, on 6 June 1972 with glyphosate using bromacil as the standard recommended herbicide. An assessment 97 days after application showed 83% weed control with glyphosate at 1.1 kg/ha compared with bromacil 71% at 7.2 kg/ha (see Table 5).

TABLE 5: 1972 NEW ZEALAND INDUSTRIAL TRIAL, HAMILTON
Percentage Knockdown/Control. Score 0 to 100 (100 = dead)

Treatment (kg/ha)	*Days After Treatment* 30	41	49	97
glyphosate 1.1	50	59	90	83
glyphosate 2.2	60	84	92	89
glyphosate 4.4	80	82	94	96
bromacil 7.2	40	56	75	71

Weed species present at time of application: Yorkshire fog; prairie grass; cocksfoot *(Dactylis glomerata)*; paspalum; sweet vernal *(Anthoxanthum, odoratum)*; celery-leaved buttercup; narrow-leaved plantain *(Plantago lanceolata)*; catsear *(Hypochaeris radicata)*; sheep's sorrel *(Rumex acetosella)*.

ORCHARDS

Glyphosate was evaluated against amitrole for weed control in peaches in Australia. Good initial control was obtained with glyphosate at 2 kg/ha with the exception of dock (*Rumex* spp.) 20 days after application (see Table 6).

TABLE 6: 1972 AUSTRALIAN ORCHARD TRIAL
Percentage Knockdown/Control 20 Days After Application.
Score 0 to 100 (100 = dead)

Treatment (kg/ha)	**a*	*b*	*c*	*d*	*e*	*f*
glyphosate 0.5	20	30	10	10	—	80
glyphosate 1.0	50	70	50	40	—	90
glyphosate 2.0	90	100	80	60	—	100
glyphosate 3.0	90	100	70	70	80	—
glyphosate 4.0	90	100	95	80	100	100
amitrole 2.5	General chlorosis of all species.					

*a = Prairie grass
b = Fumitory *(Fumaria* spp.)
c = Narrow-leaved plantain
d = Dock
e = Cape weed
f = Yorkshire fog

A trial was established on Pinotage grapes in 8-year-old vines at Te Kauwhata, New Zealand, on 21 March 1972. Glyphosate gave good paspalum control at 1.1 kg/ha 65 days after application (see Table 7). An assessment made 203 days after application showed very little live paspalum tissue above or below ground.

TABLE 7: 1972 NEW ZEALAND GRAPE TRIAL

Percentage Knockdown/Control. Score 0 to 100 (100 = dead)

Treatment (kg/ha)	Days After Treatment 15	30	65
glyphosate 1.1	77	82	92
glyphosate 2.2	100	97	97
glyphosate 4.4	100	100	98

DISCUSSION

From results obtained to date, glyphosate appears to control a wide spectrum of annual and perennial grass and broadleaved weeds at low rates of application.

Annual grass control occurs within some 3 weeks of application dependent upon time of application and growth stage of the weed.

As glyphosate is inactivated upon soil contact, annual grass and broadleaf reinfestation may occur, hence trials are being conducted to evaluate the efficacy of glyphosate plus residual type herbicides in order that long-term annual and perennial weed control can be achieved.

Although glyphosate appears to be limited as regards crop selectivity, no phytotoxic effects have been noted in either Australia or New Zealand when the compound was applied as a trunk-directed spray in orchards and vineyards.

It would seem that glyphosate could prove an important and versatile post-emergence herbicide for weed control in many and varied situations.

NK-049: FROM NATURAL PRODUCTS TO NEW HERBICIDES

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Summary

Discovery that anisomycin exhibited plant-growth regulating activity led to synthesis of methoxydiphenylmethanes and methoxybenzophenones which also showed various plant-growth regulating activities. A representative compound, NK-049(3,3'-dimethyl-4-methoxybenzophenone) was developed as a pre-emergent herbicide with excellent margin of selectivity for rice. NK-049 is a biodegradable herbicide with a high level of safety in the environment.

ANISOMYCIN

Discovery of the phenoxy herbicides indicated that perhaps a new herbicide could be found by synthesis and by biological assessment of compounds that had a structure analogous to that of a natural plant-growth regulating substance. On the other hand, a number of useful herbicides have been found by systematic screening of a number of different compounds synthesized without regard to their relationships to any natural plant-growth regulating substances.

One of the writers (Munakata) has for a number of years conducted research on plant-growth regulating substances produced by micro-organisms, and in 1967 isolated a plant-growth inhibitory substance from *Streptomyces* sp. No. 638, a species recorded from the suburbs of Singapore. Chemical studies (Yamada *et al.*, 1972) revealed that the substance was identical with anisomycin (Fig. 1), an antibiotic effective in the treatment

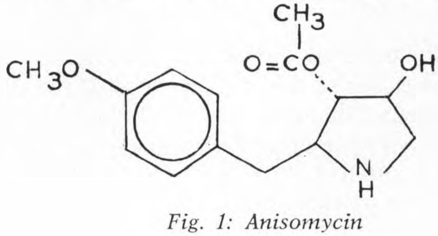

Fig. 1: Anisomycin

of trichomonas disease, described by Sobin and Tanner (1954). However, no one had previously reported the plant-growth regulating activity of anisomycin.

The herbicidal activity of anisomycin observed was as follows: Anisomycin at 50 ppm reduced radicle growth of barnyard grass (*Echinochloa crus-galli*), crab grass (*Digitaria sanguinalis*), lucerne (*Medicago sativa*) and rice by more than 80%. On the other hand, seedling growth was reduced by less than 40% at 50 ppm. Thus, anisomycin strongly inhibited the radicle growth but was less effective on seedling growth. Occasionally, herbicides cause roots to hypertrophy or knot, or cause them to shorten. Development of radicles from a seed was inhibited by anisomycin.

ANISOLE DERIVATIVES

The first step was to synthesize compounds (I) (Fig. 2) with a partial moiety (*p*-anisole radical) of anisomycin, and study their structure-activity-relationships.

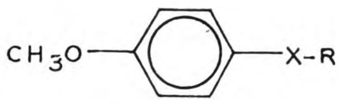

Fig. 2: Anisole derivatives (I), where X is CH_2 or CO, and R is aromatic or heterocyclic radical.

Not only did these derivatives exhibit a similar biological property to that of anisomycin, but various other properties were also found as follows:

(1) Most of the compounds, X = CH_2 and X = CO, at 100 to 500 ppm, strongly inhibited radicle growth of rice, barnyard grass, crab grass, lucerne, tomato and turnip at germination. It is noteworthy that a very simple compound such as *p* methoxydiphenylmethane exhibited strong activity.

(2) In general, radicle-growth inhibitory activities of *p*-methoxydiphenylmethanes were greater than those of the corresponding *p*-methoxybenzophenones. For example, at 500 ppm 3-chloro-4′-methoxydiphenylmethane reduced radicle growth of barnyard grass by 90 to 100%, but 3-chloro-4′-methoxybenzophenone by only 0 to 10%.

(3) An excellent margin of selectivity for rice was observed. For example, 4-methoxy-3′-methyldiphenylmethane and 4-methoxy-3′-methylbenzophenone did not affect radicle growth of rice at 500 ppm, but radicle growth of barnyard grass, crab grass, and lucerne was reduced by 80 to 100% at 100 ppm.

(4) Geotropic and phototropic responses of rice and barnyard grass were eliminated by 2-carboxy-4′-methoxydiphenylmethane and 2-carboxy-4′-methoxybenzophenone at 500 ppm.

(5) Sixteen compounds induced chlorosis in seedlings at 500 ppm. Three compounds, 4-methoxy-2′-methylbenzophenone, 4-methoxy-3′-methylbenzophenone, and 4,2′-dimethoxy-3′-methylbenzophenone, induced chlorosis in barnyard grass, but not in rice.

BENZOPHENONE DERIVATIVES

The next step was to study benzophenone derivatives (II), (Fig. 3), giving up diphenylmethanes, because benzophenones are intermediates in the synthesis of diphenylmethanes and, as described above, chlorosis-inducing benzophenones had been found. Compounds that induce chlorosis and thus inhibit chlorophyll formation or photosynthesis in plants, can reasonably be considered potential weapons for killing weeds. The photosensitizing property (Ivie and Casida, 1971) of benzophenone and the herbicidal activity of alkylated benzophenones (Erickson and Schlesinger, 1954) were therefore also considered.

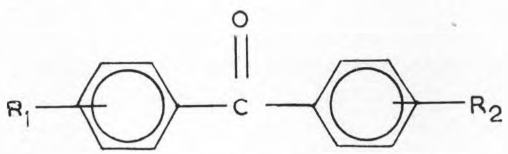

Fig. 3: Benzophenones (II). R_1, R_2 — substituent

The advantages of the methoxy group versus the methyl group and the meta-methyl group versus the ortho- or para-methyl group in regard to selectivity for rice should be emphasized. Correlation of chlorosis-inducing activity and radicle-growth inhibitory activity for rice or barnyard grass was poor in a statistical sense. Apparently, however, compounds effective in inducing chlorosis also greatly reduced radicle growth of barnyard grass. Consequently, 4-methoxy-3′-methylbenzophenone (NK-062) and 3,3′-

dimethyl-4-methoxybenzophenone (NK-049) were selected from the methoxy-methylbenzophenones and their herbicidal activities assessed in paddy fields. In laboratory tests, NK-062 exhibited the highest margin of selectivity for rice and the highest inhibitory activity for radicle growth in barnyard grass. NK-049 exhibited less inhibitory activity for radicle growth, but the highest chlorosis-inducing activity in barnyard grass in laboratory tests. The herbicidal effect of NK-062 was unsatisfactory even at 6 to 10 kg/ha. On the other hand, NK-049 completely induced chlorosis in barnyard grass and provided a satisfactory herbicidal effect at 4 kg/ha, although weak chlorosis was occasionally observed in rice stems at 6 kg/ha. The results indicate that the chlorosis-inducing activity is an important part of herbicidal action.

DEGRADATION OF NK-049 IN ENVIRONMENT

Preliminary findings are that NK-049 is degraded by sunlight and by soil micro-organisms, and thirteen metabolites have so far been identified. The methoxy group was decomposed to the hydroxy group. The methyl groups were oxidized to carboxy group(s) via carbinol(s) and carboxaldehyde(s). The benzophenone skeleton was broken to m-toluic acid and 4-hydroxy-m-toluic acid. It is well known that m-toluic acid and 4-hydroxy-m-toluic acid are metabolized by micro-organisms — *e.g., Pseudomonas* species — to oxygenated aliphatic carboxylic acids via hydroxylation of the benzene ring and ultimately to propionic, acetic, and/or formic acid. In a paddy field, NK-049 residue was reduced to 0.012 ppm in the soil 30 days after an application of 4 kg/ha and to less than 0.004 ppm after 60 days. In acute toxicity experiments, NK-049 caused no symptoms in both mice and rats at an oral dose of 4,000 mg/kg. The identified metabolites caused no symptoms in mice at an oral dose of 1,000 mg/kg. NK-049 might therefore be regarded as a biodegradable herbicide with high safety in the environment.

MANUFACTURING PROBLEMS

NK-049 is synthesized by condensation of m-toluic acid with o-methylanisole in the presence of polyphosphoric acid. The two intermediates are easily obtained from petrochemicals. No pollution in the environment might be expected from its manufacture. This fact assumes significance as industrial pollution becomes more and more serious.

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THE TRIAZINONES, A NEW CHEMICAL GROUP OF HERBICIDES, DEMONSTRATED BY METRIBUZIN

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Summary

Metribuzin is a selective herbicide from the group of asymmetrical triazinones, with excellent herbicidal effect, whether applied pre- or post-emergence. Because of the low dosage rates of between 0.5 and 1.5 kg a.i./ha and its fast degradation in the soil, the product is also environmentally safe. Depending on the type of crop, treatment is done pre- or post-emergence. Potatoes may be treated at either time. There are no difficulties with subsequent growth of other crops after the application of metribuzin.

