RESOURCE ALLOCATIONS FOR FUTURE WEED CONTROL ACTIVITIES

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SUMMARY

The community is questioning the regular use of herbicides which has been practiced for over 100 years. Over the next 12 years it is estimated that food production will need to increase by 30% [as calories/unit area/day]. Evaluation of a no pest control option suggests it would reduce crop production by 70 - 100% representing an annual loss in revenue of A\$5.2 to 7.5 billion for Australia. Implementation of a no pesticide option was estimated to lead to a reduction in Australian revenue of A\$1.8 to 2.3 billion after 5 years even with a A\$1.4 to 1.5 million research programme which integrated cultivation with biological control, allelopathic and natural compounds, ecological shifts and physical control methods. The preferred option was assessed as one which reduces the use of herbicides whilst maintaining an increase in crop yields. It was estimated that herbicide use can be reduced by 33% after 5 years and around 60% after 10 years. To achieve these aims a research budget of A\$1 million/annum would be necessary to investigate the priority areas defined as better methods of cultivation, assessing and predicting ecological shifts, improving herbicide application efficiency, defining the best timing of herbicide applications and optimising economic returns from weed control practices. The recommendations are considered in relation to present government and industry weed control resources and how they could be rationalised to address these priorities.

INTRODUCTION

The aim of this address is to consider why the community is so concerned about the use of pesticides and how government has changed its policies to reflect and redress the concern. An assessment of the validity of such concern will be attempted mainly in relation to weed control.

Pesticides have been regularly used for over one hundred years. Control of mildew in vines started such use. Since then numerous organic compounds have been developed to control all kinds of pests. There has been a rapid increase in the range of such products since the 1940s. They have been widely used and have been vital in ensuring significant yield increases. For example wheat production in Europe increased by 128% and in Australia by 33% between 1949 and 1983 (Anon.). Much of the increase reflects adequate weed, pest and disease control. Reviews of the history of weed control have been made for USA and Canada (Timmons 1970), Europe (Smith and Secoy 1976) and Australia (Cuthbertson 1972).

It was Rachel Carson's renowned book 'Silent Spring' in 1962 that brought the problems of pesticide use and mis-use to the attention of the public. This was soon followed by the 2,4,5-T controversy which precipitated from reports on birth abnormalities in laboratory animals and the claimed adverse effects to health by Vietnam war veterans (Parsons 1988). More recently in Australia there has been debate on insecticide residues in meat. Each of the issues has played a significant role in changing public attitude to pesticides and, thus, how government perceives pesticides should be used.

Proc. 42nd N.Z. Weed and Pest Control Conf.

I would like to consider some of these issues being mindful of a statement of Eue (1985) "Disapproval of the use of herbicides continues to grow among that segment of the world population that has abundant favourably priced food".

THE VALUE OF PEST CONTROL

Food requirements

All of this audience will expect each day to have good nutritious meals in adequate quantities. Can this be achieved with an increasing world population and a cultivated land area which cannot be expanded to keep pace with increased food requirements? Whilst many may think Australia can increase its area of cultivated land, Pratley (1987) suggests the opposite. He based his estimates on Nix (1976) and showed that already 11% of the land with good cropping potential was urbanized and that urbanization, salting and acidification are rapidly encroaching on the remaining land. Above this, deserts are increasing at a rate of 30 ha/day (Bellamy pers. comm.). From Table 1 estimates show that it will be necessary to increase food production [as calories/unit area/day] by 30% over the next 12 years. If this estimate proves to be accurate food production will, unquestionably, be the prime preoccupation of mankind. Unfortunately the past decade has been concerned with butter, wheat, and sugar and whatever mountain created by protectionist communities. Over the past 12 months dramatic changes have occurred — a poor harvest in Europe, a drought in the USA and all of a sudden the mountains of grain have disappeared. Wheat prices have jumped by 30-40% already. The public should realise that the difference between a so-called glut and shortage revolve around only a $\pm 5\%$ change in the world wide average production of small grains. It is nearly impossible to budget to such a level of accuracy, particularly as crops are so dependent upon the weather. I therefore support the predictions of Ruthven (1987) and Eue (1985) that crop production will need to be increased over the next decade and that, in particular, production of higher protein food will occur (Ruthven 1987). Even so we will need every resource available to us to achieve the increases necessary if we are to maintain our current food intake levels. Crop production per unit area will therefore have to be increased by means of new plant varieties, providing a well balanced fertilizer regime and ensuring adequate protection against the effects of insects, weeds and diseases.

