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of New South Wales

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THE WEED SOCIETY OF NEW SOUTH WALES

FORMATION AND OBJECTS

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

(a) To promote wider interest in weeds and their control.
(b) To provide opportunities for those interested in weeds and their control, to exchange information and ideas based on research and practice.
(c) To encourage the investigation of all aspects of weeds and weed control.
(d) To co-operate and, where appropriate, affiliate with other organizations engaged in related activities in Australia and overseas.
(e) To encourage the study of weed science and the dissemination of its findings.
(f) To produce and publish such material as may be considered desirable.
(g) To foster the development of an Australia-wide weeds organization.

MEMBERSHIP

(a) Membership is of three classes, "ordinary", "honorary" and "corporate body", and is open to to all those individuals and corporate bodies respectively who are interested in weeds.
(b) Honorary members are elected from persons who, in the opinion of the Executive Committee, have made major contributions to the objects of the Society and have the same rights as ordinary members.
(c) Corporate body members may nominate one representative to the Society who has the same rights as an ordinary member.

Membership fees are: private members $5 annual subscription, corporate body members $10 joining fee and $10 annual subscription. Fees are payable on the first day of March in each year.

PROCEEDINGS

The sixth volume of proceedings, edited by Dr. B. A. Auld, includes the papers presented by invitation at the Symposium on the Environmental Implications of Weed Control, held at the University of Sydney on 19th and 20th November, 1974.

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

Applications for membership, payment of subscription and orders for copies of the Proceedings should be sent to the Treasurer, Weed Society of N.S.W., P.O. Box K287, Haymarket, N.S.W., 2000.

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Symposium: The Environmental Implications of Weed Control

KEYNOTE ADDRESS: "WHITHER WEEDS?"

R. W. PRUNSTER*

When asked by the symposium organizer to deliver this "Keynote Address" I expressed misgivings since I had not been directly involved in weeds research since 1940. Assurances were given that this would be an advantage, implying that one might approach the task more dispassionately or with a more open mind. One can also demonstrate his naivety and lack of personal knowledge of the spectrum of work and of the people concerned in modern weed research. Misgivings and apologies are in order.

This symposium, under the title "The Environmental Implications of Weed Control" aims to provide a forum for examination of the environmental and social effects of weed control, now and in the future. Perhaps the text can be provided by quoting at random from Kelvin Green's[1] 1967 paper on "The Future of Weed Science".

"Let us consider the impact of to-day's discussions for weed science. They point out the need for problem definition . . .

"In defining the problem, it is becoming necessary to learn the nature of the competition between weed and crop, indeed of the whole botany of the weed complex – its ecology and physiology. These are basic to a complete understanding of weeds – and indeed of crops – yet our present knowledge is small . . .

"Mechanical weed control – the hoe and the cultivator – has long been with us but development was slow until the general acceptance of the tractor . . .

"We must admit that a great amount of *ad hoc* effort has been involved in the screening and evaluation of herbicides to achieve registration, markets and official recommendations. This has been inevitable in a period of such rapid development.

"The continuing application of chemical innovation in the control of vegetation will, I believe, lead us to strange, new paths . . .

"During the next decade, weed workers will become far more concerned with less direct effects of herbicide use. One of these is the fate of the chemical. We are already aware of spray drift . . .

"The impact of soil residues will be felt much more in future. The direct effect of residues of atrazine, trifluralin and picloram may influence crop rotation. Indirectly, very little is yet known of the interaction between herbicides and soil biology and soils themselves, and of the movement of the more persistent materials through soils, possibly into ground water . . .

"Residues found in or on the crop are also particularly important whether for flavour, health or even political reasons . . .

"All forms of lack of control over chemical dispersal are important in a modern society. We shall become increasingly concerned with them and shall call for and from other disciplines, especially soil science and microbiology . . .

"Biological control, by insects or pathogens will become more important, but always of lesser importance than other methods . . .

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1 Green, K. R., 1967. – The future of weed science. *Proc. Weed Soc. N.S.W.* 1:20-1 to 20-4

"A weed seems to be any plant which has some undesirable characteristics."

This perceptive view of the future of weed science reminds me of two stories from the thirties when I first joined the small band of weed research workers. At this time a good portion of the literature on weeds emanated from France. My definition of a weed at that time was the one given in Professor Paterson's lectures at the University of Western Australia – a weed is a plant growing out of place. But I greatly preferred the French expression for noxious weeds – *Les Méchantes Herbes.* It needs more than literal translation. The noun, *herbes,* means plants; it is feminine in gender and therefore recalcitrant: the adjective, *méchant,* translates directly as naughty and referred to the young connotes waywardness rather than destructiveness. Thus one can envisage a weed as a "wayward, recalcitrant plant" calling for understanding to make it amenable.

The second story concerns a newspaper cartoon strip pasted behind the door of a laboratory I shared, at times, with Greenham and Cashmore. One of the characters in the cartoon was tall and thin, garbed in clerical attire, leaning on a hoe in a tidy back garden. He was speaking, over the fence, to his short tubby neighbour reclining in a hammock in the midst of a weedy jungle. Said the cleric "I've hoed these weeds, I've poisoned them and I've burned them. I don't know what to do next." Replied the helpful neighbour, "Perhaps, then, you should learn to love them!"

It is little to wonder at that in those days we tried primarily to be concerned with the biology of the weed species and its autecology and synecology in relation to its kind and to the productive species with which it competed whether as pastures, arable crops, horticultural crops, forests, or in the special environment of irrigation supply and drainage channels.

A historial review may point to some interesting advantages that weeds workers have had up to the present and it may also indicate how they have been, for a period, deflected from their early-determined research priorities.

Strang[2] has made an excellent historical review of research administration in relation to weeds work. It is a record of close collaboration at all levels – institutional and individual – between Commonwealth and each of the States. Perhaps it fails to make specific reference to the later collaboration of the chemicals industry with the government organizations. In any case it is a story of a closer and longer period of collaboration than other groups of workers have been privileged to enjoy. Long may it continue.

As an ex C.S.I.R.O. worker there is an urge to place the initial credit for this collaboration with Rivett, Dickson and Currie. Beginning with the co-operation, in 1920, of the Advisory Council for Science and Industry with the Commonwealth Prickly Pear Board in prickly pear control, Rivett was imbued after the formation of C.S.I.R. in 1926[3] with the need to define the fields of research that properly belonged to the States and those which the States would wish the Commonwealth to undertake. Meetings begun in 1927 led to the conference in 1934 out of which the Standing Committee on Agriculture was formed and later the Australian Agricultural Council. The six State Co-ordinating Committees on Weed Research were formed in 1935 and were replaced, circa 1966, by a single Weeds Committee. Australian Weeds Conferences have been sponsored in 1954, 1960, 1965 and 1970 to communicate up-to-date research information on weeds and their control and, more recently scientifically recognized Weeds Societies, like the Weeds Society of New South Wales, have been formed which convene their own Conferences and Symposia.

But while Rivett was concerning himself with State Commonwealth co-operation

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[2] Strang, J., 1972. – A jubilee of research administration 1920-70. *Proc. Weed Soc. N.S.W.;* 5: 9-24.

[3] Currie, G. A. and Graham, J., 1974. – "C.S.I.R. 1926-1939: Fair weather 1926-28; Riding out the storm 1929-35; Setting new courses 1936-39. (Unpublished).

over the broad spectrum of agricultural research, Dickson[4] pinpointed the need for C.S.I.R. to be specifically interested in weed research and he had earlier defined the pattern of research by decrying the lack of autecological knowledge on some weed species. But it fell to Currie to lead weed research in C.S.I.R. and from his early involvement in the prickly pear programme he was imbued with the spirit of co-operation and collaboration. An entomologist in the C.S.I.R. Division of Economic Entomology, he was equally at home with the ecologists, chemists and physiologists of the Division of Economic Botany or with officers of the State's Department of Lands and Survey and of the Departments of Agriculture responsible for administering the Noxious Weeds Acts. This is amply demonstrated by the way he had been helped to collate the information for the first comprehensive report[5] on weed problems in Australia.

This fortunate, or fortuitous, development of collaboration and facile research communication has been a most important factor in the development of weed research in Australia and it must be maintained and strengthened in the future as the need further develops for involving a wider spectrum of scientific disciplines into integrated weed research programmes.

Since 1906 the States have required that, in the public interest, noxious plants must be eradicated and penalties could be imposed for failure to comply with the orders issued by the Local Government authorities ultimately responsible for administering the Acts. A noxious plant is a weed declared noxious by proclamation. *Eradication* was the operation imposed as a social obligation almost seventy years ago. When the stimulus for weed research developed in the twenties it was because of the public outcry about spending large sums to pay noxious weed inspectors for bringing action against landholders while neither the inspectors nor Government could advise the landholder how to eradicate the weeds and avoid the liability to prosecution. A lot of resources were being directed – with success – towards the eradication of the worst weeds, prickly pear, and the outcry was for means of eradicating all other noxious plants. Though ecologists were appointed to C.S.I.R. to study weed problems, social pressures demanding the *eradication* of weeds placed them in a peculiar position. As Auld[6] puts it: "Paradoxically the first publication to arise from this newly conceived ecological approach was one dealing with 'experiments with weed killers' on skeleton weed (Cashmore and Carn, 1938)".

What government and society were demanding was the "magic wand" of a once-waved poison or a once-released insect that would completely remove proclaimed undesirable aliens from our lands and our minds forever.

The range of "weed killers" was short – common salt; some sulphates, two chlorates, one borate, the arsenicals and sulphuric acid. They were essentially unselective except, perhaps, between annuals and perennials and, in retrospect, social pressures led to a sad waste of time and intellectual energy. On the positive side it led Greenham[7] into his continuing studies of translocation, but for the rest of us it was a boring routine of weedkiller compound x concentration x acid penetrant x season x weed species x time of day for application. In retrospect it is amazing that any ecological investigations were reported at all, but they were. (See the bibliography to Auld's[6] paper to the 1972 symposium of this Society.) It is little wonder that Clarke[8] was prompted to publish that noxious weed

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[4] Dickson, B. J., 1929. – The work of the division of economic botany 1928-29: *Coun. Sci. Ind. Res. (Aust.) Pamph.* 14.

[5] Currie, G. A., 1936. – A report on a survey of weed problems in Australia. *Coun. Sci. Ind. Res. (Aust.) Bull.*, 60.

[6] Auld, B. A., 1972. – Ecological and cultural studies. *Proc. Weed Soc. N.S.W.* 5: 25-30.

[7] Greenham, C. G. and Wilkinson, T., 1942. – Studies on chemical weedkillers with special reference to skeleton weed.
4. Further spray trials and toxicity investigations with a note on translocation. *J. Coun. Sci. Ind. Res. (Aust.)* 15: 154.

[8] Clarke, G. H., 1937. – Noxious weed investigations as a negative phase of agricultural research. *J. Aust. Inst. Agric. Sci.* 3: 206-11.

work was a negative phase of agricultural research and that many weeds research workers left the field during the war years.

Basically society had not permitted weeds workers to resolve their problem into its two parts: first the drastic control of proclaimed undesirable aliens on lands not used for agricultural production and, second, the amenable control of *les méchantes herbes* that interfered with the man-modified vegetation complex that made us efficient agricultural producers. To my mind this hampered the development of weed science over more than twenty years.

And then, with the end of the war, the "hormone-like" organic herbicides literally burst upon us.

I recall Griffiths-Davies' excited arrival in Melbourne to beard the C.S.I.R. Executive for additional resources to make a concentrated attack on agricultural weeds. Here were these simulated plant metabolites, metabolites that the plants themselves utilized to control their growth: they were not "poisons"; with the help of the organic chemist (as he was then called) the prospect of molecular reorganization of the compounds was almost infinite: they could be highly selective: they could be used in low concentration and application could be the major cost in their use: we need no longer think in terms of eradication; we would be able to control the development of weeds to the degree and at the time it was needed. Davies had that kind of enthused imagination and foresight.

The major advances made in this period are well documented: the great investment and scientific contribution made by the chemical industry as well as the fortunate market advantage offered by the extensive agricultural and pastoral environment in Australia: the ease of communication for weeds workers through the States' Weeds Co-ordinating Committees paid off. Progress was rapid compared with the previous twenty years.

Comment, or opinion, is offered on three aspects.

First is that the chemical industry was extremely fortunate, in the sense of social responsibility, in its development of herbicides vis-à-vis its development of insecticides. They were not (as Davies had said) "poisons" and there has been little to worry about concerning their effect on animal species, on the environment generally and the "balance of nature". There is little need to document the problems in this area that have developed with the use and misuse of insecticides. Problems have arisen because of the nature of the insecticides themselves and also because of the increasing social awareness of "pollution" in all its forms and the accompanying demand for the social accountability and responsibility of science. Some of the new generation of herbicides are proving persistent and we seem to know little of their fate in soils or in water, or of the means or time scale of their degradation. This lack of knowledge should be corrected and, as Green said, microbiologists and soil scientists will be needed to help in assembling the new knowledge. But most important, care is needed to maintain the advantages held over many years of not contributing to "pollution". Because of increasing social awareness in this area these problems should be rapidly defined so that the appropriate research can be undertaken.

The second comment is that the very success of the new generation of herbicides again deflected us from the original rationale of a scientific approach to weed problems through study of the ecology and physiology of the weed-crop-soil-water-nutrient complex. The rapid development of new herbicides and of knowledge of their effects is probably reaching an asymptote and refinements in their use will now, perhaps, increasingly depend on the accumulation of knowledge in other disciplines. It is hoped that at last the ecologist, physiologist, plant bio-chemist, microbiologist, soil scientist and agronomist will be given the research priorities they need and deserve to accumulate knowledge for the future resolution of weed problems.

The third comment, which arises from the first two, is that the time has come to plan for the thorough integration of weed research as well as of weed control programmes. In all areas of biological research the interdisciplinary "team" approach has developed and the need can be cleary seen for this in weeds work. With the prospect of an increasing rate of change in Australian agriculture itself, the need to plan to this end becomes more urgent. R. W. Downes[9] discusses some aspects of change in agricultural research thinking that might be equally applied to weeds research. It can be expected that the effects of the too heavy reliance on insecticides for pest control in some agricultural situations will point the need for weeds workers to keep their minds open to the development of integrated control programmes using any or all of the methods available. As Green said in 1967: "All too often, of course, herbicides and other farm tools are used unsoundly by expecting too much of them."

The agricultural economist seems to have been overlooked in planning weeds research and weed control programmes. Most of the economics of weeds has been concerned with three areas. 1. Estimates of "national loss" of production caused by weeds. This might be a good strategy for setting up the emotional climate for a plea for research funds, but is not very useful economics. 2. The cost/benefit for industry in developing a new herbicide. This will give guidelines for pricing the new product and indicate the degree of market penetration and development needed for a "pay off", and 3. "User" economics which say in effect that spraying will give an additional yield of 10 bushels and a return to the grower of $15 per acre over and above the costs of the chemicals. Such generalization is inappropriate for advising an individual farmer.

If and when the weeds worker seeks the collaboration of the agricultural economist he should seek it at the time of planning his experiments. In this way he will assure himself of obtaining the appropriate data for incorporation into studies of real management and production economics.

Dealing with the administration of weeds research, Strang[2] gives some account of the sources of funds for these purposes. Generally, they seem to have been drawn from "Industry" research funds, from the C.E.S.G.* and, for longer term work, from the Australian Department of Agriculture through the Government to Government arrangement for supporting regional research projects. C.E.S.G., combined with Consolidated Revenue and industry, provide the support for State weed projects but long term interdisciplinary research relied on long term funds already substantially committed.

As the total of research expenditure increase as a proportion of the G.N.P., they naturally come under closer public scrutiny vis-à-vis expenditures in other areas like health, education, social services and defence. Government, that is society, increasingly demands greater accountability in science, both in the accepted accounting sense and in the moral sense.

In moving from the more or less "ad hoc" applied approach to weed problems into interdisciplinary team programmes of basic research more thought should be given to the appropriate sources for funds.

Society, that is Government, is essentially the only source of support for basic science. It is done largely for reasons of prestige – science for the sake of science. In applying for funds in this area the application must show that it is good science worthy of scrutiny by, and competition from, the leading scientists in the disciplines concerned. In entering this elite, weed science will demonstrate its own prestige. It may be a slow and painful process, but a necessary one for it it clear that weeds research now needs long term sustained support for basic studies.

