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The Importance of Weeds and the Advantages and Disadvantages of Herbicide Use.

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Summary

The impact of weeds, defined as plants growing in places where they are not desired, is considered on the basis of human and animal welfare; production of food and fibre; soil degradation; environmental hazard and economic impact. In particular the relationship between weed control and soil erosion is identified. Indeed it is calculated that if herbicides are withdrawn from the market place then crop yields would decline by 10% and much more in some situations. This would result in an estimated increase in the world's undernourished to 1,868 million by the turn of the century. An assessment of the current weed control practices is made for crops, pastures and other situations by considering natural, biological, mechanical and chemical methods. The concerns of the public are appraised in relation to soil residues, health of users and bystanders and environmental degradation. The use of natural and biological control methods are considered to be unsatisfactory alternatives to current practices as in most situations they are too specific and resource demanding. There were found to be a number of potential adverse effects on the environment resulting from herbicide use. In particular changes in the microflora were noted but were generally transient. Residues in underground water, though in low concentration, were identified as a possible concern. A prediction of future control strategies are made for both agricultural and non agricultural areas by including public attitudes and needs. This clearly indicates the need for changes to present policies. In particular there needs to be more multi-disciplinary projects to investigate reduced tillage systems and ways of improving the efficiency of herbicide use. It is recommended that this latter project should be funded by generating a levy of 1% against herbicide sales. It is also suggested that the current trend of increasing consumer driven research needs to be changed, as it is leading to short term research and having too much impact on government research direction. It is recommended that the Commonwealth and States each develop clear research objectives and that requests to funding bodies should only be on a State/Commonwealth basis, subsequent redistribution of the funds being by a State selected panel. Other areas in which research direction should be changed include biological control, to include grazing animals, and an increase in activity on environmental weeds. It is concluded that practitioners of weed control need to adopt new approaches but that their development will be difficult in view of the trend for increased consumer orientated research and decline in the research and extension base. This trend will have to change.

Introduction

There has been, and continues to be, considerable public disquiet about the use of herbicides. This is evidenced by the frequent newspaper reports linking problems with human health to herbicide use. These alleged effects can either be by way of direct contact, as in the case of the applicator, or as a bystander, or indirectly through residues in the water, air or produce. Whilst scientific studies invariably refute the connection, (Parsons 1988, Mathews 1989) the media and some sections of the general public continue to promote the link.

One of the reasons for the different views could well be that the effects of herbicides, potential and actual, are emphasised by pressure groups. These can be rational or exaggerated and thus decision making is difficult when one is not aware of the evidence. The central problem of rational herbicide use is to reconcile the differing interests of a wide range of community groups. Parsons (1988) listed these groups as:- the frustrated scientist; the 'out of her/his field' scientist; the medical profession; the mischievous academic; the media; the anti science/anti technology movement; the genuinely concerned citizen; the pseudoconcerned citizen; the politician and the union movement. Therefore if there is to be support from the majority of the community, which would equate to rational use, most of these groups must approve their utilisation. Furthermore as most of the public debate has concerned itself with the alleged adverse effects of herbicides the benefits need also to be considered. This will be done in this paper as the public is not able to see the direct evidence of benefit derived from herbicide use, and thus it must be informed.

This is necessary as, to date, authorities have failed to provide the necessary commitment, means and mechanisms to mount an objective campaign to inform the public on the risks and benefits of herbicide use. It is hoped that this paper will rectify this situations to some extent.

1. Definition of a weed

Before we can consider this subject we must be in agreement with a definition of the target. Weeds have originated from a wide range of taxonomic families, occupy a range of environments and exhibit a wide variety of colonising strategies. There are a number of definitions to describe a weed, King (1966) lists ten. Even so none enables one to characterize all plants that could be weedy. Whilst the definition supported is 'A plant growing where it is not desired' (Shaw 1956) many are attracted to that attributed to Emmerson 'A plant whose virtues have not yet been discovered' or to Professor Beal 'A plant out of place'. Whatever definition is used the attributes particularly important to weeds include:- prolific reproduction, photoperiod neutrality, early and long period of flowering, self fertility, unspecialized or wind pollination, easy hybridization, continuous seed production, great seed longevity and resistance to deep burial, numerous widely dispersed seeds, seeds mimicking harvested grain, asexual reproduction, hardy propagules easily spread, dormancy pre-adapted to human activity. Such plants should also have:- aggressiveness and competitive ability: rapid seedling growth, rankness, winter hardiness, edaphic and environmental tolerance, preference for disturbed soils, rosette formation, allelopathy but self-compatibility, toxicity, unpalatability, intraspecific variation, plasticity of growth, deep rooting, nitrophilous, parasitic habit, herbicide resistance and exotic origin (Batra 1981). Some of the most important weeds are the most numerous plants on the planet. Even so, few basic studies on such plants exist. This reflects the lack of support for weed science as it is very unglamourous in the eyes of the public. There are a number of important weedy species growing in Australia. Combellack (1987) has attempted to list them, as both existing and emerging species, by land use category.

2. Impact of Weeds

This paper will attempt to consider the burden that weeds impose on mankind by assessing their impact on a range of situations.

A. Human Welfare

i. Poisoning

Bracken (*Pteridium esculentum*) is a widely distributed native plant. This seemingly innocuous plant is far from that if it mimics its European counterpart, *Pteridium aquilinum*. That plant is implicated in human welfare problems on four accounts. Firstly, Evans *et al*. (1972) reported that a carcinogen, known to exist in the plant, was found to pass through the milk of cows and mice in sufficient quantities to be of concern. This led to epidemiological studies to ascertain whether there was a connection between the higher levels of stomach cancer found in North Wales and the source of milk and water (Galpin and Smith 1986). Their study showed that milk was not implicated and that this was due to bulking of milk since the 1930s. The potable water source, the second possible avenue of intake, had also changed as there was less dependence on individual wells and small streams. The study 'failed to implicate waterborne contamination derived from bracken'. The third possible route of entry is inhalation of spores. The spores are particularly carcinogenic, and appear to contain two distinct carcinogens. One is more stable and appears to induce leukemia, the other appears to produce gastric cancers only if fresh spores are used (Evans 1986). Following further studies Evans (1986) concluded 'for people working in dense bracken areas the use of face masks is to be advocated'. The fourth mode of entry is by ingestion. The Japanese eat the crozier stage as a salad. This has led to a higher incidence of stomach cancer (Hirono *et al*. 1972).

It can thus be reasonably concluded that bracken poses a significant threat to the welfare of humans on at least two accounts, ingestion and spore inhalation. The possibility of water transporting carcinogens, whilst inconclusive in the North Wales study, may prove to be positive if 'local' water derived from areas heavily infested with bracken is consumed over a long period. Similarly milk obtained from such areas may induce cancers.

With the above conclusion in mind it is unbelievable that a recent text could consider the use of this plant for both medicinal and food uses (Stern 1986). It is not until the final line of the article that any connection with cancer is identified. This clearly demonstrates a need for more careful consideration of the literature before suggesting such a plant as a "natural food". Other plants are poisonous when eaten. For example castor oil plant (*Ricinus communis*) or philodendron often cause poisoning in children and adults suffer psychotic effects from angel's trumpet (*Datura candida*). Indeed it is reported that plants are the second most frequent hazardous material ingested by children under 5 years of age (Oehme 1978).

ii. Allergies

A weed of note that imparts allergenic responses is parthenium (*Parthenium hysterophorus*). This annual plant was first collected in Queensland in 1955 and has spread rapidly since that time (McFadyen and McClay 1981). Like bracken it has no adverse physical attributes. However it does contain sesquiterpene lactones which impart serious allergenic reactions in humans who are in frequent contact with the plant (Towers 1981).

There are also those plants that exacerbate asthma. eg. Paterson's curse (*Echium plantagineum* and *E. vulgare*); perennial ragweed (*Ambrosia psilostachya*); poverty weed (*Iva axillaris*); capeweed (*Arctotheca calendula*) and ryegrass (*Lolium* spp.). Those which contaminate produce include examples such as wild garlic (*Allium vineale* L.) and melilotus (*Melilotus indica*).

iii. Physical discomfort

A plant which affects human welfare on a purely physical basis is blackberry (*Rubus fruticosus* L. agg.). Whilst there is no record of its introduction, it is known to have been present in the early 1800s in NSW (Parsons pers. com.). This weed mostly invades disturbed sites in high rainfall areas. The spiny canes form impenetrable thickets which infest riverbanks, encroach onto walking paths, invade productive land and replace desirable vegetation. The seemingly unrelenting tenacity of this weed has caused many landholders despair when attempting eradication. Its ability to invade abandoned farmland, the rapid reinvasion of cleared walking tracks or stream banks and its ability to encompass disused farm buildings exemplifies its vigour. Other spiny plants which form impenetrable thickets are gorse (*Ulex europaeus*) and the cacti (e.g.*Opuntia* spp.)

Other weedy plants that fall into this category include spiny emex (*Emex australis*), spiny burr grass (*Cenchrus* spp.), khaki weed (*Alternanthera repens*)and caltrop (*Tribulus terrestris*). These species grow in places frequented by humans and produce fruit that have spines. These frequently penetrate the skin and even shoes, and tyres can be punctured.

There are also those that interfere with the handling of hay, for example thistles (e.g. *Cirsium* and *Carduus* spp.), barley grass (*Hordeum* spp.), spear grass (*Stipa* spp.), Bathurst and noogoora burr (*Xanthium spinosum* and *X. occidentalis*).

iv. Food and fibre availability

There is a group of people in the community who consider it would be environmentally beneficial if mankind stopped using herbicides, indeed any form of weed control, and reverted to a more primitive form of agriculture. This may appear to be an exciting prospect to some, but is impractical. It has been estimated that in the USA the hunter gatherer type of civilisation requires there to be 200 ha per person, 750 ha/ family of five, if adequate food supplies are to be collected (Pimental, M. 1984). This compares with 750 ha per person for Canada in the productive areas to 14000 ha on marginal land (Clark and Haswell 1970). Based on 150 ha per person the United States could support a human population of 20 million, however in view of the large tracks of relatively unproductive land the figure is more likely to be 10 million. On the same basis the world could only support 100 million or approximately 1/50 of the present population (Pimental, M. 1984).

Assuming that the majority would not support this style of living, one has to estimate the possible effects of changes to current weed control strategies on food and fibre production. Crop losses of 50% were suggested by Borlaug (1972) if pesticides were banned. Walker (1970) postulated that food production would decrease by 25 to 30% if pesticides were eliminated. According to Pimental (1976) approximately 33% of all crops were lost annually to pest damage, 13% attributable to insects, 12% to pathogens and 8% to weeds. It has been estimated that the losses due to weeds would amount to 9% for all crops if no herbicide was used. This compares with an 18% loss if no insecticides were used and 15% without fungicides (Pimental *et al*. 1978). These figures are difficult to comprehend when the same authors estimated losses to be 13.8% for weeds 7.1% by insects and 10.5 % by pathogens before the widescale use of pesticides. Other authors, McWhorter (1984) and Combellack (1987) have estimated that, even when current weed control practices are used, a 10% loss in annual production is appropriate to account for the direct effects of weeds in reducing crop yields and quality of produce, causing livestock losses and decreasing the efficiency of fertilisers, irrigation, harvesting and grain drying. Furthermore Combellack (1989) has estimated that whilst a 'no pest control' option would reduce productivity by 70% a no herbicide option would reduce production by 25 to 35% in the short term (5yrs.) and 20 to 30% in the longer term.