TABLE 1: World population, arable land and food consumption (Based on Eue [1985]).

Year	Population Persons x 10 ⁶	Cultivated Land km ² x 10 ⁶	Food Consumption Calories/ person/day	Necessary Food Production Cals/km ² /day x 10 ⁴
1970	3700	13.3	2520	70.1
1981	4500	14.3	2630	82.8
1988	5100	14.6	2690	94.0
2000	6600	14.9	2755	122.0

TABLE 2: Financial losses due to weeds in agricultural crops

Direct Costs	(A) \$ million	Indirect Costs	(A) \$ million
Cultivation	710.4	Yield Losses	713.0
Herbicides	263.0	Product Contamination	142.6
Application	40.0		
	1013.4		855.6

TOTAL: (A)\$1869.0 million

Importance of pest control

If we assume that an increase in crop production is necessary how can this be achieved without pest control? In the first place one should question whether pests are worth controlling. Estimates for the losses due to weeds in the USA were reported to be (US)\$20 billion annually (Shaw 1983). Of this total (US)\$13 billion represents a 10% annual loss in agricultural production due to the direct competition of weeds, which reduces crop yields, quality of produce, causes livestock losses, increases cost of fertilizers, irrigation, harvesting, grain drying, transportation and storage (McWhorter 1984). Estimates for financial losses due to weeds and their control in Australia were (A)\$2.096 billion based on 1981/82 data (Combella 1987). Using 1986 data (Tables 2 and 3) total financial losses are now estimated to be something over (A)\$3 billion, a figure which neither includes many of the externality effects nor risk estimates. Even so, it is obvious that weeds impose a significant burden on society. Similar estimates for insects and pathogens have not been found. If it is assumed that they impose a burden which relates to pesticide sales (see Table 4) then losses due to insects would be (A)\$783 million and for pathogens (A)\$187 million.

Overall therefore financial losses due to pests and the costs to control them could well be of the order of (A)\$4.0 to 4.5 billion for Australia. Of this figure, something over (A)\$2 billion would be indirect losses and thus potential income.

TABLE 3: Financial losses due to weeds in Australia, (A) \$ million.

	Direct	Indirect	Total
Agricultural Crops	1013.4	855.6	1869.0
Horticultural Crops	62.7	240.3	303.0
Pastures	70.8	900.3	971.1
Non-crop Areas	176.6	?	176.6

TOTAL: (A) \$3315.7 million

TABLE 4: Pesticide sales

	World %	Australia %	N.Z. %
Herbicides	43.0	70.0	61
Insecticides	30.5	20.0	15
Fungicides	20.5	10.0	21
Other	6.0		5

Total Value (US)\$ 20 billion (A)\$376.350 million (NZ)\$101 million

THE NO PEST CONTROL OPTION

What would be the consequence if pests were not controlled? Benefits would include savings of (A)\$1.319 billion resulting from direct expenditure to control weeds. In 1987 this included (A)\$341.6 million in herbicide sales and a further (A)\$205 million to apply them. The remaining 60% of direct expenditure (approx. (A)\$772.4 million) was spent on mechanical control. This data vindicates the concerns of Buchanan (1978) who stated "You and I know differently, but often our non-weed science colleagues think only of chemicals when weed science is mentioned". In the case of insecticides, fungicides and plant growth regulators little is spent on mechanical control. Thus savings relate to their purchase price at the farm gate which for 1987 were for insecticides (A)\$75 million and fungicides/plant growth regulators (A)\$38.5 million plus an estimated (A)\$90 million for their application. As direct costs to effect pest control in Australia amount to approximately \$1.52 billion, this would be saved.

The effect of not using *any* control measures has been estimated to reduce crop yields by 70-100%, resulting in a (A)\$5.229 to 7.470 billion reduction in value, and animal production by 5 to 10% or (A)\$3.974 to 7.944 billion (Combella 1988). Overall therefore an estimated (A)\$9.203 to 15.414 billion decrease in revenue would be experienced by the Australian community. Thus the ratio of expenditure on pest control to increased revenue is from 6:1 to 10:1 which is a good rate of return.

ALTERNATIVE CONTROL OPTIONS

Obviously, because it is not feasible to have no control measures, what alternatives are there and what would be the consequences of their use? Two strategies are possible which can be conveniently considered as:—

- (i) to eliminate the use of pesticides;
- (ii) to reduce pesticide use.