Industry – including the "Industry" funds – support science not for the sake of science, as such, but for a non-scientific endpoint in terms of profit. They support it because it is less uncertain than basic research, both in the time needed for the pay off,

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*Commonwealth Extension Services Grant

[9] Downes, R. W., 1974. – Agriculture and agricultural research in the Australian environment; *J. Aust. Inst. Agric. Sci.* 40: 25-8.

and in the fact of its applicability. It must still be good science but the end point must be reasonably assured.

The two points that emerge for future weed research are:

1. To make a concerted move towards basic science to accumulate the pool of information for the resolution of future weed problems. While doing this the ecologist should be given rein at last, to define and help resolve the complex of problems that weeds impose on our agriculture.

2. Heed should be taken of the world move towards greater accountability in science, both in the strict accounting sense and in the need to protect the environment in which we live. In this latter sense weeds workers have maintained very high standards over more than 50 years. They should jealously protect these standards.

One thing we can be sure of: We will always have "*Les Méchantes Herbes.*"

THE ENVIRONMENTAL IMPACT OF WEED CONTROL PRACTICES IN CROPS AND PASTURES

G. B. BALDWIN*

Introduction

The title of this paper poses a number of interesting questions.

1. What have been the effects of past and current weed control techniques on our surroundings?
2. Have these been major or minor?
3. Are these effects causing problems?
4. What are the social implications of any such effects?

I believe it is impossible to give answers to these questions except in a very general way because of the many facets of weed control and numerous crop and pasture types that could be included.

Apart from herbicides, a number of other techniques are used for weed control in crops and pastures throughout Australia. Pre-sowing cultivation, strategic grazing, mowing or slashing, the addition of fertiliser and trace elements, the introduction of legumes to change soil fertility levels, and burning are some of the techniques that are used alone or in combination for weed control in management programmes.

A measure of the diversity of the range of herbicides that are used can be obtained by noting that some twenty different herbicides are currently being recommended in South Australia for weed control in cereals and legume pastures. This figure would double if the herbicides that are used in other field crops and grass pastures grown in Australia were included. Each herbicide or management technique may have a different impact, either directly or indirectly, on the environment and therefore I have decided to separate the practices involving the use of herbicides from others. I will try to answer some of the questions posed in my opening remarks with respect of each division.

The Impact of Weed Control Practices Not Involving the Use of Herbicides

The object of these management techniques has always been to modify the immediate crop or pasture environment to favour the growth of the desirable, economic plant. In some instances a lack of information of the impact on the environment of these practices has, in fact, created new weed control problems or aggravated old ones.

In the late 1940's the clearing of land on Eyre Peninsula in South Australia resulted in major infestations of *Senecio pterophorus* DC. This problem was dramatically reduced by the establishment and management of legume pastures on this cleared land. In the late 1950's successive cropping with cultivations for weed control on these newly established areas of relatively low fertility dramatically increased the problem of this introduced plant in these cereal areas. The leaching of soil nutrients and the breakdown of soil structure and organic matter are now seen as the environmental changes which were enhanced by cultivation. It was these changes in the soil environment which led to the return of this problem.

Moore (1957), showed how the modification of the natural habitat of a native pasture by cultivation and heavy grazing with domestic stock permitted the establishment of introduced weedy species.

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Overseas workers such as Williams and Ross (1970), and Herron *et al.* (1971) have reported on changes in the weed flora with changes in tillage practice. Apart from these ecological changes, I believe major changes in the soil environment have occurred in some areas of Australia as a result of past practices.

Dry cultivation, a recommended technique in South Australia for the control of *Asphodelus fistulosus* L. and *Marrubium vulgare* L., two important weeds of lower rainfall pastures, has created wind erosion problems on sandy soils (Young, 1962). Fallowing to conserve soil moisture and nitrogen has been widely practised throughout the wheat belt of Australia. Although this practice has decreased in recent years it was considered traditional to fallow in the 1940's and in these years some 70 per cent of wheat was grown on long fallow in South Australia (Beare, 1962). Fallows were maintained in a weed-free condition throughout the year by cultivation. Herriot (1954), noted that the farmer who ploughed, harrowed, and cultivated early in the fallowing season usually found he had provided ideal conditions for small seeded weeds to germinate. He therefore had to cultivate again to stop weeds using stored soil moisture. As a result soil tilth became finer, more weeds were encouraged to grow, and a vicious cycle began. He suggested that spraying, not tillage, was an answer to weed control.

Tillage operations are time-consuming. Farmers often worked soils for weed control that were either too wet or too dry at high speed, and further aggravated the soil problems. Pre-sowing cultivations had a major impact on the soil environment prior to the establishment of recognised legume pastures in the rotation and the widening of rotations in Australia. In many areas soil structure deteriorated and serious wind and water erosion problems developed. Surface sealing and crusting followed heavy rains after seeding and crops failed to break through the seal. Water needed for crop and pasture growth was lost by runoff as soil permeability declined. Contour banks had to be constructed and farmers educated to reduce tillage, widen rotations, and build soil fertility by growing legume pastures.

The introduction of the rust fungus *Puccinia chondrillina* Babak and Syd. into cereal and pasture areas for the biological control of *Chondrilla juncea* L. may have environmental impacts which have not as yet been recognised. The discharge of millions of spores into the atmosphere by this pathogen may increase human asthmatic and allergy problems.

With the restricted summer growth of skeleton weed as a result of fungal attack in South Australia, lighter soils and sand ridges are again prone to drift as the stabilising influence of this weed is reduced. More acceptable agricultural plants will have to be introduced into these areas to reduce this new erosion risk.

Some Conclusions

There has been an impact on the environment as a result of our non-herbicidal weed control activities. Pre-sowing cultivations in cereal production have had a major influence on the soil environment. This is not generally recognised as primarily being the result of weed control practices. The problem still exists although it is not of the same magnitude that it was thirty years ago.

With the current awareness of the need for integrated weed control, and the need to maintain or improve the soil environment coupled with the trend to minimum tillage, I cannot see the problem increasing. The change in the soil environment resulted in major crop and pasture management difficulties and in the 1940's this caused a serious fall in farm incomes. Some areas in South Australia have never fully recovered. Social implications followed and farms and towns in marginal areas were abandoned as the result of the shift in the rural population.

The Impact of Weed Control Practices Based on the Use of Herbicides

Many different herbicide formulations and active ingredients are used in crops and pastures for weed control in Australia today. It is this method of weed control that creates the greatest amount of public concern and is believed by some to have the greatest impact on our environment.

A discussion on this subject pre-supposes some knowledge of the complexity of the processes acting when a herbicide is introduced into the environment. Detoxication, degradation, and disappearance of herbicides from the environment involve biological decomposition, photo-decomposition, and chemical decomposition. Their transfer within the environment can occur as the result of removal at harvest, atmospheric movement, movement through the soil, movement in surface water or surface soil, adsorption by soil colloids, or absorption by plants.

Kearney (1970) concluded that for a herbicide to pose a threat to man or his environment it must have the following properties:–

1. Its acute, or oral toxicity must be sufficiently high to cause an imminent health hazard by direct ingestion by man or wild life.
2. Its physical and chemical properties must cause it to:–
   (a) Move from its site of application in water, air, or on migrating soil particles.
   (b) Persist for extended periods of time in soil, plant or animal.
   (c) Partition into fatty tissues of species of lower or higher tropic levels.
   (d) Cause some physiological or reproductive damage to the non-target organisms in the food chain.

If we begin by examining the properties of some of the herbicides that have been used in crops and pastures for weed control in Australia in relation to these criteria it will, I believe, help give some idea of the extent of their impact on the environment. The lack of Australian information in some of these fields makes it necessary in many instances to refer to overseas work.

The Toxicity of Herbicides to Man and Wild Life

Snelson (1970) concluded that most modern herbicides were of low mammalian toxicity, they were of very low toxicity to birds, but were of low to moderate toxicity to fish. Two herbicides, dinoseb (2-(1-methylpropyl)4,6-dinitrophenol) and paraquat (1,1′-dimethyl-4,4′-bipyridylium) used in crop and pasture situations for weed control in Australia required special mention. Mellanby (1967) has given a general summary of the environmental impact on man and on wild life in Britain of DNOC (2-methyl-4,6-dinitrophenol). Dinoseb has similar effects. Orchard (1951) warned of the hazard that di-nitro herbicides presented to the Australian farmer. Fortunately the use of these herbicides in Australia has been limited, mainly as a result of the development of less hazardous compounds. Dinoseb is still recommended, however, in cereal and pea crops.

The use of paraquat for weed control in crops and pastures in contrast has increased in recent years. At a joint meeting of FAO and WHO experts on pesticide residues (1970) it was noted that man must be considered more sensitive to paraquat than other species thus far examined. Acute oral toxicity figures for guinea pig, cat, and cow were quoted as 30, 35, and 50-75, mg ion/kg bodyweight. Paraquat, it was suggested, should be a herbicide whose handling is restricted to trained professional personnel. In an article by Hall (1974) it was reported that the Civil Aeronautics Board of America had warned crop dusters that: "In small quantities paraquat can have a delayed and irreversible effect on the lungs. There is no antidote. By the time the victim realises that his lungs are damaged it is usually too late to save his life".

Morton and Moffett (1972) have reported on the toxicity of a number of herbicides to honey bees. Although paraquat was among the more toxic herbicides, they concluded that herbicides are more likely to injure colonies by depriving them of the plants on which they forage for nectar and pollen rather than through direct effects as poisons.

Movement of Herbicides From the Site of Application

The main blot on the herbicidal record has resulted from the drift of phenoxy herbicides onto susceptible horticultural crops and ornamental plants. The high volatility under Australian climatic conditions of some of the ester forms of 2,4-D (2,4-dichlorophenoxyacetic acid) has contributed to this problem. Damage has occurred in all states over a wide range of susceptible crops. The drift of two other herbicides paraquat, and picloram (4-amino-3,5,6-trichloropicolinic acid) has also been noted. Both aerial and ground spraying equipment have been involved.

The movement of picloram in either surface runoff water, or attached to soil particles is suspected of having caused growth deformities in garden plants in one instance in South Australia. Silt was removed from a dam in a field where picloram had been applied at rates necessary for perennial weed control, and used to topdress a garden area. Overseas workers have recorded that initial losses of picloram in runoff water have been greater on sod than on fallow (Trichell *et al.*, 1968).

In Australia the amount of damage caused by herbicides moving from the site of application has been small relative to the amount of herbicide applied in crop and pasture situations.

The Persistence of Herbicides for Extended Periods of Time in Soil, Plant or Animal

The rate of disappearance of 2,4-D and MCPA (4-chloro-2-methylphenoxyacetic acid) is rapid and of the order of a few weeks to months (Kearney *et al.*, 1969). Residues of these herbicides which are widely used in crops and pastures in Australia are not usually experienced at normal use levels. Wells (1972) working in the Victorian Mallee showed that when equivalent rates of 2,4-D and picloram were applied for the control of *Chondrilla juncea* L. in wheat, residues of picloram seriously affected the growth of *Medicago* spp., in the following year. He estimated that in one soil type the maximum picloram concentration tolerated by germinating medic was .0016 p.p.m. No damage occurred in the following year from 2,4-D sprays.

The use of picloram has been restricted in crops and pastures because of its soil residual activity on leguminous species. Legumes have a vital role in building soil fertility on the Australian agricultural scene. Swain (1970) felt that herbicide residues were an increasing problem to irrigated cropping in New South Wales and he felt more research was needed.

The continual use of diuron (N′-(3,4-dichlorophenyl)-N,N-dimethylurea) at recommended rates in established perennial grass and legume seed crops in South Australia has not led to a build up of herbicide residue in the soil (Kloot pers. comm.). There is increasing evidence, however, that the degradation pattern of individual herbicides may be altered by the presence of other herbicides or pesticides (Sheets and Kaufman 1970).

Although the behaviour of many herbicides in Australian soils is not well understood, the carry-over problems that do occur are few and often result from not following label directions. Band spraying, the use of lower rates by the addition of oils or other additives to increase effectiveness, and the use of more precise and accurate equipment are seen as ways of reducing the incidence of this problem.

Residues in Food or Animal Tissues

Snelson (1970) reported that the use of herbicides in Australia on food crops was extremely limited. Early applications to crops had created no residue problems at harvest. Soil applications limit uptake and plants metabolise compounds into inactive metabolites. There is no concentration in fruit or in seeds of plants, and there is no concentration in the fats of animals. He concluded by noting that the Food and Agriculture Organisation and the World Health Organisation had both agreed that herbicides presented no health problem or trade problem in the inter-change of food products between countries.

Damage to Non-target Organisms

The impact of herbicides on the physiology and reproduction of non-target organisms has been looked at extensively by overseas workers. Pacewiczowa (1969), Grossbard (1970), Manninger *et al.* (1970), Gillberg (1971) and Gour and Misra (1972) have looked at the effects of herbicides on *Rhizobium* spp., and on the symbiotic relationship between bacteria and some legume species. Manninger *et al.* (1970) found that eight strains of *Rhizobium* were inhibited by concentrations of paraquat at levels used in the field. While most workers have reported that at normal field rates there are no effects on the growth and reproduction of *Rhizobium* spp., it is an important facet of environmental impact that we in Australia cannot afford to overlook.

Wilkinson and Lucas (1969) found inhibitory effects on the growth of soil fungi when herbicides were used at concentrations within the range likely to be experienced in the field. Two herbicides, linuron, (N′(3,4-dichlorophenyl)-N-methoxy-N-methylurea) and paraquat, were found to be more fungitoxic than others. Szegi (1970) has reported on the marked inhibition of cellulose decomposing fungi by paraquat at low concentrations. Cellulose decomposition is important as it is part of the scavenging function of soil microflora. Some herbicides have been found to reduce populations of earth worms and soil insects (Honczarenko 1969).

The importance of soil micro-organisms in cyclic processes that are essential to the normal functioning of man's ecosystem are well recognised. There is a wide range of possible effects, either direct or indirect, of herbicides on soil microbes. Research workers agree that this field needs careful study to avoid any permanent disruption to these processes.

Formulation components are known to have different effects on soil microbial populations (Grossbard *et al.* 1972). Sheets and Kaufman (1970) are concerned that not enough attention has been given to the toxicity of herbicide degradation products on soil microflora. They believe from reviewing the research to date, however, that the hazard to soil microbial populations from herbicides is of a low order.

Other Effects

The continual use of herbicides in certain crops and pastures in Australia has had an impact on the ecology of the plant associations growing therein. Johnson (1968) has commented on the changing flora under various herbicide regimes in cereals in Australia. Rademacher *et al.* (1970), Ubrizsy (1970), and Barralis (1972), have recorded changes in crop and pasture weed associations overseas.

Weed control practices using herbicides have had beneficial environmental effects. These are too often overlooked by people prepared to condemn the use of all pesticides as the result of a problem in one area of pesticide usage. Barrons (1973) has given examples of some of these benefits as they have occurred in the United States. Herbicides, he points out, have made it possible to increase yields per unit area from crop lands, and more land has been made available for permanent pasture, recreational areas, wild life reserves which may otherwise have been needed for crop. The practice of minimum tillage can depend on the use of herbicides to control weeds. This practice has reduced soil erosion and its consequential pollution of air and water. Benefits in soil structure and compaction have been observed. Similar benefits can be claimed in Australia.

Some Social Implications

Snelson (1970) commented on the revolution in social structure that was occurring as a result of the use of herbicides in crops in developing countries. Women and children were released from the task of hand weeding crops and an increase in literacy and educational standards followed.

There is no doubt in my mind that the increase in the use of herbicides in cereal growing areas of Australia has reduced the number of man hours that have had to be spent spent cultivating or harrowing for weed control in the past. One can only guess to what use farmers have put this extra time.

Public concern and pressure from horticulturists and other groups following the drift of phenoxy herbicides onto susceptible plants has resulted in legislation in most states to control the application of herbicides. Technological developments, such as the use of herbicides, often require more education, and more knowledge and skill than old ways.

It is interesting to note that herbicides now dominate the pesticide market in the United States, and sales are predicted to rise to $US950M. in 1975 (Farm Chemicals 1970).

Changes in tenancy, farm size, income levels, farm production efficiency and migration of farm workers have been accentuated and accelerated by the adoption of chemical weed control methods in the United States (Miller 1970). These changes, although not well recognised, are occurring in Australia too. It has been suggested that we have moved into the era when the brain is now more important than the muscle.

Some Conclusions

I believe that weed control practices involving the use of herbicides have had, overall, marked beneficial effects on the soil environment. These effects will become more noticeable in the future.