It is therefore clear that a reduction in effectiveness of present weed control strategies could result in decreased yields, for example if the use of herbicides were discontinued. The effect of such a policy on food production must therefore be related to both national and global food needs and to the economic consequences before implementation, as both affect human welfare. Combellack (1989b) has estimated that to accommodate predicted food needs by the year 2000 production, as cal./km^2/day, will need to be increased by 20 to 30% depending upon population growth rate and average food intake. Using the caloric intake and population data of Alexandratos (1988) there needs to be an increase of 30%. Thus if herbicides, indeed any weed control strategies were to decline in effectiveness and thus reduce yields, the projected food needs will not be met. This would result in an increase in the number of people receiving an inadequate diet. Indeed it can be estimated that a reduction in food production of 10%, thus a net increase of 20 rather than 30% in food production, will result in approximately 1,985 million more people living on less than 1900 cals/day by the year 2000, i.e. undernourished, than the prediction of 117 million of Alexandratos (1988). Apart from the human suffering of such people, mostly in other countries, it must be realised that if a 'no pesticide' policy was introduced into Australia then there would be a loss in revenue estimated to be $1.8 to 2.3 billion per annum (Combellack 1989a) or A$113 to A$144 per person. The cost of food would also increase dramatically, a four to five fold increase was predicted if such a policy were implemented in the United States (Borlaug 1972). In Australia this figure would be lower as 60 - 80 % of most of the widely grown crops are exported; even so a two to three fold increase could be anticipated. This would increase expenditure on food, per household, from A$94/week (adapted from Anon 1984)to A$188 or A$282/week. Whilst some may suggest that if Australia withdrew the use of herbicides it would have little consequence on food availability on a global basis it should be realised that Australia contributes approximately 10% of the world commodity cereal market (Furzer 1987). As these foods are commonly destined for developing countries, where they comprise nearly 60% of the diet, their withdrawal would disadvantage the poor most of all. As was pointed out by Pimental (1984) man's survival, and that of all the natural biota associated with him in his ecosystem, depends on adequate supplies of energy in the form of food. As the developed countries, which comprise a quarter of the population but consume one third of the food, are unlikely to reduce their food requirements greatly it will be the citizens of the underdeveloped nations who will suffer most should there be a reduction in the effectiveness of weed control activities.

v. Recreation

A few weedy plants affect the recreational activities of society. For example thickets of blackberry along stream banks reduce access for fishing. The same species can reduce access along walking tracks. Species such as Canadian pondweed (*Elodea candensis*), water hyacinth (*Eichhornia crassipes*), salvinia (*Salvinia molesta*), cape water-lily (*Nymphaea capensis*), parrot feather (*Myriophyllum aquaticum*) are examples of the many aquatic plants that can foul the propellers on boats and reduce swimming access. Infestations of a plant which has spined seeds, for example bindi eye (*Calotis cuneifolia*), spiny emex and caltrop, reduces the comfort of barefoot walkers and sunbathers. Infestations of annual meadowgrass (*Poa annua*) in golf greens often leads to premature browning off in the summer, and thus a poor playing surface. The establishment of pernicious perennial weeds in the garden means increased weeding, examples include oxalis (*Oxalis* spp.), couch grass (*Cynodon dactylon*), paspalum (*Paspalum dilatatum*), English ivy (*Hedera helix*) and wandering jew (*Tradescantia albiflora*).

vi. Safety

Weeds reduce safety by obscuring advisory signs on roadsides; increasing fire hazards particularly along roadsides and on industrial sites; causing railway fettlers to stumble; reducing traction on railways; blocking drains and thus exacerbating floods; scratching people with their spines; poisoning people and animals and by inducing electrical short circuits.

B. Animal Welfare

i. Poisoning

There is a considerable volume of literature on the effects of poisonous plants on animals. This is not surprising since there are approximately 1000 poisonous plants in Australia (Everest 1981). As they are so numerous it would not be difficult to rationalise that they are one of the principal causes of economic loss to the livestock industry as has been reported in the western states of the USA (James 1978). This author estimated mortality losses of 3-5% annually and correctly pointed out that the more subtle losses such as the effect on weight gains, management losses and forage losses may surpass the obvious ones. Their effect on the well-being of the animals is also undocumented. In any event grazing animals will continue to consume sub lethal quantities of poisonous weeds and therefore the consequences of such a diet needs to be investigated.

The reliability of data collection on plant poisoning is a problem as often the animals are in remote situations making accurate and timely post mortems impractical. Also the farmer is unwilling to pay for an autopsy as many of the intoxicants produce no pathogenic lesions or recognisable biochemical changes (Whittem 1978). Mostly there are few data generated to confirm the diagnoses due to lack of funds and even the difficulty of identifying the correct plant material.

Animal poisoning can occur in most situations where grazing is practiced. For example in native pastures a number of native species are known to impart toxic symptoms. Plants in the genus *Gastolobium* contain substantial quantities of monofluoroacetic acid, better known as 1080. *Acacia georginae* is another native which contains, though generally in less quantity, the same poison. *Pimelea* (riceflowers) is a genus of some 80 species, only a few of which are toxic and then only to cattle and not sheep (Kelly and Seawright 1978). However in intensively grazed pastures a number of toxic species take advantage of increased fertility. Examples include variegated thistle (*Silybum marianum*) and docks (*Rumex* spp.). Whilst in run down pastures another suite of species invade; examples include bracken, ragwort (*Senecio jacobaea*) and St. John's wort (*Hypericum perforatum*).

There are a wide range of poisons. One of the more common toxins causes photosensitisation. These occur in plants such as St. John's wort, bishop's weed (*Ammi* spp.), and buckwheat (*Fagapyrum esculentum*). A number of other toxins affect the heart, included are the cardiac glycosides contained in plants such as milkweeds (*Asclepias* spp.), rubber vine (*Cryptostega grandiflora*) and cape tulip (*Homeria* spp.). The cyanogenic glycosides are present in 125 plant species but are in toxic quantities in only a few. Examples include blue couch (*Cynodon* spp.), linseed (*Linum usitatissimum*) and birdsfoot trefoil (*Lotus* spp.). Intoxication usually occurs from the production of HCN which is more likely to occur in ruminants than non ruminants (Seawright 1982). High levels of oxalates, up to 15% of dry weight, occur in some members of the Oxalidaceae and Chenopodiaceae. The weedy plants soursob (*Oxalis pes-caprae*) and soft roly poly (*Salsoli kali*) are two important members of the respective families. Other families contain these toxins including the Gramineae, for example spiny burr grass (*Cenchrus* spp.), panic grass (*Panicum maximum*) and kikuyu grass (*Pennisetum clandestinum*). The pyrrolizidine alkaloids are mostly found in the families Compositae, Leguminoseae and Boraginaceae. The frequent genera involved are *Senecio* spp (ragwort and fireweed), *Crotolaria* spp (bird flowers), *Heliotropeum* spp (heliotrope), *Amsinkia* spp. (amsinkia) and *Echium* spp. (Paterson's curse). Effects of the more than 100 alkaloids in this group usually display chronic toxicity (Seawright 1982). The most susceptible domesticated animals, in decreasing susceptibility, are pigs, poultry, cattle, horse and goats.

Also well known to the grazier are plants that contain nitrate. Weeds which are known to accumulate this material are mintweed (*Salvia relexa*), variegated thistle and pigweeds (*Portulaca* spp). Monogastric animals are more resistant to such plants as they are unable to convert it to nitrite, the precursor to ammonia, the material that imparts the toxic effect. One could also add to the list the oestrogenic materials which adversely affect pregnancy. The two important compounds implicated are isoflavens in clovers (*Trifolium* spp.) and coumestans in *Medicago* spp..

I emphasised that both native and introduced weedy plants contain a wide range of 'natural' toxins which mostly induce chronic symptoms. Indeed their incidence is such that it would be difficult for the grazing animal to avoid all such plants and the majority will be affected to some extent during their lives. Apart from this array of toxins, the grazing animal has to contend with mycotoxins, materials produced by toxigenic fungi associated with grazed plants.

ii. Carcass damage

Another aspect of animal welfare is the effect of awned weeds such as barley grass, certain bromes (*Bromus* spp.), spear grasses and those with fruit which have hooks such as noogoora, Bathurst and Californian burrs. The awned grasses, in particular, seriously damage the eyes of sheep and penetrate their pelts. With barley grass the eye damage is initially the result of the awns but at later stages conjunctivitis and keratitis sets in (Hartley and Atkinson 1972). These authors also found that eye damage significantly reduced growth rates. Atkinson and Hartley (1972) reported that 100% of lamb skins were seedy in pastures infested with barley grass and that up to 20% were damaged.

iii. Tainting product

A weed that is able to taint product if eaten in sufficient quantity at the right time is wild garlic. It imparts a strong garlic flavour in milk after only a few minutes of grazing and it takes about six hours of grazing on non contaminated feed before the flavour is lost (Parsons, 1973). The same weed imparts a strong odour to wheat and thus infested samples are rejected at the silo. Fat hen (*Chenopodium album*) is also reported to taint milk (Mitich 1988). In a study by Tudor *et al.* (1981) sheep meat derived from animals grazing on parthenium pastures was found to have a distinctive aroma and be tainted. Other weeds that taint produce are hexam scent (*Melilotus indica*), and a wide range of brassica and umbelliferous weeds that taint milk and horehound (*Marrubium vulgare*) and brassicas which taint meat (Campbell 1988).

iv. Physical discomfort and wool contamination

The thistles are one of the most important group of plants in this category. These are highly visible and, because of their spines, are often not eaten. In dense infestations wool can be downgraded due to contamination and productivity decreased due to scabby mouth. The awned grasses, such as the genera *Stipa*, *Astrida*, *Bromus* and *Hordeum* are particularly damaging to sheep. The awns penetrate the pelts, cause abrasions to the mouthparts and often damage the eyes. The burrs of the genus *Xanthium* also cause physical damage and discomfort (Martin and Carnahan1982). It would be reasonable to assume that animals with damaged pelts would be at best uncomfortable and more likely distressed when heavily penetrated. Studies on other awned species have not received equal research attention. The hooked spines on the burrs when tangled in the wool are difficult to remove (Parsons 1973, Martin and Carnahan 1982). Spiny burr grass has spined burrs which are able to penetrate animals hoofs causing lameness and to attach themselves to wool (Campbell 1988). They cause severe discomfort to humans and animals alike. Other plants with similar characteristics are spiny emex (Gilby and Weiss 1980) and caltrop (Parsons 1973). Red dock (*Rumex brownii*) has hooked seeds which often adhere to wool in large numbers and cause minor discomfort. Spiny rush (*Juncus acutus*) when dense, becomes impenetrable to stock because of the spiny leaves (Parsons 1973). African boxthorn (*Lycium ferocissimum*) is a shrub which has sharp spines and is often used to form hedges (Parsons 1973). Galvanised burr (*Sclerolaena birchii*)is a widespread native shrub that restricts access and causes injury (Auld and Martin 1976).

v. Food availability

Wherever weeds occur in pastures they occupy space that could be utilised by more desirable species. Thus where animals graze it is necessary to provide a pasture which is as free of weeds as possible. Whilst this may appear obvious, in reality it is a complex and difficult task. In the first instance basic data to differentiate between a weed and a desirable species are limited to those plants that are obviously weedy such as serrated tussock (*Nassella trichotoma*) (Campbell 1974), heliotrope (*Heliotropium europaeum*) (Dellow and Seamon 1987) or Parramatta grass (*Sporobolus africanus*) (Jacobs 1985 cited by Campbell 1988). Other species have disputed weediness, Paterson's curse is such a plant. Piggin (1977) considered it to useful because young plants have similar nutritive value to subterranean clover (*Trifolium subterraneum*), however Cunningham, Mulham, Milthorpe and Leigh (1981) consider it has no valuable assets and is thus a weed. Other species are of value when young but a weed when mature, for example barley grasses. African lovegrass (*Eragrostis curvula*) is useful for beef cattle and soil stabilisation in dry areas but if not managed properly becomes dominant and less attractive (Campbell 1983). One of the most invasive weeds of pasture, blackberry, is the preferred diet of the goat and thus cannot be regarded as weeds if these animals are grazed. One could add to these few observations a number of questions such as the relative palatability between species, relative production rates for common pasture species, and the relative production of grazing animals for single and mixed swards. Defining the parameters that make a plant a weed in pastures is a neglected area of research probably for two important reasons: firstly it is too resource demanding to conduct appropriate studies and secondly there is little pressure from graziers for such studies and this will persist until productivity from pastures needs to be greatly increased.