INTRODUCTION

The chemistry and manufacture of triazinones were first described by Dornow *et al.* (1964). In the course of research into heterocyclic combinations, triazinones were also synthesized by Westphal in the chemical scientific laboratories of Bayer AG and examined specifically for their herbicidal properties. Biological research had already shown in 1965 that triazinones are extremely effective herbicides, and the whole subject was described for the first time by Westphal *et al.* (1966).

Triazinones can be used both pre-emergence and post-emergence. The majority of the examined triazinones possess a better herbicidal effect if used post-emergence, after the weeds have developed their first leaves; in other words, less active substance is needed in post-emergence application compared with pre-emergence application to achieve the same herbicidal effect (Kampe, 1972).

MODE OF ACTION

Systematic investigations have shown that triazinones are strong photosynthesis inhibitors. They inhibit the photosynthetic electron transportation in the spectrum of the second light reaction. A 50% inhibition of Hill's reaction in isolated chloroplasts is

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achieved with concentrations of approximately 10^{-7} molar. The pI_{50} value for the substance 4-amino-6-*t*-butyl-3-methylthio-1,2,4-triazine-5 (4H)-one (metribuzin) is 6.63. pI_{50} = negative logarithm of the molar concentration which causes a 50% inhibition of Hill's reaction (Draber *et al.,* 1968). The water-solubility of metribuzin is 1200 ppm.

Draber and colleagues have reported on the structure-activity-correlation of triazinones (1968, 1969, 1972). Fedtke (1972) reported on the influence of triazinones on metabolism, in particular of metribuzin.

In addition to these physiological investigations, trials were carried out to examine the possible application of the various triazinones for weed control. It was found that the herbicidal activity is changed with varying substitution, but, on the other hand, that an interesting selectivity exists in relation to the various crops (Eue *et al.,* 1969). Because of its herbicidal potency and its excellent selectivity, metribuzin was developed for practical application under the trade name "Sencor".

Metribuzin was tested in various formulations. The first product was BAY 6159 H, a 70% wettable powder. Apart from "Sencor" 70% WP (in France known as "Sencoral"), 50% and 30% wettable powders are also under investigation.

Extensive toxicology investigations have been made, which are dealt with in detail elsewhere (Loeser and Kimmerle, 1972). The acute oral LD_{50} for male rats is 2200 mg/kg. Dermal and inhalation toxicity are low.

BIOLOGICAL PROPERTIES

HERBICIDAL ACTIVITY

Metribuzin has good effects against both monocotyledonous and dicotyledonous weeds, with the relatively small dosage rates of 0.5 to 2.0 kg/ha. (The data given here refer to the 70% wettable powder, unless otherwise stated.)

The substance is absorbed via the roots as well as the leaves. Application post-emergence is therefore more effective.

The rates needed for pre-emergence application vary from 0.75 to 2 kg/ha. Soils with a higher content of organic matter and clay — *i.e.,* soils which have a higher absorptive capacity — require larger quantities. However, on bog soils with a humus content of more than 10%, even increased quantities do not usually give adequate effectiveness. On these soils, post-emergence application is preferable.

The response of different weed species to metribuzin applied pre-emergence is given in Appendix 1.

It should be specially noted that metribuzin is very effective against representatives of the species *Echinochloa, Digitaria* and *Setaria,* which are usually difficult to control. Metribuzin is also effective against a large number of hard-to-control dicotyledonous weeds.

The best results are achieved in the period between the emergence of the weeds and the development of 3 to 4 leaves. Later treatment is usually less effective.

Possible Uses

Potatoes

Treatment is carried out after the final ridging, if possible when the ridges have settled, and shortly before the potatoes emerge. Thus, treatment should be as close as possible to the emergence date, because at that time the ridges have settled and the majority of the weeds are in the sensitive juvenile stages. Treatment can also be carried out after the emergence of the first potato plants. The rates of 0.75 to 1.5 kg/ha required are calculated according to soil type and humus content.

For post-emergence application, lower rates of 0.5 to 0.75 kg/ha are required. This method is preferable, in particular on humus-rich soils (10% and more).

Temporary damage in the form of leaf pallor can occur, but this does not usually have an adverse effect on yield (Eue, 1971). However, different potato species react differently: whereas some varieties grown in Europe tolerate the post-emergence treatment less well, test results from the U.S.A. and Japan are generally positive.

The best time for application is between emergence and the stage at which the first potato plants reach a height of 5 to 10 cm.

Tomatoes

Grown from Sets

Tolerance of metribuzin in tomatoes is extremely good, whether applied pre- or post-planting. If applied pre-planting, a rate of 0.75 kg/ha is required.

For application post-planting, 0.5 kg/ha of metribuzin is sufficient. The best time for treatment is after the tomatoes have become established and the weeds have emerged.

Direct-sown Tomatoes

The application of metribuzin to direct-sown tomatoes, which occur predominantly in warmer climates, can be recommended only for experimental purposes, at a rate of 0.5 kg/ha for treatment at the 4- to 6-leaf stage. Results available so far vary considerably with respect to tolerance; in certain circumstances, therefore, and in particular depending on the tomato variety, there may well be possibilities for its use.

Soya Beans

A large number of products are applied to this crop; however, several widespread weed species, such as *Abutilon theoprasti* and *Xanthium pennsylvanicum* are insufficiently controlled. Metribuzin, which is effective against these weeds, is a useful supplement to the existing range of herbicides. In areas suitable for the cultivation of soya beans, rates of 1.0 to 1.5 kg/ha are applied pre-emergence, while in medium-heavy soils with more than 2% humus content the rate is reduced to 0.75 kg/ha; light, sandy soils should not be treated.

Metribuzin can usefully be mixed with other herbicides such as alachlor and trifluralin, its addition at 0.5 to 1.0 kg/ha improving effectiveness against dicotyledonous weeds in particular.

Sugar Cane

Sugar cane tolerates treatment with metribuzin at rates up to 10 kg/ha. Depending on soil type and the extent of weed growth, a rate of 1.0 to 3.0 kg/ha is necessary.

Combinations with diuron or hormone weedkillers are very effective and economical. A combination of 1 kg/ha metribuzin and 1 kg/ha diuron is notable for its long period of effect, while combinations with 2,4-D are particularly suitable for the control of perennial weeds. The recommended dosage rate is 1.0 kg/ha of metribuzin and 2.0 kg/ha of 2,4-D.

Asparagus

Sown asparagus can be treated pre-emergence with 0.5 kg/ha immediately after sowing. Plants are treated after ridging up, but before the emergence of the spears, at a rate of 1.0 kg/ha. At the end of the cutting season, and after working down the ridges, metribuzin is sprayed at 1.0 kg/ha. Tolerance in asparagus is good (Kampe, 1972).

Following Crops

Because of its low persistence in the soil, there are no cultivation problems in the normal crop sequence after the use of metribuzin. In certain circumstances, when early development of the treated crop has been unfavourable as a result of environmental influences, the crop may have to be ploughed in. In these cases the planting of a following crop becomes necessary before metribuzin has been broken down in the soil. The selection of the subsequent crop should take into account crop sensitivity to metribuzin. Sensitivity of the crops examined increases in the follow-order: potatoes, soya beans, tomatoes, asparagus, carrots, broad beans, peas, sugar beet, winter barley, kidney beans, wheat, spring barley, oats, red beets, cucumbers, rape, and all kinds of vegetables, such as cabbage, lettuce and onions.

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APPENDIX I

Susceptibility of monocotyledons and dicotyledons to various dosage rates of metribuzin applied pre-emergence

(xxx 90-100% eradication; xx 75-89% eradication; x under 75% eradication)

Weed Species	*Rate (kg/ha)* 0.75	1.0	2.0
MONOCOTYLEDONS			
Agropyron repens (couch grass)	x	x	xx
Alopecurus myosuroides (blackgrass)	xx	xxx	xxx
Avena fatua (only post-em.) (wild oat)	xx	xxx	xxx
Brachiaria sp. (signalgrass)	xx	xxx	xxx
Commelina communis (dayflower)	xx	xxx	xxx
Cynodon dactylon (Bermuda grass)	x	x	xx
Cyperus esculentus (yellow nutsedge)	x	xx	xxx
Digitaria sp. (crabgrass)	xx	xxx	xxx
Echinochloa crus-galli (barnyard grass)	xx	xxx	xxx
Eleusine indica (goose grass)	xx	xxx	xxx
Lolium rigidum (Wymmera ryegrass)	xx	xxx	xxx
Lolium temulentum (darnel)	xxx	xxx	xxx
Panicum dichotomiflorum (fall panicum)	x	xxx	xxx
Poa annua (annual meadow grass)	x	xxx	xxx
Setaria sp. (foxtail)	xx	xxx	xxx
Sorghum halepense (Johnson grass)	x	x	xx
DICOTYLEDONS			
Abutilon theophrasti (velvet leaf)	x	x	xxx
Amaranthus chlorostachys (= *A. hybridus*) (pigweed)	xxx	xxx	xxx
Amaranthus graecizans (tumble pigweed)	xxx	xxx	xxx
Amaranthus retroflexus (redroot pigweed)	xxx	xxx	xxx
Amaranthus spinosus (spiny amaranth)	xxx	xxx	xxx
Ambrosia elatior (= *A. artemisiaefolia*) (common ragweed)	xx	xx	xxx
Anacyclus sp.	xxx	xxx	xxx
Anagallis arvensis (scarlet pimpernel)	xxx	xxx	xxx
Anthemis cotula (mayweed)	xxx	xxx	xxx
Antirrhinum orontium (calf's snout)	xxx	xxx	xxx
Brassica kaber (wild mustard)	xx	xxx	xxx
Capsella, bursa-pastoris (shepherd's purse)	xxx	xxx	xxx
Cassia obtusifolia (sicklepod)	x	xx	xxx
Centaurea cyanus (cornflower)	xxx	xxx	xxx
Chenopodiu album (common lambsquarter)	xx	xxx	xxx
Chrysanthemum leucanthemum (oxeye daisy)	xxx	xxx	xxx
Datura stramonium (jimsonweed)	xx	xxx	xxx
Daubentonia texana (coffee weed)	xx	xxx	xxx
Diplotaxis erucoides (dog mustard)	xx	xxx	xxx
Fumaria officinalis (fumitory)	xxx	xxx	xxx
Galeopsis ladanum (large-flowered hempnettle)	xxx	xxx	xxx
Galinsoga parviflora (smallflower galinsoga)	xx	xxx	xxx

Weed Species	Rate (kg/ha) 0.75	1.0	2.0
Galium aparine (catchweed bedstraw)	x	x	x
Helianthus annuus (sunflower)	xx	xxx	xxx
Ipomoea sp. (morning glory)	x	xx	xxx
Lamium purpureum (red deadnettle)	xxx	xxx	xxx
Lapsana communis (nipplewort)	xxx	xxx	xxx
Malva neglecta (common mallow)	x	x	xx
Matricaria sp. (chamomile)	xxx	xxx	xxx
Melochia corchorifolia (redweed)	xxx	xxx	xxx
Mercurialis annua (annual mercury)	xxx	xxx	xxx
Mollugo verticillata (carpet weed)	xxx	xxx	xxx
Oxalis stricta (woodsorrel)	xxx	xxx	xxx
Papaver rhoeas (corn poppy)	xxx	xxx	xxx
Physalis subglabrata (smooth groundcherry)	x	xx	xx
Polygonum aviculare (prostrate knotweed)	xx	xxx	xxx
Polygonum blumei (smart weed)	xxx	xxx	xxx
Polygonum convolvulus (wild buckwheat)	xx	xx	xxx
Polygonum lapathifolium (pale smartweed)	xxx	xxx	xxx
Polygonum pennsylvanicum (Pennsylvania smart-weed)	xx	xxx	xxx
Polygonum persicaria (lady's thumb)	xx	xxx	xxx
Portulaca oleracea (common purslane)	xxx	xxx	xxx
Rhaphanus raphanistrum (wild radish)	xxx	xxx	xxx
Senecio vulgaris (common groundsel)	xxx	xxx	xxx
Sesbania sp. (sesbania)	xx	xxx	xxx
Sida spinosa (teaweed)	xx	xxx	xxx
Sinapis arvensis (charlock)	xxx	xxx	xxx
Solanum nigrum (black nightshade)	x	x	(x)xx
Solidago sp. (goldenrod)	xx	xxx	xxx
Sonchus oleraceus (annual sowthistle)	xxx	xxx	xxx
Spergula arvensis (corn spurry)	xxx	xxx	xxx
Stellaria media (chickweed)	xxx	xxx	xxx
Taraxacum officinale (common dandelion)	xx	xxx	xxx
Thlaspi arvense (field pennycrass)	xxx	xxx	xxx
Urtica urens (burning nettle)	xxx	xxx	xxx
Veronica sp. (speedwell)	xxx	xxx	xxx
Viola arvensis (field violet)	xxx	xxx	xxx
Xanthium pennsylvanicum (common cocklebur)	xx	xx	xxx

MC-4379: A NEW BROADLEAF HERBICIDE

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MC-4379 ("Modown") is being developed for selective pre-emergence and directed post-emergence weed control in such crops as soya beans, corn, sorghum, small grains and rice. In rice it shows promise as a pre-emergence treatment for sown rice and as a pre-plant treatment for transplanted rice.