Option 1 — To Eliminate the Use of Pesticides

For many in the community this is the more attractive option and certain active groups have suggested that government should attempt to achieve this goal. Obviously, it is possible to legislate against the use of pesticides but what would be the consequences of such an action. To assess the effect one needs to assess which non-pesticide control strategies are available, whether they could be implemented, direct costs to implement them and the effect such strategies would have on productivity.

(i) Increased cultivation

Some calculations can be made using the very limited data generated to support organic farming. For example in an organic farming system weed control, using cultivations pre-plant and again post-sowing, has generally been inferior resulting in yield decreases of around 40% when compared with conventional herbicide/fertilizer treatments in wheat crops (Wookey 1985). The cost of control in both financial and energy terms is greater with mechanical cultivation than herbicides (Alder *et al* 1976). Indeed, Alder *et al* (1976) reported that pesticides contributed less than 5% of total cultural energy whilst fuel contributed 35-50% for a range of crops. Also increased cultivation will exacerbate soil erosion and soil compaction (Pratley 1987). Even so research into more suitable machinery, for example implements that are less aggressive and require lower draft, is likely to be of value (Brown and Huzzey 1987). Timing of cultivation has also been shown to be important and needs further investigation (Wookey 1985). Thus increased cultivation should not be considered as an alternative unless integrated with other strategies and/or further research is executed.

(ii) Biological Control

Australia has a history of supporting biological control and over the past decade 20-30% of weed researcher time has been devoted to this activity (Blacklow *et al* 1979; Combellack 1987). The Rural Industry research funds have also allocated significant funds to support this research. Of the \$756,400 allocated to weed research in 1983/84 \$209,600 (28%) was destined for the biological control of three species (Blacklow *et al* 1979). Even with all this effort few outstanding successes have been achieved: Control of *Salvinia molesta* (Forno 1987), *Chondrilla juncea* (narrow-leaf form) (Cullen 1981), *Opuntia* spp. (Dodd 1927), *Alternanthera philoxeroides* (Julien 1981), *Ericocereus martinii* (McFadyen and Tomley 1981) and *Eichhornia crassipes* (Wright 1981) are examples where good success has been achieved.

These projects are labour intensive [1.3 scientists/project], costly [av. \$650,000/project if not previously investigated] and long-term [9 to 14 years the average time to introduce an organism] (Harley and Wright 1987). There is also a lag phase while the organism population increases and becomes effective. More recently the use of mycoherbicides has been under investigation in Australia (Nikandrow *et al* 1984). This follows an overseas trend of an increase in the use of fungal plant pathogens for biological control (Julien 1987). This technique may be of value where a high degree of specificity is required and remains a relatively untapped area for research. Also Combellack (1988) has estimated that if the five target plants under investigation in Victoria were totally controlled the reduction in herbicide inputs would be no more than 4%; the more likely result would be 2%. As there are 1000 alien species in Victoria and over 100 are significant weeds it is evident that considerable resources would be needed over a lengthy period to significantly reduce herbicide inputs. The community's expectation from this type of research is almost certainly too high. Let me emphasize that it has a place in weed control but it should never be considered as a viable option to replace most of the herbicide used.

(iii) Allelopathic Compounds and Natural Herbicides

Whilst research in this area has been neglected and said to be speculative, an

intensive research programme is considered to be worthwhile by McWhorter (1984). He suggested that such products could (i) reduce losses due to pests, (ii) provide increased protection of crop plants using natural toxicants and (iii) increase crop yields by treatment with natural growth stimulants. Takahashi *et al* (1983) in their comprehensive review of compounds isolated from plants list a large number of phytotoxic compounds which could be used as selective herbicides. More recently a paper by Duke and Lyndon (1987) identified a number of 'natural' compounds, i.e. compounds found in plants, which have some phytotoxic properties. Limited research in this area is being undertaken in Australia in, for example, *Datura stramonium* (Lovett *et al* 1987). Lind (1987) has suggested that future directions for allelopathic research should include the need to directly utilize allelochemicals from plant sources and genetic manipulation of crops, for example cucumber, which have a natural capability for suppressing weed growth (Putnum and Lockerman 1979). The integration of allelopathic crops, e.g. sorghum, barley, wheat and oats, into rotations should be considered as they have been found to suppress certain weed species (Putnum and De Frank 1983).