C. Production of Food and Fibre

i. Crop yields

In Australia there are over 430 weedy species in 59 families recorded on arable land (Medd 1987). This flora varies considerably between states, regions, districts and farms. It is influenced by geography, opportunity and farming practice. A judgement whether to control weeds in crops must be based on accurate recognition in the first instance. After identifying the species it is necessary to assess the effect that they may have on the expected yield. This would depend upon the density of each species, their relative competitive ability, their size and that of the crop, their potential to affect harvesting or product quality and their influence on subsequent cropping options. This is not easy as there is a lack of data on most species in most crops. Streibig *et al.* (1989) have reported on the relative competitive effect of nine species of weeds that grow in Australian wheat crops. They concluded that whilst there was a lack of precision in defining relative competitive effects, this was not so important in crops that have low (1.5 to 2.0 t ha^{-1}, common in Australia) compared with high (6.0 to 8.0 t ha^{-1}, common in Europe) yields. Whilst the data generated by Streibig *et al.* (1989) are useful they are in no way complete as the data used to generate the competitive indices were based on experiments which measured the effect of a single species and generally at one time of removal. In reality a number of weed species occur in a crop and the time of weed removal is important. For example in cotton, common cocklebur (*Xanthium strumarium*) adversely affects cotton seed yield if allowed to compete for more than 2 to 4 weeks (Snipes, Street and Walker 1987). In soybeans Harris and Ritter (1987) found that fall panicum (*Panicum dichotomiflorum*) need not be removed until 8 to 12 weeks after crop emergence. In another study (Curran, Morrow and Whitesides 1987) wild oats (*Avena fatua*) at densities of 32 and 65 plants m^{-2} did not affect yields of lentils if left to compete with the crop for up to 5 weeks. However if they remained for 7 weeks the yield was reduced by 32% at the lower density and by 61% by the higher density if they remained until harvest. The situation is complicated by the fact that one crop variety may be more or less tolerant than another. For example Reeves and Brooke (1977) reported that wheat varieties showed variable tolerance to annual ryegrass whilst Henson and Jordon (1982) reported a similar effect for wild oats on the same crop. A further complication is whether the crop is transplanted or direct seeded. For example Weaver, Smits and Tan (1987) have reported that direct seeded tomatoes are reduced in yield by 80 to 90% by nightshades (*Solanum* spp.) at a density of 8m^{-2} whilst if transplanted the reduction is only 20 to 30%.

Another aspect of weedy plants is their ability to host diseases of crops. The more closely the botanical affiliation of the weed to the crop the greater is the likelihood that disease transmission will occur. The range of disease extends from bacteria and fungus to nematodes and virus. Well known examples include the club root disease of cabbage and other brassicas (*Plasmodiophora brassicae*) which can be transmitted by several cruciferous weeds (King 1966). In North America the stem rust of wheat (*Puccinia graminis*) with its alternative stage on common barbery (*Berberis vulgaris*) is well documented (King 1966). Other examples include the two diseases which cause footrot of wheat in North America (*Ophiobalus* and *Helminthosporium* spp.) which are found on English couch grass (*Elymus repens*) (Mitich 1987) and the *Rhizopus* spp. associated with kochia (*Kochia scoparia*) which reduces the germination of sugar beet (Wiley, Schweizer and Ruppel 1985).

The benefit from removing the weeds, and predicting the optimal time of their removal, is extremely complex and is beyond the capabilities of most. The lack of fundamental knowledge is disturbing and has meant that general estimations based on limited data, experience and intuition have to be made. Because of this, even when some control measures are used, there is still an overall loss estimated at around 10% in crop production (Zimdahl 1980, McWhorter 1984, Combellack 1989). This is almost certainly a conservative estimate as must be realised from the above data. For example the losses can range in wheat from zero for low densities of fumitory (*Fumaria officinalis*) (Wells 1979), to 100% as in the case of hardheads (*Acroptilon repens*) (Pritchard and Streibig 1989), to an increase in yield in the case of the leguminous "weed" *Triponello polycerst* in wheat in India (Kapoor and Ramakrishnan 1975). In the latter studies the conclusions are difficult to support as one would have expected a greater yield increase in the low nutrient treatments if nitrogen was the limiting factor. This is a subject in desperate need of research if accurate predictions of the value of weed control to crop production is to be possible.

ii. Animal production

Certain plants in pastures can be defined as weeds at one growth stage, for example mature barley grass, and yet be regarded as a useful fodder plant when young. Other plants which are useful to prevent erosion may be of doubtful value in the pasture, for example skeleton weed (*Chondrilla juncea*). Further, the interaction between weeds and animal production is a complex issue as there are no consistent agronomic properties that distinguish weeds from other pasture plants (Campbell 1988). Furthermore Bosworth, Hoveland and Buchanan (1986) reported that the in vitro digestibility of a number of 'weeds' and cultivated forage plants showed that generally there was little difference between them up to and including the flowering stage of the forbs and the boot stage of the grasses. The weedy plants did however mature more quickly and loose nutritive value between this stage and fruiting. Indeed, the results indicate that the nutritive value of the 'weeds' was superior to warm season perennial grasses. Unfortunately relative productivity was not measured, therefore a relative productivity index could not be made. The types of plants that definitely impart weedy characteristics include:- poisonous plants; competitive weeds with low productivity; plants that are unpalatable; injurious plants and those that cause contamination. There is a paucity of reliable information on this subject, which has been recognized for some time (Johnston 1972, Auld 1981, Campbell 1988). That which does exist clearly indicates the magnitude of the losses imposed. (See section G.(i.) Economic Impact.)

Weeds in pastures can be conveniently grouped as low productivity grasses, nitrophilous forbs, poisonous plants and unpalatable species.

Plants which can be included as low productivity grasses include the genera *Stipa* and *Astrida*. (speargrass and wiregrass). These are perennial species characterised by low palatability and nutritive value. Silver grasses (*Vulpia* spp.) are included in the group. These are annuals which occur in the cooler higher rainfall areas, and are relatively unpalatable and unproductive. Serrated tussock causes greater reductions in carrying capacity than any other pasture weed in Australia (Parsons 1973). Barley grasses are annuals which provide good fodder before seed set but in New Zealand reduce productivity, as live weight gain, by up to 30% and wool production by 25% if seed set occurs (Hartley and Atkinson 1972).

iii. Product tainting

It will be realised from section 2.iii. that a few weeds cause tainting problems in produce. However as there are few citable references on this topic the previous comments cannot be added to.

iv. Product contamination

This can take the form of contaminating produce to be used for food or as a fibre. Whilst it is known that a number of plant propagules are contaminants of grain crops, documentation of the extent appears to very limited. Records of grain samples rejected at silos are kept by the various grain authorities. The standards for the level of acceptable contamination is also governed by the same bodies. Mock and Amor (1982) used such data to assess the rate of spread of brome grasses in the Victorian Mallee. They found that over the period of study, 1978 to 1981, the percentage of silos docking barley samples rose from under 5% to over 11.5%. Unfortunately reduction the value of the barley to the farmer was not included. Another weed which has been assessed is wild radish (*Raphanus raphanistrum*) in wheat (Donaldson 1986). In this instance the author collected and inspected samples of wheat from 229 silos and found the weed present in only six.

In the case of fibre, it is awned grasses and those species with hooked seeds, such as *Xanthium* that pose the greatest problems. Bathurst burr was found as a contaminant in no less than 27% of the NSW and 8% of the Victorian wool samples in 1979 (Martin and Carnahan 1982). Contamination of wool by noogoora burr was found to be more common in Queensland, affecting the wool from 32% of the holdings surveyed, whilst from NSW it was only 3.6 %.

D. Soil Degradation

The relationship between soil degradation and weed control activities was recognized as early as 1917 (Call and Sewell cited by Callaghan and Millington 1956). Unfortunately the relationship has received relatively scant attention. In particular there have been very few joint projects between weed and soil scientists and this position persists. For example, over the past decade there have been only a few weed related projects funded by the National Soil Conservation Programme, almost all in Queensland. This is a disgrace when one realises that the principal cause of soil degradation relates to cultivations mainly carried out to control weeds.