For the past three years, extensive field tests in many parts of the world have shown it to be effective on a wide range of broadleaf weeds and certain annual and perennial grasses, under widely varying conditions. During 1972, in the United States, Mobil has worked with 65 co-operators conducting both laboratory and field tests with MC-4379 in 39 states. The results of these tests are reviewed in this paper. Persistence studies, residue analyses, metabolite and toxicological studies show the herbicide to be environmentally compatible and its cost economics are quite favourable.

Toxicological and environmental fate studies show it to be acceptable for broad-scale use. No residues have been found in soya beans, corn, sorghum, wheat, barley, oats and rice.

Some early phytotoxicity to soya beans, corn and sorghum has been observed from pre-emergence application, usually associated with heavy rainfall while the crop is still small, but this effect is transient. Significant yield improvements have been observed on all crops during three years of field testing. The mode of action appears to be a contact effect on the germinating seed and primary roots. Radioactive tracer techniques show no translocation from the roots. Soil micro-organisms appear to metabolize the compound readily.

Pre-emergence applications are most promising for control of many broadleafs and certain grass weeds, on a wide range of soil types under a variety of climatic conditions. Rates of 1.68 to 2.24 kg/ha appear as effective on high organic or clay content soils as on the lighter soils. Generally, residual control persists for 5 to 10 weeks, depending upon rainfall, soil type and weeds present. Soil incorporation decreases herbicidal activity and is not recommended.

Post-emergence applications as directed sprays on the more tolerant crops have given good results at rates of 1.12 to 1.68 kg/ha. Overall foliar application will cause moderate to severe contact injury. With directed sprays the crop plant usually recovers rapidly, since injury is localized to a small proportion of the plant tissues. MC-4379 has been successfully tested as an emulsifiable concentrate and a wettable powder.

Performance tests show excellent pre-emergence activity on many of the important broadleaf weeds and good control of certain grasses. Post-emergence treatments when used as directed sprays provide an effective weed control with activity equal to or greater than the pre-emergence treatments. Overall post-emergence applications will cause contact toxicity and stunting of crops. Herbicide activity has been little affected by varying soil types and moisture. Low temperatures appear to prolong the activity.

As MC-4379 is primarily a broadleaf herbicide, many combinations with commercial and experimental grass killers were field tested in 1972 and were found to give generally excellent broad-spectrum control.

Combinations found to be particularly effective are:

(1) In soya beans — dinitroaniline herbicides such as trifluralin, chloroacetanilides such as alachlor, and thiocarbamates such as vernolate.

(2) In corn and sorghum — chloroacetanilides such as alachlor and propachlor, the triazines such as atrazine, and thiocarbamates such as EPTC and butylate.

(3) In rice — compounds in the aforementioned chemical classes are also desirable, particularly benthiocarb, butachlor and molinate. In addition, combinations of anilides such as propanil are effective.

In 1972 MC-4379 used alone gave broadleaf control effectiveness of 90% + in 42 tests, 75 to 90% control in 6 tests, and less than 75% control in 4 tests. Applied in combination with a commercial grass killer, control of 90% + was achieved in 38 tests, and 75 to 90% control in 8 tests; in 3 tests less than 75% control was reported.

MC 4379 used alone gave grass control effectiveness of 90% + in 10 tests, 75 to 90% in 17 tests, and less than 75% control in 24 tests. In combination with a grass killer 90% + control was obtained in 38 tests, 75 to 90% control in 5 tests and less than 75% control in 8 tests.

In New Zealand, MC-4379 is being tested as a herbicide on a variety of crops. Results in respect of degree and spectrum of weed control, crop tolerance and method of application are in general agreement with those reported from North America. In the coming season it is expected that investigational work will be expanded, especially on cereal and legume crops.

RESIDUES IN RICE AND SOIL TREATED WITH OXADIAZON

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Summary

Oxadiazon and its metabolites were analysed by gas chromatography in unpolished rice and straw of rice plants which had been cultured and harvested in rice fields treated with oxadiazon. No oxadiazon or its metabolites were detected in unpolished rice from plants treated with 0.5 to 1.0 kg/ha. On the other hand, 0.12 ppm of oxadiazon was detected in straw from treatment with 0.75 kg/ha, but no metabolities were found. As a result of analysis for persistence of oxadiazon in treated paddy soil under flooded conditions by the same procedure, the half-life was inferred to be from two to three months, and some decomposition products were detected.

Oxadiazon was originated by Rhone-Poulenc S.P.A., France, and developed by Nissan Chemical Industries Ltd., Japan, as the first successful soil-incorporation herbicide in Japan. It has appropriate persistence, if applied under paddy conditions. It also has a strong herbicidal effect and displays excellent weed control during the whole growth period of rice. Studies on mammalian toxicity established its safety before it went on sale in Japan in 1972 for use in rice.

To elucidate the metabolism of oxadiazon in plants and soil, the amounts of the residue of oxadiazon and eleven kinds of supposed metabolites in unpolished rice, straw and soil, were analysed by gas chromatography.

ANALYTICAL METHODS

As indicated in Table 1, the supposed metabolites were classified into five groups, and the analytical procedure for each group was investigated. Table 2 shows the conditions of GC analysis.

TABLE 1: OXADIAZON AND THE SYNTHETIC METABOLITES

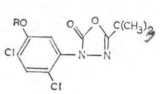
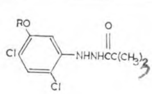
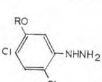
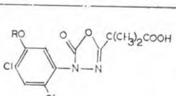
R					$(CH_3)_3C.COOH$
$(CH_3)_2CH-$	G1 (oxadiazon)	A3	—	C3	
CH_3—	G2	A2	H2	C2	T
H—	G3	A1	H1	C1	

TABLE 2: GAS CHROMATOGRAPHY AND THE OPERATING CONDITIONS

	Compound Group				
	G	*A*	*H*	*C*	*T*
Detector	ECD	ECD	FTD	ECD	FID
Column	1.5% NGS	1.5% NGS	15% SE-30 or 1.5% NGS	1.5% NGS	15% PEG
Column temperature	190° C	195° C	200° C	195° C	120° C

G and C Groups: These were extracted with acetone (for C group, HCl was added) two times, concentrated under reduced pressure, partitioned with hexane and acetonitrile, and then after the concentration of acetonitrile phase (in the case of soil dichloromethane was used) they were separated by TLC. Both G3 and Cl, 2, 3, which were methylated with diazomethane-ether, and the rest were cleaned through a Florisil column and analysed by GC.

A Group: After extraction of unpolished rice with acetone, partition with hexane and acetonitrile and concentration of the acetonitrile phase, and after extraction of straw and soil, dissolution in dichloromethane and concentration, they were separated by TLC (benzene and ethyl acetate). A3 was methylated with diazomethane and then analysed by GC.

H Group: The compounds in this group are quite labile and change even in aliphatic solvents such as alcohol, ether and aromatic solvents at room temperature in a short time; they were therefore made into compounds of Schiff base which is stable in acetone, and analysed. However, it is difficult to get reliable data unless the operation is accomplished at room temperature in five to six hours. There is therefore little possibility that the compounds in this group are present in a free state in plants and soil, and they are considered to be rapidly metabolized into more stable compounds.

T Compound: Unpolished rice was extracted by acetone under acidified conditions, and the extract distributed with hexane and acetonitrile after concentration. The acetonitrile phase was treated with borax to remove fatty components. Then, after partition with dichloromethane and concentration, the dichloromethane phase was analysed by GC. The straw extract, after pigment was removed by phosphotungustic acid, was analysed by GC. The soil extract was partitioned with dichloromethane and analysed by GC.

The detection limits of each compound obtained by the above methods are listed in Table 3.

TABLE 3: DETECTION LIMITS (ppm) OF OXADIAZON AND THE METABOLITES

Part Analyzed	*Compound Group* *G*	*A*	*H*	*C*	*T*
Unpolished rice	0.001	0.004	0.001	0.001	0.013
Straw	0.001	0.008	0.01	0.003	0.08
Soil	0.002	0.001	0.001	0.001	0.01

OXADIAZON AND ITS METABOLITES IN UNPOLISHED RICE AND STRAW

Unpolished rice and straw which were cultured and harvested in the paddy field treated with oxadiazon were collected from 14 prefectures all over Japan and analysed with respect to oxadiazon and its metabolites.

Neither oxadiazon nor its metabolites was detected from unpolished rice in treatments of 0.5 to 1.0 kg/ha. On the other hand, 0.12 ppm of oxadiazon was detected in straw, but no metabolites were detected. This result indicates that a small amount of oxadiazon in the soil is absorbed by the contact site of the plant, but it is not easily transferred into the grain. This corresponds with the result of hydroponics experiments (Kawamura *et al.*, 1971) which showed that oxadiazon absorbed by the roots was mainly distributed in the leaf sheath and little of it was transferred to young leaves.

OXADIAZON AND ITS METABOLITES IN SOIL

To evaluate the oxadiazon half-life and its decomposition process in soil, a Wagner pot was filled with roughly 3 kg of fertilized paddy soil and treated with oxadiazon emulsion equivalent to 1.0 kg active ingredient per hectare. The treated soil was watered to maintain a flooded condition (3 to 5 cm depth) and placed in a greenhouse. For analysis, 150 g samples were collected immediately after treatment, and at monthly intervals for three months. Just before sampling, the soil in each pot was thoroughly mixed to give a uniform sample. Results are given in Table 4.

TABLE 4: PERSISTENCE OF OXADIAZON AND METABOLITES IN THE SOIL TREATED WITH 1.0 kg/ha KEPT UNDER FLOODED CONDITION
(—: undetected)

Compound	*Months after Treatment* 0	1	2	3
G1	0.470	0.326	0.280	0.177
G2		0.002	0.001	
G3		0.002	0.004	
A1		—	—	
A2		—	—	
A3		—	—	
H1		—	—	
H2		—	—	
C1		0.002	0.008	
C2		—	—	
C3		—	0.001	
T		—	—	

As the oxadiazon decreased by about 40% two months and 60% three months after treatment, respectively, the half-life of oxadiazon in soil is inferred as 2 to 3 months. Some metabolites, G2, G3 and C1, were found a month after treatment. Two months after treatment G2 had decreased, whereas G3 and Cl increased, and C3 appeared. This result suggests that the main decomposition process of oxadiazon could be dealklyation of the isopropyl substituent on the benzene ring and oxidation of the butyl substituent on the oxadiazoline ring.