(iv) *Ecological Shifts in Weed Flora*

The excellent summary of Haas and Streibig (1982) showed that changing weed patterns and weed distribution were due to the interaction of herbicides, fertilizers, tillage practices, crop types and rotations. Thus a change in any of these factors will slowly lead to a shift in the flora. To develop a management system to regulate the population of defined species will require a practice which adequately disrupts the seed production cycle and exhausts the soil reservoir of seeds (Medd 1987a). This will require a more analytical weed management system, using a whole farm approach (Medd 1987b). Therefore management practices and crop rotations offer scope to manipulate the occurrence of weed species. Unfortunately, it is not only a poorly understood area, it lacks resourcing, it is complex and will necessitate long-term projects if it is to provide practical strategies. This is an approach which could well provide a way of significantly reducing herbicide inputs. More resources are considered worthwhile.

(v) *Physical Control*

This includes the use of electromagnetic radiation and electricity to control pests. The use of gamma radiation has been studied as a method of controlling seedling weeds and seeds (Sanwald and Koch 1978), but its use is not supported because of possible mutagenic effects. Laser radiation has also been evaluated but provided only transient effects on plant growth (Couch and Gangstäv 1974). Heat radiation has been studied using a number of strategies including non-selective control of vegetation and band flaming between crop rows (Sanwald and Koch 1978) and stimulating the germination of seed of *Chrysanthemoides monilifera* (boneseed) (Lane and Shaw 1978). Whilst control of weeds by flaming has only been successful if the weeds are less than 5 cm, this method does have the benefit of reducing the impact of both insect and fungi pests. The use of VHF radiation has also been tested with promising results and prototypes have been developed (Boyd 1973) but little has been reported in recent years. High voltage electrical discharge systems have also been trialled (Dykes 1977; Knievel and McKee 1977). From this work damage to weeds appears to be dependent on voltage and exposure time. It would appear that physical control is unlikely to provide little more than a transient effect on emerged plants but it may have a significant role if used as heat to induce germination of weed seeds, e.g. *Chrysanthemoides monilifera*. Physical barriers such as woven cloth which prevent the emergence of weeds is an alternative that is used in small scale plantings.

(vi) *Integration of Non-Pesticide Control Techniques*

It should be realised that no one non-pesticide option will provide control of the spectrum of weeds that confronts growers of crops. If a suitable integrated control approach is to be developed it should be based on a strategy which maximises the effects of cultivation and ecological shifts. Knowledge of the allelopathic effects of crops on weeds, and weeds on crops, should be used to help delineate ecological shifts. Classical biological control and 'physical control' should be reserved for the more intractable problems probably in crops or situations which are extensive and/or have low value. The inputs for this option are shown in Figure 1. It can be seen that the ecological shifts

Fig. 1: The No Herbicide Option for Crops

in weed spectra before cultivation can be influenced by management such as rotations and grazing, allelopathy [for example, *Portulaca oleracea* and *Digitaria ischaemum* have been reduced by 70 and 80% in numbers by residues of sorghum (Putnam and De Frank 1983)] and biological control [e.g. *Chondrilla juncea* (Cullen 1981)]. Predictions of the effect of these inputs on the anticipated weed flora is necessary if weed control is to be optimised. The judicious use of cultivation would then follow. This would involve the use of equipment which killed unwanted vegetation without exacerbating soil erosion or compaction. Accurate timing is necessary to reduce the number of cultivations. The use of 'natural' herbicides and inundative biological control agents may be of limited value. The use of 'physical control', particularly to stimulate germination may have a place. Following the sowing of the crops, weeds will emerge and can be controlled by mechanical cultivation, mycoherbicides, 'natural' herbicides or 'physical control'. The information base to serve such an option is sparse. To generate adequate knowledge will necessitate long-term studies with adequate resources. The chances of obtaining weed control similar to that obtained by herbicides is very unlikely.

Assuming a no weed control strategy reduces yield by an average 70%, the implementation of an integrated non-pesticide strategy, based on present knowledge, would probably reduce losses 30 to 40%. In the short term, 5 years, a reduction in the losses to 25-35% could be anticipated. In the medium term, 10 years, a further 5% reduction in losses could be anticipated. It is postulated that, in each case, implementation costs would be equivalent to 20-30% of the cost of herbicides, reflecting costs of purchasing and running new equipment. Increased research costs estimated at (A)\$1.4 to \$1.50 million/annum (see Table 6) would be incurred. Therefore the loss in revenue of crops after 5 years could be (A)\$1.77 to \$2.32 billion and after 10 years (A)\$1.29 to \$1.84 billion at 1986 value.