At the turn of the century, cultivation for dryland crops was based on an initial deep ploughing, 20 - 25 cm, followed by frequent cultivations to produce a fine tilth which supposedly had the following attributes:-

* a loose surface which enabled rapid penetration of water
* a soil water capacity that was increased because the soil was subdivided into small particles
* increased capillary power
* when the soil crusted it prevented evaporation
* cultivation was thought to break the capillary action and thus reduce evaporation
* sunlight and air were able to be admitted to the soil

* a fine deep tilth which enhanced root growth
* soil bacterial growth were thought to be enhanced
* wind erosion was supposedly reduced
* plants were thought to be able to withstand drought due to the greater water storage. (Callaghan and Millington 1956)

It will be realised that at this time the importance of weed control was not recognized. The work of Call and Sewell (1917) (as cited by Callaghan and Millington 1956) showed that where a soil surface was kept free of weeds, but undisturbed, moisture losses over the summer were lower than for 'dust mulches'. The later work of Veihmeyer (cited by Leeper 1963) clearly indicated that weeds were significant users of soil moisture. It was found that one plant in a tub of soil removed as much water in 3 weeks as did a soil surface exposed to the sun over a two year period. Interestingly whilst the importance of weeds to water loss was clearly shown it was still under debate in the 1960s. Leeper (1963) states 'According to the old view it is necessary to work the land after every fall of rain in order to break the capillary tubes. According to the modern view it is not even necessary to cultivate to save water, so long as weeds can be killed in some other way'. He went on to cite work that confirmed the 'modern view'. Interestingly at about the same time soil incorporated herbicides were introduced to control annual grasses. These required varying degrees of cultivation to provide adequate incorporation and after a decade and more of use it was realised that they were causing more problems than they were solving. This, together with the introduction of suitable non residual herbicides led to the development of reduced tillage techniques. In particular the introduction of paraquat enabled direct drilling of both crops and pastures by the early 1970s (Pratley and Rowell 1987). Even though this, and other, reduced tillage techniques have been adopted it is suggested that there is little evidence that they are used for its beneficial effects on the soil in winter rainfall areas (Pratley and Rowell 1987). It has been postulated that these techniques have been adopted largely due to increasing costs of frequent soil preparation (Pratley and Cornish 1985). In summer rainfall areas the need for better soil protection is widely recognized (Pratley and Rowell 1987). Even so implementation of the reduced tillage farming ethic is widely espoused (Pratley and Cornish 1985, Pratley and Rowell 1987 :Pratley 1987, Poole 1987 and Ridge 1986). Ridge (1983) correctly stated that 'the benefits of fallowing accrue by the removal of weeds which would otherwise utilise moisture and nitrogen, host pathogens and set seed which would germinate in the following crop. Hence the large investment in conventional cultivation machinery and the costs associated with its use are directed principally at weed removal - a task which can be just as readily achieved using herbicides. ' he went on to point out that 'They (the farmers) can no longer afford the luxury of recreational tillage because of its cost and because of its damaging effects on the soil structure.' There is therefore a clear need to encourage farmers to embrace conservation farming. This may mean lower returns in the short term for benefits in the longer term in horticultural crops (Olssen and Cockroft 1980). In wheat growing areas some seasons may favour conventional tillage and others direct drilling (Poole 1987). The latter author cites work of Jarvis (1983) which showed that over seven seasons there were consistently lower yields using direct drilling on a loamy sand, increasing yields with direct drilling on a clay loam and no differences on a sandy red brown earth. It will thus be realised that this is a complex issue. One has to question whether our knowledge may not be more advanced had a multi-disciplinary approach been undertaken in reduced tillage research. There is a need to ensure that soil and weed science together with agronomy and engineering are considered in future projects.

E. Energy Input

Central to any discussion on this topic is the underlying thesis that 'The ecological system of which man is a part is fundamentally a network of energy and mineral flow' (Pimental 1984). A measure of the success of any agricultural system is the production of an adequate food supply by utilising as much solar energy as possible and by minimising fossil energy inputs. This equation is all too frequently ignored, or more likely not understood, as there is a continual thrust toward greater productivity per unit area based on increasing inputs of artificial fertilizers generated from fossil fuel. For some time the ratio most commonly used to measure efficiency of production is the ratio of energy inputs to outputs. Such a ratio can vary from over ten to one for the production of maize using only manpower to 4.3 using oxen and 3.4 when using horsepower and 3.5 when a tractor is used to produce the same crop (Pimental 1984). There are difficulties in relating each of these ratios as the yields of maize used in the equations varied from 1944 to 941 to 7000 and 7000 kg/ha for the respective ratios. One should also realise that in the latter two figures, substantial inputs were included for fertilizer, electricity for drying and a quite unrealistic figure for pesticides, particularly herbicide (7000 kg/ ha)(*sic*). Thus, whilst one should not compare the ratios in this instance, it is the sort of data that are needed to allow accurate comparisons between systems. The same author has reported other calculations to demonstrate the ratio of energy inputs to outputs for a range of seventeen crops. These data show that the most efficient crop, lucerne gave a ratio of 13:1 whilst it was 5:1 for oats, to 0:6 for tomatoes and 0:2 for lettuce. The development of systems to improve these ratios depend upon a reduction in fossil fuel inputs. Those inputs that use most of the energy are fertilizers, particularly nitrogen, energy to make and run the machinery, and pesticides.

What has this to do with herbicide use? Obviously if it is possible to reduce fossil energy inputs and yet maintain outputs, hence improve the ratio, the use of herbicides should be encouraged, all other things being equal. The energy required to manufacture a herbicide varies from over 100,000 k cal./kg. for glyphosate and paraquat to 24,200 for 2,4-D (Pimental 1980). Thus one has to relate the product to be used to the potential energy savings from not using machinery for example. Such calculations have not been made for Australian cropping areas. The basis for such calculations could be derived for machinery from that generated by Bowers (1985) who reported on tillage energy data for a range of equipment on a number of soil types. Certainly, if as predicted by Shaw (1985), fuel reductions of 50% could be achieved from reduced tillage adoption, thus increasing the use of herbicides, the energy balance would show a significantly higher energy ratio. For example the use of 1.5 litres of glyphosate ha^{-1} (45,000 k cals. approx.) could save 6 to 7 litres of fuel (68,400 to 79,800 k cals.) or a saving of 20 to 30,000 plus k cals. ha^{-1}. Thus herbicides are energy efficient but to confirm this more detailed calculations are needed for a range of eventualities. Furthermore a comparison of the energy inputs for the production of food and fibre by Hall (1984) shows that in order of decreasing energy inputs they are fertilizer, field operations, irrigation, drying, pesticides and machine manufacturing. Indeed the energy inputs for pesticides were reported to be less than one fifth of that for fertilizer. The same author assessed the annual energy inputs into the food system in the USA. This showed that 35% was devoted to food production, 35% to food processing and packaging and 30% to food storage, transportation and preparation.

Some might suggest that the use of mowers is more suitable than sprays for the control of weeds. This could not be supported on an energy basis as the energy required to mow a sward (Fluck and Busey 1988) is greater than that to spray with 2,4-D at 1.4 l ha^{-1} using the data of Huzzey (1986) and Pimental (1980).

It is concluded that we should be mindful that 'Man's survival and that of all the natural biota associated with him in his ecosystem, depends on adequate supplies of energy in the form of food' (Pimental 1984). Herbicides have played and should continue to play a major role in achieving that objective on the basis of the energy equation.

F. Environmental Hazards

i. Replacement of native flora

In answering the brief 'Why the flora of Australia is worth preserving' Bellamy (1988) mentioned three plants, mountain ash *Eucalyptus regnans* the worlds tallest flowering plant, *Hakea victoriae* 'the strangest member of a plant family which includes some very strange shrubs and trees', and *Austrobaileya scandens* 'a living relic whose pollen grains closely resemble the oldest known fossil pollen'. He stressed that these three plants are key plants in the world's genetic base. Retention of the genetic base is espoused by many as a major reason for the retention of native vegetation in reference areas. Other reasons include the value to tourism and to future generations for their enjoyment and academic stimulation.

It is claimed by Carr, Robin and Robinson (1987) that environmental weeds constitute the greatest single conservation problem, as almost all types of native vegetation are being invaded or will be invaded in the future. This thesis is supported by policy makers as Kirner (1988) stated that 'Weed invasion and the capacity of weeds to dominate should be recognized as a significant threat to both the production and conservation values of public land'. Fox and Fox (1986) generalised the susceptibility of natural communities to invasion as follows:-

i there is no invasion of natural communities without disturbance
ii disturbance may be a completely novel event or may be an alteration to a natural disturbance
iii the principle outcome of a disturbance is the creation of a spare resource
iv there is greater invasion with prolonged, repeated or intense disturbance
v rich communities are less susceptible to invasion than depauperate communities
vi all plant formations (e.g. grasslands, heathlands, woodlands forests) are susceptible to invasion
vii however, some formations are more likely to be disturbed and therefore to be invaded.

Support for the notion that introduced plants are invading native vegetation is given by Gullan (1988). He reported that nearly a quarter of the wild vascular plants in Victoria have been introduced since European settlement. Most of these have been introduced for agricultural or horticultural purposes (Gullan 1988). The farmed areas of Victoria are most affected, while the large tracts of unalienated land are least affected, by invading species. Gullan (1988) also reported that 17% of the species in native grassland communities were weedy compared with approximately 11% in coastal and around 2% in salt marsh, dry forest, rainforests, swamps and heath. Some of the more important introduced weeds in such situations include English ivy (Calder 1988), boneseed (*Chrysanthemoides monilifera*) (Calder 1988, Fox 1988)) and blackberry (Amor and Harris 1979).

Whilst all native vegetation has been invaded by introduced species botanists are also concerned about the proliferation of non indigenous natives. Their concern is accommodated in the definition of an environmental weed by Carr (1988):- 'Naturalised, non-indigenous plant species outside the agricultural or garden context which adversely affect the survival or regeneration of indigenous species in natural or partly natural communities'. The term indigenous in this definition is restricted to those plants growing within their natural geographic range. Of concern are those native plants that are rapidly invading, and reportedly destroying, other native vegetation outside their geographic range. Three such examples are coast tea-tree (Leptospermum laevigatum), sweet pittosporum (Pittosporum undulatum) and coast wattle (*Acacia soporae*) (Carr 1988). There is also concern that introduced taxa may result in further detrimental hybridization as has been reported between *Acacia mucronata* and *A. longifolia* in Victoria (Carr 1988).

Roadsides are considered to be important contributors to reservoirs of remnant vegetation and as corridors for fauna in some areas. Studies of the vegetation on roadsides (Lane 1976, Lane 1979) have shown that its composition is influenced by the management of adjoining land. Even so, the species contained in the easement were markedly different from those found in adjoining pastures, conversely the sown pasture species were not plentiful on the roadsides. These studies supported the views of other authors (Moore 1971, Amor and Twentyman 1974). Following these studies it was recommended that to achieve more effective control not only should the weeds be sprayed but the establishment of desirable plants should be encouraged (Lane 1979).

As much of the public land in urbanised areas is in the form of linear reserves these are regarded as a valuable resource. These areas are invariably very visible, easily accessible and usually frequently used. Weeds in these situations affect their aesthetics, access, restrict waterflow, harbour vermin and disadvantage neighbours by invading their properties. Weed control measures have to be handled with diplomacy, and thus significant community consultation, and considerable care (Seymour 1988).

In summary, weeds present a significant threat to the integrity of native flora. Even though the value of weed control in such areas has not been assessed any such attempt should consider the extra benefits in relation to the costs involved (Tisdell 1988). The need for such assessments is all the more pressing now that areas of public land are expected to be extended, from 985,000 to an estimated 2,133,000 ha over the period 1987 to 1992 (Combellack 1988), without the funds to manage them (Tisdell 1988).

ii. Effects on native fauna

Invasive weeds alter the structure of plant communities and thus disrupt breeding sites and food availability and type for native fauna. For example invasion of holly (*Ilex aquifolium*) has led to an increase in frugiverous birds such as the blackbird in the Victorian, Dandenong Range (Calder 1988). The overall faunal implications of such changes are not well understood.

iii. Fire

Weeds in certain situations present a significant fire hazard. Grasses along linear reserves are noted to increase the fire hazard (Seymour 1988). Other plants that pose a significant fire hazard include furze (Parsons 1973) and the brooms (*Genista* and *Sarothamnus* spp.).

While weeds may impose a fire hazard others invade native vegetation following a fire. Boneseeds are weeds that respond to fire. Exposure to a fire is sufficient to stimulate over 90% of the seed bank to germinate (Lane and Shaw 1978). Whilst this is an advantage for its establishment, it is also used in strategies developed to effect its control. Once the seed has germinated it is possible to spray the seedlings with a selective herbicide and reduce the seed bank to a very low level in the one operation.