INVESTIGATION OF AN ABNORMALITY IN RICE ATTRIBUTED TO HERBICIDE CONTAMINATION OF IRRIGATION WATER

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Summary

In the Coleambally Irrigation Area of New South Wales about 12 hectares of rice developed abnormalities which were responsible for the failure of at least one and possibly three plantings on the same property. The possibility that irrigation water was contaminated with herbicides used for channel maintenance has been considered. The symptoms, characterized by root growth inhibition, mesocotyl elongation and severe chlorosis, did not correspond to those obtained in the laboratory with TCA, 2,2-DPA, amitrole or amitrole/ammonium thiocyanate except at high concentrations. Analysis of water by a gas-liquid chromatographic method showed that trifluralin was not the contaminant.

INTRODUCTION

Rice is sometimes sown by air in the Coleambally Irrigation Area of New South Wales. Seed is pre-germinated and distributed into the permanent flood water. Rapid root development is vital for successful establishment. In the spring of 1971, three unsuccessful attempts were made to establish one 12 ha Kulu crop. Poor root growth and general lack of vigour in the third planting was initially attributed to grazing by large numbers of snails present. An adjacent area of land was used in a fourth attempt to establish a rice crop. Calrose seed was sown by air on 6/11/71. Four days later, contortion and chlorosis of seedling coleoptiles and inhibited development of the primary roots were observed throughout the crop, although insects and snails were absent. Seed, soil and water samples were collected and attempts were made to identify the source and nature of the agent responsible for the disorder.

METHODS AND RESULTS

Measurements of electrolytic conductivity and pH in the water overlying the Calrose area were within the normal range, suggest-

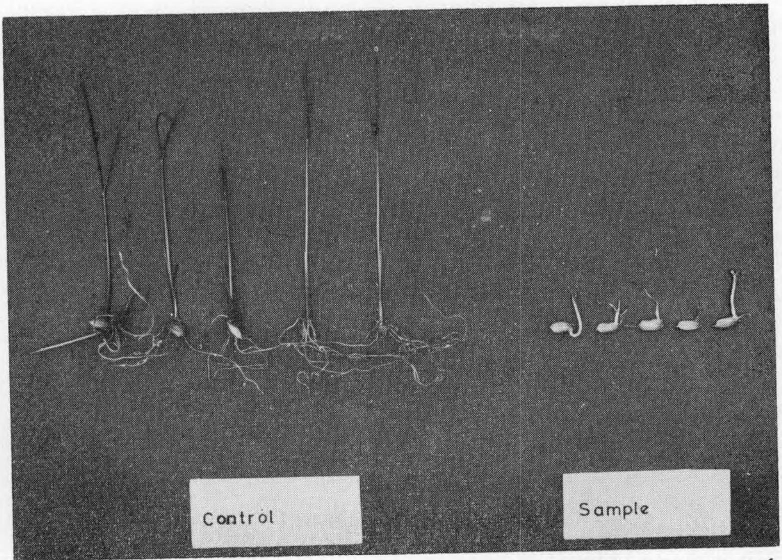

Fig. 1: Rice seedlings after exposure to tap water (control) or water collected on 21/12/71 from the Calrose problem area (sample) after 7 days in a growth cabinet at 27° C and light intensity of about 10 mW/cm² for 17 hr/day.

ing that the salinity of the water was unlikely to affect rice establishment.

In the glasshouse or growth cabinets, symptoms of the disorder were reproduced when germinating rice was grown in soil or water from the problem area. In severely affected rice (Fig. 1) root growth was inhibited and shoots were chlorotic. When secondary roots were present they were sparse and darkly coloured with few root hairs. The mesocotyl was sometimes noticeably elongated.

The abnormality occurred in rice seedlings grown in topsoil (0 to 7.5 cm) and subsoil (7.5 to 15 cm) from both areas where attempts had been made to establish rice, in flood water from the Kulu area, in water from the supply ditch to the Kulu area, in mud from the bottom of the main canal near the offtake point to the property, and in surface soil from a lucerne area which had been watered during the same period as the rice. It did not occur in seedlings grown in "contaminated" water after boiling, nor in tap water from the research station which was used as control. Seedlings were not affected when grown in surface soil from an adjacent area of similar soil type which was not irrigated during the period of rice establishment, suggesting that the agent responsible was transported to the problem area in the irrigation water. The toxicity persisted in soil for at least 2 to 3 weeks and was fairly non-specific, affecting several plant species. Roots of lucerne seedlings grown in topsoil from the problem area were poorly developed and dark brown with few root hairs, and germination and emergence of wheat, oats, barley, soya bean and sunflower were severely reduced.

The possibility that irrigation water was contaminated with TCA, 2,2-DPA or amitrole — chemicals used to control weeds in irrigation channels — has been considered. TCA and 2,2-DPA are believed to interfere in protein metabolism and characteristically inhibit the growing points of shoots of grasses, and amitrole upsets glycine synthesis, producing pale plants with withered growing points (Van Overbeek, 1964). Trifluralin, a herbicide used for control of grass weeds in summer crops, was also suspected because of its relatively long persistence in soils (Kearney *et al.*, 1969) and because its recognized effects on germination and root growth could correspond to those of the disorder.

In controlled environment cabinets, the effects of a range of concentrations (1, 5, 10 and 20 ppm) of TCA, 2,2-DPA and amitrole on germinating rice seedlings were compared with symptoms of the disorder observed on seedlings grown in "contaminated" water. Mixtures of amitrole and equimolar ammonium thiocyanate, a synergist, were also used.

In solutions of TCA and 2,2-DPA, seedlings developed dark green shoots and root growth was moderate. These symptoms did not correspond to those observed in "contaminated" water where shoots were chlorotic and roots suppressed.

Exposure to amitrole (more than 1 ppm) and amitrole/ammonium thiocyanate gave symptoms similar to those of the abnormality. However, in the field, a proportion of the amitrole would be inactivated by adsorption at soil surfaces (Sund, 1956; Ercegovich and Frear, 1964) and routine treatments of nearby canals by the Water Conservation and Irrigation Commission of New South Wales are unlikely to account for a dosage of at least 18 kg amitrole, calculated* to be required to give a concentration of 1 ppm in the water. The relatively short persistence of amitrole in soil, of the order of 2 to 4 weeks (Riempa, 1962; Ashton, 1963)

*Assuming 1 ppm in water 15 cm deep over 12 ha and no losses by adsorption.

suggests that amitrole is unlikely to cause the abnormalities observed in successive crops of rice.

A method was developed for analysis of trifluralin in water by extraction into *n*-hexane and determination by gas-liquid chromatography using an electron capture detector. Trifluralin was not detectable (less than 0.03 ppm) in samples of water giving severe abnormalities in rice seedlings.

DISCUSSION

Of the several herbicides initially considered, trifluralin has been eliminated. Symptoms produced by TCA and 2,2-DPA do not correspond to those of the disorder. It seems unlikely that amitrole was the contaminant because of its short persistence and restricted use in the area.

Diuron has been suspected of being implicated in a disorder of rice in the Ord Irrigation Project, Western Australia (G. A. Pearce, 1972, pers. comm.) and analytical techniques are now being developed for this herbicide.

A number of other explanations, including waterborne pathogens or the presence of non-herbicidal toxins, have not been discounted. There are several reports (Patrick and Koch, 1958; Horowitz and Friedman, 1971) that crop and weed residues can produce toxic substances, especially when decomposition occurs in anaerobic conditions (Welbank, 1963; Ohmann and Kommedahl, 1964). The effects of toxins on several species described in detail by Patrick and Koch (1958) seem to correspond to the abnormalities described.

CONCLUSIONS

Abnormalities which prevented the establishment of at least one and possibly three crops of rice appear to have been caused by a contaminant which was present in the irrigation water. The nature of the abnormality, the extent and uniformity of distribution, and persistence of the agent for at least several weeks, are difficult to explain in terms of chemicals commonly used to control weeds in canals and ditches.

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PHYTOTOXICITY OF PICLORAM TO WHEAT AND LUCERNE IN SOIL AND NUTRIENT SOLUTION

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Summary

The phytotoxicity of picloram to wheat and lucerne, and the effect of soil type on toxicity, were determined by growing plants in nutrient solution and various soils containing known amounts of herbicide. From 30 to 40 times more picloram was required to reduce the growth of wheat by 50% than was required for a similar reduction of lucerne in all except one growth medium. The toxicity of picloram to both crops was greatest in the nutrient solution and the sandy loam soil and least in the clay soil. The minimum concentrations which reduced the growth of the crops were approximately 0.1 ppm for wheat and 0.001 ppm for lucerne. Residues of picloram in the soil, therefore, must be reduced below these levels before wheat or lucerne could be grown without damage.

INTRODUCTION

Picloram is a very effective herbicide for the control of skeleton weed (*Chondrilla juncea*), which is a widespread perennial weed in the cereal growing areas of south-eastern Australia. Application of approximately 1 kg/ha will kill the weed, while rates of 35 to 70 g/ha will give control for several months. The persistence of picloram in the soil, however, presents a problem when this herbicide is used in cereal-growing areas, as residues may damage the cereal crop and prevent the establishment of legumes. Legumes, such as lucerne (*Medicago sativa*), annual medics (*Medicago truncatula* and *M. littoralis*) and subterranean clover (*Trifolium subterraneum*) are an integral part of the rotation in the cereal growing areas of south-eastern Australia. This paper presents information on the toxicity of picloram to wheat and lucerne.

MATERIALS AND METHODS

The phytotoxicity of picloram to lucerne and wheat was determined by growing plants in nutrient solution containing known amounts of herbicide. Seeds of both plants were germinated in sand and, after 8 days for wheat and 12 days for lucerne, the seedlings were washed from the sand and transferred to glass jars containing 500 ml of Long Ashton nutrient solution plus added picloram. The concentration of picloram added ranged from 0.01 to 6 ppm for wheat and from 0.00032 to 0.01 ppm for lucerne. The effect of soil type on toxicity was studied by a similar procedure using soils characteristic of the Victorian cereal-growing areas as the growth media. The soils used were as follows:

Mallee — alkaline, calcareous, sandy loam
Wimmera black — dark grey, friable, calcareous clay
Wimmera red — red-brown loam
Goulburn valley — red-brown loam

Picloram at concentrations ranging from 0.032 to 10 ppm for wheat and from 0.00032 to 0.06 ppm for lucerne was added to 200 g of soil contained in paper cups and the seeds were then sown into the treated soil. The fresh weights of plants were measured after about 3 weeks for those grown in nutrient solution and after 32 to 33 days for those grown in soil.

RESULTS AND DISCUSSION

To compare the toxicity of picloram to wheat and lucerne in the various growth media, an ED_{50} value was determined for each crop in each medium. The ED_{50} value is the effective dose of herbicide which reduces the growth of the crop by 50%. It was calculated by plotting the fresh weight of topgrowth as a percentage of the untreated against the logarithm of the picloram concentration and reading off the concentration which reduced the growth by 50%. The ED_{50} values obtained for wheat and lucerne in nutrient solution and the several soils are shown in Table 1.

These results show that from 30 to 40 times more picloram was required to reduce the growth of wheat by 50% than was required for a similar reduction of lucerne, with the exception of the Goulburn valley soil where about 100 times more picloram was required for wheat than for lucerne. There was also a

TABLE 1: ED_{50} VALUES FOR WHEAT AND LUCERNE IN SEVERAL GROWTH MEDIA

	ED_{50} — ppm Picloram	
	Wheat	*Lucerne*
Nutrient solution	0.1	0.003
Mallee soil	0.22	0.007
Wimmera black soil	0.6	0.02
Wimmera red soil	0.35	0.009
Goulburn valley soil	0.4	0.004

marked effect of soil type on the toxicity of picloram to both crops. In the Mallee soil about twice as much herbicide was required to reduce the growth of both crops by 50% as was required in the nutrient solution, while between 3 and 4 times as much was required in the Wimmera red soil and 6 to 7 times as much in the Wimmera black soil. In the Goulburn valley soil, the ED_{50} value for wheat was 4 times that for nutrient solution, but with lucerne there was little effect of the soil on the toxicity of picloram.