Option 2 — (A) Reduction in the use of Herbicides

[Efficient utilisation of herbicides]

This option should aim to reduce pesticide inputs by, for example, 25% in 5 years and 50% within 10 years. Such aims have been set by the Danish government. To

TABLE 5: Ways of reducing herbicide use.

	% Herbicide Saving	
	Theoret. maximum	Practical
1. Application efficiency	20 to 25	10 to 12.5
2. Use of more effective formulations and adjuvants	5 to 15	5 to 10
3. Timing of application	25 to 50	20 to 30
4. Spraying weeds only where they occur	30 to 75	25 to 50
5. Acceptance of lower levels of weed control consistent with optimizing economic return	20 to 30	20 to 30

TABLE 6: Resourcing Option — Elimination of herbicides — Crops.

Input	No. of Staff		Cost/annum (A)\$ 1986	% Contribution to weed control	
	Sci.	Tech.		Year 0 - 5	Year 6 - 10
Cultivation	4	2	250,000	75	55
Biological	5	4	400,000	2.5	10
Allelopathic	3	2	200,000	5	7.5
Natural herbicides	3	2	200,000	2.5	5
Physical	2	1	130,000	2.5	5
Ecological shift	5	3	300,000	12.5	17.5
Total	22	14	1,480,000	% productivity c.f. present - - 30 to 40	% productivity c.f. present - - 25 to 35

Science staff 40,000
Tech staff 25,000
& Operating

achieve these aims a number of areas of research need to be considered. The most important areas are shown in Table 5.

(i) *Application Efficiency:*

This can be improved by careful selection of nozzles. Nozzle selection is important to achieve uniform spray distribution (Combella *et al* 1982). Also the material from which they are constructed governs wear rate (Combella and Richardson 1987) which in turn affects distribution (Combella 1984a). Furthermore, Combella and Richardson (1985) reported that a reasonably stable boom having a coefficient of variation in spray distribution of less than 12% could be used with 12.5% less herbicide without loss of weed control. Work by Maybank *et al* (1974) and Grover *et al* (1978) shows that there are large variations across (>100%) and along (>30%) the swath. Indeed it was estimated that the dose rate could be halved if distribution was improved (Maybank *et al* 1974). Other factors in application efficiency are droplet size and its influence on capture (Combella 1984b), droplet trajectory (Richardson 1987), boom stability (Nation 1980; Nation 1982) and electrostatics (Law and Lane 1981; Parham 1982; Pascoe 1985). As losses within the target area (40-95%) are far greater than those outside the target area (0-30%) (Combella 1982), more attention should be devoted to this aspect as there is scope for improvement. Efficient application would almost assuredly permit pesticide savings of 12.5% even with present knowledge. Further

research effort could well double this figure within 5 years if research effort was adequately resourced. The most likely areas of reduction are by spraying weeds where they occur and further evaluation of droplet capture by manipulating their trajectories and impaction characteristics.

(ii) *The Use of More Effective Formulations and Adjuvants:*

Testing the effectiveness of adjuvants is demanding as their effect is usually difficult to detect above experimental variation. The parallel line assay technique developed by Streibig and Thonke (1985) allows for more accurate assessments. Using this technique the addition of Ulvapron (paraffinic emulsified oil) at 2% has been shown to provide a 25% improvement in the herbicidal effectiveness of diclofop methyl (Moerkerk pers comm. 1988). This work and previous studies (Dempsey *et al* 1985; McShane 1986) also showed that the addition of adjuvants increased collection by the crop. This could account for some of the variation in the tolerance of different varieties of wheat (Lemerle *et al* 1987). In summary many claims are made about the improvement in the effectiveness of herbicides following the addition of adjuvants. Unfortunately much of the data to support the claims is circumstantial. This is an area worthy of further study providing good experimental techniques are used.