In other situations the suppression of fires has resulted in a changes in the flora. Fox (1988) reported that where fires had been less frequent in an urban reserve in Sydney the native shrub sweet pittosporum (*P. undulatum*) has increased in both extent and vigour to the detriment of other natives.

iv. Water flow

The unimpeded flow of water along rivers and supply and drainage channels is important when managing water resources. A number of weeds are found in flowing water and if allowed to grow unchecked result in a slowing of flow. This can lead to possible flooding, difficulties in meeting water demands in irrigation areas and to poor drainage. Also the build up plant debris can be a threat to structures such as bridges particularly during flooding. Some of the important species include:- in slow moving water, water hyacinth; azolla species (*Azolla* spp.); salvinia (*S. molesta*); floating pondweed (*Potamogeton tricarinatus*); common watermilfoil (*Myriophyllum variifolium*); elodea (*Elodea canadensis*); curly pondweed (*Potamogeton crispus*); common reed (*Phragmites australis*); rushes (*Juncus* spp.) and reed sweetgrass (*Glyceria maxima*). In fast moving water there are fewer species, examples include the two relatively common species, clasped pondweed (*Potamogeton perfoliatus*) and ribbonweed (*Vallisneria gigantea*) (Sainty and Jacobs 1988). The control of weeds with herbicides in flowing water, if necessary, requires one to exercise extreme care in view of the likely users downstream.

G. Economic Impact

The financial losses due to weeds in Australia have been estimated to be A$2,096 million on the basis of direct and indirect losses using 1981/82 data by Combellack (1987). More recently the same author has estimated them to be A$3,315.7 million using 1986 data (Combellack 1989). Note that this figure does not include externality effects nor risk estimates. One can thus assume that weeds impose a significant burden on society.

i. Crops

In his estimates of financial losses for Australia due to weeds in agricultural crops Combellack (1989) suggested that direct losses represented A$1013.4 million, comprising A$710 million for cultivation, A$263 million for herbicides and A$40 million for their application. Indirect losses were estimated to be A$855.6 million, A$713 million accounting for yield losses resulting from lack of weed control and A$142.6 being for product contamination thus downgrading in value. In total, therefore, weeds impose losses estimated to be A$1869 million. Added to this estimate should be those for horticultural of A$303 million comprising A$240.3 million on indirect losses and direct losses of A$62.7 million.

Attempts to derive a better way of predicting returns from spraying crops have been numerous over recent times. Most have been based on weed control thresholds. Early estimates assumed that the response of yield to weed density was described by either a linear (Marra and Carlson 1983) or a curvilinear model. The latter have been reviewed by Cousens (1985). Of the models evaluated the rectangular hyperbolae was found to provide the best relationship. Cousens (1987) and Streibig *et al.* (1989) have used this model as a basis to enable estimates of economic returns based on competitive ability, herbicide kill, weed free yield, herbicide cost and thus the economic density for a given species. As explained earlier these models do not consider weed complexes and/or time of removal or changes to edaphic conditions. Suffice to say that it is pleasing to note that this important aspect of weed control is receiving increased attention.

ii. Pastures

Combellack estimated pasture weeds to impose a burden of A$971.1 million, there being A$900.3 million on indirect costs and A$70.8 million direct costs . These estimates need to be compared with those of other authors of a more specific nature. For example it has been estimated the losses due to six weeds plus one partial assessment, for NSW, amounted to A$120 million in one year (Campbell 1988). The impact of toxic plants on livestock production in Australia has been estimated at A$80 million /annum (Culvenor 1985). The most important contributors to the estimate were loss of potential production due to the space being occupied by the weeds and their effect on breeding. The effect of chronic poisoning was not estimated and yet this is assuredly a significant contributor. The net social benefits resulting from the control of serrated tussock have been estimated to be between A$187-334 million over 10 years for a state (NSW) wide control programme (Vere, Sinden and Campbell 1980). In an economic assessment of losses to the wool industry by weeds commissioned by the Australian Wool Corporation, the estimates indicate losses totalling A$568.5 million are incurred (Anon 1988). Of this figure A$184.9 was estimated to have resulted from vegetable fault in wool and A$ 264 million due to a range of awned grasses from mortality, skin, pelt and carcass damage. Estimates for the loss in potential output due to thistles were A$ 15 million. This compares with the A$48 million estimate of Bruzzese and Heap (pers. com.) for thistles in Victoria. The enormous variation between the estimates of the latter authors points to one or the other of the estimates being astray. The value of herbicides is one area of difference. There was an estimated A$30 million spent on all pasture weeds and of this A$5 million on thistles (Anon 1988) whilst Bruzzese and Heap (pers. com.) estimated A$6.7 million was spent on herbicides in Victoria. In the estimates of Combellack (1989) the value of herbicide inputs were A$26 million for Australia based on industry sources. Certainly the figure of Bruzzese and Heap (pers. comm.) is far too high for Victoria a more realistic estimate would be around A$1.2 to 1.5 million. This brings into question the remainder of the estimates by these authors as they appear at variance with those of others.

The data for the economics of weeds in pastures is based on crude estimates in the main, and even when based on surveys, as per Anon (1988) and Bruzzese and Heap (pers. com.), the resultant estimates cannot be regarded with too much confidence. There is therefore a need to generate a better basis and methodology for future assessments. The approach taken in New Zealand, where it was shown that control of barley grass increased monetary returns by NZ$64 to 94 ha^{-1}, by Hartley and Atkinson (1978) would appear to be more appropriate. They were based on measured losses from controlled experiments.

iii. Public lands

It is much more difficult to assess the value of controlling weeds on public and recreational land as the service it provides are not estimated (Tisdell 1988). The costs of controlling weeds on such land are usually greater than for similar densities on private land because of the restrictions on the techniques used. They also tend to be more time consuming. The benefits of controlling such weeds include a reduction in the discomfort of users, maintenance of plant diversity, improvement in access, aesthetics, lowering the possibility of fires, improving amenity. It is difficult to estimate the value of such intangibles. Other more tangible benefits include a reduction in the movement of weedy plants from the public land onto the adjoining private land, and control of weeds in forests lead to increased growth rates. Weed control in waterways may result in increased fish numbers, the quantity and quality of water from public land catchments (Tisdell 1988). There are some less obvious benefits, for example as television or film locations, value of weed free reference areas to the botanists, preservation of the resource for future generations (Tisdell 1988). The same author has derived a formula to enable an economic analysis of such plants (Tisdell 1988). As it is necessary to deploy scarce resources in the most appropriate way it is suggested that this formula be tested on a park or recreation area.

iv. The environment and human welfare

Calculating environmental costs of herbicides is very difficult. Some of the inputs will be impossible for example the loss of human life. Pimental *et al.* (1980) estimated that poisonings due to pesticides cost the USA community US$184 million accounting for deaths and hospitalisation. The figure was not broken into the various categories of pesticides, therefore it is not possible to assess the proportion ascribed to herbicides. In view of the much lower toxicity of both herbicides and fungicides, compared to insecticides, these are not likely to be the dominant contributors. Other costs included in the estimations of these authors were poisoning of animals and contamination of livestock US$12 million, reduced natural enemies and pesticide resistance US$286 million, honey bee poisonings and reduced pollination US$135 million, fishery and wildlife losses US$11 million, crop destruction resulting from drift US$70 million and government pesticide pollution controls US$140 million. In total US$826 million based on 1980 data. It must be stressed that these figures relate to all pesticides and that herbicides are not likely to be a the dominant contributor. Even so, the use of herbicides does have an unknown economic impact on the environment and on human welfare in Australia. An estimate of the impact would be valuable and should include the effects on humans, through direct poisoning, hospitalisation and cancer. It should also estimate their effect on native flora and fauna. Estimates of the costs to government to control their use has been made at A$125,000/annum by Belcher (1988).

3. Control Options

i. Nil

The ecology movement may well support, at least in theory, this option. If this were practised seeds would be sown without cultivation and without any form of post sowing weed control. It is not difficult to understand that few of the eight species of plants, that together with ten animal species, contribute over 80% of the worlds food would not be very productive under such circumstances. It has been suggested that crop productivity would decline by 70-100% (Combellack 1989). This would not be an acceptable scenario to the majority as it would mean that society would have to live as hunter gatherers. As previously pointed out this would mean that the world could support an estimated population of only 100 million or 1/50 of the present population (Pimental, M. 1984). The effect of this scenario on animal production has not been estimated but it would obviously be significantly reduced.

ii. Natural and biological

Natural in this instance is defined as the use of any system of control that does not involve the use of mechanical methods that require fossil fuels or 'unnatural', that is, manufactured chemicals. Thus the use of allelopathy, defined by Rice (1984) as 'any negative or positive plant response mediated through chemicals produced by another plant' would be considered. In particular the planting of rotation or companion crops would be practiced. There has been an increase in interest in this technique. Several reports of weed suppression following another crop, or by using the residues of another crop, have been reported. For example the residues of sorghum (*Sorghum bicolor*) and oats reduced the weight of pigweed (*Portulaca oleracea*) by over 70% and that of smooth crabgrass (*Digitaria ischaemum*) by at least 85% (Putnam 1987). In another study the residues of *Tagetes patula* inhibited the germination of a number of weeds without affecting maize (Altieri and Doll 1978). Other workers have selected more allelopathic accessions of a crop (cucumber) to suppress the growth of proso millet (*Panicum miliaceum*) and white mustard (*Brassica hirta*) (Putnam and Duke 1974).

Other natural control measures include the use of natural herbicides. A number of natural compounds which have phytotoxic properties have been reported by Takahashi *et al.* (1983) and Duke and Lyndon (1987). A commercial herbicide that contains a natural product moiety is cinmethylin (CINCH, Shell Chemical Co.). A portion of this molecule is cineole, a terpene that occurs in desert plants (Putnam 1987). This author suggested that production of herbicides from plants offers scope particularly if they can be manipulated to increase their yields of useful metabolites.

Manipulation of grazing is another possibility. A study of the effects of four pasture management treatments haycutting, heavy grazing, burning and a control on the densities of ryegrass (*L. rigidum*) in a subsequent wheat crop have been reported by Reeves and Smith (1975). They noted that hay cutting, heavy grazing or burning significantly reduced ryegrass densities in the following four year cropping sequence, however yield increases were restricted to the first two years.

Biological control is a further alternative. Most of the substantial research effort on this activity in Australia has been directed toward the control of weeds in pastures or bushland. Two notable exceptions are skeleton weed and spiny emex and both have been subject to classical biological control programmes. The control of skeleton weed with the rust *Puccinia chondrillina* is well documented (Cullen, Kable and Catt 1973, Hasan 1974, Cullen and Hasan 1988). It has been estimated that the density of skeleton weed has been reduced to one hundredth of the original (Cullen and Hasan 1988). Obviously neither the latter authors nor Julien (1987) have been alerted to the ingression of a form of skeleton weed which is resistant to *P. chondrillina*. This form has reverted to densities approaching those before the release of the rust even with the effect of the two introduced arthropods *Eriophyes chondrillae* and *Cystiphora schmidti* (Shepherd pers. comm.). Whilst two insects, *Lixus cribricollis* and *Perapion antiquum*, have been introduced to control spiny emex in Australia, they have not established (Julien 1987). A third crop weed to be subject to a test programme is silver leaf nightshade (*Solanum eleagnifolium*) with a nematode (*Orrina phyllobia*) but the agent proved to be insufficiently specific (Field pers. com.).