The toxicity of picloram to both crops, thus, was greatest in the sandy loam soil and least in the clay soil. Analysis of these soils for clay and organic matter content has not yet been carried out and, therefore, it cannot be determined if there is a correlation between ED_{50} values and clay or organic matter content. However, Grover (1968) found a correlation between the ED_{50} of picloram for sunflowers and soil organic matter, but no correlation existed between ED_{50} and clay content or cation exchange capacity. The increase in ED_{50} with increasing organic matter was attributed to adsorption of picloram by the soil organic matter.

The ED_{50} value is useful for comparing the toxicity of picloram to crops in different soils. However, much lower concentrations will have a detrimental effect on the growth of plants. In these trials the minimum concentration which reduced the growth of wheat was 0.06 ppm in nutrient solution and from 0.1 to 0.2 ppm in soil, while lucerne growth was reduced by 0.001 to 0.003 ppm. Therefore, where picloram is used for weed control, the residue in the soil must be reduced to less than 0.1 ppm before wheat can be grown without damage and to less than 0.001 ppm before lucerne can be established and not be affected by the herbicide. By assuming that one hectare of soil 15 cm deep weighs 2 million kg, a concentration of 0.1 ppm would be obtained by an application of 0.2 kg/ha spread throughout the surface 15 cm of soil. Molnar *et al.* (1967) reported that wheat yields were reduced considerably by about 0.2 kg/ha of picloram when applied to the crop. The maximum picloram concentration tolerated by germinating medics in a sandy Mallee soil has been reported as 0.0016 ppm (Wells, 1972) which, by the above assumption, would be obtained by an application of 3.2 g/ha.

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THE EFFECTS OF TEMPERATURE AND SOIL TYPE ON ATRAZINE PERSISTENCE

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Summary

Six contrasting soils were fortified with atrazine and incubated at constant temperature. At intervals of 2 or 3 weeks, residual atrazine was extracted and determined by gas-liquid chromatography. Atrazine dissipation approximated to a first-order reaction. In general, the first-order rate constant was exponentially related to 1/temperature in accordance with Arrhenius' equation. Soil type affected persistence appreciably. Half-lives ranged from 0.9 to 6.4 weeks at 44.5° C, 6.5 to 25 weeks at 29.6° C and approximately 35 to 167 weeks at 15.2° C. Rates of dissipation were poorly related to atrazine adsorbed or individual soil properties.

INTRODUCTION

Atrazine is widely used for weed control in maize and sorghum. It remains active in the soil for about 10 months (Kearney *et al.*, 1969) and has been reported to affect susceptible crops growing closely in rotation.

This paper reports a study of the kinetics of atrazine dissipation from some contrasting Australian soils. Previous investigations (Armstrong *et al.*, 1967; Armstrong and Chesters, 1968) have shown that atrazine is hydrolysed to hydroxyatrazine by a non-biological reaction apparently catalysed by adsorption at soil surfaces. Therefore, the relationship between rate of dissipation and adsorption was investigated. The data obtained will be used in attempts to predict the persistence of atrazine in different soil environments.

MATERIALS AND METHODS

SOILS AND INCUBATION CONDITIONS

Six contrasting soils were used (Table 1). Organic carbon was determined by the method of Tinsley (1950), clay ($< 2\mu$) by pipette separation, and pH in 0.02 M calcium chloride solution at a soil:solution ratio of 1:2.5. Atrazine adsorption was measured as previously described (Bowmer, 1971).

Soils were passed through a 2 mm sieve. Atrazine in 2 ml acetone was added to samples of 10 g soil in glass containers to give a concentration of 100 ppm in the soil. The acetone was evaporated at room temperature in an airstream, the soil mixed, and water added to approximately field capacity (Table 1).

Incubation temperatures were 15.2 ± 1.4, 29.6 ± 0.5 and 44.5 ± 0.9° C. At least 18 samples of each soil were prepared and at least 6 samples were incubated at each temperature. Containers were opened at weekly intervals to maintain an aerobic atmosphere and water was added to replace evaporative losses. Samples were withdrawn at intervals of 2 to 3 weeks and stored in deep freeze until analysis.

Analysis for Atrazine using Gas-liquid Chromatography (GLC)

The method was modified from Tindle *et al.* (1968), and Mattson *et al.* (1970). An internal standard, propazine, was used to compensate for small losses in partitioning, and small changes in detector sensitivity in GLC.

Soil samples were extracted by simmering under reflux for 1 hour with 80 ml of a solution of 80% acetonitrile in water. A clear extract was obtained by centrifuging and a sample (20 ml) was placed in a separating funnel with 5 ml of 50 ppm propazine internal standard in 80% acetonitrile. Water (150 ml), methylene chloride (15 ml) and sodium sulphate (about 2 g) were added and the atrazine and propazine partitioned into the methylene chloride by shaking for 2 minutes. The methylene chloride was allowed to separate, collected, and evaporated to dryness. Samples were finally taken up in 5 ml acetone for GLC.

A Hewlett Packard Series 7620A GLC with model 15161A alkali flame detector (AFD) was used. The column was a 1.8 m glass coil packed with 1% cyclohexane dimethanol succinate on AW-DMCS treated Chromosorb W, 80/100 mesh. Temperatures were: column 195° C; injector port 200° C; and detector 350° C. The flow rate of the nitrogen carrier gas was 50 ml/min. Injection volume was 1 μl. The optimum detector response was obtained at flow rates of hydrogen 10 ml/min and air 180 ml/min and with the crystal positioned very close to the jet tip. Retention times were propazine 3.48 minutes and atrazine 4.00 minutes. Calibration curves were prepared for mixtures of propazine and atrazine in acetone for a range of concentration ratios. Subsequently, atrazine in soil extracts was calculated from comparison of propazine: atrazine peak height ratios in samples and standards.

TABLE 1: THE EFFECT OF SOIL TYPE AND TEMPERATURE ON FIRST-ORDER RATE CONSTANT *(k)* AND ACTIVATION ENERGY *(ΔE)* FOR ATRAZINE DISSIPATION

Soil	*Organic Carbon %*	*Clay %*	*Predominant Clay Mineral*	*pH*	*Water* %*	*Adsorption†* K'_{10}	K'_{100}	*k week*$^{-1} \times 10^3$ *15.2° C*	*29.6° C*	*44.5° C*	*ΔE kcal/mole* *15.2-29.6° C*	*29.6-44.5° C*
Pelican clay	6.0	54	montmorillonite	5.4	55	84	560	19.6	106	739	20.6	24.9
Hanwood sandy loam	0.6	17	—	5.4	20	7	54	9.4	80.6	384	26.2	20.0
Wollongbar clay loam	1.9	45	kaolin and iron oxides	6.2	22	24	150	11.7	71.4	220	22.0	14.5
Willalooka sand	1.1	59	fine-grained illite	6.7	34	7	70	11.5	48.3	380	17.5	26.4
Kent sand	0.2	61	fine-grained kaolinite	4.3	17	3	20	5.1	28.6	219	21.1	26.1
Grey medium clay from Carrathool, N.S.W.	1.6	61	—	7.0	34	22	174	4.2	27.2	109	22.9	17.8

*Water content during incubation.

†Atrazine adsorbed on soil (μmol/kg) when in equilibrium with a solution of 10 (K'_{10}) or 100 (K'_{100}) μmol/l.

To examine the reproducibility of the technique each soil was fortified in duplicate with 34 ppm atrazine then analysed as described. Atrazine estimated from a comparison of peak height ratios in samples and standards was 101.3 ± 1.3% of that added. Checks showed that, when samples were incubated for 12 weeks at 29.6° C then analysed without the addition of propazine internal standard, there was no interference from atrazine metabolites in the propazine region on chromatograms.

RESULTS

The results for two soils shown in Fig. 1 demonstrate that atrazine dissipation conforms quite well to first-order kinetics:

$$kt = ln\,[a/(a-x)]$$

where a = initial concentration of atrazine at time $t = 0$; $(a-x)$ = residual concentration at time t; and k = velocity constant of the reaction.

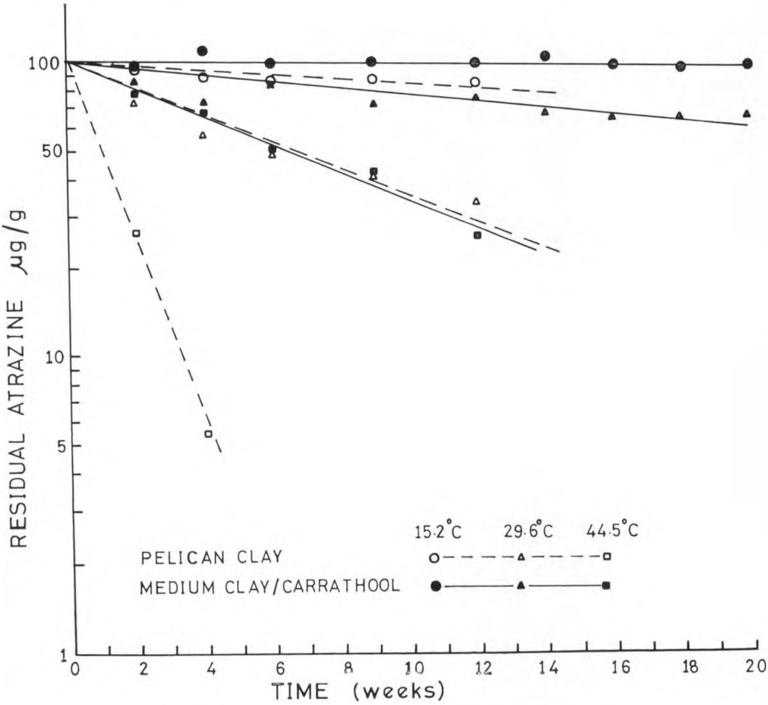

Fig. 1: Rate of atrazine dissipation from soils.

Velocity constants (Table 1) for all soils were calculated from the slopes of the plots of the logarithms of residual atrazine against time of incubation.

DISCUSSION

Soil type had a large influence on the rate of atrazine dissipation. At 29.6° C the reaction was 3.9 times faster in Pelican Clay than in a medium clay from Carrathool; corresponding half lives ($0.693/k$) were 6.5 and 25 weeks, respectively. At 44.5° C half lives were 0.9 and 6.4 weeks. At 15.2° C dissipation was very slow so that it was difficult to estimate reliably. Half lives obtained by extrapolation were approximately 35 and 167 weeks, respectively.

In general the first order rate constant was exponentially related to 1/temperature in accordance with the Arrhenius equation:

$$ln\ (k_2/k_1) = (\Delta E/R)\ .\ (1/T_1 - 1/T_2)$$

where k_1 and k_2 are the rate constants at temperatures T_1 and T_2, ΔE is the activation energy, and R is the gas constant. Activation energies for atrazine dissipation were calculated (Table 1).

These values are higher than the activation energy of 10.8 kcal/mole calculated by Zimdahl *et al.* (1970) for atrazine dissipation from soil, indicating a more temperature-dependent reaction. Taking the mean of all soils, dissipation was 5.7 times slower at 29.6° C than at 44.5° C and 6.1 times slower at 15.2° C than at 29.6° C.

Although previous studies (Armstrong *et al.*, 1967; Armstrong and Chesters, 1968) have shown that atrazine hydrolysis is catalysed by adsorption at soil surfaces, the relationship between rate of dissipation and adsorption observed (Table 1) was poor. This may reflect the contrasting nature and effect of different adsorption sites. Adsorption on carboxyl resins (Armstrong and Chesters, 1968) and the presence of humic acids in buffered systems (Bowmer, 1969) have been observed to accelerate hydrolysis. In contrast, adsorption at clay surfaces seems to have a protective effect (Armstrong and Chesters, 1968; Bowmer and Crawford, 1968). It seems that more information on the distribution of atrazine between organic matter "active sites", clay "safe sites", and soil solution will be required before it is possible to predict atrazine persistence from a knowledge of adsorption or individual soil properties. In addition, pH has been shown to have a large influence on both adsorption (Frissel, 1961) and rate of atrazine hydrolysis (Armstrong *et al.*, 1967) which is difficult to disentangle from the effects of other soil properties.