Herbicides moving in the atmosphere have created problems from time to time but their impact on the environment has not been a major one although it often receives a great deal of publicity.

The opportunity for some form of detrimental impact always exists in the complex processes that involve herbicide detoxication, degradation and disappearance. The fact that we have had few problems in the past should not give us a false sense of security.

The establishment of the Technical Committee on Agricultural Chemicals as the "watch dog" requiring detailed information of the possible environmental impact of new herbicides introduced into Australia is seen as a positive step to reduce such risks. It must be recognised, however, that it is not always possible to tell from laboratory experiments and small scale field studies the possible effects upon all components of the environment when a compound is used widely under practical conditions.

Industry has a role in minimising environmental impact by developing herbicides which:—

1. Are known to be easily ecologically degradable.
2. Will not impose limitations on crop rotations.
3. Have low toxicity and volatility characteristics.

The social implications of the widespread use of herbicides in crops and pastures in Australia would seem to me to be quite dramatic if they follow the same pattern as that seen in the United States.

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EFFECTS OF SOME ECOLOGICAL METHODS OF WEED CONTROL ON THE AGRICULTURAL ENVIRONMENT IN NEW SOUTH WALES

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Weeds are usually defined as: plants out of place; plants in place; undesirable plants; harmful plants; inferior plants; etc. A major conflict arises in using the term 'weed' when a plant is considered undesirable in one situation but desirable or tolerable in another. For example, 63% of farmers in a New Zealand survey considered barley grass (*Hordeum murinum*) a weed, but 37% did not (Wasmuth, 1972). *Paspalum dilatatum* is a major 'weed' of golf courses but a valuable pasture species on the coast of New South Wales. Thus, classifying a plant as a 'weed' can only be substantiated if the situation in which it occurs is specified, and even then opinions will differ. Perhaps the greatest advantage of the term 'weed' is that it generally replaces two or more words and thus contributes to brevity.

What we generally mean by 'weed control' in agricultural situations is, the replacement of one plant with another. If the process is done correctly the replacement is superior to the original and this 'weed control' should really be termed 'pasture improvement'. In water and on industrial sites we are mainly concerned, at the moment, with removing all or nearly all plants but, in future, we may find suitable plant populations for these areas which will obviate the necessity for repeated spraying.

Ecology has been variously defined as: 'the study of organisms in relation to their environment'; 'the nature of selection pressures, defence, reproduction, feeding, social spacing, community structure and energetics'; 'man versus nature'; 'elaboration of the obvious'; 'a discipline primarily associated with discarded beer cans for recycling centres'; and, simply 'awful ain't it'. If we select the definition of ecology with regard to weeds as, 'the study of weeds in relation to their environment', then, ecological methods of weed control must include biological and chemical techniques as well as the use of pastures, crops and grazing management. Autecology can be taken to mean the study of the weed itself, and when this information is related to the whole environment, it becomes ecology.

Recently there has been a call for less work on chemical and more on ecological methods of weed control (Quinlivan, 1972). It seems to me that herbicides are part of the ecological control process just as cultivation is a method for removing undesirable plants and preparing a seedbed for desirable replacements. In short, 'ecological' is a mis-used term. It refers to the complete story of weed control, not just a part of it.

'Ecological methods of weed control' are generally regarded as those which use findings from autecological studies, as well as animal management or improved pastures to control, remove or replace undesirable plants. Thus this paper will be restricted to a discussion of these aspects of weed control in New South Wales with special emphasis on the need to replace undesirable species with those perennial improved species which provide long-term botanical stability of the pasture.

Background Knowledge

Quinlivan (1972) points out that our understanding of the 'ecology' of undesirable plants and the research effort being channelled into this subject is far from satisfactory. Although studies have been or are being made on the ecology or autecology of: skeleton

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weed (*Chondrilla juncea*); serrated tussock (*Nassella trichotoma*); barley grass; Wimmera ryegrass (*Lolium rigidum*); blackberry (*Rubus fruticosus*); St. John's Wort (*Hypericum perforatum*); nodding thistle (*Carduus nutans*); galvanised burr (*Bassia birchii*); and other undesirable plants, there are still many which have not been studied. In the past the unpopularity of studying the taxonomy, distribution, competitive ability of, and the influence of soil, climate and management on, undesirable plants was probably due to faster and more practical control solutions being obtained by agrostological or agronomical studies. Certainly basic knowledge can explain the reasons for the success of agronomic methods of control or suggest additional treatments that should be adopted. Thus, perhaps the best method of investigating the control of undesirable plants is to study concurrently the basic aspects of the plant in question and the practical methods of its control.

Management

Intensive Grazing

Intensive grazing by sheep has been used to suppress barley grass (Myers and Squires, 1970), capeweed (*Arctotheca calendula*) (Carter, 1968), Paterson's curse (*Echium plantagineum*) (Anon., 1968), *Poa* tussock (*Poa labillardieri*) (Anon., 1973*a*) and other undesirable plants. This method of weed control usually entails the imposition of high stocking rates. For example, at least 44 sheep per hectare are required to graze the regrowth from *Poa* tussock after burning (Anon., 1973*a*).

The disadvantages of intensive grazing are that only a relatively small part of the property can be treated and, if no competitor is sown, the weed returns the following year. Also, only certain classes of sheep can economically withstand the stress of grazing undesirable plants, (e.g. wethers, dry ewes), which further limits the proportion of a property that can be intensively grazed.

Forcing sheep to graze serrated tussock, supplemented or not, can cause them to lose weight and die (Campbell and Barkus, 1965; Campbell and Irvine, 1966). Forcing sheep to graze barley grass and thistles can result in animal diseases, physical injury, and lower returns due to damage to the pelt and vegetable fault in the wool (Atkinson and Hartley, 1972; Shugg and Vivian, 1973).

Intensive grazing using cattle is limited because loss of liveweight or death of animals can prove more costly than other forms of control.

If intensive grazing is taken to the extreme it becomes overgrazing which in semi-arid areas in the past led to the destruction of much of the better native vegetation and its replacement with inferior species. For example, Ratcliffe (1936) estimated that 75-90% of the saltbush in South Australia was killed by overgrazing – many excellent stands being reduced to drift sand. Donald (1946) realised that carefully regulated grazing was the only efficient means of utilizing and stabilising pastures in semi-arid areas. More recently research has shown (Anon., 1971) that correct grazing management will allow the co-existence of grasses and saltbush which in turn gives higher productivity, protection from wind erosion and a stable pasture.

Thus, intensive grazing with sheep and cattle appears to be a short-term method of weed control with numerous disadvantages. However, intensive grazing using goats has yielded promising results in the control of some undesirable plants in the central tablelands of New South Wales. Contrary to sheep and cattle, goats dislike succulent clovers and grasses and thus graze associated plants, leaving the improved species to compete with the undesirables that remain after grazing. For example, goats will eat fibrous plants such as: blackberry; sweet briar; mature variegated (*Silybum marianum*), nodding and spear (*Cirsium vulgare*) thistles; and some *Eucalyptus* suckers in preference to white clover, (*Trifolium repens*), subterranean clover (*T. subterraneum*) and succulent growth of phalaris (*Phalaris tuberosa*) (B.I. Trimmer, private communication).

As goats are complementary to sheep and cattle, the possibility of controlling other undesirable plants on the Tablelands of New South Wales, e.g. *Poa* tussock, serrated tussock, and Chinese shrub (*Cassinia arcuata*), needs investigation.

In low rainfall country the use of goats to remove unwanted scrub species is being investigated (Anon., 1973*b*). Because goats do not eat some aromatic woody plants, the danger of creating a 'goat resistant' scrub has been recognised and methods of overcoming this, e.g. burning, are being investigated.

Lax Grazing

Spelling a newly sown pasture for the first year after sowing is necessary to control regeneration of serrated tussock seedlings (Campbell, 1963). The improved species grow faster than the tussock seedlings, eventually shading them and killing them. A similar animal-free period could prevent regeneration of other weeds, e.g. *Poa* tussock, in newly sown pastures.

Where serrated tussock infests an established pasture, spelling during spring and summer periods can reduce the infestation (Campbell, 1974*a*). Deferring grazing until winter or spring reduced the population of slender thistles (*Carduus pycnocephalus* and *C. tenuiflorus*) in a ryegrass pasture in Tasmania (Bendall, 1973) and offers a possible method of control for other thistles.

In these situations the exclusion of the grazing animal favours the desirable species at the expense of the undesirable species. In each case however, the improved species, which included a perennial grass, had to be established by using agronomic techniques, otherwise spelling would not have had the desired effect.

Improved Pastures

Generally the response of native plants to superphosphate is not sufficient to exclude the more invasive weeds nor to give economic increases in animal production.

Naturalised or introduced species are generally necessary to repel or control the more invasive weeds. However, in large areas of New South Wales topdressing with superphosphate and sowing with legumes has resulted in the exclusion of the dominant native perennial grasses and subsequent invasion, due to the increased soil fertility, by thistles, barley grass, brome grasses (*Bromus mollis, B. sterilis*), horehound (*Marrubium vulgare*), and other undesirable plants. These plant associations represent unstable sub-climax pastures. Their botanical composition varies wildly with seasonal influence and they are susceptible to invasion by even less desirable plants, e.g. serrated tussock.

The agronomic short-comings of such plant associations, result in lack of production in dry periods, bloat, animal disease and injury, and management problems. The introduction of a strongly perennial improved grass, e.g. phalaris into these sub-climax pastures can stabilise the botanical composition and make it resistant to invasion by barley grass (Tiver, 1954), Paterson's curse (Michael, 1970), some thistles (Michael, 1968*a*; 1968*b*), and perhaps other undesirable plants. The introduction of the perennial grass is generally preceded by one or two crops to take advantage of the increase soil fetility and to reduce the seed population of unwanted plants. More recently herbicides and aerial techniques have been used to introduce perennial grasses and legumes (Wheatley and Phelps 1973; Campbell, 1974*b*) into sub-climax pastures.

Control of other undesirable plants on arable and non-arable land is usually achieved by, respectively, cultivation or the use of aerial techniques. In most situations it is desirable to include a strongly perennial grass in the pasture mixture sown to replace the undesirable plant. Australian commercial phalaris has proved superior to cocksfoot (*Dactylis glomerata*) and ryegrass (*Lolium perenne*) in providing long-term control of serrated tussock (Campbell, 1974*a*). However there is a need for an even more competitive grass than Australian Commercial phalaris to provide more efficient long-term control of serrated tussock. Development of two new phalaris cultivars (Anon., 1974) may assist in fulfilling this need. Perennial grasses have also been shown to assist in the control of St

John's Wort (Moore and Cashmore, 1942) and carpet grass (*Axonopus affinis*) (R. J. Martin, private communication) on the tablelands and coast of New South Wales respectively.

In much of the slopes and plains of New South Wales there is a serious shortage of suitable perennial grasses that can provide stable pastures and efficient weed control. Sirocco phalaris is a recent development but it is not adapted to the drier western areas. Lucerne is used to control some weeds in western New South Wales but the extent of its utilization is limited by the environment.

Conclusion

This paper emphasised that ecological methods of weed control on agricultural land must entail the replacement of undesirable plants with strongly perennial pasture species that can give long-term weed control and botanical stability in a pasture. Perennial grasses, e.g. phalaris, and perennial legumes, e.g. lucerne, have been most successful in achieving these objectives. However, the area of New South Wales to which these species are adapted is limited. New cultivars or species are necessary for the drier areas of New South Wales. The ecological replacement of inferior plants with better species has increased agricultural production, reduced erosion and increased soil fertility and has thus greatly improved the agricultural environment in New South Wales.

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THE ENVIRONMENTAL IMPACT OF WEED CONTROL IN PUBLIC PARKS AND GARDENS

W. GENTLE*

Introduction

Parks and gardens account for a great percentage of the recreational use areas to which weed control chemicals are applied. By emphasising the public garden component, attention is also focussed on areas where local governing bodies apply the greater percentage of formulations used. Use of these is not inconsiderable. The 40 or so Councils which form the local governments of the Sydney region consume annually about 50,000 kg of of prepared formulations, more than half of which is 2,4-D. Addition of private garden usage in Australia's largest metropolitan complex therefore indicates an intensity of weedicide usage which usually escapes evaluation if one confines the exercise solely to agricultural practice.

Herbicide Compounds Used

Materials used can be listed as being principally:

2,2, DPA (Dalapon):	2,2, dichloropropionic acid
2,4-D amine:	2,4-dichlorophenoxyacetic acid amine
2,4-D ester:	2,4-dichlorophenoxyacetic acid ester
2,4,5-T:	2,4,5-trichlorophenoxyacetic acid
Ametryne:	6-ethylamino-4-isopropylamino-2-methylthio-1,3,5-triazine
Amitrole:	3-amino-1,2,4-triazole
Atrazine:	2-chloro-6-ethylamino-4-isopropylamino-1,3,5-triazine
Bromacil:	5-bromo-6-methyl-3(1-methyl-n-propyl) uracil
Diuron:	N'-(3,4-dichlorophenyl)-NN-dimethyl urea
Fenoprop:	2-(2,4,5-trichlorophenoxy) propionic acid
Paraquat:	1,1'-dimethyl-4,4'-bipyridylium ion
Simazine:	2-chloro-4,6-bisethylamino-1,3,5-triazine

Calcium hypochlorite and copper sulphate: (Algal control)

Of this list the most used, singly or in mixture, are 2,2,DPA; 2,4-D; and Amitrole. By extending the subject area to include national park or forest areas used for recreation the usage of 2,4,5-T also becomes a significant addition because of its widespread application to control woody weeds, particularly lantana.

Nature of Problems Engendered in the Environment

While most agricultural weed control applications tend to remain close to the target or, if they do drift, tend to affect very similar crops or situations, those used in parks and gardens are less likely to do this. They are often used in very close proximity to other users, to other activities, and to other sorts of land use, and frequently they move well away from the original points of application before bringing about unintended environmental damage.

This feature can be traced to two characteristics of the specialised environment in which they are used. Firstly, it is often the built environment in which the park or public

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garden is itself located as a *built,* and not a *natural* component. Secondly, water is applied frequently or natural water sources are often concentrated by this environment and in turn concentrate weedicides. Further, water often originates in the upper watersheds of park areas and spills from them throughout the entire hydrological system of the region.

As an artificial environment, the park or garden has artificial ecosystems. As the last "ecological" refuge in an urbanised area it attracts a denser, less representative and more artificial population of animals, birds and insects than the naturally balanced system contains. Environmental impacts are therefore often less predictable because they have been less studied then impacts under "natural" conditions. Human impingement on such ecosystems is also complete and unnatural. Recreational use brings people into direct contact with chemical formulations either on target areas or on fixtures affected by drift. The spread of various formulations at application, or later, takes them often into some degree of contact with closely adjacent residents.

Within parks and gardens ecosystems the following broad environmental problem categories are therefore important:

Persistence of weedicides
Transport of residues, especially in drainage systems
Food chain magnification, especially in artificially dense populations
Acute toxicity effects
Indirect toxicity effects, for example from solvents such as dieselene used to convey the active ingredient

Later problems which arise from weedicide usage are such matters as the disposal of empty containers. Again there can be a concentration mode provided by a limited number of disposal sites for the empties within the very few watersheds of a metropolitan area. Allied problems revolve around the extensive use of unskilled wages labour at every stage from mixing to final container disposal. The contrast with agricultural usage is obvious with the agricultural context favouring the involvement of self-interested individuals, professional contract skill, and a better appreciation of inherent risks.

Some Specific Problems

Paralleling the general problem areas outlined, it is possible to make some predictions about special features, arising from use in public parks and gardens. Degradation of commonly used 2,4,5-T and 2,4-D is accelerated in warm moist microclimates in which there is abundant organic matter. Under conditions favouring constant pressure of human use or where an understory of shrubs and grasses is discouraged by artificial means, this set of conditions does not eventuate.

On the other hand, undegraded chemical hormone weedicide is very likely to run-off or to be washed off by park irrigation and to contaminate ponds, weirs and streams where some of the organisms, particularly protozoa and water plants, are distinctly sensitive to both 2,4,5-T and 2,4-D. In water finding its way quickly into coastal estuaries the effect of these particular non-degraded chemicals on phyto-plankton and oysters can be particularly marked.

A secondary effect of dead aquatic fauna and flora is the lowering of oxygen saturation with consequent damage to other parts of the estuarine system. Apart from this, depletion of the food chain for other organisms is undesirable from the viewpoint of efficient ecosystemic functioning.