There have been four major projects on water weeds. Alligator weed control with an insect *Agasicles hygrophila* which is quite effective in the aquatic situation but without success in terrestrial habitats (Julien 1981). Another project has had limited success is the control of water lettuce (*Pistia stratiotes*) with the insect *Procecidochares utilis*. Unfortunately this insect was parasitised by a native insect causing its numbers to decline (Harley *et al*. 1984, Julien 1987). There has been good control of water hyacinth reported following the introduction of three insects, two of which have had some effect, in particular the insect *Neochetina eichorniae* (Wright 1981). Another recent success is the introduction of the insect *Cyrtobagous salviniae* for the control of salvinia (Room *et al.* 1981). This is destined to become one of the classic biological control success stories.

Most of the biological control projects are directed toward the control of weeds in pastures/bushland. Some thirteen species have been subject to investigation: There has been some success with the Chrysolina beetles against St. John's wort, particularly in the open (Parsons 1973). Lantana (*Lantana camara*) has been the subject of biological control programmes for over 70 years, the first insect of the 18 or so introduced being in 1914 (Julien 1987), control is still erratic. The likelihood of successful attempts to control perennial ragweed (*Ambrosia artemissiifolia*) are still unclear (Julien 1987). Control of prickly pear (*Opuntia stricta*) with *Cactoblastus cactorum* is one of the classic biological control success stories. In a review of biological control and distribution of cactus species in Australia (Hosking, McFadyen and Murray 1988), the status of 23 species is considered, many are reported to be well controlled or suppressed. Attempts to control ragwort with biological control has received considerable resources over a long period of time. The first insect was introduced in 1930 (*Tyria jacobaeae*) and another three since that time. Control to date has been very limited in area with the flea beetles (*Longitarsus* spp.) being the most promising agents. A major project has been initiated in Queensland on parthenium weed. Six insects have been introduced but have provided only very limited control (Julien 1987). Biological control of Paterson's curse and boneseed are two recently initiated projects. The illegal introduction of the rust *Phragmidium violaceum* (Parsons, Field and Bruzzese 1984) led to suppression of some species of blackberry (Bruzzese and Field 1985). However, to the common observer the effect has been at best marginal. The final weed which has had a significant programme is groundsel bush (*Baccharis halimifolia*). No less than 12 insects have been introduced over a period of 20 years, of these three apparently provide partial control (Julien 1987). Other weed species that have had some investigation are gorse, sensitive plants (*Mimosa* spp.) and crofton weed (*Ageratina adenophora*).

Grazing animals have apparently not been recognized as biological control agents by those involved in this activity. Neither Julien (1987) who edited a 'World catalogue of agents and their target weeds' nor the international four yearly conferences on biological control appear to recognize the value of grazing mammals. This serious omission should be rectified as considerable evidence exists to show that animals can be very useful in controlling weeds. For example St. John's wort has been reportedly well controlled by sheep and cattle (Campbell and Dellow 1984). Goats have provided useful suppression of poa tussock (*Poa labillardieri*) (Campbell *et al.* 1984), severely defoliated blackberry, ring-barked 50% of sweet briar (*Rosa rubiginosa*), ate 90% of the variegated thistle present (Dellow *et al.* 1987), reduced the ground cover of illyrian thistle (*Onopordium illyricum*) from 10 to 0.1% (Campbell and Holst 1987), provided up to 87% reduction in seed heads of saffron thistle (*Carthamus lanatus*) (Pierce 1987) and Campbell *et al.* (1979) has found that goats will significantly reduce the density of serrated tussock. Sheep are known to provide suppression of ragwort, particularly crossbreds (Parsons 1973) and Wiltshire horns (Harradine 1987). In view of the success of the projects with grazing animals, with very limited resources, and the increasing difficulties of introducing insect and fungal biological control agents estimated to be between 9 and 14 years (Harley and Wright 1987), it may be prudent to deploy resources from the classical system to this avenue of endeavour.

More recently attempts have been made to develop mycoherbicides. Two products are reported to be marketed in the USA by Templeton (1987). One contains *Colletotrichum gleosporoides* for the control of northern jointvetch (*Aeschynomene virginica*) and the other *Phytopthora palmivora* for the control of stranglervine (*Morrenia odorata*). There is increased interest in this avenue of weed control, there being projects on 18 weed species in 14 countries outside and 10 within the USA (Templeton 1987). One of these projects is investigating the control of Bathurst burr with the fungus *Colletotrichum xanthii* in Australia (Nikandrow, Weidemann and Auld 1984).

In summary, biological agents are capable of providing a significant level of control in a limited number of situations. The area in which there has been the least amount of success with biological agents is cropping and it is emphasised that over 70 % of herbicide use is in this segment. It must therefore be stressed that if the community requires a substantial reduction in herbicide use then natural/biological control strategies are not likely to provide the answers in the short nor long terms.

iii. Mechanical

The control of weeds by mechanical means has underpinned control strategies for centuries. Smith and Secoy (1976) noted that grubbing implements were used several thousand years ago. Developments of implements has followed the progress in power whether by man, animal or tractor. As has been pointed out expenditure on mechanical control is approximately two and quarter times more than for herbicides in cropping systems in Australia.

The accidental discovery of the stump jump plough by Smith in 1876 (Brown and Huzzey 1987) revolutionised cultivation in Australia. The plough was a fundamental tool in breaking new ground for the cereal farming technique used at the turn of the century (Pratley and Rowell 1987). Weed control following the initial ploughing was usually effected by an early double discing and then frequent harrowing (Pratley and Rowell 1987).

Since that time better materials, hardened steels, even ceramics, have allowed cultivation equipment to become more efficient and durable. Also, because of present concerns about soil loss, less aggressive implements have been developed. These include blade ploughs, rod weeders and chisel ploughs with sweep points (Brown and Huzzey 1987). The retention of stubble has meant that cultivation equipment was developed to handle this heavier growth. This has meant wider tine spacing and changed tine arrangements to allow flow of stubble material. For a farmer to embrace the conservation ethic he will need to purchase new equipment. Because of the costs of such equipment it is increasingly necessary for him to demand versatile implements which by necessity lead to compromise. For example, the development of scarifiers and chisel ploughs for this purpose necessitated wider tine spacing which in turn leads to reduced weed control (Brown and Huzzey 1987).

Equipment for special purposes has been developed, for example, a no-till drill for the planting of maize into atrazine treated soil. This unit comprises modified hoe openers which move the treated soil to allow germination in a herbicide free zone (Dowell, Solie and Peeper 1986).

The lack of Australian derived information on this critical aspect of weed control points to the lack of understanding of the importance of mechanical control by public administrators and funding bodies. There is a need for the initiation of a multi-disciplinary project to improve tillage practices. Such a project must involve weed science, engineering, agronomy, soil science and economics. The project would have to be long term, have as its aim the development of a strategy that maintained or improved productivity whilst reducing soil loss. The current ad hoc approach must be stopped.

iv. Chemical

There is a voluminous literature on this subject and therefore it will not be possible to review this topic but rather provide an overview.

Herbicides vary widely in their properties. The early herbicides were mostly by-products of the chemical industry. For example arsenic trioxide, a smelter waste, iron sulfate, a by-product of the steel industry, and waste oils from the oil and gas industries. Salt and sodium chlorate are further examples. In contrast to these chemicals, specifically manufactured organic materials are now commonly used. These newer materials generally act on specific enzyme systems in the plants and thus are generally required in lower amounts. Although these herbicides affect vital metabolic processes their mode of action have been determined with accuracy for only a few materials. Of course it is not necessary to have knowledge of this process to use the materials effectively. Determination of the processes involved is usually of greater value to those synthesizing new materials, but is also important in the understanding of resistance.

Selectivity of herbicides, between weeds and crops, is dependent upon differing physiological processes, physical characteristics, application techniques and placement of the herbicide.

Herbicides comprise a wide range of molecular configurations, and have in the past been grouped on a chemical classification basis. This has become increasingly difficult as the range of chemicals broadens. They are therefore now more frequently grouped by use pattern. For example pre-planting, pre or post emergence or by crop or situation in which they are to be used.

The newer herbicides are generally used at significantly lower dose rates. Effective weed control with products such as salt at 1 tonne/ha to sodium borate applied at some 20 to 30 kg a.i./ha, the triazines typically around 1.5 to 2.0 kg a.i. /ha., the phenoxyacetics around 0.5 to 0.75 kg. a.i./ha to the newer sulfonylureas at 0.005 to 0.02 kg. a.i./ha. The ever declining rate of active material means that their application should be more accurate, this has not been entirely possible as application research has lagged behind.

There are available a wide range of products capable of selectively controlling weeds in almost any situation. The user of such materials is presented with such an array of products that it is increasingly difficult to decide which product is the most suitable. Indeed the area of service delivery in weed control is sadly lacking. The final selection of the product to use, the rate which should be used, the optimal time of use and the best way to apply it is increasingly left to the discretion of the reseller, who often does not inspect the problem. This has developed over time as both the government and manufacturing industry have withdrawn support for the user. Concurrently the community has demanded cheap, plentiful produce without residues. The answer to the community request should not be to impose further government controls but to increase the level and quality of available advice. No matter how this is achieved, by government, industry, resellers or consultants, in the end the consumer will pay. To provide a satisfactory responsible advisory/research base on this topic would require each member of the community to part with 50 cents per annum.

The use of herbicides is widespread. For example over 60% of all wheat crops grown in Australia are sprayed (Reeves 1981). Further it has been estimated that some A$263 million is spent on herbicides for the control of weeds in agricultural crops (Combellack 1989) and a further A$40 million to apply them onto crops. The most widely used herbicides in crops are chlorsulfuron, diclofop, glyphosate, trifluralin and 2,4-D.

It will be realised that any herbicide is subjected to a wide array of tests relating to toxicology, residues and efficacy before it can be sold. The amount of data required grows exponentially with time. The costs are of course passed on to the user and thus ultimately the consumer through the producer. The increasing demand for information also increases the time taken to register a product. This has happened because government resources to process the information have not kept pace with the increased requirements of the registration authorities. Indeed, in industry over recent years, there have been greater increases in staff numbers in this area than in most others. One has to question its validity in view of the very negligible problems caused in the past with significantly less well researched products. The questions that should be considered:- is there problem? what is the problem? to what does it afford a risk? Such an assessment should be conducted on a rational not emotive basis.