Observations in the field are being compared with predictions based on the data presented here. Results should indicate how far a knowledge of temperature and soil type can be used for prediction and whether other factors — *e.g.*, water regime and uptake by plants — need to be considered.

ACKNOWLEDGEMENTS

Some of the soils described in Table 1 were supplied by Dr R. J. Swaby; clay minerals were described by A. R. P. Clarke, CSIRO Division of Soils, Adelaide. I am grateful to Miss A. Price, CSIRO Division of Irrigation Research, Griffith, N.S.W., for technical assistance and to D. Swain, Department of Agriculture, N.S.W., for help in preparing the text.

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BEHAVIOUR OF SODIUM ARSENITE IN SOME WEST MALAYSIAN SOILS

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Summary

Clay soils were found to adsorb larger amounts of arsenic than sandy soils and consequently less was leached away by water. The arsenic in sandy soils was more available for plant uptake than in clay soils. The growth of rubber *(Hevea brasiliensis)*, soya bean and groundnut was affected adversely by the presence of arsenic. In rubber, the chlorophyll content of the leaves was reduced and the greatest concentration of arsenic was found in the roots.

INTRODUCTION

Until recently, sodium arsenite has been one of the most commonly used herbicides in West Malaysian rubber plantations. The application of four to six rounds per year of this chemical at the rate of 22 kg/ha was the usual practice. To assess the hazards of the residual toxicity and the leaching to waterways, some studies were conducted on the toxicity and adsorption of arsenic in the soil. This paper summarizes the results obtained.

EXPERIMENTAL

Leaching and Adsorption of Arsenic in Five Soil Types

Leaching

The leaching of arsenic through columns of five different soils was studied. The details of these soils, numbered 1 to 5, are given in Table 1. Three inverted, bottomless, Winchester quart bottles were taken for each soil type and partially filled with 2 kg of soil. The moisture content of this soil bulk was adjusted to 20% by weight. 500 g of the same soil type as that in the bottles was next moistened and mixed with 100 ml of solution containing 0.375 g of sodium arsenite. On a weight basis, such a quantity is equal to 1,680 kg/ha of sodium arsenite. This soil/arsenite mixture was placed on top of the 2 kg of soil in the bottle. The surface was covered with copper gauze and a thin layer of coarse sand.

TABLE 1: SOIL DESCRIPTION

Soil Series	Great Soil Group	Soil Classification 7th Approximation (at Sub-order level)	Soil Texture
1. Sungei Buloh	Alluvial	Psamment	Loamy sand
2. Serdang	Red and yellow podzolic	Udult	Sandy loam
3. Munchong	Latosol	Orthox	Clay loam
4. Selangor	Alluvial	Aquent	Silty clay
5. Prang	Latosol	Orthox	Clay

The treatments were allowed to stand for 3 days. On the fourth day, 500 ml of water (equivalent to 4.5 cm of rain) was slowly poured on to the column of soil and the resultant leachate was collected and analysed for arsenic content (Sandell, 1940). This leaching was repeated at 3-day intervals until the leachates contained no arsenic.

When leaching was completed, the soil was allowed to dry out and the top 500 g of soil carefully removed and analysed for arsenic. The soil below this top 500 g was next carefully sampled in 2.5 cm depths and the first four layers were analysed for arsenic.

Adsorption

The adsorption of arsenic in these soils was then studied. To 100 g samples of the five soils, 500 ml of solutions containing 62.5, 125, 250, 375, 500 and 625 mg of sodium arsenite, respectively, were added (62.5 mg sodium arsenite/100 g soil = 2.75 kg/ha of sodium arsenite).

The soil suspension was shaken for 30 minutes, allowed to stand overnight and then filtered and washed until the filtrate was free from arensic. The total quantity of arsenic in the filtrate was determined.

UPTAKE AND TOXICITY IN PLANTS

Centrosema pubescens *and rice*

200 g samples of each of the previous five soils were mixed well with 40 ml of aqueous solution containing 0, 12, 24, 48, 72, 108 and 144 mg of As_2O_3, as sodium arsenite, respectively. The mixture was air-dried for 3 days and then leached twice with 250 ml water, the leachates being collected separately and analysed for As_2O_3 content.

TABLE 2: LEACHING OF ARSENIC THROUGH SOIL

As_2O_3 content in soil after leaching (mg/g)

			Depth below top 500 g (cm)				
Soil	*Replication*	*Top 500 g of Soil*	*0-2.5*	*2.5-5.0*	*5.0-7.5*	*7.5-10*	*Total As_2O_3 in Leachates (cm)*
1. Loamy sand	1	0.172	0.159	0.078	0.046	0.035	0.705
	2	0.182	0.137	0.145	0.049	0.038	0.906
	3	0.172	0.164	0.099	0.605	0.049	1.324
2. Sandy loam	1	0.192	0.183	0.134	0.104	0.045	0.511
	2	0.195	0.138	0.120	0.096	0.052	0.999
	3	0.195	0.170	0.076	0.047	0.037	0.807
3. Clay loam	1	0.472	0.190	0.184	0.189	0.182	0.064
	2	0.456	0.180	0.184	0.195	0.196	0.038
	3	0.496	0.185	0.184	0.201	0.202	0.032
4. Silty clay	1	0.376	0.132	0.032	0.026	0.024	nil
	2	0.392	0.106	0.028	0.023	0.021	0.018
	3	0.352	0.105	0.034	0.027	0.022	nil
5. Clay	1	0.344	0.050	0.014	0.014	0.014	nil
	2	0.360	0.050	0.017	0.017	0.015	nil
	3	0.360	0.042	0.016	0.014	0.015	nil

After leaching, the soil was transferred into Neubauer dishes and covered with a thin layer of sand. Fifty pre-germinated *Centrosema pubescens* seeds were planted per dish. The dish and contents were kept at a constant weight by the addition of water. After some weeks, the *Centrosema* plants were cut at soil level and dried and weighed. The plant material was analysed for arsenic content.

Rubber Seedlings (Hevea brasiliensis)

Tjir 1 selfed seeds were grown in pot-sand culture (Bolle-Jones, 1954). During the first 3 months' growth, two thinnings were done, leaving behind 5 plants per pot. Arsenic was first applied after 4 months' growth as given below:

As_0 level— no arsenic was given
As_1 level — 2.5 ppm As (increase to 5 ppm after 3 weeks)
As_2 level — 7.5 ppm As (increase to 15 ppm after 3 weeks)

The first sampling was done after 10 weeks of daily arsenic applications when three plants per pot were removed. The dry weights of the plants were taken and the various plant parts were analysed for arsenic as well as chlorophyll, rubber hydrocarbon in petiole, and major elements. Two further samplings of one plant per sampling were carried out at the 20th and 27th week after commencement of the arsenic applications.

Soya Bean and Groundnut

The 0 to 10 cm of a sandy clay loam soil from the tree rows of a rubber plantation which had received repeated routine applications of sodium arsenite over the past several years were collected and filled into pots. As a control, soil from the inter-rows was taken, where comparatively much less sodium arsenite had been applied in the past. Soya beans and groundnuts were planted and grown to maturity and the component plant parts were analysed for arsenic.

RESULTS

LEACHING

Table 2 shows the results of the leaching experiment. The sandy soils, Nos. 1 and 2, retained markedly less arsenic in the top 500 g of soil than clay soils (Nos. 3, 4, 5). Furthermore, very little arsenic, or none at all, could be found in the leachates from the clay soils.

Adsorption

When different amounts of arsenic were mixed with the soils, the amounts that were washed out by water are given in Table 3. The two sandy soils (Nos. 1 and 2) retained lower amounts of applied arsenic than the other three soils. With the sandy soils, the percentage recovery in the filtrate was similar for all levels of applied arsenic but, with the clay soils, the percentage recovery increased with the level of applied arsenic. This is particularly so for soil No. 5, which was also shown to be the most retentive of arsenic compared with the others.

TABLE 3: ADSORPTION OF ARSENIC IN SOIL

Soil	*Amount added (g)*	*Amount Recovered in Filtrate (g)*	*% Recovery in Filtrate (g)*
1. Loamy sand	62.5	31.20	50.0
	125.0	59.25	47.4
	250.0	136.44	54.6
	375.0	181.03	48.3
	500.0	249.60	49.9
	625.0	297.18	47.6
2. Sandy loam	62.5	31.64	50.6
	125.0	63.04	50.4
	250.0	104.60	41.9
	375.0	191.73	51.1
	500.0	255.40	51.1
	625.0	340.18	54.7
3. Clay loam	62.5	14.28	22.9
	125.0	38.08	30.5
	250.0	88.58	35.4
	375.0	118.38	31.6
	500.0	185.95	37.2
	625.0	218.33	34.9
4. Silty clay	62.5	22.94	36.7
	125.0	51.42	41.1
	250.0	94.21	37.7
	375.0	161.17	43.0
	500.0	201.19	40.2
	625.0	263.04	42.1
5. Clay	62.5	5.30	8.5
	125.0	14.83	11.9
	250.0	42.62	17.1
	375.0	87.98	23.5
	500.0	131.82	26.4
	625.0	175.79	28.1

EFFECT ON *Centrosema pubescens*

The results are given in Table 4. The growth of *Centrosema* in soils Nos. 1, 2 and 4 reflected the amount of arsenic present in the soil. In soils Nos. 3 and 5, however, though the arsenic contents were high, *Centrosema* grew relatively better.

Centrosema was able to take arsenic up more readily from soils Nos. 1 and 2 than from soils Nos. 3, 4 and 5.

TABLE 4: EFFECT OF ARSENIC ON *CENTROSEMA*

Soil	*As_2O_3 retained in Soil (mg)*	*Wt of Centrosema as % of Control*	*As_2O_3 in Centrosema (ppm)*
1. Loamy sand	—	100	11
	8	142	13
	14.2	122	24
	21.4	106	38
	35.5	104	70
	68.0	48	91
2. Sandy loam	—	100	8
	8.5	108	29
	16.0	87	29
	36.3	61	65
	56.4	74	95
	68.2	52	140
	80.6	nil	nil
3. Clay loam	—	100	22
	11.5	110	20
	22.1	105	26
	43.2	120	23
	63.0	109	34
	91.9	94	30
	117.1	107	50
4. Silty clay	—	100	18
	11.3	82	22
	22.1	89	29
	43.0	54	32
	63.7	41	57
	93.0	52	50
	123.0	36	49
5. Clay	—	100	6
	12.0	87	26
	23.2	85	34
	47.4	101	27
	70.6	86	34
	104.8	78	9
	138.1	60	62

Effect on Rubber Seedlings

Just before the second sampling — *i.e.*, after 20 weeks of continuous application of arsenic — visual symptoms of arsenic toxicity were clearly manifest in the leaves. The main characteristics were yellowing of lower whorl laminae with purpling on underside of some. Leaves fell after yellowing and the symptoms were always more severe in lower storeys. The leaves were at first diffuse yellowish green and later became bright golden yellow with some tip and marginal scorch. The leaves were smaller in size. The symptoms resembled those of phophorus deficiency. Abundance of infection by the fungus *Colletotricum* in the top leaves was also seen.

Table 5 shows that the dry weight of the rubber plant was reduced by arsenic, especially in the second and third samplings.

The chlorophyll content of the laminae was less in the plants treated with arsenic (Table 6). This was the case in all the three samplings. The chlorophyll content of the leaves in the lower whorl was reduced to a greater extent than in the younger leaves.

The accumulation of arsenic in the roots was clearly shown even in the first sampling. In the stem and leaf, however, only small differences in arsenic content between the control and treated plants were observed.