(iii) *Timing of Application:*

Studies have shown that early removal of annual weeds requires less herbicide (Pierce 1978; Felton 1978; Edmund and York 1987) and sometimes results in better yields (Pierce 1978). Studies on perennial weeds have also shown that attention to timing of application will result in more effective control at similar dose rates (Parsons and Amor 1968; Hartley *et al* 1983). There are too few studies which relate the timing of applications to weed control and subsequent yield. Obviously such information is fundamental if herbicides are to be used efficiently. The limited data available (for example Pierce 1978; Edmunds and York 1987) would indicate that savings of 25 to 30% of herbicide are possible. Also higher dose rates are recommended by companies when the weeds are at a more advanced growth stage. More effort should be devoted to encouraging users of pesticides to apply them when the lowest dose rates can be used. Using legislation to prevent users applying dose rates lower than those recommended on the label should **not** be supported. As every attempt should be made to reduce pesticide inputs, the label should reflect the upper limit and users encouraged to use as little as possible.

(iv) *Spraying Weeds Only Where They Occur:*

Many weeds occur in patches and vary in density where they occur. If not sprayed the more conspicuous species, for example perennials such as *Acroptilon repens* or *Chondrilla juncea*, and the annuals *Raphanus raphanistrum* and *Avena fatua*, demonstrate this thesis at harvest. Whilst it is suggested that most weed species are restricted in distribution in a field, mixtures of herbicides are used to ensure control of the range of species encountered. Savings in herbicide can be made if weed species are accurately mapped within the treatment area. With this information calculations can be made to assess herbicide savings by calculating the area to be sprayed by the components of the mixture on individual species. Limited data has been generated in an area infested with *Raphanus raphanistrum* and *Avena fatua* and savings of up to 70-80% were indicated (Combella and Richardson 1987). Further studies are strongly recommended.

(v) *Acceptance of Lower Levels of Weed Control Consistent with Optimising Economic Returns:*

The density or number of plants per unit area is basic to competition studies as plant growth responds in a plastic manner to available resources. Thus plant yield is only independent of density when plants are small or widely spaced. However plant competition is such a complex subject, being dependent upon density, species proportion and spatial arrangements, that no one model is completely suitable. A number of relationships between weed density and yield have been described. Reviews of the various models by Radosevitch (1987), Cousens (1987) and Cousens *et al* (1987) are highly recommended reading. Cousens (1987) has been particularly critical of the relevance of statistical thresholds and suggests that an economic threshold is more

important. He suggests they include herbicide cost, its expected performance and produce price. Streibig *et al* (1988) have used these inputs to rank the relative competitiveness of some Australian weeds (*Acroptilon repens* > *Chondrilla juncea* > *Raphanus raphanistrum* > *Lithospermum arvense* > *Brassica tournefortii* > *Amsinckia hispida* > *Lolium rigidum* > *Lamium amplexicaule* > *Fumaria officinalis*). They concluded that the effect of poor precision of estimating the threshold is not as critical in crops which have low (1.5 to 2.0 t/ha) compared with high (6.0 to 8.0 t/ha) yields. Aldrick (1987) pointed out that there was too much variability in prediction methods due to (1) a shift in crop yield from a weed density-dependent to an independent relationship; (2) effect of density on essential growth factor competed for; (3) relative competitiveness between weed species; (4) effect of environment on competitiveness; and (5) effect of time of emergence on competition. The effect of time of removal should be added to these variables. In view of the interest in this aspect of weed control over recent years, more accurate predictions of the effect of weed density on yield will be possible. However implementation of such predictions, which almost assuredly will necessitate acceptance of less weed control, will meet with problems of

Fig. 2: The Herbicide Option for Crops.

adoption by the farmer (Cussans 1987). To overcome this problem long-term studies should be initiated, using available predictive models, so that farmers can be shown that the remaining weeds do not impose more intractable and/or costly problems in the future. The latter is the main reason for the farmers' concern but not the only one; appearance of weeds in crops also ranks highly (Cussans 1987).

In crops, integration of the above elements (see also Figure 2) would almost assuredly permit the defined aims to be achieved within the time frame suggested. Furthermore these aims could be achieved whilst crop production continued to increase, as weed control levels could be adjusted to economic returns. Judicious use of herbicides in a flexible manner should be the outcome of this option. Annual savings of approximately A\$100 million in herbicide costs plus application, could be expected within 5 years. The estimated costs to finance research for this option is (A)\$765,000/annum (Table 7). No reduction in value of crops is anticipated.

TABLE 7: Resourcing Option — Reduction in herbicides — Crops.