4. Current Control Practices

i. Crops

The most common methods of weed control in crops are cultivation and herbicides. In the conventional system the land is cultivated a number of times depending on the length of the fallow. In a short fallow (2-3 months), as few as three cultivations are normal whilst it is not uncommon for seven to eight to be carried out on a long fallow (8 to 15 months). Under the latter cropping strategy, the crop would be sown into a clean seed bed and post-emergent weed control effected as and when necessary. Such weed control may be mechanical, particularly in row crops, or with selective herbicides as in cereal crops. Alternative systems are increasingly being employed, for example, reduced tillage or even direct drilling. In these strategies, cultivations are replaced by herbicides. Details of the various systems have been described by Poole (1987) and Amor and Ridge (1987) for winter crops, and by Holland, Doyle and Marley (1987) for summer crops. Control of weeds in horticulture is more varied as in some situations, such as orchards, mowing is frequently the preferred method, though cultivation is also widely practiced and in some orchards, such as citrus, total weed control using herbicides is the most efficient. Another form of weed control used is that of mulches, whether by straw, plastic or bark. Variations of, and mixtures of, these four weed control methods are also often used, they are reviewed in part by Tisdall and Huett (1987).

Apart from the more obvious weed control operations the astute farmer is alert to the benefits of manipulating weed density in the crop by means of management. For example, strategic grazing can reduce the burden of seeds by preventing seeding in the year before planting. This technique is commonly used by those farmers who have sheep. Even so, it must be realised that to implement an effective strategy requires experience because timing is important (Myers and Squires 1970). Also it does impose an opportunity cost to move the animals. Another way of reducing the seed burden is to spray top (Jones *et al.* 1984) or spray graze (Pearce 1972). In both of these methods the pasture is sprayed to prevent seeding directly or with the aid of the grazing animal.

As pointed out previously, biological control has not played a significant role in the control of weeds that affect cropping. The notable exception is skeleton weed which was reduced to a very low level following the release of the fungus *Puccinia chondillae*. The original dominant form of the weed was susceptible but has since been replaced by a tolerant form.

In summary, most farmers employ integrated weed control. The level of integration depends to a large extent on the type of farming enterprise particularly on the availability of animals.

ii. Pastures

Control of pasture weeds is based on an integrated approach involving mechanical, grazing and biological control and in some cases herbicides.

Pasture weed control is mostly carried out by grazing animals because it is relatively cheap. The effect of grazing pressure on the level of weeds is not well documented other than for the control of particular weed species (see section 3.ii.).

Apart from grazing, pasture improvement is commonly recommended to suppress the existing weeds or subsequently germinating seedlings (Parsons 1973). Herbicides are used to control such species as thistles, capeweed, bracken, serrated tussock, blackberry and annual grasses. Expenditure on herbicides for this purpose, approximately A$20 to 25 million, is very low when related to the area of sown pastures and grasses in Australia, 27.5 million hectares and thus an average expenditure of 73 to 91 cents per hectare.

It was assumed by Combellack (1989) that almost as much is spent on mechanical control, for example mowing, slashing and burning as there would be on herbicides. Thus of the total expenditure of A$70.8 million spent on pasture weed control in Australia, approximately A$25 to 30 million would be spent on mechanical control.

Research on biological control is directed at a number of pasture weeds. The more important projects under consideration at present are aimed at controlling Paterson's curse, thistles (*Circium* and *Carduus* spp), ragwort, parthenium and the basic work has been completed for the fungus *Phragmidium violaceum* for blackberry control.

iii. Other Situations

The control of weeds in aquatic environments may be by biological agents as is mostly the case for salvinia and to a lesser extent water hyacinth. The use of mechanical removal, particularly in drains, is commonly practised. However it is costly and slow but necessary when siltation and weed growth restricts water flow. Herbicides are used to control such species as cumbungi, Canadian pondweed and pondweeds and a wide range of other species in certain situations.

Control of weeds along roads is necessary to ensure visibility and to reduce the fire hazard. Herbicides, comprising a knockdown and residual, are mostly used for this purpose. This extent of this activity is growing as it is far more efficient than mechanical control using mowers or other types of cutters or hand chipping. Similar practices, are used in industrial situations.

The control of weeds on public lands including National parks is more exacting than in other situations. Therefore hand pulling, small cutting machines and in some situations controlled fires are used. Where appropriate selective post-emergent, non-residual herbicides are employed to control such weeds as blackberry. Biological control of this species and boneseed is under investigation . In this situation the encouragement of species native to the area is of a high priority.

In productive forests, the control of weeds, mostly grasses and shrubs, is usually achieved by using herbicides.

In the home garden weed control is mostly by hand labour either by pulling or mechanical removal. Herbicides are used rarely to control pernicious weeds such as flatweed (*Hypochoeris radicata*), oxalis (*Oxalis pes-caprae*) and paspalum (*P. dilatatum*).

5. Appraisal of Concerns

i. Residues

When members of the public are exposed to statements indicating that less than 0.1% of the pesticide applied to crops reaches the target pests (Pimental and Levitan 1986) they have a right to ask why. Indeed this figure is by no means atypical of the inefficiency of insecticide use. For example the above authors calculated that only 0.003% of the pesticide applied to control *Pieris rapae* in cabbage was consumed by the pest. Even more striking is the calculation of Joyce, Uk and Parkin (1977) that only 0.0000001% of the DDT applied reached the target insect *Heliothis*. In an estimate of the efficiency of post emergence spraying of herbicides Combellack (1981) noted that up to 2% was collected by the crop and 5% by the seedling weeds, and 30 to 60% by mature weeds when spot spraying (Combellack 1979). These figures compare with those of Brian (cited by Graham-Bryce 1977) of 30% for paraquat when controlling grass weeds and the 0.1 to 5% for the post-emergent control of weeds in maize (Pimental and Levitan 1986). In his review of loss of herbicide from ground sprayers, Combellack (1982) noted that significantly more spray loss occurred within rather than outside the target area. Obviously all that material that is not retained, or utilised, by the target plants is a possible environmental hazard. Some work has been directed toward improving collection by target plants. For example Combellack and Richardson (1985) and Richardson (1987) have reported that spray collection efficiency is dramatically increased if the spray sheet is directed along the direction of travel at certain forward speeds. In view of the losses within the target area more research should be conducted to reduce contamination of the soil and possibly underground water.

a Residues In Soil

Herbicide residues in the soil have been extensively studied both within and outside Australia. The literature on this subject is so extensive as to preclude a review in this paper. The interested reader is referred to a text such as Hance (1980) and reviews such as Johnstone (1987). In general there appear to be few incidences of significant carryover of herbicide residues in most instances. The papers do clearly show that there are large differences between sites (Hance 1980) even within sites (Johnstone 1987). Also trifluralin was reported to be more persistent if a dry summer followed application (Johnstone 1987), and similarly atrazine was less readily degraded at low soil moisture and below average temperatures (Ferris 1985 cited by Johnstone 1987). From the evidence reported, soil residues of the most commonly used herbicides in the cereal areas are unlikely to present a significant problem other than in a dry year following application. However there are data for some of the more persistent herbicides used to control perennial weeds in cereal crops such as clopyralid, picloram or dicamba. Furthermore there are no Australian reports of the more persistent herbicides used in non-crop areas, for example triclopyr, hexazinone and diuron. It is unlikely that such materials will pose any great concern and therefore extrapolation from data generated elsewhere should suffice for those herbicides mentioned.

b Residues in Water

There are no known residue studies of underground water in Australia and yet this is a very emotive topic in Europe and North America. Potential herbicide residues in underground water are determined by soil type, nature of the chemical, management and climatic factors. Important factors which determine the presence of herbicide, and its quantity, in an aquifer is the amount used and the density of use with respect to the recharge zones. Also important is the rate of water movement through the soil. The properties of the herbicide are also of importance, for example how it partitions between the soil and water and its stability in the soil and water. The prediction of residues in aquifer systems is a complex topic and has been the subject of a number of studies overseas. These have been dominated by the generation and testing of models. Examples include Chemical Migration in Soil (Nofzinger and Hornsby 1985); Pesticide Root Zone Model (Carsel *et al.* 1984); Leaching Model for Pesticides (Wagnet and Hutson 1986) and Groundwater Loading Effects and Agricultural Management Systems (Leonard and Knisel 1988). The latter is an extension of Chemicals Runoff and Erosion from Agricultural Management Systems (Knisel 1980). It appears that this field of endeavour comprises many theoreticians and few practical scientists. This is supported by the fact that all of the models are designed to cope with the 'average year' however it will invariably be the atypical year that causes the problem. Also it must be realised that the effects of rainfall distribution are more significant for short than long half-life herbicides (Leonard and Knisel 1988).

One of the more persistent herbicides that has been studied is picloram which can be phytotoxic for up to five years in some soil types (Lym and Messersmith 1988). Picloram has a relatively high water solubility, 430 ppm at 25°C (Anon 1983). This herbicide is known to leach readily in coarse textured soils but more slowly in fine textured ones (Burnside, Wicks and Fenstar 1971). One would therefore expect this herbicide to find its way into underground water in areas of intense use. Recent surveys by Lym and Messersmith (1988) and Smith and co workers (1986) have separately detected and reported such residues. The former workers found that whilst occurrence of this herbicide was not uncommon, 132 out of 527 wells, in areas where picloram had been used for the control of leafy spurge (*Euphorbia esula*), concentrations detected were calculated to be at least 100 times below that suggested as acceptable for water for human consumption. In the other study picloram was found in ground water at 120 cm depth, at sites away from the treated areas. It was also detected at very low levels, 26 months after application in a lake one km from the treated area. Again the concentrations can be calculated to be significantly lower than those acceptable in potable water.

In other studies the herbicide atrazine has been detected in groundwaters. In a study of 20 wells in the USA, atrazine was found in 14 at concentrations ranging from 13 to 1110 ng/L (Pionke *et al.* 1988). The quantity and spatial distribution of the residues reflected atrazine use in the fields. This herbicide has been detected in other studies for example in the shallow groundwaters under continuous corn growing in on irrigated sands in Nebraska (Junk, Spalding and Richard 1980). In Australia there may well be small residues of this herbicide in those areas that have low water tables, use irrigation and grow crops where atrazine is frequently applied.

c. Residues in Food

This is a very emotional topic, however it must be emphasised that it is rare to find herbicide residues in food in quantities to be of concern because of the time between treatment and harvest. For example the published data for linuron, a product which has limited use, for a range of crops show them to be less than 0.1 mg/kg whilst the tolerance for this material ranges from 1.0 in the USA to 0.05 mg/kg in the Netherlands for potatoes (Maier-Bode and Hartel 1981). These authors concluded that the residue levels are not exceeded in good agricultural practice. However, residues are possible, if products are not used in accordance with the label directions. For instance a farmer could spray a pasture for weeds and graze before the withholding period has expired, this could lead to residues in the meat or milk.

Whilst herbicide residues in most crops are invariably insignificant the picking of freshly sprayed blackberries is one way of consuming fruit contaminated with an above the recommended residue level. Studies on the residues of 2,4,5-T by Donaldson and Irvine (1979) showed that 19.4 ppm of the herbicide was present immediately after spraying. This declined to 11.0 ppm by two weeks after. They calculated that for a 60 kg person to eat sufficient to reach the LD-50 for rats they would have to consume 900 kg of freshly sprayed fruit. Labels of products used for the control of blackberries should state whether canes with ripe fruit can be sprayed.

In summary providing the herbicide is used in accordance with the label recommendations, the level of residue in foodstuff will be much less than the maximum residue level set by the National Health and Medical Research Council.

d. Residues in the Air

Herbicides are most commonly applied by spraying machines either ground based or from the air. To effectively distribute the spray over the target area the liquid must be converted into droplets before distribution. Some of the droplets may move from their intended course for a variety of reasons, notably wind, eddy currents or miss-direction.