Analysis for the nutrient contents of the various plant tissues and the rubber hydrocarbon did not give any clear pattern of differences.

Effect of Residual Arsenic

Chemical analysis showed the treated soil had an arsenic content of 175 ppm compared with the control with 23 ppm. The

TABLE 5: EFFECT OF ARSENIC ON DRY WEIGHT OF RUBBER SEEDLINGS

	Treatment		
	As_0	As_1	As_2
At 1st sampling:			
As applied per plant (g)	2.61	51.11	148.11
Total dry weight per plant (g)	73.4	69.4	59.0
At 2nd sampling:			
As applied per plant (g)	5.01	253.51	600.51
Total dry weight per plant (g)	221.8	139.8	106.2
At 3rd sampling:			
As applied per plant (g)	8.45	453.51	1200.51
Total dry weight per plant (g)	525.4	250.5	106.0

TABLE 6: EFFECT OF ARSENIC ON RUBBER SEEDLINGS

	As (ppm) in Plant Parts				*Chlorophyll (mg/g dry matter)*		
Treatment	*1st Sampling*	*2nd Sampling*	*3rd Sampling*		*1st Sampling*	*2nd Sampling*	*3rd Sampling*
As_0	21	10	22	Top whorl laminae	6.32	5.40	5.58
As_1	22	11	32		5.94	5.58	5.50
As_2	24	24	45		5.40	3.40	2.56
As_0	59	32	31	2nd whorl laminae	6.48	5.98	5.04
As_1	57	40	52		5.84	5.20	3.98
As_2	56	52	76		5.44	2.62	1.74
As_0		47	42	3rd whorl laminae		5.12	4.62
As_1		63	68			3.80	3.78
As_2		76				2.42	
As_0	6	2	3	Green stem			
As_1	6	6	6				
As_2	8	8	10				
As_0	8	3	2	Brown stem			
As_1	10	8	6				
As_2	12	9	7				
As_0	34	17	29	Root			
As_1	119	136	432				
As_2	368	338	618				

dry weights of the soya beans and groundnuts as a percentage of control were as follows:

	Dry wt of Plants % Contrl	*Sun-dried wt of Seeds* % Ctrl
Groundnut	66	57
Soya bean	104	11

It was observed that, though the soya bean plant weight was not depressed by the high arsenic contents in the soil, the plants remained green and very few pods were formed at the time of harvest.

A significant amount of arsenic was accumulated in the leaves and roots of both crops as shown by Table 7.

TABLE 7: UPTAKE OF RESIDUAL ARSENIC BY GROUNDNUTS AND SOYA BEANS

	As ppm in Groundnuts		*As ppm in Soya Beans*	
	Treated	*Control*	*Treated*	*Control*
Leaves	34.2	5.0	16.8	11.2
Stem and petioles	4.0	1.7	2.2	2.4
Roots	84.2	16.6	43.7	14.4
Seeds	2.2	1.2	3.1	5.5

CONCLUSIONS

The hazard of arsenic being washed or leached into waterways is greater with sandy soils than with heavier soils after the use of sodium arsenite for weed control. After repeat applications, buildup of arsenic can occur in soil and in crops that are subsequently grown. At present, the use of sodium arsenite is prohibited in catchment areas. However, the results obtained here suggest that a total ban on this chemical would be desirable.

ACKNOWLEDGEMENT

The work of ex-RRIM staff who initiated this subject of study is gratefully acknowledged. The author also thanks E. Pushparajah who encouraged the writing of this article and the Director of the Rubber Research Institute of Malaysia for his kind permission to present this paper.

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ADSORPTION AND DISAPPEARANCE OF BROMACIL AFTER APPLICATION TO HAWAIIAN SOILS[1]

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Summary

Adsorption of bromacil in three Hawaiian soils as determined by equilibration was well related with residue levels found in the field. While a decreasing adsorption gradient with depth of soil was found by laboratory test, this was not consistent in the field samples. Bromacil applied to the field disappeared rapidly as indicated by residue analysis and was essentially non-detectable in 12 months.

Particularly in view of the present awareness of various aspects of pollution, the recommendation for use of a pesticide must be preceded by appropriate experimentation on its persistence in the environment. The effectiveness of the herbicide bromacil has been demonstrated in Hawaii on weeds prevalent in pineapple fields (G. M. Yamane, unpubl. data). Comprehensive reviews on the behaviour of herbicides in soil have been presented by Upchurch (1966) and Sheets and Harris (1965) who summarized existing information on persistence of herbicides in soil. However, no data on bromacil were included. The kinetic degradation of bromacil in an Oregon soil has been reported by Zimdahl *et al.* (1970) who found nearly 50% degradation after 6 months at 31.2° C. Helling (1971) and Rhoades *et al.* (1970), using soil thin layer chromatography, showed bromacil to be highly mobile.

This study involved the use of bromacil as a herbicide for the eradication of miscellaneous tropical perennial grasses and the persistence of the chemical in the field. The latter aspect of the work is reported in this paper.

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[1] Jour. Series No. *1562* of the Hawaii Agricultural Experiment Station. The research was supported by a grant from the Department of the Army, Ft. Detrick, Maryland.

MATERIALS AND METHODS

Field Experiments

Three field experiments designed to test the herbicidal effect of several chemicals were located on two different islands, two on Kauai and one on Oahu. Plant growth consisted primarily of tropical grasses. Descriptions of the soils follow:

Wailua, Kauai: Soil series — Hanalei; family — very fine, oxidic, non-acid, isohyperthermic; subgroup — typic fluvaquents; pH 5.3; organic matter, 3-4%; elevation, 6 m.

Kapaa, Kauai: Soil series — Kapaa; family — clayey, oxidic, isohyperthermic; subgroup — typic gibbsiorthox; pH 5.3; organic matter, 6-7%; elevation, 170 m.

Helemano, Oahu: Soil series — Helemano family — clayey, kaolinitic, isohyperthermic; subgroup — tropeptic haplustoks; pH 4.5; organic matter, 3-5%; elevation, 450 m.

TABLE 1: BROMACIL CONTENT OF SOIL AT VARYING DEPTHS AND INTERVALS AFTER APPLICATION OF 33.6 kg/ha. WAILUA, KAUAI
(Soil series: Hanalei)

*Soil Depth (cm)**	*Bromacil Content (ppm†) Month of Sampling*				
	1	*4*	*6*	*9*	*12*
0	9.17	2.34	1.58	0.64	0
0	12.24	0.70	0.58	0.71	0
Mean	10.70	1.52	1.08	0.68	0
15		0.71	1.66	0.69	1.14
15		0.39	0.43	0.73	0
Mean		0.55	1.04	0.71	0.57
30		1.02	2.13	1.20	0
30		0.52	0.21	1.00	0
Mean		0.77	1.17	1.10	0
60				0.24	0
60				0.35	0
Mean				0.30	0

*0 cm = 0 to 2.5 cm; 15 cm = 12.5 to 17.5 cm; 30 cm = 27.5 to 32.5 cm; 60 cm = 57.5 to 62.5 cm.

†Oven dry basis. All comparable check samples show no bromacil.

Bromacil was sprayed at the rate of 33.6 kg/ha in 374 litres of mixture. There were two replicates with plot size of 5.5 × 9 m. Soil samples were taken at various depths and time intervals (see Tables 1 to 3). Each sample represented a composite of 4 subsamples taken within the plot. The well-mixed sample was stored in heavy plastic bags at approximately 5° C until ready for analysis which was made on the moist sample. Dry matter was obtained by oven drying at 105° C to constant weight and all data are reported on the dry basis.

Adsorption Study

A 5 g moist soil sample was mixed with 25 ml of aqueous solution of bromacil in increasing concentrations and allowed to equilibrate for 24 hours on a shaking machine (New Brunswick model 5, rotary flask shaker, 160 rpm). The concentration of added bromacil ranged up to 52 ppm which is much less than its

TABLE 2: BROMACIL CONTENT OF SOIL AT VARYING DEPTHS AND INTERVALS AFTER APPLICATION OF 33.6 kg/ha. KAPAA, KAUAI

(Soil series: Kapaa)

*Soil Depth (cm)**	*Bromacil Content (ppm†) Month of Sampling*						
	1	*2*	*3*	*4*	*6*	*9*	*12*
0	5.35	3.60	1.04	0.66	0.55	0.15	0
0	3.91	3.09	1.12	0.62	0.54	0.29	0
Mean	4.63	3.34	1.08	0.64	0.54	0.22	0
7.5	5.01	1.68					
7.5	6.27	4.93					
Mean	5.64	3.30					
15	5.68	4.62	1.83	0.91	0.57	0.37	0
15	5.64	5.60	2.34	1.53	0.48	0.28	0
Mean	5.66	5.11	2.08	1.22	0.52	0.32	0
30			1.57	0.61	0.88	0.12	0
30			2.11	0.49	1.03	0.15	0
Mean			1.84	0.55	0.96	0.14	0
60						0.33	0
60						0.24	0
Mean						0.28	0

*0 cm = 0 to 2.5 cm; 7.5 cm = 5 to 10 cm; 15 cm = 12.5 to 17.5 cm; 30 cm = 27.5 to 32.5 cm; 60 cm = 57.5 to 62.5 cm.

†Oven dry basis. All comparable check samples show no bromacil.

solubility of 815 ppm. The equilibration period was adequate for maximum adsorption of bromacil as no increase was found for longer periods. A four-hour shaking gave nearly similar results. After equilibration, the sample was centrifuged at 15,000 rpm for 10 minutes and 1 ml of the supernatant mixed with 50 ml of ethyl acetate. Moisture was removed by adding 3 g of anhydrous sodium sulphate followed by mixing and estimation of bromacil by injecting 5 μ of the supernatant into the gas chromatograph (below). The net level of bromacil found after correcting for moisture in the soil sample is indicative of the degree of adsorption.

Analytical Method

Apparatus

Microtek gas chromatograph, model DSS-161, equipped with nickel-63 electron-capture detector. The column (A) was of Pyrex glass, 1.22 m in length, 6.35 mm in o.d., 3.97 mm i.d. containing 60-80 mesh gaschrom Q coated with 5% GE-XE60 Silicone gum plus 0.2% Epon Resin 1001. Operating temperatures

TABLE 3: BROMACIL CONTENT OF SOIL AT VARYING DEPTHS AND INTERVALS AFTER APPLICATION OF 33.6 kg/ha. HELEMANO, OAHU
(Soil series: Helemano)

*Soil Depth (cm)**	*Bromacil Content (ppm)† Month of Sampling*					
	1	*2*	*3*	*4*	*6*	*12*
0	7.30	1.07	0.45	0.24	0.12	0
0	—	0.78	0.32	0.42	0.12	0
Mean	7.30	0.93	0.38	0.33	0.12	0
7.5	1.80	1.35				
7.5	5.12	1.02				
Mean	3.46	1.18				
15	1.35	1.03	0.34	0.61	0.04	0
15	4.67	0.91	0.72	0.49	0.07	0
Mean	3.01	0.96	0.53	0.55	0.06	0
30			0.22	0.42	0.04	0
30			0.53	0.46	0.04	0
Mean			0.38	0.44	0.04	0

*0 cm = 0 to 2.5 cm; 7.5 cm = 5 to 10 cm; 15 cm = 12.5 to 17.5 cm; 30 cm = 27.5 to 32.5 cm.

†Oven dry basis. All comparable check samples show no bromacil.

were as follows: injector port, 240° C; column, 235° C; and detector, 230° C. Retention time was 3.2 min. An alternate column (B) containing 60-80 mesh chromosorb W, acid-washed, DMCS treated, coated with 10% DC200 Silicone, 12,500 cs and subsequently treated with 3-10 μl injections of "Silyl 8" at a column N temperature of 210° C gave similar chromatograms. The "Silyl 8" treatments were given at hourly intervals followed by overnight conditioning. Retention time was 2.2 min.