Input	No. of Staff		Cost/ annum (A)\$ 1986	% Contribution to reduction in herbicide use	
	Sci.	Tech.		Year 0 - 5	Year 6 - 10
Application efficiency	2	1	120,000	10	10
Formulations/ adjuvants	1	1	75,000	2.5	2.5
Timing of application	3	2	200,000	10	10
Optimising economic returns	2	1	130,000	7.5	10
Spraying patches	4	2	240,000	5	20
Total	11	6	765,000	35	52.5

TABLE 8: Resourcing Recommended Option — Crops.

Input	No. of Staff		Cost/- annum (A)\$ 1986	% Contribution to:			
	Sci	Tech		0 - 5 years		6 - 10 years	
				Weed control	Reduction in herbicides	Weed control	Reduction in herbicides
Ecological shifts	5	3	300,000	12.5	5	17.5	10
Cultivation	4	2	250,000	40.0	7.5	35	15
Application efficiency	2	1	120,000	47.5	7.5	47.5	10
Timing of application	3	2	200,000		7.5		10
Optimising Economic returns	2	1	130,000		5		15
Total	16	9	1,000,000		32.5		60

Fig. 3: The Integrated Option for Crops

Option 2 — (B) Integration of Efficient Utilisation and Non-herbicide Techniques

This is the recommended option (see Figure 3) as it would enable even further reductions in pesticide use. It is suggested that teams to research ways of reducing pesticide use and monitoring and predicting ecological shifts would be essential. Inputs into biological control, effect of management systems on flora and mechanical control are considered to be beneficial but are unlikely to be as cost effective and should thus have lower priority. Research in the areas of allelopathy, natural herbicides and 'physical control' are regarded as speculative and thus should receive the lowest priority for funding. As previously pointed out classical biological control is resource demanding and therefore it should only concern itself with the more intractable and/or widespread problems. The use of inundative biological control (e.g. mycoherbicides) is seen as more likely to be successful and to be less labour intensive. Such materials could provide control of species in sensitive situations. Further work on mechanical control is seen as necessary. This work, together with some of the application research, would require inputs from engineers. Any developments in mechanical control using cultivation should also be related to soil loss and amelioration assessments. The number of staff required would depend upon the number of projects undertaken. Estimates have been made and are presented in Table 8.

From the data presented in Table 7 it will be seen that the community can expect the same revenue from crops and yet have a reduction in pesticide use of at least 25% after 5 years and 50% after 10 years if option two is adopted. Adoption of option one is

not considered a viable alternative in view of the loss in value of crop production. To integrate the best areas of option one, i.e. cultivation and monitoring ecological shifts, with those of option 2, i.e. application efficiency, timing of application and optimising economic returns would appear to be the best overall option. The cost of researching this option is shown in Table 8. This option would not incur loss of yields and would enable reductions in herbicide use estimated at 33% after 5 years and around 60% after 10 years. In my view this latter option should be implemented.

IMPLICATIONS

Community Acceptance

The recommended option may not be favoured by all in the community as some expect pesticides to be eliminated. Whilst it is realised that the data presented here needs to be more thoroughly examined, by way of for example a critical economic assessment, it can serve as a guide when debating such issues as a rational approach to pesticide use or how best to deploy scarce government resources.

Though not discussed in the paper, it is emphasised that a significant commitment to extension will be necessary if the results of research are to be adopted. Adoption of some of the anticipated outcomes could well be difficult, for example unsightly crops due to remnant weeds (Cussans 1987). The government may be unwilling to resource an extension programme containing strategies which are complex, could result in losses if not correctly implemented, thus imposing a fear of possible litigation, and which are anticipated to be relatively slow to be adopted. Also the pesticide industry is unlikely to be supportive as they may assume that the strategies will erode business.

In summary the community needs to carefully assess the costs and benefits of changing our dependence on the use of pesticides. A survey which includes consumer attitudes to quality, quantity and cost of change needs to be rationalised with an assessment of concern over residues and/or other implications of pesticide use. A decision should then be made as to the policy needed when the survey is assessed in relation to producers' incomes and effects on export income. I would anticipate that such an enquiry would resolve that a reduction in pesticide use is the preferred option. Furthermore I would suggest that the majority of the community prefer adequate, high quality food at cheap prices rather than substantially more costly food of a lesser standard and where export income is to be reduced by (A)\$1 to 2 billion per annum

Government Research Priorities for Weed Control

It is my opinion that there are four relatively neglected areas of research which are fundamental to current needs:—

1. Assessment of economic impact.
2. Minimisation of soil, air and water residues.
3. Influence of weed control on soil erosion.
4. Control strategies for weeds on public lands.