Given that the greatest usage of weedicide by local government authorities in parks and gardens appears to be for total vegetation control along open drains and near drained areas (alongside roads and footpaths), the influence of park and garden usage on the environment is probably greatly under-estimated at present. This is particularly so when it is considered that non-target organisms affected through the hydrological regime will very often be removed by distance from the consciousness of the controlling authority. The concentration of both population and park or garden areas close to estuarine drainage lines further aggravates possible damaging episodes due to lack of time for biodegradation to occur.

Indigenous fauna, especially the leaf eaters, are placed at some risk, usually over-estimated, by weed control activities in parks and gardens, as are valuable plants. Sensitivities of some plant species are well known. In general the overall environmental effect on the flora is related more to carelessness with the chemicals concerned than to persistent or cumulative effects arising from the chemicals themselves.

Synergistic effects, especially of 2,4-D, probably need more evaluation. There are reports of augmentation of residual effects of insecticides applied mixed or in proximity with 2,4-D, resulting in unintended toxic effects on useful non-target insects such as bees. 2,4-D has also been linked with synergistic augmentation of the poisonous effect of plant species containing cyanogenetic glycosides and in some national park usages this may be important, if proved of general significance at particular seasons of the year.

Environmentally the aesthetics of chemical control as opposed to mechanical weed control can be important in parks and gardens. Extensive areas, or long strips, of dead and dying vegetation, despite the economies of chemical control methods, may not fit in with the overall objective of attractive park and garden surroundings.

Solutions

Environmental hazards relate more to methods of application than to inherent chemical hazards. It is true that episodes such as the inclusion of dioxin in 2,4,5-T colour this appraisal, but given the range of materials most commonly used in weed control in parks and gardens it is equally true to say that stupid, careless, unnecessary or uneducated usage is the chief hazard.

Education of users must continue to have a top priority. Not only is it important to stress the need for protective clothing, careful application, understanding of the labelled instructions, careful disposal of containers, but it is also necessary to demonstrate concrete examples of environmental misuse to supervisors. Environmental linkages are *not* readily apparent to other than professionally trained people. Coupled with the national "she'll be right" approach, extensive damage at a later time or at a distant location can result from the fact that apparent ecological damage is not in evidence and therefore the significance of careless methods is unappreciated at the supervisory level. Environmental protection in the broad sense cannot therefore be achieved without user education as a primary step.

As a secondary step, the professional can superimpose the strategy of alternative control methods, but he must be aware that any weed control process which is not attractive economically in the intensive care environment of park and garden management will not be embraced very enthusiastically on purely environmental grounds. The chemicals in use are attractive economically and are flexible enough in their useful attributes to be the basis for tolerable weed control programmes.

As a third step, integrated pest control programmes should be instituted. The chief advantage is reduction in the amount of chemical required – always a desirable step environmentally.

As a fourth step, legislative research is required to decide how to legislate effectively to restrict unnecessary or unwise usage. Without legislative research, restrictive legislation along conventional lines is unlikely to be successful or enforceable. Compulsory labelling was a big step forward but legislative incentives to ensure that key provisions of the label are complied with are still needed. It may well be that legislation requiring the education of users is the only practical step.

Conclusion

The park and garden environment, especially viewed in the public usage context, is a specialised one in respect to weedicide usage. Hydrological regimes are more important than may appear in determining the extent of environmental damage arising most basically from poor or ill-advised application practices. Educative processes are seen as the most effective means of improving the present situation.

EXOTIC PLANTS IN URBAN BUSHLAND IN THE SYDNEY REGION

D. ADAMSON* and R. BUCHANAN*

Exotic plants are studied by certain categories of botanists and ignored by others. Ornamental plants attract the horticulturalist, crop and pasture plants claim the agriculturalist, and weeds force their attention on both. The academic botanist usually prefers to study native plants in relatively undisturbed communities, reflecting the traditional academic viewpoint as well as the intrinsic botanical importance of our native plants. However, at the present rate of development of bush for commercial purposes, the botanist browsing in the undisturbed community is often, figuratively speaking, only yards ahead of the chain saw, the bulldozer, the mining dredge or the rising water of a new dam.

This picture of the preferences and professional commitments of botanists in Australia is of course oversimplified, but not many would argue with the general picture. One consequence is that exotics within communities of native plants have been little studied because of the disturbed nature of the communities or their lack of agricultural interest. Quite simply, bush invaded by exotic species (weeds) is a botanical no-man's-land despite its considerable academic and practical implications. This paper is a preliminary examination of the problem and its implications using Sydney as an example.

Since white settlement, the flood of new species and the changed environmental conditions mean that rapid evolutionary change can be expected as new groupings of plants occupy the disturbed areas (Stebbins, 1971; Baker and Stebbins, 1965). The rapid changes are also of interest to ecologists but the research and teaching potentials of weedy bushland have been overlooked. Botanists should also be interested in the spread of exotics for the long-term future of the native vegetation and its associated animals. Legislation to create national parks can protect native communities from direct human destruction but it cannot prevent their invasion by exotics. Although most bushland is fairly free of exotics, their spread is well under way in vulnerable environments. Vulnerable environments include those with high moisture, high nutrients, and high input of propagules. The relic rainforests on our east coast are in this category, as are the patches of bushland surrounded by urban development in the Sydney district. White settlement is still a very recent event in Australia and the extent of exotic invasion of vulnerable areas of urban bushland can be taken as an early warning of future changes in similarly vulnerable but more remote areas.

Urban Bushland in the Sydney Region

Shale and sandstone determine Sydney's topography, soils, vegetation and pattern of settlement. Most of the shale areas have been cleared of native vegetation. Residual bushland occurs mainly in the sandstone areas where the rugged topography has retarded urban and agricultural development. Sydney has bushland only because of the commercially inhospitable country to the south of Botany Bay and to the north of Port Jackson. The total amount and distribution of bushland within the Sydney region is not known. Large areas occur in about four local government areas because large national parks come within their boundaries. By contrast, pieces of bushland under local control are individually small but surprisingly numerous. These small bush areas often follow

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drainage lines in valley bottoms so that they contain well-watered, high nutrient soils and are vulnerable to exotics. Bush on skeletal sandstone soils is remarkably resistant to invasion because of low nutrients and variable soil moisture.

Urban bushland is under increasing pressure from competing interests and even previously inhospitable land is attractive for developments, such as houses, factories, service routes (electricity lines, sewers, gas pipes or expressways), and sports areas. To illustrate the pressures it is possible to quote examples of court cases to prevent use of bush for sports areas, of direct action by residents to prevent clearing of bush, and of the appearance of bushland as an issue in council elections.

Sydney is now at the stage where its residual bushland has to be justified in the face of intense pressure for development. Probably the most important argument in favour of urban bushland is its contribution to variety within the urban environment. Bushland fills important aesthetic, recreational, educational and scientific functions within cities which are not catered for otherwise. Children's adventure recreation is one example which is often overlooked. Organized sports have groups exerting pressure on their behalf but children who use bush as a play area do not. Another consideration is the increase in community interest in urban bushland and native plants over the last two decades reflected in the gardening of native plants and the growth of societies devoted to native plants and and bushland preservation.

The general issues discussed above may seem remote from the problems of exotic weed invasion. However, the trends and attitudes discussed above indicate that the problem is one of practical importance as well as academic interest. Residents' groups and some councils are already making considerable attempts to control weeds in bushland. The environmental implications of our handling of urban bushland over the next decade or so are quite considerable for the Sydney region and an awareness of this seems to be well-established within the community.

Problems of Exotic Weed Control in Bushland

Beadle, Evans and Carolin (1972) note on the jacket of their book that the Sydney region has an unusually rich flora of about 2000 indigenous species of plants, with an extra 450 exotic species of plants naturalized in the area since white settlement. Of this massive input of exotics, most are confined to very disturbed environments such as agricultural land, roadsides, and railways, but a few are successful invaders of bush. These are our main concern.

The Lane Cove Municipality illustrates problems common thorughout the Sydney region. Figure 1 shows the elongated shape of the bush areas which make up about 6.8% of the municipality. Typically, the bush in the whole of the Lane Cove Valley up to Pennant Hills and Wahroonga is dissected into elongated areas. This has the desirable effect of bringing bushland into the heart of the residential areas and diversifying the urban environment. However, dissection of bush areas increases their periphery and so increases the impact of the surrounding urban area, especially in terms of propagules and nutrients. The National Parks in Sydney face the same problem of plant and nutrient spill from adjacent residential areas.

The impact of exotics on urban bush is obvious to any observer but the situation can be illustrated by measurement of three species established in the Lane Cove Valley.

Tradescantia albiflora Kunth. is a common prostrate garden weed and an extremely effective colonizer of most shady bushland. It can dominate the ground layer to the exclusion of other plants. It is still actively extending its range in the Sydney bushland but no data exists to document this observation. It is an excellent example of an exotic which has spread from peripheral gardens and from dumped garden refuse. It is also distributed by flood flow down creeks. An area covered by a mat of *Tradescantia* 45 cm thick was sampled (Table 1). The stand was growing beneath stringybark (*Eucalyptus globoidea*

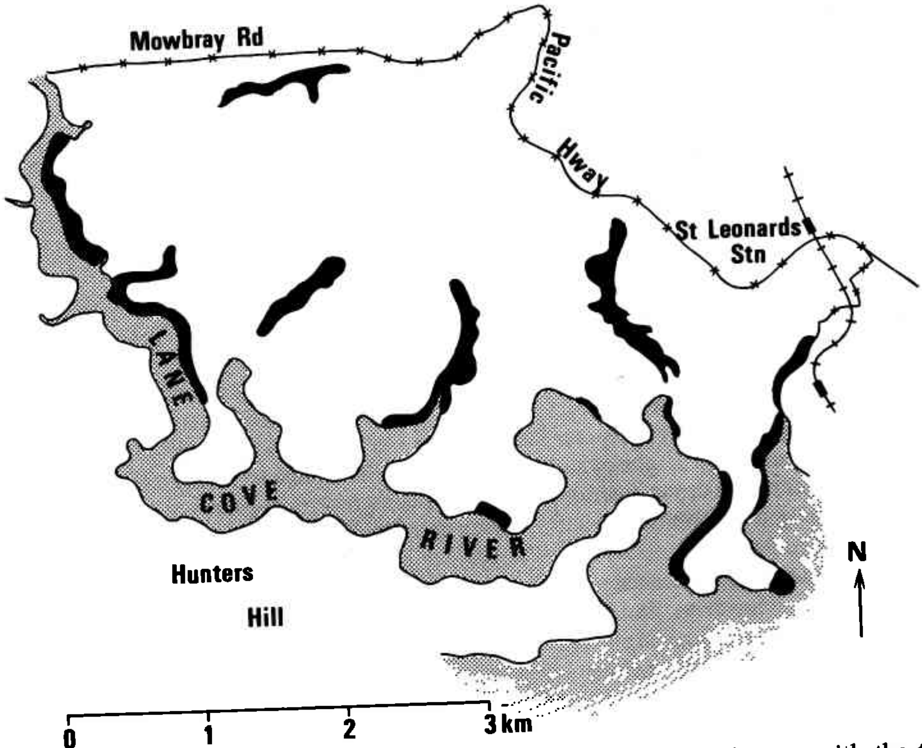

Figure 1. Map of Lane Cove Municipality. Shading shows the bush areas with the tree canopy reasonably intact and the ground or shrub layer in variable condition. Some privately-owned areas omitted.

Blakely) and *Pittosporum undulatum* Vent., in deep shade (light intensity about 0.8 mcal cm^{-2} sec^{-1} i.e. 2 to 3% of full sunlight) with brief periods of sun during the day. The results illustrate the success of *Tradescantia albiflora* as an invader of moist shaded habitats. Each of the 35,000 nodes along the one kilometre of stems in each square metre is a vegetative propagule capable of re-establishing the stand. The leaf area index of 7.5 (ratio of leaf area to ground area) is remarkably high, especially for a plant growing in deep shade.

TABLE 1: *TRADESCANTIA ALBIFLORA* KUNTH.*

Stems and leaves:–	
total fresh weight (g)	7600
total dry weight (g)	685
Leaves:–	
total number	19700
total area (m^2)	7.5
Stems:–	
total length (m)	1100
total number of nodes	34300

*Yield of *Tradescantia albiflora* per square metre. Thornleigh Park, Upper Lane Cove River valley.

The two species of privet, large-leaved privet (*Ligustrum lucidum* Ait.) and small-leaved privet (*L. sinense* Lour.) are becoming dominant on moist fertile soils of valleys. The success of these plants seems to depend upon abundant seeding and the survival of young plants under extremely low light. Privet seedlings can swamp out native species beneath a dense canopy. When a break in the canopy occurs, literally hundreds of suppressed but surviving small privets are available to exploit the extra light. Measurements in Lane Cove Park (Gore's Creek) show that 200 to 600 small privets and only one or two small native plants are commonly found per square metre in infested areas.

Two main strategies have been applied to removing exotics from bushland. One depends on hand-weeding with minimal soil disturbance, starting from the uninvaded bush and working gradually into heavily infested areas. This method is described by Bradley (1971). The second approach is to clear densely infested areas and to replant with native species. The desirability or practicability of both approaches has been questioned. An objective study is needed of various methods, taking account of time, costs, long-term results in relation to initial aims, and applicability to different environments and species. No such evaluation has been made. In the meantime it is premature to dismiss the first approach as too time consuming and the second as necessarily leading to dominance of the ground flora by exotics.

From our experience, several points seem clear.

1. The input of propagules and nutrients must be minimized. Lane Cove Council's experience is that dumping of garden waste in bushland virtually stops when the bush is seen to be tended.
2. Bush is cheap to maintain in relation to the upkeep costs of other forms of parkland. With severe infestation by exotics, the initial costs are quite high but still lower than initial costs for formal parkland.
3. Weed control in bushland requires knowledge and skills different from those for formal parks and gardens. Work by untrained and poorly supervised staff leads to disastrous mistakes. No suitable training exists in horticultural or other courses.
4. Methods causing minimum disturbance seem suitable for bushland which is not severely infested with difficult weeds.
5. The clearing method opens large areas of ground to high light. Dominance of the ground flora by exotics then becomes almost inevitable in vulnerable situations without follow-up treatment. There is little experience of follow-up treatments most likely to promote a native ground flora. Possibly, native ferns such as *Culcita dubia* (R. Br.) Maxon could be used to create a ground cover in valleys and on south and east-facing slopes.
6. It seems clear that a combination of approaches is sensible within any area. The staff of Lane Cove Council follows this principle and shows an admirable willingness to experiment with different methods in different situations. They also encourage and co-operate with the work of groups of local residents.

Control of weeds in bushland requires a sophisticated approach. Spraying of large areas with herbicides is quite correctly condemned as totally inappropriate in a bush context, but the precise use of herbicides in carefully judged situations is appropriate. It is necessary to emphasize the complexity of the ecosystem in which this type of weed control is carried out and the inappropriateness of some agricultural weed control methods. The agricultural chemical industry would be wise to proceed with caution and to encourage use of a range of methods. It should take great care to discourage inappropriate use of agricultural chemicals in bushland because of its biological complexity.

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THE ENVIRONMENTAL IMPLICATIONS OF WEED CONTROL IN AQUATIC SITUATIONS

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Aquatic weeds have special significance from an environmental point of view, largely because of the value of the water medium in which the weeds grow. Water is used, not only for biological life processes and primary production, but also for manufacture, health, transport, drainage, recreation, aesthetic and other purposes. Consequently the possibility of environmental effects resulting from uncontrolled growth of aquatic weeds and from unbridled and careless weed control operations is very real and covers a very wide spectrum.

Some of these environmental effects are discussed in this paper. Both the direct effects from the presence of the aquatic weeds themselves and the indirect effects resulting from the control measures applied will be considered. In particular, attention is drawn to the impending infestation of the Murray-Darling river system with water hyacinth (*Eichhornia crassipes*), requiring immediate preventive action to be taken. Emphasis will also be given to the problems of nutrient enrichment of inland waters and to the possibility of private and commercial aquaria spreading new weed species.

Direct Effects of Aquatic Weeds

Increasing use of Australia's rather limited water resources, has made the direct effects of aquatic weeds better known and better understood. Some of the main effects are listed below:

(i) *Biological*

Growth of water plants can lead to far-reaching changes in the biological regime. Aquatic weeds are an essential part of biological productivity but, when the density of the weed is high, useful biological species, e.g. sport fish, are at a competitive disadvantage.