Carrier gas flow was 80 ml and purge gas flow was 20 ml of nitrogen per minute for either column. In general, column B gave better resolution than Column A.

Sampling of Soil

The sampling of the surface 0 cm of soil included approximately a 2.5 cm layer. Other depths were sampled with a 5 cm auger inserted horizontally. This would include a cut ± 2.5 cm of the indicated depth.

Procedure

Transfer 25 or 50 g of moist soil to a 500 ml Erlenmeyer flask, add about 100 ml ethyl acetate, bring to a boil on an asbestos-covered hotplate and digest for about 3 minutes while pressing out any large particles with a stirring rod. Cool, filter and wash with small portions of ethyl acetate until a volume of 150 ml is obtained. Evaporate filtrate to dryness on a steam bath and dissolve the precipitate with 20 ml 1 N sodium hydroxide. Transfer to a 125 ml separatory funnel using small amounts of the alkali and extract interferences with two 50 ml portions of hexane. Extract the bromacil from the alkali with two 50 ml volumes of ethyl acetate. Evaporate the combined ethyl acetate extracts if necessary and dilute to a suitable volume. In the event the ethyl acetate extract is highly coloured, pass it through a 1 × 10 cm column of florisil and wash with 10 ml of ethyl acetate.

Inject 5 μl of the extract containing no more than 5 ng of bromacil into the chromatograph at an attenuation of 64.

Inject 5 μl volumes of 0.20 to 1.00 ppm standards in ethyl acetate and calculate areas under the peaks by multiplying the height of the peak by the width at the half height. Prepare the standard curve by plotting areas against ng bromacil. Determine ng bromacil in the sample by referring sample peak areas to the standard curve.

Comments

This method is a modification of methods described for the determination of bromacil and terbacil by Pease (1966a, b) and by Joliffe *et al* (1967). The use of "Silyl 8" treated DC200 column is a definite improvement. Bevenue and Ogata (1969) found that a mixture of DC200 and QFl fluorosilicone as the column coating gave good results.

The extraction of bromacil from soil by digesting with ethyl acetate was preferred over 1% sodium hydroxide because of greater solubility in the former solvent (Joliffe *et al.*, 1967) and freedom from highly coloured impurities extractable with the latter solvent.

RESULTS AND DISCUSSION

Adsorption versus Field Residue Analysis

Soil-herbicide laboratory adsorption tests may conveniently predict persistence of the herbicide in the field. Figures 1 and 4 and Tables 1 to 3, giving adsorption and residue data in the surface layer, show this relationship for three Hawaiian soils. While the differences are apparent between the Hanalei and either the Kapaa or the Helemano soils, the latter two do not appear to

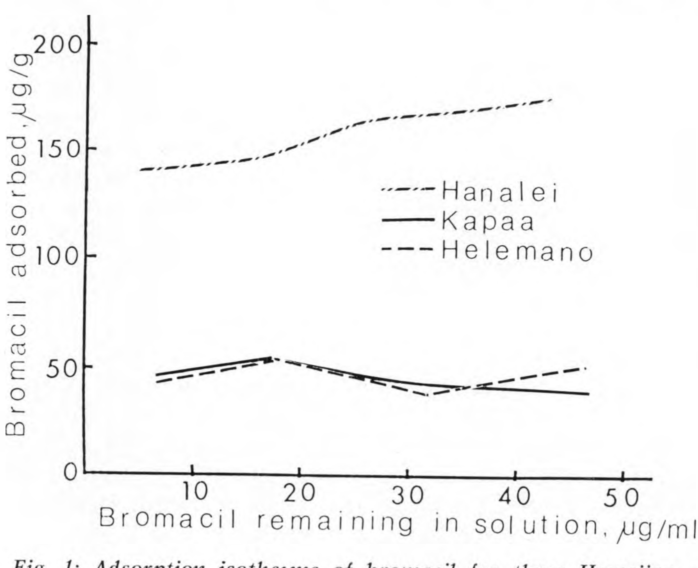

Fig. 1: Adsorption isotherms of bromacil for three Hawaiian soils.

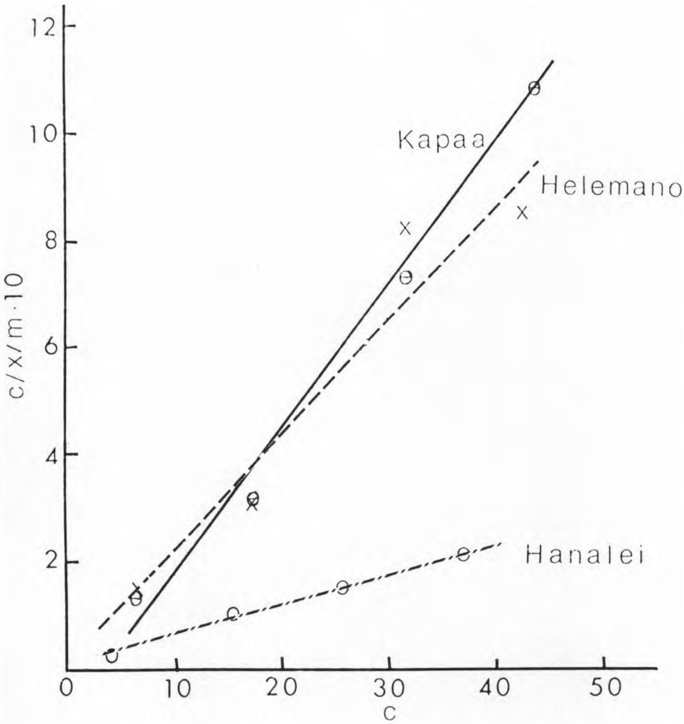

Fig. 2: Langmuir plot of bromacil adsorption data for three soils. Lines plotted by the method of least squares.

differ. The Hanalei paddy soil definitely shows a consistently higher retentiveness for bromacil than the other soils.

Adsorption of bromacil follows the Langmuir plot as shown in Fig. 2. Linearity of the data is indicative of monomolecular adsorption and existence of adsorption maxima.

Adsorption of bromacil as affected by organic matter and pH is not apparent among the soils tested. The very fine clay content of the paddy-type Hanalei soil is doubtless more responsible for its higher retentiveness.

With increasing depth of soil, lower adsorption of bromacil is evident under laboratory conditions as shown in Fig. 3, using the Helemano soil. Comparison of these data with the actual values found for the field samples, however, show an inconsistent trend of higher and lower values in the latter samples. This is understandable as this condition may easily be brought about by an irregular pattern of rainfall and leaching.

DISAPPEARANCE IN THE FIELD

Disappearance of bromacil in the field occurred rapidly for all soils (Tables 1 to 3 and Fig. 4). When compared with the first analysis at the 1-month interval, the 2-month interval showed a loss of 87% (7.30 to 0.93 ppm) for the surface layer of the

TABLE 4: CUMULATIVE RAINFALL DATA (mm)

Months	*Hanalei*	*Soil Series* *Kapaa*	*Helemano*
4	1227	1362	986
6	1403	1707	1504
9	1575	2123	1940

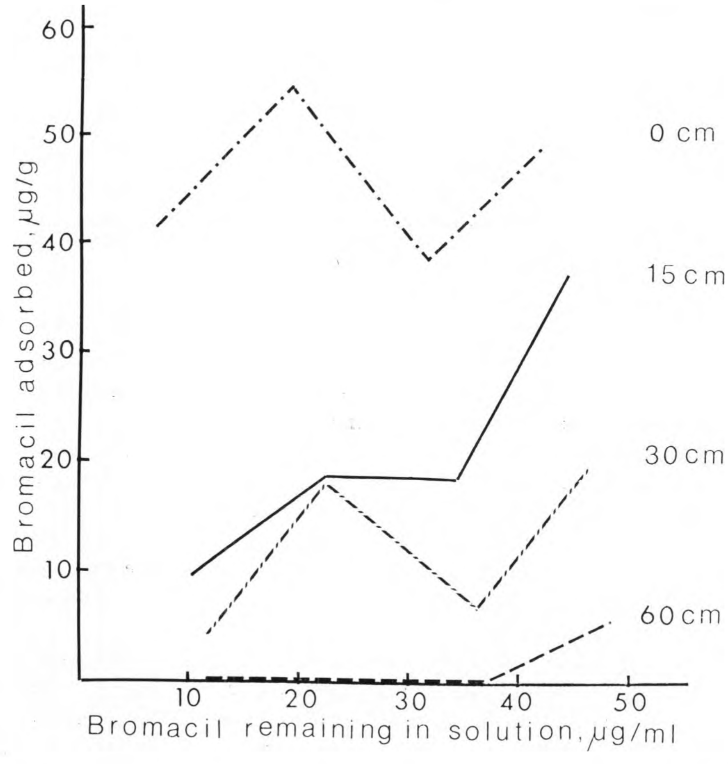

Fig. 3: Adsorption isotherms of bromacil at various depths of the Helemano soil.

Helemano soil. At the 4-month interval, all of the soils contained less than 20% of the content at the 1-month interval. Thereafter a decreasing gradient of concentration was seen up to 9 months. With the exception of one sample of the Hanalei soil, bromacil was undetectable after 12 months.

The relatively high solubility of bromacil in water, 815 ppm, places rainfall as an important factor in the disappearance of bromacil. Table 4 gives rainfall data, which, with one exception, are lowest for the Hanalei soil in which residues are highest. Combined with a higher degree of adsorption for bromacil, it is readily seen why residues are highest for this soil. The opposite holds for the other two soils.

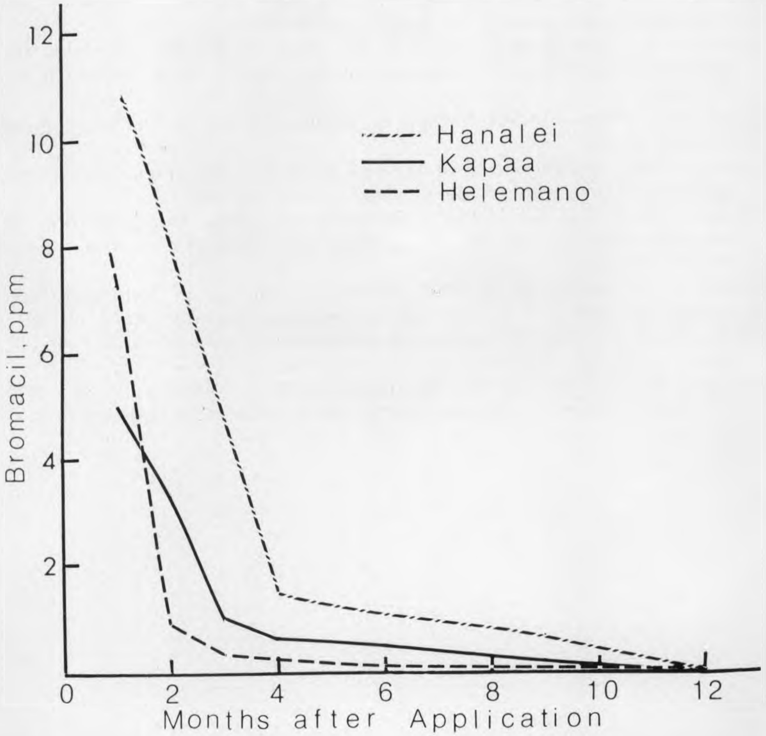

Fig. 4: Disappearance of bromacil after application to 3 Hawaiian soils; analysis of surface layer. Difference between Hanalei and others significant at P = 0.01. N.S. between Kapaa and Helemano.

These data agree with the high mobility of bromacil as indicated by soil thin-layer chromatography (Helling, 1971; Rhoades *et al.*, 1970). Besides mobility, biological or chemical degradation of bromacil is doubtless an important factor involved in its disappearance from soil (Zimdahl *et al.*, 1970).

ACKNOWLEDGEMENT

The assistance of R. T. Sakuoka in the field experiments and soil sampling is gratefully acknowledged.

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