Each of these need to be considered —

(1) Assessment of economic impact

Combella (1987) wrote "Users and the community alike will demand increasingly sophisticated economic data to support the continued use of herbicides". I re-emphasize that need. The value of controlling weeds on both public and private land needs to be assessed if society is to accept the need for control measures. For this to be possible it will necessitate the development of better economic models to predict effect on production on private land and externality effects on public lands particularly National Parks. In the case of noxious weeds the potential to and rate of spread will also need to be estimated if a rational economic assessment is to be made. These are difficult areas requiring a high level of conceptual analysis and experience.

Certainly there is an urgent need for an in-depth economic assessment of weed control activities. The concern shown by Combella (1987) about the lack of economic assessment in Australia is true for world-wide weed science activity. Less than 1% (380) of the 41,272 abstracted weed science papers over the past 10 years have been on economics. Australia has contributed 32 of these and New Zealand 5 [Table 9]. The lack of economic data is the achilles heel of weed science as without economic data weed

TABLE 9: Papers on Economics — 1978-1987.

	YEAR									
	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Total number of Abstracts	4288	4339	4322	4625	4125	3646	4080	3580	4463	3804
No. of Abstracts on Economics	38	40	61	51	44	22	36	34	32	22
No. of Abstracts on Economics by Australia	1	1	15	1	3	2	1	5	2	1
No. of Abstracts on Economics by New Zealand	2	2	0	0	0	0	0	0	0	1

science is unable to adequately argue for scarce resources. This is a vitally important project area.

(2) *Minimisation of soil, water and air pollution*

To achieve this objective a number of areas need to be addressed, e.g. monitor residue levels in soils and produce; devise systems to reduce herbicide inputs; define economically optimal levels of weed control; develop ways of efficiently utilizing herbicides; develop biological control of defined species; conduct biology and ecology research on specified weeds; develop better mechanical control techniques; develop appropriate herbicide mixtures; measure the impact of weeds on productivity; assess the impact of whole farm management practices on weed occurrence; assess, and where appropriate, develop 'physical' weed control methods.

Many of these areas have been considered within the paper. It is evident that this is an extremely important area which requires co-ordination of effort. This is regarded as the most important area of research need in the USA (McWhorter and Barrentine 1988).

(3) *Influence of weed control on soil erosion*

We often forget that 50-70% of any cultivation is for the purpose of weed control. Even so, few projects which concern soil erosion involve weed scientists, indeed frequently agronomists are overlooked. Research areas which need weed science input are timing and method of cultivation; defining the optimum number of cultivations for different soil types, cropping systems and rotations; assessing the effect of 'weed' removal in relation to topography and rainfall and its influence on soil erosion.

This is an area of neglect and an area dominated by soil scientists as far as funding is concerned. In my view weed scientists should develop viable projects, in conjunction with soil scientists.

(4) *Control strategies for weeds on public lands*

Weed control methods for 'environmental' weeds are poorly developed. The areas which need addressing include land classification, and an inventory of weeds on different land types; the intended purpose of the land and thus the level of weed control expected; a better knowledge of the weeds that invade such land; an assessment of available control methods and the development of new or more efficient methods where appropriate and basic ecological research.

With an increasing area of land being declared as National Parks (in Victoria for example in July 1982, 985,113 ha, by December 1987 it was 1,432,659 and it is expected to increase to 2,132,819 ha by 1992) there will be growing pressure for more informed advice.

(5) *Resourcing the needs*

Scarce government resources must be encouraged to develop fundamental information and be involved in co-ordinated projects which meet defined priorities. In my view it could well be argued that too many government resources are being utilised in researching chemical weed control. As government funding is unlikely to rise

significantly for weed control activities, there is a definite need to redirect effort from chemical control into the areas described above. The pesticide industry will thus be responsible for significantly more development work. Of course these costs will have to be passed onto the grower and ultimately the consumer under the present system. I repeat a previous suggestion: "it is suggested it [more research and development] could be achieved at little extra cost if more co-operation between companies was exercised — for example the Agricultural Veterinary & Chemicals Association could operate a research pool, or they could sponsor research workers attached to appropriate research centres" (Combella 1987). The latter system would ensure maximum utilisation of expensive facilities and co-operation between workers. The increased use of consultants goes some way towards rationalisation.

I conclude with the words of Knake 1975: "Weed Scientists should reach out to new unexplored horizons with imagination and creativity".

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