Excessive growth of emergent weeds, for example *Typha* and *Phragmites* species, can also reduce the value of swamps for water birds. Weed growth can be so dense that some water birds are not even able to gain access to the water surface. On the other hand, aquatic plants in moderation are of importance for shelter and nesting. These are simply physical effects caused by the sheer bulk of weed growth affecting part of the biological system but the chemical changes, which aquatic weeds produce in the water itself, can be of greater biological significance (see iv below).

(ii) *Soil Stability*

Aquatic plants, particularly *Phragmites, Typha* and *Paspalum* species, rushes and sedges can play a useful role in stabilizing soil and silt. These plants mostly have extensive stoloniferous root systems, they prefer shallower water and are well adapted to erosion control at the margins of waterways.

(iii) *Hydraulic*

The physical presence of weeds in water completely changes the flow characteristics of the waterway. In irrigation channels it is not unusual for the flow to double

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following the removal of weed by chemical treatment. Weed growth in irrigation channels and drains wastes water and promotes silt deposition. Weeds can also restrict the flow, cause flooding and reducing irrigation production.

In Victoria the efficiency of delivering water through irrigation systems has risen spectacularly from 45%, some twenty years ago, to approximately 75% today. The larger part of this improvement has resulted from cleaner channels following the adoption of chemical weed control operations. Losses of water by transpiration may also occur and it has been estimated that water hyacinth, for example, increases water losses some 400% above the normal evaporative loss from the water surface. In the western United States it is estimated that almost 2 million acre feet of irrigation water are wasted annually through lake weed infestations (Aboaba, 1973).

(iv) *Chemical*

Weed growth in static water affects its chemical composition particularly with respect to oxygen, nutrients and organic matter. Submerged aquatic weeds release oxygen by photosynthesis and when growth ceases the plants respire and decay; the the oxygen levels then drop spectacularly. Either extreme can be harmful. Carbon dioxide is used in photosynthesis resulting in changes in hardness and pH. For example, vigorous algal growths have reduced water hardness by one-third. Photosynthetic levels are closely related to nutrient levels, and, when photosynthesizing, aquatic weeds will effectively remove nutrients from water. They have even been used to treat sewerage, the nutrients being removed by growing the weeds and then harvesting them.

Another common result of excessive weed growth is the tainting of domestic water supplies. Some algae render the water unpalatable, moreover the toxic effects from the blue-green algae are well known.

(v) *Aesthetic and Recreational*

Aquatic weeds are often attractive to look at, but when growing to excess, or in the wrong place, they can be very ugly. They may interfere with swimming, boating, fishing and hunting and are capable of destroying completely the amenity of the water, making recreation not only unpleasant but hazardous.

There are a number of other effects which in some overseas countries are of importance. These include interference with river transport, blockage of hydroelectric installations, competition with rice and other crops and encouragement of mosquitoes and snails which act as alternate hosts for serious human diseases including malaria, encephalomyelitis, filariasis and schistomatosis.

Indirect Effects from Control Measures

Any use of chemicals for controlling aquatic weeds would be irresponsible if it did not take into account the side effects which might result from the treatment. Water contamination, for example, must be considered in relation to *all* the end uses to which the water might eventually be put, including domestic, stock, industrial, irrigation, aquatic life and recreational uses. In Australia our Irrigation Authorities have, for 20 years, been acutely aware of the difficulties and dangers inherent in using chemicals in aquatic situations. As a result, conservative policies have been developed which have withstood the many tests of time. The most severe of these was the publication of Rachael Carson's book "Silent Spring" in 1963, generating a wave of public awareness and misinformed comment. The awareness was a good thing, the misinformed comment and the over reaction which resulted (of which the virtual banning of DDT is one example) was not.

The important safeguards for aquatic weed control operations lie, first, in the selection of the chemicals which are permitted for use in water and second, in the adoption of strict controls and limitations over the manner of their use (Bill, 1970; Dunk, 1965). The major aquatic herbicides in use in Australia are listed in Table I; their use has been reviewed by other writers (Bill, 1969; Bowmer, 1973) and will not be considered here.

TABLE I: MAJOR AQUATIC HERBICIDES
(Bill, 1970; Bowmer, 1973)

Chemical	*Persistence in water*	*Toxicity* *Mammals*	*Fish*	*Crops*	*LD50 Rates mg/kg*	*Approx. usage by state water authorities.* *N.S.W. kg*	*VIC. kg*
Acrolein	X	XXX	XXX	X	46	38,000	26,000
Xylene	X	XXX	XXX	X	1,590	20,000	10,000
2 2 DPA	XX	X	X	XX	9,330	17,000	19,000
Amitrole	XXX	X	X	XX	25,000	4,000	9,000
TCA	XX(?)	X	X(?)	XX	3,320	2,200	18,000
Diuron	XX	X	X	XXX	3,400	3,000	2,000

KEY: X — non-persistent in water (days) or non toxic,
XX — moderately persistent in water (weeks) or moderately toxic,
XXX — very persistent in water (months) or very toxic.

Only chemicals of low mammalian toxicity are normally used in water weed control operations. The exception to this is acrolein which, although toxic, is not persistent in water and rapidly degrades or evaporates.

Where the manner and amount of herbicide use is such that residues in water occur, it has been the practice in Victoria to have tolerances for water set by the Pesticides Review Committee, which includes representatives from the Victorian Ministry for Conservation and the Departments of Health, Agriculture, Lands, and Fisheries and Wildlife and the State Rivers and Water Supply Commissions. In the case of amitrole these limits have also been confirmed by the Commonwealth National Health and Medical Research Council. The existing herbicide tolerances for water, developed in Victoria and used also in New South Wales, are amitrole 0.002 ppm, 2,2, DPA 0.002 ppm and diuron .004 ppm. This cautious approach to the use of herbicides in aquatic situations has kept damage to the minimum. The only harmful indirect environmental effect of significance has been to fish, which are often killed within the confines of the channel systems when acrolein and xylene are used. This is an undesirable effect, but no way has yet been found of avoiding it.

The irrigation authorities in Australia, remembering the scope and complexity of their weed control activities, have a remarkable record, extending over decades, for safe and effective herbicide use. This has been difficult to achieve because, as Table I shows, the major aquatic herbicides are unsatisfactory from an environmental point of view. Most of the herbicides use remain active in water for long periods; acrolein and xylene are the only unstable herbicides and they kill fish and are difficult to handle, being inflammable explosive and volatile; acrolein also has a high mammalian toxicity.

The task of those using aquatic herbicides would be greatly simplified if tailor-made chemicals were available for use in water. The ideal aquatic herbicides for protecting the environment should be quickly degraded in water, becoming harmless to humans, animals, aquatic life and cultivated plants. There is a need for such chemicals to be developed. Industry has made remarkable progress in the development of herbicides suitable for land weeds. If their screening and research programmes could now be directed towards a reduction in hazards and towards a study of the mechanisms of deactivation, then safer and better treatments for aquatic weeds could be found.

Biological control measures are an alternative to chemicals and some success is being achieved overseas through the use of fish, freshwater snails, the manatee, the flea beatle, competitive plants, and plant diseases (Holm *et al.*, 1970; Zetter and Freeman, 1972). Caution is of course needed in considering the introduction of any of these measures as there is a real possibility of harmful side effects. In southern Australia the European Carp is reported to be having a substantial effect on weeds in irrigation and drainage systems. This low grade introduced fish, through disturbing the silt in drains and channels has removed as much as 45 cm of the bed. However, the disadvantages outweight the advantages. There is, for example, a likelihood of increased seepage from the bed of the channels and water treatment plants may be needed to restore some of the damage to water quality caused by the carp.

Environmental Problems of the Future

Although a satisfactory degree of aquatic weed control is currently being achieved for most situations, there are three developing problems which, if allowed to get out of hand, will have extremely serious results for Australia in future, namely:–

(i) The impending spread southwards of water hyacinth, into the vast Murray-Darling river system.

(ii) The nutrient enrichment or eutrophication of inland waters with its accompanying stimulus to algal blooms and aquatic weeds generally.

These are both future weed problems of grand dimension.

(iii) A third possible future problem of which we should be aware is the danger of accidentally introducing new weed species to our waterways through the source material widely available in commercial and private aquaria.

(i) *Water Hyacinth in the Murray-Darling System*

One of the great achievements of noxious weed control activity in Australia has been the containment of water hyacinth to northern New South Wales, Queensland, and Western Australia. In Victoria and in South Australia there have been a number of outbreaks and occurrences of water hyacinth from time to time but, in each case, these have been painstakingly located, identified, and eradicated. Water hyacinth, will certainly spread south, if it has the chance. Occasional outbreaks have already occurred in the Ovens River, a tributary of the Murray in Victoria, at Doctor's Flat on the Murray near Albury, at Torrumbarry 150 miles downstream, and at Ramco Lagoon adjoining the Murray River in South Australia. These outbreaks were identified at the very early stage and controlled. However control is seldom complete and even after 20 years annual treatment of seedling regrowth is still needed. Our experience with this vicious weed in southern Australia has shown beyond any doubt that water hyacinth will grow and spread with vigour even in the colder regions.

There are at this very moment some 22,000 acres of water hyacinth in the Murray-Darling System which is not under control. This vast potential source of infestation has grown from a single plant since 1955. It is established in the Gingham water course, a system of anabranches, of the Gwydir River located at Moree near the Queensland-New South Wales border. The weed is held back by a stabilized log raft but *any major flood,* perhaps that of last year, or this year, or next, *could divert the river and infest the Murray for all time.* Once this happens, as it inevitably must, water hyacinth will spread like wild-fire and chemical treatment will be virually impossible because of the wide use of the water for both domestic and irrigation purposes. The bill will then run into millions of dollars per annum and even then the result, in terms of the hydraulic and economic effects on the Murray, will be disastrous. Surely we can learn from the tragedies repeated time and time again in other countries (Holm *et al.*, 1970).....

> "Water hyacinth was first reported in the Congo River in 1952 and in less than three years it had spread 1600 km from Leopoldville up to Stanleyville. In 1954 it had already begun to block transportation. Buoys were submerged and navigation channels were hidden. Fish spawning areas were blocked. Many fishing grounds were destroyed by darkness and lack of oxygen as the weed cover became more dense, and, as a result, the riverine communities were denied their principal source of protein. Using herbicides applied from ships, planes and helicopters, by 1957 Belgian scientists had directed the clean-up of more than 1600 km of the river at a cost of $1 million. In spite of this massive effort, Le Brun reports that in the same year water hyacinth was still floating past Leopoldville on the way to the sea at the rate of 136 metric tons per hour. During the turbulent years following independence, the Congo government services could not maintain the weed control programme and the Congo River is again badly infested.
>
> The history of the infestation of the upper White Nile is equally tragic. The first report of the weed in the White Nile was in 1958. Again, the multiplication and spread took place so quickly that even the best efforts of the Sudan Government could not organise a campaign in time to contain the weed. A staff of 200 workers equipped with ships, planes, and land vehicles was organised to keep the river and harbours open. During the early 1960's, the water hyacinth team of the Sudan was able to keep the weed under control in the most critical areas with herbicides. At one time the cost of this operation was $1.5 million per year."

Clearly the responsible authorities, namely the New South Wales Departments of Agriculture and Local Government, and the River Murray Commission must combine and act decisively and quickly before it is too late. The answer is simply to:—

(a) spray the weed now, immediately whilst it is contained and before it spreads and

(b) to institute a regular system of aerial and ground surveys and inspections assisted by colour aerial photographs, to locate any future infestations before they spread.

These actions are of far greater significance than anything else that can be done to preserve the aquatic environment of south-eastern Australia.

(ii) *Eutrophication of Inland Waters*

Eutrophication is simply the enrichment of our water with nutrients — particularly phosphates and nitrates. This is a natural process which normally occurs very slowly, but some modern practices have accelerated eutrophication leading to excessive growths of aquatic weeds, which destroy the appearance and reduce the value of inland and estuarine waters. Both urban and agricultural development of our catchments have contributed to this problem. The main factors operating, apart from the direct discharge of sewerage into water, have been the clearing of land, pasture improvement, increased use of fertilizers, and increased numbers of livestock. Agricultural development and intensification has been a major factor in the eutrophication process and if this is allowed to continue, unchecked, more and more problems will develop. Monitoring systems and tight control of all discharges into natural waters will be necessary to avoid the degradation of water supplies and to preserve the amenity of our natural waters.

(iii) A third problem, which is with us now, and is threatening the future, arises from the exotic aquatic weed material to be found in commercial and private aquaria throughout Australia. If these weeds are discarded into waterways they can add enormously to our present problems. There is a good case for expanding the lists of noxious aquatic weeds to eradicate some of those introduced plants at present found only in aquaria.

Conclusion

I have aimed in this paper to illustrate the growing importance of aquatic weeds in our environment. Much has been achieved in past years by controlling the most difficult of these weeds, but serious problems are developing for the future and unless firm action is taken the environment in which Australians live, work and play will be markedly poorer.

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ECONOMIC ASPECTS OF WEED CONTROL

B. R. DAVIDSON*

The purpose of any form of weed control is to remove or decrease the number of unwanted species from a crop or pasture and so increase the yields of the useful species by removing or reducing competition for light, water and mineral elements. Weed control can be achieved in a number of ways including cultivation before and after sowing and the use of both post and pre-emergence herbicides. None of these methods are mutually exclusive, they can be applied either singly or in combination, or one may be substituted for another.

It is the work of the economist not only to decide if the value of the increase in yield is sufficient to cover the cost of a particular form of weed control, but also to determine the optimum amount of any form of weed control which should be used in a given situation, and the optimum combination of methods of control where more than one form of weed control is available. All of these tasks can be achieved by using the conventional theories of production economics.

Theoretical Aspects

The nature of costs

The costs associated with any form of weed control are normally of two types:

(a) Fixed costs

These include all costs which will not vary if there is a small variation in the amount of given treatment. Such costs include permanent labour and the depreciation of machinery. Thus an increase in the number of interrow cultivations from one to two cultivations can be achieved without purchasing additional machinery or labour if the second cultivation is carried out when labour and machinery are not being used for any other purpose.

There is obviously a limit to the additional amounts of a particular treatment which can be given without increasing fixed costs and these often vary widely with the type of treatment given. Thus an increase from two to four in the number of pre-sowing cultivations to destroy weeds might involve doubling the machinery and labour required for cultivation if the period available for land preparation is short. On the other hand the quantity of a herbicide which can be applied in any one treatment can be increased indefinitely without increasing labour or machinery costs.

In some instances fixed costs may be non-existent. If cultivations are carried out with permanent farm labour which would not otherwise be employed and with machinery which is required for other purposes on the farm, but which is not required when weed control operations are carried out, then fixed costs are zero. Or in economic terms labour and machinery have no opporunity cost.†

(b) Variable costs

These include all the costs which will increase if the amount of a treatment is increased. Thus if the number of cultivations is increased, fuel and machinery repair costs will increase in proportion to the number of cultivations. Similarly the cost of herbicide

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†Opportunity cost is defined as the profit a resource would earn in its most profitable form of employment.

will increase in proportion to the strength at which it is used. In some cases all costs are variable costs. This situation arises if the fixed factors such as labour and machinery have no opportunity cost, or if all resources are hired on a per unit area or per quantity of a resource applied basis as in the case of the aerial application of a herbicide by a hired contractor.

The Optimum Level of Application

The level of weed treatment which will give the greatest return, or have the least loss can be established if the relationship between the level of application and yield over a wide range of applications is known.

As the number of treatments (or strength of application of a herbicide) is increased from zero, yields may first increase at an increasing rate. As the number of treatments increases further yields will normally only increase at a decreasing rate and finally may actually decrease as treatments may become harmful to plant growth at high levels. A relationship of this nature which is referred to as an input-output relationship or a production function is shown in Figure 1 where the zones of increasing-decreasing and negative returns are also identified. The data on which Figure 1 is based are shown in Table 1 for a number of cultivations of wheat fallow after first ploughing and discing. With no further treatment of the fallow, 1,000 kilograms of wheat would be obtained. However, further workings by destroying weeds increase yields first at an increasing rate and then at a decreasing rate until yields finally decline because of the destruction of soil structure. From the same data it is also possible to calculate the marginal return obtained from each additional cultivation, that is the increase in yield which occurs for each additional treatment or any part of the production function (Table 1, Figure 1). Similarly average returns or the increase in yield per total number of cultivations at any one point of the production function can also be established (Table 1 and Figure 1). Marginal returns will always equal average returns at the point where average returns are at a maximum.

FIG. 1 RELATIONSHIP BETWEEN YIELD AND CULTIVATION

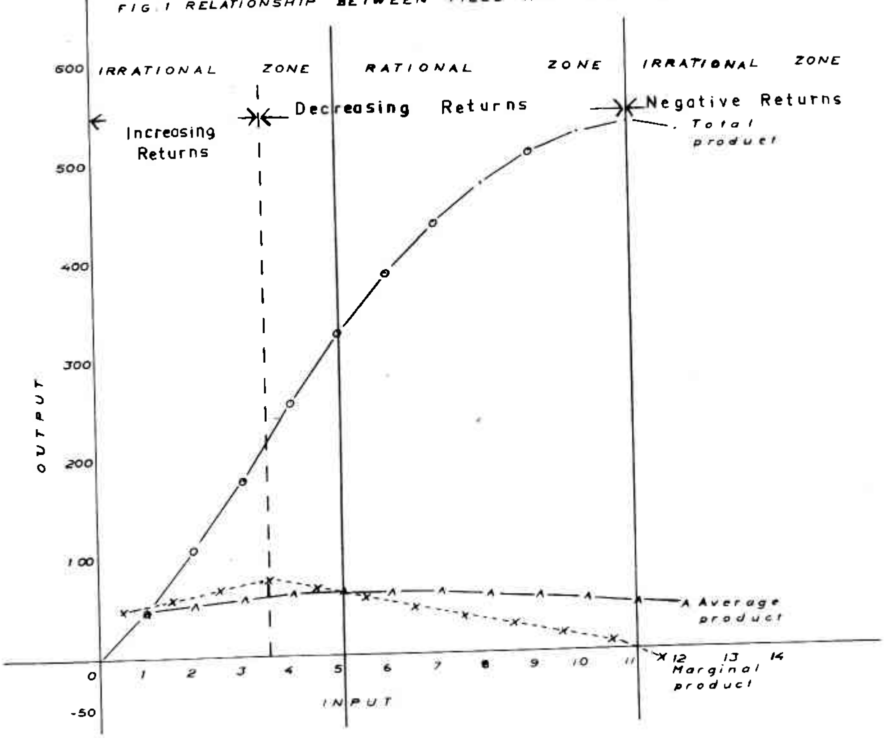

TABLE 1: TOTAL AVERAGE AND MARGINAL PRODUCTS FOR WHEAT AND FALLOW CULTIVATION

Number of workings of fallow	*Production of wheat (kg)*			
Units	*Total yield*	*Total product*	*Marginal product*	*Average product*
0	1,000	0		
1	1,050	50	50	50
2	1,110	110	60	55
3	1,180	180	70	60
4	1,260	260	80	65
5	1,330	330	70	66
6	1,390	390	60	65
7	1,440	440	50	63
8	1,480	480	40	60
9	1,510	510	30	57
10	1,530	530	20	53
11	1,540	540	10	49
12	1,530	530	-10	44

The optimum level of application will always lie in the zone of diminishing returns. If a cultivation is worth carrying out at all then it is obvious that while increasing returns persist the increase in yield from the last treatment is always higher than from the treatment before it. The optimum level will also be beyond the point where average returns are at a maximum as until this point is reached the yield per unit of cultivation is increasing. On the other hand the optimum point must be less than where negative returns begin as beyond this point further cultivations cause yields to decrease.

Thus a rational zone of decision, in which the optimum level of application must lie, exists. It extends from the point where average returns are at a maximum to the point where negative returns begin and can be determined from the physical relationship between the number of treatments or level of treatment and yield. In Figure 1 the rational zone extends from 5 cultivations where the average product is at a maximum to 11 cultivations as after this number of workings negative marginal returns are obtained.

The rational zone is the same regardless of the cost of the treatment or the price of the commodity produced. The only situation where this would not be true would be one where either the product had a negative price or the treatment a negative cost.

To determine the optimum level within the rational zone it is necessary to know the marginal cost of each treatment (i.e. the cost of the last treatment; this is normally constant) and the marginal revenue (marginal product x price) associated with each treatment within the rational zone.

Total revenue, marginal revenue and marginal cost based on the physical data in Figure 1 and Table 1, were calculated on the assumption that the variable cost of each cultivation is 50 cents per hectare and the price of wheat is 2 cents a kilogram. The results of the calculation are shown in Figure 2 and Table 2 and indicate that marginal costs equal marginal returns when both equal $1. This is at the point where 7 cultivations costing a total of $7 are carried out giving a total increase in product of 440 kilograms, a marginal product of 50 kilograms and a total additional revenue from fallow cultivation of $8.80 (Figures 1 and 2 and Tables 1 and 2).

FIG. 2 RELATIONSHIP BETWEEN REVENUE AND CULTIVATION

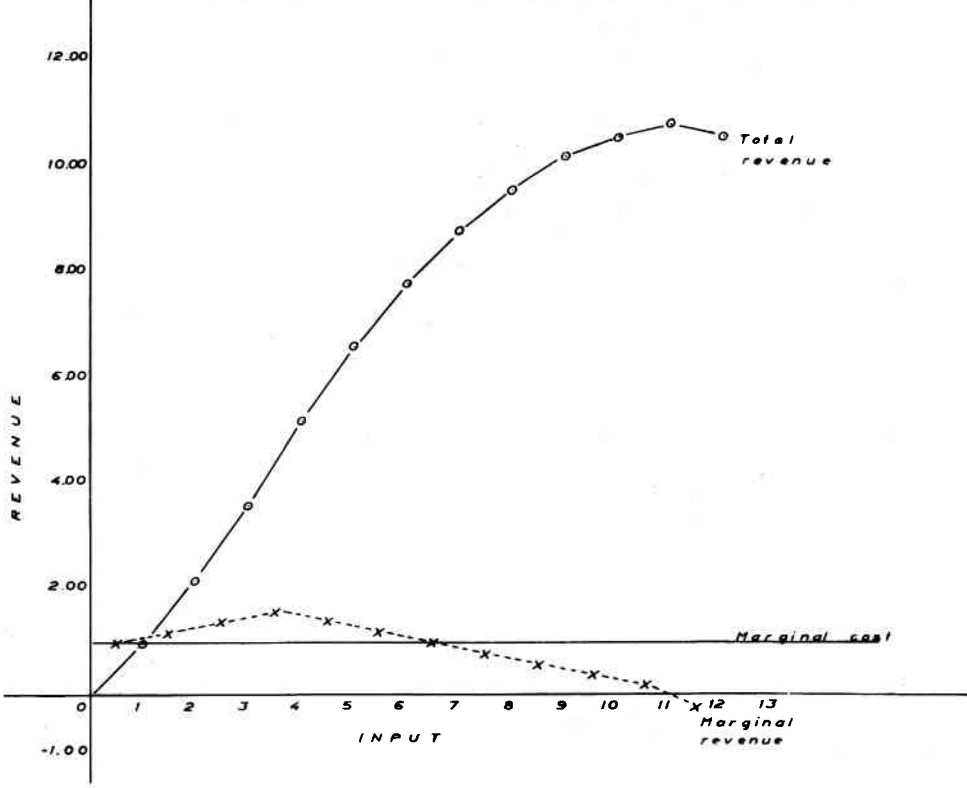

TABLE 2: TOTAL AND MARGINAL COSTS AND REVENUE FROM WHEAT CULTIVATION

Number of cultivations	*Variable cost*		*Additional returns*		
	Total *$*	*Marginal* *$*	*Total product* *kg*	*Total** *revenue* *$*	*Marginal revenue* *$*
0	–		0	0.00	
1	1	1	50	1.00	1.00
2	2	1	110	2.20	1.20
3	3	1	180	3.60	1.40
4	4	1	260	5.20	1.60
5	5	1	330	6.60	1.40
6	6	1	390	7.80	1.20
7	7	1*	440	8.80	1.00*
8	8	1	480	9.60	0.80
9	9	1	510	10.20	0.60
10	10	1	530	10.60	0.40
11	11	1	540	10.80	0.20
12	12	1	530	10.60	-0.20

*Wheat at 2 cents per kilogram.

The optimum point is where marginal cost equals marginal returns because it is always worth spending $1 if more than $1 is obtained in return. The only exception is where capital is limited and it is impossible to carry out all operations to the point where marginal cost equals marginal returns. In other words one may have to choose between applying more fertilizer or more herbicide because, with the capital available, it is impossible to apply both to the point where marginal cost equals marginal return. In this situation all resources should be used to the point where marginal returns to the last $1 spent on each are equal. The optimum level of application within the rational zone is also the point where the ratio between the marginal quantity of the product and marginal quantity of the resource is equal to the inverse price ratio between the two.

$$\Delta O/\Delta R = P_R/P_O$$

With each cultivation costing $1 and each kilogram of wheat 2 cents

$$P_R/P_O = 100/2 = 50$$

and the marginal output per cultivation ($\Delta O/\Delta R$) = 50 when 7 cultivations are carried out.

The optimum level of application is either the point at which maximum profits or minimum losses are obtained from treatments. Whether a loss or a profit is sustained can be quickly determined by calculating if the total increase in revenue from treatments at that level (additional yield x price) is greater than the total cost, both fixed and variable, of the treatment at that level. As the additional return from the 7th cultivation exactly pays its cost, 6 is the optimum number.

The total cost of 6 cultivations of fallow are as follows:

Fixed cost	$
Depreciation of cultivator $600 @ 7 per cent	42
Fuel and repairs to tractor @ $1 per cultivation for 6 cultivations over 500 hectares = $1 x 6 x 500	3,000
Total costs	$3,042

The cost should be compared with an increase in yield of 390 kilograms per hectare valued at $0.02 or ($0.02 x 390) $7.80 per hectare and (500 x $7.80) $3,900 giving an increase in profit ($3,900 - $3,042) = $858 from 500 hectares of wheat.

If the price of the product increases the optimum level of weed control will increase. Thus when wheat was priced at 2 cents per kilogram the optimum level of cultivation was 7 cultivations. If the price is increased to 3 cents per kilogram, marginal revenue is greater than marginal cost when 8 cultivations are carried out (Table 2). Conversely if the cost of cultivations are increased the optimum level declines. If the marginal cost of cultivation is increased from $1 to $2, 3 cultivations would be the optimum number (Table 3).

The Optimum Combination of Control Methods

Given that control of weeds can be achieved by two methods, the optimum combination of the two can be found provided

(a) both are being applied in the diminishing returns section of their own production function

(b) that the same level of yield can be obtained over a range of combinations of both methods. The optimum combination is the point where the ratio of the marginal rates of substitution of the two treatments is equal to the inverse ratio of their prices. A hypothetical example of a combination of various numbers of fallow cultivations each costing 50 cents and the application of herbicide at different strengths, any combination of which will give a wheat crop of 2,000 kilograms per hectare, is shown in Table 4. The opportunity cost of the equipment and labour needed to carry out the operations is zero in both cases (i.e. there are no tixed costs). An optimum combination is achieved at 8 cultivations

TABLE 3: THE EFFECT OF INCREASING PRODUCT PRICE ON THE THE OPTIMUM LEVEL OF CULTIVATION

Number of Cultivations	*Marginal cost $*	*Additional returns* Product kg	Revenue $	Marginal revenue $
0		0	0	
1	1	50	1.50	1.50
2	1	110	3.30	1.80
3	1	180	5.40	2.10
4	1	260	7.80	2.40
5	1	330	9.90	2.10
6	1	390	11.70	1.80
7	1	440	13.20	1.50
8	1	480	14.40	1.20*
9	1	510	15.30	0.90
10	1	530	15.90	0.60
11	1	540	16.20	0.30
12	1	530	15.90	-0.30

*Wheat at 3 cents per kilogram

TABLE 4: OPTIMUM COMBINATION OF FALLOW WORKING AND APPLICATION OF HERBICIDE NEEDED TO PRODUCE 2,000 KILOGRAMS OF WHEAT PER HECTARE

Cultivations Total number	Marginal applications x	*Herbicidal treatment* Total quantity g	Marginal application g y	*Costs* Cultivation $	Herbicide $	Total $
0		550	0.00		11.00	11.00
1	1	450	0.50	100	9.00	9.50
2	1	360	1.00	90	7.20	8.20
3	1	280	1.50	80	5.60	7.10
4	1	210	2.00	70	4.20	6.20
5	1	150	2.50	60	3.00	5.50
6	1	100	3.00	50	2.00	5.00
7	1	60	3.50	40	1.20	4.70
8	1	30	4.00	30	0.60	4.60*
9	1	10	4.50	20	0.20	4.70
10	1	0	5.00	10	0.00	5.00

* Cultivations @ 50 cents per cultivation.
Herbicide @ 2 cents per gram
Py / Px = 50/2 = 1/25
x/y = 1/25 with 8 cultivations
= least cost combination of treatments of = 4.60 per hectare.

and 30 grams of herbicide when the marginal rate of substitution between cultivations and herbicide is approximately 1/25 and equal to the inverse ratio of the 50 cent price of cultivations and the 2 cent per gram price of herbicide.

A decrease in the price of cultivations will move the optimum level of cultivation to one containing more cultivations and a lower strength of herbicidal treatment. An increase in the price of cultivations or a decrease in the price of herbicide will have the opposite effect.

Sources of Data

While the theory required to establish the optimum level of application of a treatment or combination of treatments is simple, the data on which such calcultions may be based is difficult to obtain. The results of treatments on any one crop will vary with the physical environment and thus the production function or factor relationship can vary between regions and between years. It is only when a number of years of data are available that definite conclusions concerning optimum level of treatments or combination of treatments can be drawn.

Two possible sources of data exist and both present their own problems. In theory data from farmers using different levels of weed treatment in a homogeneous region can be used to establish a production function by means of regression analysis, in which the effect of weed treatments can be isolated from factors affecting yield. However, it is often difficult to find a number of farmers using differing levels of weed treatment and still more difficult in practice to separate the effect of weed treatments from other factors affecting yields, because of the high levels of correlations that are often found between the treatment examined and other factors affecting yield. The problem can be overcome by using experimental data where factors other than the one being examined are standardised. However, the results obtained on farms using the same technology are seldom the same as those obtained under experimental conditions. While some work has been done to establish the ratio between farm yields and experimental yields, the ratio established is only an average over a period of years for a large number of farmers within the region where the experiment was conducted (Davidson and Martin, 1968). In addition the ratio can only be applied to a region with the same physical environment as that in which the experiment was conducted and to farms within the region where all cultural practices (e.g. levels and type of fertilizer, rotation and amount of cultivation) were the same as in the treatment of the experiment with which the ratio of farm to experimental yields was established. The ratio is only true over a number of years. In poor years farm yields are almost equal to experimental yields but in good years they are much less.

The ratio is not a guide to individual farmers' yields as these can vary widely from the mean. Some farmers obtain yields equal to the experimental yield even in good years.

Thus there are definite limits to the usefulness of data obtained from experiments. It can only be used to measure the increase which might be obtained in yield by the average farmer over a number of years in a similar environment and where cultural practices are the same. The relationship of average farm yields to average experimental yields appears to depend on the intensity with which labour and capital are used which in turn depends on the average commercial acreage of the crop. For small horticultural crops grown on 2 hectares, average farm yields are 90 per cent of average experimental yields. However, the ratio drops rapidly as average crop area increases. Crops grown on 80 hectares or more seldom have an average farm yield of more than two thirds of the experimental yield even when environmental conditions and cultural practices are the same.

Problems of Experimental Design and Interpretation

Traditionally field experiments consist of a small number of treatments with each treatment replicated many times to establish the differences in yield which are due to factors other than the treatment being examined. Thus the effect of no herbicide and

½ or 1 kilogram of herbicide on a crop may be examined with each treatment replicated 5 times. However, it is impossible to plot a production function through three points with any degree of confidence although 15 observations are available. An economist would need many more points of reference. Ideally the economist would like to know the yield responses for each incremental 100 grams from no herbicide application up to an application of 2 kilograms. The points given would enable him to plot a production function with some confidence in its accuracy and after allowing for the relationship between farm and experimental yields to find the optimum level of application of any one treatment. However, if each of the 21 points are to be replicated 5 times the experiment would be extremely expensive to carry out.

One solution which has been suggested is to use a large number of unreplicated treatments over a wide range of application and analyse the results by means of regression analysis by discounting future reductions in revenue to the present time, using an appropri-between the means. A compromise would be to replicate a central point within the treatment. The use of such techniques have been discussed by Dillon (1966), Anderson (1971) and others. Any technique which gives a large number of observations over the whole range of treatments will make the selection of the optimum point of application easier.

Residual Effects

In certain situations some weed treatments can have residual effects which will reduce the yields of subsequent crops grown after the crop treated. Provided the reduction in yield for each level of treatment in future crops can be assessed and the price of the crop is known this effect can be incorporated in the normal production function analysis by discounting future reductions in revenue to the present time using an appropriate interest rate and deducting the sum so calculated from the total revenue at each level of application and then proceeding with analysis in the normal way. If residual effects are beneficial they should be treated in the same way but added rather than subtracted from the total revenue curve.

The Economic Evaluation of a Change in Weed Control Methods

Often the amount of information available is insufficient to select the optimum point of application by means of production function analysis. A very useful tool to employ when the number of alternatives is limited, is the partial budget. The procedure is simply to establish the answer to the following four questions:

(a) What costs will be avoided?
(b) What new revenue will be gained?
(c) What new costs will be incurred?
(d) What old revenue will be lost.

If (a + b) > (c + d) then the change is worth making.

Thus if a farmer growing 1,000 hectares of a crop might know that he can replace 6 cultivations with one herbicidal treatment and the change will enable him to sell 1 tractor, he might also know that by doing so his crop yield will increase by 2 kilograms per hectare.

A partial budget could be prepared:

(a) What costs will be avoided?	$
Depreciation on one tractor $5,000 at 10%	500
Interest on capital invested in 1 tractor $5,000 @ 10%	500
Cultivations: 6 @ 0.5 hours per hectare = 3 hours/hectare = 3,000 tractor hours, fuel @ 25 cents per litre & 2 litres per hour (3,000 x $0.25 x 2)	1500
Tractor repairs 50 hours @ $6 per hour	300
Total Costs Avoided	$2,800

(b) New revenue gained:	$
2 kilograms of grain @ 4 cents = 8 cents/hectare from 1,000 hectares (= $0.08 x 1,000)	80
(c) New costs incurred:	
Herbicide @ 50 cents per hectare ($0.50 x 1,000)	500
One treatment @ 0.5 tractor hours per hectare = (0.5 x 1,000) 500 tractor hours; fuel @ 25 cents per litre and two litres per hour = (500 x $0.25 x 2)	250
Repairs, 8.4 hours @ $6 per hour	50
Total New Costs Incurred	$800
(d) Old revenue lost	nil

a + b = ($2,800 + $80) = $2,880
c + d = ($ 800 + $ 0) = $ 800
Increase in profit = $2,080

Economic Factors Affecting Weed Control in Australia

Moisture is the factor which limits plant growth in Australia. Normally crops and improved pastures can only be established in regions with a growing season of more than five months where a growing month is defined as one where $\text{Precipitation}/\text{Evaporation}^{0.75} > 4$.

Although only one third of the Australian continent has a growing season of more than five months the area of such land is extremely large in terms of the nation's population. It has been estimated that Australia would have to have a population of 50 millions before it was as short of well-watered land as the U.S.A. is at present and 138 millions before the ratio of well-watered land to population equalled that of Western Europe (Davidson, 1969).

Because of the high ratio of arable land to population in Australia, land has always been cheap in terms of labour. In these circumstances systems of farming which used large areas of land and little labour have normally been profitable. On the other hand intensive types of farming which required high inputs of labour have normally been unprofitable.

The small Australian population also meant that any large agricultural industry had to rely on export markets. As Australia had a comparative advantage in terms of land and a comparative disadvantage in terms of labour over the main importing countries in Europe and the U.S.A. and Japan, the large agricultural industries which did develop were those producing cereals and animal products under extensive farming conditions. Of the 18 million hectares sown to crops in Australia, 66 per cent are the broad acre cereals, wheat, barley, oats and sorghum, and a further 27 per cent are fodder crops. Intensive fruit and vegetable crops are sown on less than 2 per cent of Australia's cropped area.

Expensive methods of weed control are only profitable if either a large increase in yield is obtained or the commodity produced is highly priced so that small increases in yield are worth the extra cost of the treatment. As 93 per cent of Australia's crops consist of low priced cereals and fodder crops, very large increases in yields would have to be obtained to make expensive weed treatments worth while.

Because economic success in Australia depended on obtaining a large output per man rather than a large output per hectare, Australian yields tended to be low compared with other countries. Wheat and other cereal yields in Australia are less than half those obtained in Europe. Thus a given weed treatment which was profitable if it increased cereal yields by 10 per cent in Europe would have to increase cereal yields in Australia by at least 20 per cent before it was equally profitable.

Intensive methods of weed control are normally only justified on high yielding and high priced crops. Australia's crops are low-yielding by world standards and only a very small proportion of Australia's crop area is devoted to highly priced crops. In these circumstances cheap methods of weed control which can be applied over a large scale are likely to be the most important ones in Australia.

Just as Australia had to develop its own non-labour intensive methods of cultivation and harvesting before it became an important crop exporter, so it must develop methods of weed control which are suitable for an agriculture which depends on using small quantities of highly paid labour and large areas of cheap land. Nothing could be more fatal than to slavishly follow the methods of weed control developed in Europe and the U.S.A. where the ratio of population to arable land is much lower than in Australia.

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DEVELOPMENTS IN THE BIOLOGICAL CONTROL OF WEEDS

J. M. CULLEN*

Introduction

It is probably a legitimate question to ask how the term development is relevant to biological control. After all, it is not immediately obvious in what way one can develop from a rationale superbly effective in its basic form as long as forty years ago. In attempting to answer this question I shall briefly summarise current practice and progress in the biological control of weeds and point out future activities which will follow fairly obviously from this approach. Finally I shall suggest the possible directions this science might or should take in the future.

The Present Situation

I shall assume a certain familiarity with the underlying philosophy of a traditional biological control programme i.e. the concept of a plant introduced to a new country without the complex of natural enemies which help keep it under control in its native environment, and the aim of biological control in attempting to restore a satisfactory balance by importing those enemies specific to that plant. A successful result to such a programme, which produces self perpetuating control throughout the range of a weed, has obvious advantages. Economic gains can be enormous through increased production and decreased expense on other control measures. In a world increasingly sensitive to the potential dangers of the liberal use of chemicals in the environment and also to the conservation of resources in general, a system which relies on nature alone for its effectiveness and continuity, has a lot to recommend it over and above the straightforward economic aspects.

In practice, the idea of re-establishing a balance between a weed and its natural enemies has led in the past to the introduction of organisms to Australia to control prickly pear *Opuntia* spp., lantana *Lantana camara* sens. lat., St. John's wort *Hypericum perforatum* L., crofton weed *Eupatorium adenophorum* Spreng., noogoora burr *Xanthium pungens* Wallr., gorse *Ulex europaeus* L. and ragwort *Senecio jacobaea* L. with varying degrees of success. The lantana programme has been rejuvenated and is looking quite hopeful, while programmes for skeleton weed *Chondrilla juncea* L., groundsel bush *Baccharis halimifolia* L. and *Emex* spp. are proceeding vigorously at the present time. Activity is in fact quite extensive in this field in Australia, and this is indicative of the world situation. There are programmes of this nature being tackled by Canada, U.S.A., N. Zealand, S. Africa, Chile, Czechoslovakia and by the Commonwealth Institute of Biological Control on behalf of several other countries. The techniques of this approach are now well developed and there are many weeds which might be considered as candidates for exhaustive investigation using what are now fairly standard guidelines. The list of weeds introduced to Australia from Europe, S. Africa and the Americas obviously provides considerable potential for future activity in this field. Very few weeds, even those already considered at some stage in the past, have been fully studied in the manner which we now know they should be tackled. This applies particularly to the geographic region which should be the most productive of effective natural enemies i.e. the evolutionary origin of a weed or subgenus (Harris, 1971; Wapshere, *in press*), and those areas with environments

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most similar to those where a weed is a problem. It also applies to the range of organisms considered for importation, which is now less restricted, in part due to the more general acceptance that if any damage is produced, an organism could be useful. There is an upsurge of interest in the use of fungi, which will be continued, though there are some limitations because of the lack of knowledge of mechanisms of host specificity and their maintenance. Nonetheless, in recent years there has been the importation and release of *Puccinia chondrillina* Bubak & Syd. in Australia for skeleton weed control, of *Phragmidium violaceum* (Schultz) in Chile for control of *Rubus ulmifolius* Schott, the importation of several pathogens to Florida for consideration for aquatic weed control (Freeman *et al.*, 1973) and the importation of *Uromyces rumicis* (Schum.) for the possible control of *Rumex crispus* L. in N. America (Franc, *in press*).

Logical Developments

Assuming that the guidelines exist for the conduct of a biological control programme so as to give every chance for success, the question arises as to whether the overall efficiency of the operation could be improved. A considerable part of the resources allocated to such a programme are spent determining the degree of host specificity of an organism. Rationalisation of this process can only be of benefit, and the move towards the delimitation of a species' host range on a phylogenetic basis is an important step (Harris and Zwolfer, 1968; Wapshere, 1974). Any further progress in this field, through the derivation and application of general principles, is heavily dependent on increasing knowledge of specificity mechanisms. These are often complex behavioural and biochemical relationships and their maintenance and mutability with time involves considerable genetics. It must therefore be accepted that further progress will probably be slow and steady.

Obviously, it would be very useful to know how worthwhile such a testing programme is going to be, and also the subsequent activities of consignment, rearing and release, i.e. how effective a newly discovered organism will be in controlling a weed. If such an assessment could be made reliably much unnecessary work could be saved and the whole procedure streamlined. Unfortunately, to do so at the present time is itself very time consuming, and the basis on which such judgments might be made is the subject of considerable discussion (Harris, 1973). The theory of plant population regulation by natural enemies is very poorly developed and will remain so unless more case histories are followed in some detail. There is very little data available. It is not simple to integrate the ecology of a natural enemy (and therefore the amount of damage it can inflict) into the ecology of a weed, but it is possible, and the occasion of the introduction of a new natural enemy is an ideal time. A greater understanding of the processes involved in the weed – natural enemy system, is an area which, if it can be developed, could open up further possibilities for benefit from biological control and remove some of the limitations of this approach. It is this idea which I want to develop a little at this stage and at the risk of being slightly speculative, to try to give an idea of the sort of potential I feel biological control might develop in the future.

The Future

Fundamentally, future development is likely to be the extension of biological control to more and more weeds in less and less promising situations. Many of the limitations of traditional biological control are inherent in the basic aim of producing a situation of balance between a weed maintained at a subeconomic level, and a natural enemy persisting as an effective agent without any attention from man. There is no question about this being the most desirable solution and situations likely to produce this result have the highest priority. However, where this might not work, the possibility exists of manipulating the system in man's favour in some way, perhaps on a regular basis. There are several ting the system in man's favour in some way, perhaps on a regular basis. There are several ways this might be carried out and various efforts have already been made, some quite successfully.

To take the simplest situation, a natural enemy may not be able to contact and attack areas of weed soon enough. The obvious answer is to collect and redistribute the enemies as required. For insects, the distribution of the defoliating beetles *Chrysolina quadrigemina* Suffr. and *C. hyperici* (Forst.) to infestations of St. John's wort is in fact a very simple example. For fungi, the facilitation of inoculation of a weed provides an example of this approach, as has been successfully carried out with persimmon wilt *Cephalosporium diospyri* Crandall on weedy persimmons *Diospyrus virginiana* L. (Wilson, 1965) and oak wilt fungus *Ceratocystis fagacearum* (Bretz) Hunt. on unwanted oak trees (French and Schroeder, 1969). Alternatively, the population of a natural enemy may not increase naturally to a level high enough and/or rapidly enough to be effective, and the possibility arises of mass rearing and making regular inoculative or inundative releases. As far as I know, this has not been attempted with any insects in order to control a weed, though it has been done with parasites to control insect pests and, more relevantly, with fungi to control weeds e.g. the control of *Cuscuta* spp. in Russia using *Alternaria* sp. (Miusov and Bashaeva, 1968) and northern joint-vetch *Aeschynomene virginica* (L.) in N. America using *Colletotrichum gloeosporioides* (Penz.) sacc. f. sp. *aeschynomene* (Daniel *et al.,* 1973).

The alternative to manipulating the numbers and distribution of the attacking organism is to manipulate the environment in its favour. This area of development is probably the furthest from practical realisation at the present time but remains a distinct possibility. It is really only one step removed from the sort of consideration given now in the development of ecological and cultural methods of control, relying as it does on a good understanding of weed ecology. What it also requires is an understanding of the ecology of the natural enemy and also the ability to combine the two.

There are one or two significant points about what I shall for the moment refer to as manipulated biological control. Firstly, the advantage of no recurring expense is obviously lost but that of least possible disturbance of the environment is retained. Secondly, some of the more traditional limitations of biological control become less significant. If a natural control system is only going to be effective when augmented in some way, one automatically has control over the areas where control might or might not be desirable, thus causing fewer problems if a weed is beneficial in some situations. Again, if the effect of an enemy is to be artificially augmented, the fact that a plant is also a significant weed in its native environment is no longer a deterrent. Similarly, endemic weeds become possibilities for this approach if natural enemies are present, whose effect can be enhanced. There would seem to be a fertile field here for research and development. The demand for this sort of approach is not very great at present unlike the situation with insect pests, but it is a demand which may increase in the future.

Meanwhile it is apparent that such an approach will be heavily dependent on a better knowledge of the ecology of weed - natural enemy systems. It has also been pointed out that development in this field is necessary for improving the efficiency of traditional biological control programmes, where activity will no doubt steadily increase. The importance of this area of research is fortunately being increasingly realised and biological control programmes contain an increasing emphasis on post introduction work, which is the most efficient way of developing this field. Biological control is essentially a specialised area of ecological control and it is the level of ecological research which will largely determine the extent to which biological control will develop further from its present promising stage.

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INDUSTRIAL WEED CONTROL AND THE ENVIRONMENT

J. TOTH*

Introduction

Weed control in non-crop situations, termed "Industrial Weed Control" or "Total Vegetation Control" (T.V.C.) has become an important field, with very wide economic and environmental significance. The non-crop situations in which we use some degree of vegetation control include: roadsides, railway lines, transmission lines, sub-stations, switch yards, pipe lines, airfields, industrial sites, drains, channels, silos, storage tanks and fence lines.

Beside chemical methods of weed control in T.V.C., mechanical methods are used in a large proportion of cases. These include: mowing, slashing, discing, pruning, cutting and burning. These methods may be considered safer to the environment than chemical methods but their labour requirement and low efficiency frequently make them uneconomical.

Control measures, mechanical or chemical, are required for the following reasons:

(i) to reduce fire hazard, traffic hazard, traction losses on rail tracks, drainage problems, corrosion and rotting of equipment and materials.

(ii) to maintain access to and around installations, public utilities and storage tanks.

(iii) to prevent weed seed, insect pest and rodent infestation of neighbouring areas.

(iv) to maintain some aesthetic value of a site.

To meet all these objectives under varying soil and climatic conditions, with large variation in vegetation, could be regarded as a very challenging, but not a simple research task. In spite of this, total vegetation control has received surprisingly little research attention from universities and other institutions. This is probably due to lack of financial support from Government and Industry, who are the main beneficiaries of such research. Furthermore, T.V.C. research has not attracted the attention of students and young scientists because it requires long duration research projects, while research into other aspects of weed control may be more attractive and can lead to M.Sc. or Ph.D. degrees in the normal time.

Application of T.V.C. by Government Bodies in New South Wales

New South Wales Government departments during 1969 spent more than $3 million, in 1971 an estimated $5 million and in 1974 it could be expected that $6-7 million will be spent on total vegetation control. However, the present situation in N.S.W. is that the Government departments and semi-Governmental bodies, the major consumers of T.V.C. products, are mostly without full-time professional staff engaged on T.V.C. problems. Because of this the selection of herbicides for their needs is mainly based on the sales information of commercial firms. To add to the users' difficulties, the market offers approximately 100 trade named herbicides (mainly mixtures) for T.V.C. use, and their number is increasing.

The type and length of vegetation control required varies between Government departments quite considerably and in some, requirements are rather specific.

The Department of Railways requires total control of vegetation on the ballast, which is invaded mostly with easily killed annual plants from spilled seed from trucks,

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such as wheat and sorghum and with harder to kill grasses whose runners spread from railway tracks are mechanically maintained and the ballast is disturbed after this period, of weeds, but the weeds allowed to stay should not be too tall or a fire hazard. This Department is looking for medium long residual type of herbicides with no drift or vapour problems. Herbicides do not need residual effectiveness exceeding 1-1½ years because railway tracks are mechanically maintained and the ballast disturbed after this period resulting in loss of residual herbicide effect.

The Department of Main Roads is concerned with eradication or management of roadside vegetation. The only areas which they require to be totally weed-free are along road edges, near guide posts, near bridge abutments and firebreaks. The rest of the areas belong to the weed management field of industrial weed control. Special problems are arising on the highways and near cities, where "beautification" of roadside programmes are in progress and they are forced to look for selective control with minimal risk of drift and unsightly effect.

The Electricity Commission of N.S.W. which maintains approximately 10,000 km of transmission lines, 130 sub-stations and 12 switch yards, has two completely contrasting problems:

(a) Transmission lines – in this situation total vegetation control is unnecessary but some kind of growth retardation of the tall growing natural forest would suffice or removal of the existing trees and planting of suitable low growing species. At present after mechanical clearing, regrowing suckers and invading blackberry and lantana are causing access problems for the maintenance of transmission lines.

(b) Sub-stations and switch yards – in this situation, the total elimination of vegetation with the longest possible residual effect is desirable because of difficulties in application and consequent high cost. The herbicides used must also not be corrosive to the equipment in sub-stations and switch yards. The Electricity Commission is very much concerned with the "beautification" of its sub-stations and switch yards surrounds, where some new problems such as selective weed control between ornamental flowers and shrubs have arisen.

The Metropolitan Water, Sewerage and Drainage Board problems are along and under water pipelines as well as the control of undesirable vegetation in water reservoir areas and weeds in reservoirs. Total Vegetation Control is desired under pipelines for easy access to check for leaks. On either side of pipelines vegetation management is required and short growing grasses preventing water erosion are welcome.

Research and Environmental Problems

Most of the research in this field has been carried out by chemical companies. The results are published mainly to create and support market possibilities. Certainly, this does not mean that these studies do not contribute to our knowledge and to our better understanding of T.V.C. herbicides and problems. In fact, we all rely on them to a large degree. The only shortcoming of company research is, that it is generally restricted to their own products. Companies are unable to do studies on two- or three-way mixtures of herbicides from different manufacturers, and generally omit studies of long-term effects of herbicides on the environment.

It could be expected that T.V.C. research will grow even more in importance in the near future. Beside chemical companies, other research organisations are going to be more involved and the research effort will accelerate. But the practical implementation of research results will not improve without considerable change in the present attitude of many users. The gap already existing between research and practical utilization of research results by users could widen. It is generally known, that many good research findings are never adopted into practice because of negligent attitudes of the users. The paradox of this situation is that "the users are the main losers". The losses could exceed 30-40% of the total cost, due to one or more factors including:

- lack of professional knowledge
- inadequate equipment
- incorrect time and method of application
- untrained, temporary application teams.

In situ, any of these factors could induce an undesirable result which may not always be easily expressed in monetary terms such as: the damage to the neighbouring areas; undesirable ecological changes; pollution of water; erosion of slopes. Losses could be caused by the application of unsuitable herbicides or further losses could occur when vegetation is burned-off prior to application of some herbicides such as ureas and triazines. The burnt residue could reduce the herbicide activity by 25-30%, due to absorption.

Most of the herbicides used in T.V.C. have a lower mammalian toxicity than ordinary table salt, but despite this, safety regulations must be observed, and on some herbicides, such as hormones, further tightened.

Before any herbicide is submitted for registration important data such as oral and dermal toxicity and residues in plants are determined. We should also be more concerned with the fate of herbicide in the soil and water, its by-products, the fate of carriers and compounds accompanying the herbicides in the manufacturing process.

Conclusion

The problems of industrial weed control are not as simple as some may think. It is not just a question of how to eradicate vegetation in certain situations. We also need to predict the nature of the reaction; how we are going to affect the surrounding environment.

This all points, in my view, in one direction: that we need much more knowledge about the target plants with which we are dealing and about the tools, the herbicides, with which we are working and their long term ecological effects.

THE ENVIRONMENTAL IMPACT OF WEED CONTROL – DEVELOPMENT CHEMICALS

J. M. LANDY* and W. C. STONEBRIDGE†

When considering the impact of both existing and potential new chemicals used to control weeds, one must also take into account the environmental damage already being caused by weeds themselves and the future threat posed by their advancement.

A large range of weed species already occur on much of the land of Australia and cause substantial economic losses each year. Every major crop and agricultural district has its lists of serious weed contaminants. Economic losses resulting from weeds are difficult to assess but an estimate in 1967 of the combined crop losses on a world wide basis suggested a total value of $20 billion or 9.5% of potential crop production.

TABLE 1: ESTIMATED ANNUAL WORLD CROP LOSSES DUE TO PESTS, DISEASES AND WEEDS
(Source: Pflanzenschutz – Nachrichten, Bayer *20* 1967 p.482)

Commodity	*Actual Production*	*Potential Production*	*Insect Pests*	*Losses due to Diseases*	*Weeds*	*Total*
Wheat	265.5	351.1	17.8	33.3	34.5	85.6
Rice	232.0	438.8	120.7	39.4	46.7	206.8
Maize	218.5	339.5	44.0	32.7	44.3	121.0
Other cereals	245.1	338.1	21.2	29.9	41.9	93.0
Cereals, Total	961.1	1,467.5	203.7	135.3	167.4	506.4
Potatoes	270.8	400.0	23.8	88.9	16.5	129.2
Sugar beets & Sugar cane	694.6	1,330.4	228.4	232.3	175.1	635.8
Vegetables	201.7	279.9	23.4	31.1	23.7	78.2
Fruit Crops, incl. Citrus fruits & Grapes	141.7	197.2	11.3	32.6	11.6	55.5
Stimulants	10.2	16.5	1.9	2.6	1.8	6.3
Oil Crops	94.7	137.0	14.5	13.5	14.3	42.3
Fibre Crops	16.0	23.2	3.0	2.6	1.6	7.2
Natural Rubber	2.3	3.0	0.1	0.5	0.1	0.7

While estimates of crop losses can be argued, there is no argument that weeds cause huge production losses and in an under-fed world their impact in this context is clear.

The environmental damage of weeds, however, goes well beyond agriculture. Increasing sums of money are being spent each year to eradicate weeds in urban parklands, home gardens, railways and industrial sites. A particular difficulty, and one which must

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become increasingly more obvious in the future, is the invasion of crown lands by weeds. The threat of alien plants in national parks, forests and foreshores is being highlighted in the increased interest in conservation and by the action of various State Governments in recent years in declaring large areas as nature reservations. In the State of Victoria *Osteospermum moniliferum* threatens much of the area earmarked for a national park on the Mornington Peninsula and the potentiality for recreation and wilderness. The existing flora of the alpine and north eastern parts of Victoria are being affected by the invasion in the river valleys of weeds such as *Hypericum perforatum. H. androsaemum* and *Rubus* spp.

Weed Control Measures

All methods of controlling weeds are likely to have some impact on the environment.

Hand Disturbance of Weeds: Broad scale manual removal of weeds is only likely to be considered where labour is very cheap. It is obviously not an important method of weed control in Australia. However, there are special situations in home gardens, parkland and nature reserves where high costs may be acceptable and the consequences of other methods of control not acceptable.

Mechanical Disturbance: The use of agricultural machinery such as ploughs, harrows or rollers certainly has effects on the environment. There is no need to emphasise the importance of the removal of top soil by wind or water on exposed cultivated farm land or the consequences of the run off affecting the quality of water in streams and water storages.

Competition: Weeds can be controlled in some situations by manipulating the competition from useful crop or pasture species. This may be a matter of selecting more vigorous species or strains, changing the time of planting or adjusting grazing management.

Chemical Control: There has been a very rapid development in the use of chemicals to control weeds in the last 40 years. It would appear that no more than 10 compounds were available prior to 1950. Just fewer than 20 were discovered between 1950 and 1960. Most have been developed since 1960.

We noted 241 separate herbicide chemical identities up to 1971 although not all have become commercial products. Since then another 88 structures have been noted. There is now a very diverse range of chemical types which have proven successful as herbicides.

TABLE 2: MAIN CHEMICAL IDENTITIES WHICH HAVE BEEN DEVELOPED AS HERBICIDES

(Source: *British Weed Control Handbook* 5th ed. V.1.Extracted from Table 17,pp.354-447)

Phenols	Halogenated aliphatic acids
Benzonitriles	Carbamates
Thiocarbonyl compounds	Thiocarbamates & dithiocarbamates
Quaternary ammonium compounds	Amides
Phenoxyacetic acids	Ureas
2-(phenoxy) propionic acids	Diazines
4-(phenoxy) butyric acids	Triazines
Benzoic & phenylacetic acids	Inorganic Chemicals
Miscellaneous – with 25 separate identities	

The increase in the number of herbicides in the last 20 years stems from a search for chemicals with greater potency, more specific action and with less toxic or environmental overtones, together with the fact that emerges from Table 2 – phytotoxic activity can occur in an extremely wide range of chemical structures offering commercial incentives through their novelty.

Whilst there is no question that chemicals used in control of weeds can and do have effects which can be considered hazardous, these essentially result from misuse.

The potential hazards of herbicides can be considered under several headings:

Toxicity to the User

Herbicides are toxic to a greater or lesser extent to human beings. The thorough testing for toxicological properties before release ensures user safety when used correctly. Clearly stated recommendations are given for the safe use of herbicides and educated farmers are almost always aware of the risks associated with the product they handle.

Poisonings with herbicides are uncommon. In the U.S. statistics indicate that only 4.9% of cases of accidental poisoning are due to pesticides which is the same amount as recorded for cosmetics.

Residues in Herbage and Foodstuffs

As in the case of toxicity of a herbicide so the residue levels at normal rates of application in the crops of which it is desired to use the material have to be established before the product is registered. These levels are then related to the no effect level established from chronic toxicity studies of the material and a safety factor of at least one hundred fold applied. The margin of safety would appear to be very high. Frequently residues are not detectable despite the precise and sensitive analytical techniques now available. In general this aspect of herbicide usage is not seen as a major issue in the context of environmental impact.

Residues in the Soil

As with herbage and foodstuffs, soil residues do not normally present a hazard. Frequently the herbicide is intercepted by the foliage and only a small part of that which is applied reaches the soil. Inactivation in the soil either by direct absorption or adsorption and by microbial degradation minimises the hazard of soil residues accumulating. Specific materials which are known to be persistent and specific situations which demand repeated usage may lead to an unacceptable accumulation of residues in the soil. The monitoring of residues by chemical and bioassay is a desirable and required need for registration which allows a code of practice to minimise these effects. Because of the nature of the biological activity of the chemicals involved as herbicides, there has been no indication of accumulation through the food chain, as with, for example, the chlorinated hydrocarbons.

Damage to Surrounding Vegetation

Herbicides, particularly those with a broad spectrum effect, can damage surrounding vegetation through misapplication or from spray drift. Almost always this results from the use of faulty procedures, poor equipment or a failure to take adequate note of weather conditions. Aerial spraying, which provides the biggest problem in this regard, is now very closely controlled by regulations and there are fewer cases of faulty spray applications than in the past.

Effect on Wild Life

Herbicides are mainly used in situations where wild life protection is not vitally important, such as in crops or pastures. However, even in these situations there is little evidence that herbicides have a deleterious effect on insect or animal life. Dr K. Mellanby, Director of the Nature Conservancy's Monkswood Experimental Station, has stated that the use of MCPA, which is the largest single use of any agricultural chemical in the U.K., does not appear to have had any adverse effect on wild life in that country.

Measurements of the effect of herbicides used continually on the one area have so far failed to show significant changes in soil bacteria or micro-arthropods.

Some of the Problems Facing Chemical Development

These aspects of environmental impact which have been briefly discussed have a significant effect on the development of new chemicals for weed control.

Although the number of chemicals available has increased greatly in recent years, increasing research costs are now becoming a very serious problem (Table 3).

TABLE 3: PESTICIDES RESEARCH AND DEVELOPMENT EXPENDITURE IN U.S.A.

1967	$52.4 million
1970	$69.1 million
1971	$71.6 million

In the U.S. the cost from discovery through to marketing of a product escalated by 60% between 1967 and 1970. It was estimated that the average cost of developing a new chemical in 1970 was $5.5 million as compared with only $2.1 million in 1964.

Part of the increase in cost is in evaluation of the ecological effects of each compound. ICI has about 100 people in its environmental sciences group assessing adverse side effects and tracing the ultimate fate of the chemical in a soil or plant. This is approximately 20% of the total effort by ICI in agricultural chemical research.

The effect of increased screening costs is being shown in the last few years in the number of chemicals being tested (Table 4).

TABLE 4: TRENDS IN SCREENING

USA	*Compounds Synthesised specifically for Pesticide Activity*	*Screening of Compounds from all sources*
1967	23,500	60,400
1970	28,000	62,800
1971	26,600	60,000

It will be seen that although the number of chemicals screened increased from 23,500 in 1967 to 28,000 in 1970, there was a decline to about 26,600 in 1971. At the same time the average number of chemicals screened for each new product marketed increased from 5,400 in 1967 to 7,400 in 1971, an increase of 37% reflecting the increasing difficulty of discovering safe and effective chemicals.

At the same time the period of time required to take a compound from discovery to commercial application increased from 5 years to 6½ years (Table 5).

TABLE 5: DEVELOPMENT TIMETABLE

From	*To*	*Time*
Screening	Decision to develop	33 months
Decision to develop	Registration Submission	19 months
Registration Submission	Approval	11 months
Approval	First Sales	14 months

The current and future pattern is clear. Developmental costs have escalated and will continue to escalate. The more information we require prior to the usage of a new material, the greater its overall cost. The development of new herbicides must find a balance between the demands for information and the value of the market that may be offered. Minor crop needs may especially be affected.

The Methods of Reducing Environmental Effects of Herbicides

The effect of herbicides on the environment can be reduced in certain ways:

(i) Control of spray drift – as well as obvious improvement of procedures, the use of foaming agents now available and special nozzle systems can help in reducing the movement of sprays away from the target area. This aspect of pesticide usage – improving application techniques – is one which will receive greater emphasis in the future both from a consideration of the environment and the need for higher efficiency for cost reasons.

(ii) Timing of application – this is principally a matter of education of the farmer since the optimum timing of most herbicides is well understood. User education programmes are likely to increase in the future.

(iii) Increased selectivity – the use of herbicides with a greater degree of selectivity can lead to a minimising of the effects to desirable plants.

(iv) Biodegradability – the use of herbicides which are more readily and quickly broken down by soil microflora.

(v) Greater understanding of the mode of action, uptake and soil life of herbicides. This allows a usage pattern to be defined which minimises detrimental effects.

The Future Trend of Chemicals for Weed Control

Already we can see some of the trends which will characterise the herbicide industry in the future.

1. Herbicides will be increasingly costly to produce and much of this expense will be due to greater emphasis given to the screening of the environmental effects of chemicals.

2. There is likely to be more interaction between plant husbandry and management and with the use of herbicides as but one tool in a combined approach. We can see examples of this already in the use of grazing management to provide a suitable sward for spraying prior to direct sowing of cereal crops, or the consequent pasture fertilizer and sowing programme which may be necessary following the use of Diuron to control soursob in cereal crops in South Australia.

3. Herbicides in the future are likely to have higher intrinsic activity than in the past, and methods of increasing activity in known molecules will be sought.

4. Legislative pressures and the registration of herbicides will increase. There will be more severe toxicological, efficacy and environmental requirements. The actual number of new products is likely to decline while a wider range of usage will be sought.

5. Minor crops will offer insufficient market opportunity to justify the development costs required and will become poorly served by new products, unless there is co-operative work between Government and Industry.

6. Industry will be required to monitor residues and environmental effects generally and possibly well into the commercial life of a herbicide.

7. The value of herbicides will be seen more clearly as substituting for the high energy inputs associated with cultivation.

8. The technology of application will receive increasing attention to assist in maximising efficacy and minimising environmental hazard.

9. The validity of weed control will be questioned in the context of economics and aesthetics as well as environment. Certain plant species currently regarded as noxious may undergo a change of status dependent on where they occur and their likely contami-

nation of other areas. In non-agricultural areas attitudes will shift towards management of the plant community from the more simplistic current approach of specific weed control.

In our attitude to development chemicals for weed control we have to find a balance between the needs of our growers to improve their technology and thereby increase our food productivity and our responsibility to the conservation of our environment.

A lack of understanding of the inter-relationship of these two key issues could lead us to an extreme view on either side. If we follow either extreme we will be abdicating our responsibility to Australia's agricultural industry and to the environment in which we live.

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