Droplet Drift

The extent of the movement of droplets can be controlled by ensuring that they are mostly >100 um. (Combellack 1984). To ensure that this is achieved the user must be aware of the factors that govern the spectra of droplet sizes. They include:- nozzle size, the larger the bigger the droplets; the pressure, the higher the pressure the larger the volume of potential drift; and the angle of the spray sheet, the smaller the angle the less the drift potential. The formulation of the herbicide also has a small influence on the spectra but is of more significance in governing the rate of evaporation, and hence the decrease in droplet size between the nozzle and the target. Thus to minimize droplet drift the distance between the nozzle and the target should be kept to a minimum. Because of this it is generally more difficult to prevent droplet drift from an aircraft than a ground rig under similar conditions. The person applying the spray is bound by law to keep the spray within the area being treated (Irvine 1984). In his paper Irvine (1984) suggested that there are a number of avenues of litigation including private nuisance, although he stressed that to merit legal intervention in this instance the annoyance or discomfort must be substantial; strict liability, this relates to the escape of a dangerous substance from a property; and trespass. Many of the aerial spraying cases in the USA have succeeded on the grounds of trespass. It is therefore quite clear that the bystander has every right to be concerned if contaminated by herbicide spray drift.

The likelihood of spray, as droplet drift, from ground sprayers moving outside the target area has been reviewed by Combellack (1981). It can be concluded from the review that the amount of movement is rarely greater than 2% of the applied volume at 10 meters from the boom. However if the boom was unstable or the droplets too small, then the volume of drift could be substantially greater.

The paper of Spillman (1982) describes in detail the effect of turbulence on droplet movement. It was concluded that 225 um droplets are required for fixed wing aircraft to minimise off-target movement. In view of the complexity of this issue it is not possible to generalise for aircraft, whether fixed wing or helicopters. Suffice to say that droplet drift can be a significant problem if the wrong droplet size is generated, flying height is too great, the weather conditions adverse and the wrong formulation used.

It must be concluded that droplet drift will occur to some degree from almost every spraying mission. The amount that moves, and the distance of its movement, is determined by the many variables at the time of spraying. Under most circumstances it is likely to be a small fraction, 50 meters from the point of emission.

Vapour Drift

The loss of herbicide from the target area in the form of vapour has been of concern for some time. The theoretical principles which control this process have been discussed by Hartley (1969) and reviewed by Wheatley (1976). All herbicides have a tendency to volatilize, however the rate is controlled by passive diffusion which is generally enhanced by the mass movement of air. Other factors influencing the rate of volatilization include the physico-chemical nature of the herbicide and form of deposit on the target surface.

There have been numerous studies on the volatility of various herbicides,. for example phenoxyacetics (Grover 1976), triazines (Guenzi and Beard 1974), carbamates (Gray and Weierich 1965) and dinitroanilines (Helling 1976). The magnitude of losses due to vapour can be greater than for droplets. For example Grover *et al.* (1976) reported that up to 30% of 2,4-D ester could be lost as vapour. In the studies reported by Gray and Weierich (1965) losses of up to 60% of the carbamates could occur under certain circumstances. In more recent studies by Grover *et al.* (1985) it has been shown that vapour loss of 2,4-D can occur following rain for up to 5 days after application. Furthermore, in the study of Robinson and Fox (1978) 2,4-D vapour was found to be transported for 16 to 90 kilometres. It was found the amount transported over such distances was related to the proportion of ester or amine used, the latter formulation resulting in significantly less movement. Vapour losses can be more important than those of droplets.

ii. Health of Applicators and Bystanders

The health of the applicator and bystander is of concern to all. In particular, it is essential that the mixer and applicator read the label with care and ensure that they wear the prescribed protective clothing. Unfortunately not all are fastidious in this regard and this can lead to significantly increased contamination. For example, in a study on the insecticide ethion the amount of material which penetrated the mixers clothing was 27.6% but when wearing 100% cotton denim it was reduced to 3.8 %. The applicator had 16.5 and 0.7% penetration in the same experiment (Freed *et al.* 1980). To reduce the contamination of users with the concentrate it is necessary to introduce closed transfer systems.

iii. Environmental Degradation

a. Effects on Soil Microflora and Fauna

The effects of herbicides on the microflora varies with the material used, the use pattern, the amount reaching the ground, the soil type, the soil pH and soil moisture. There has been a general review on this topic by Wardrop (1986). It was concluded that several processes are affected by herbicides. For example the nitrogen cycle by atrazine; cellulose degradation by paraquat; bacteria legume symbiosis by trifluralin; and stimulation of cellulose decomposition by glyphosate. It should also be noted that herbicides frequently affect soil algae for example linuron and diuron (Maier-Bode and Hartel 1981), clorpropham and propham (Rajagopal *et al.* 1984) and the triazines (Kneusli *et al.* 1969). On the other hand some, for instance linuron and diuron, are active against pathogenic soil fungi such as *Fusarium* spp. (Maier-Bode and Hartel 1981). A study by Biederbeck, Campbell and Smith (1987) showed that where 2,4-D had been used for 35 consecutive years only transient changes to soil biochemical processes were noted for a short period after application. The effect of herbicides on bacteria is very varied, generally reducing some and increasing others and it is therefore not possible to generalise. There are also data, for example for linuron and monolinuron (Maier-Bode and Hartel 1981), on the effects of herbicides on soil and aquatic fauna. Such information, usually on a limited range of species, has to be developed to satisfy registration requirements, therefore much of it remains within the enclaves of industry. It should be pointed out that many believe that data should be generated for Australian flora and fauna (Wardrop 1986). As accurate studies in this area are resource demanding one has to carefully estimate their value before committing funds. Probably of more interest and value would be comparative studies of the soil flora and fauna in different farming systems, with and without herbicide inputs, to assess whether any gross changes have occurred. This approach is suggested as invariably the effect of the herbicide appears transient and often the demand is for information on long term effects. Also the variation within plots of 56 to 129% coefficient of variation (Jolly and Johnstone 1987) for herbicide residues means that interpretation of results is very difficult. It is concluded that whilst there are changes to both the flora and the fauna they appear to be transient.

b. Herbicide Resistant Weeds

In 1981 there were 29 species with well documented resistance to the s-triazine herbicides, by 1983 there were 37 and 42 by 1987 (Gressel 1987). There is now resistance of barley grass to paraquat, and of wimmera ryegrass and wild oats to diclofop methyl in Australia (Howat 1987). Ryegrass is also exhibiting cross resistance to other herbicides, for example fluazifop butyl, chlorsulfuron, metsulfuron, trifluralin, alloxydim and metribuzin. To overcome future problems it is necessary to implement a mamagement strategy. Herbicide rotations can delay the development of resistance on a purely mathematical basis, i.e. if it takes 10 years with the use of one herbicide every year by using it every 2 or 3 years will delay the onset to 20 or 30 years respectively. The use of mixtures may also help. Herbicide mixtures can be considered as two groups, (1) where they control essentially the same species or (2) quite different species. In the situation where they control essentially the same species resistance may or may not increase depending on whether the two together increase the rate of kill or not. If they are more effective then resistance build up accelerates. The mixture which controls different species is more likely to induce resistance because it is likely to be used more frequently. In summary to delay resistance build up decrease the level of control and reduce the selection pressure for resistance. To quote Gressael (1987) " The farmer does not need fantastic control, just adequate control."

6. Predicated Control Strategies

It is predicted that future weed control strategies will be based on an integration of efficient utilisation of herbicide with non-herbicide control techniques. The various options to achieve this have been explored by Combellack (1989). It was concluded that teams to investigate ways of reducing herbicide inputs and for the monitoring and predicting of ecological shifts would be essential. Further inputs into biological control and the effect of management changes on the weed flora were considered beneficial but unlikely to be cost effective. Research in the areas of allelopathy, natural herbicides and "physical" control were regarded as speculative. Inundative biological control was supported. Further work on mechanical control was considered essential, particularly as it relates to soil loss. The development of more efficient utilisation of herbicides was recognized by Combellack (1989) as essential. This development should consider five elements:- application efficiency; use of more effective formulations and adjuvants; timing of herbicide applications; spraying weeds only where they occur and the acceptance of lower levels of weed control consistent with optimising economic returns. It was estimated that such a programme would require sixteen research and nine support staff at an cost estimated to be A$1.0 million per year. It was also estimated that such a team should be able to define ways of reducing herbicide inputs by around 30% in five years and 60% in ten years in the major cropping areas. It was stressed that a significant commitment to extension would be necessary if the results of the research were to be adopted. Indeed a concurrent extension programme should enable targets of 15% reduction in herbicide use in 5 years and 50% in ten years to be achieved (Sykes pers. comm.).

In conclusion, the present research direction will need to change or extra resources be deployed to meet these suggestions. Those areas of greatest research need are:- assessment of the economic impact of weeds; minimisation of residues in soil, water, air and food (N.B. not to be confused with monitoring residues); reduction in soil degradation (to include a weed control component) and development of weed control strategies for public lands. It is to be realised that such suggestions are compatible with the Integrated Weed Control ethic defined as "A weed management system that, in the context of the associated environment and the population dynamics of the weeds species, utilises all suitable techniques and methods in as compatible a manner as possible and maintains the weed at levels below those causing economic injury" (adapted from F.A.O. definition).

7. Conclusions And Recommendations

i There is a need for the community to be informed of the significance of weeds, for example their effect on:-

- human and animal welfare
- production of food and fibre
- soil erosion/water quality
- value of public lands
- water flow
- fire, visibility and other hazards.

ii There is a need for the community to be given a better understanding of the role of herbicides with respect to:-

- improving human and animal welfare
- improving the production of fibre and food
- reducing soil erosion and improving water quality
- maintaining water flow
- reducing fire hazards and improving safety
- reducing the damage to public lands.

iii The public needs to be alerted, in a more rational way, of the problems that herbicides may pose:-

- as residues in soil, air, water and food, and
- to the health of operators, manufacturers, consumers
- and bystanders.

iv Whilst various government policies aimed at reducing pesticides "whenever possible" are accepted, concern must be expressed at resulting administrative interpretation and policy implementation. It appears that administrators have accepted the notion that pesticides, including herbicides, are a threat to human health and welfare and to the environment. This has led to the development of strategies to overcome such problems. Whilst accepting that herbicides are found in unwanted situations the review does not support that they are a significant threat to human health or the environment. It does however clearly indicate that both human and animal welfare and the environment would benefit from their continued use. It is therefore recommended that government adopt a more positive position on herbicides by carefully "assessing" the concerns about the major uses of herbicides. To achieve this objective they should engage a person(s) to develop well researched papers on matters of concern; precipitate public forums to consider such concerns; develop literature to explain the concerns; ensure that all parties involved in the use of such materials are consulted.

v The review has identified four areas of major concern which need consideration and change in policy:-

- the relationship between soil erosion and weed control has been acknowledged since 1917. However there appears a reluctance by the N S C P (National Soil Conservation Programme) to fund or initiate projects relating to weed control. The N S C P administrators should take immediate steps to promote a multi-disciplinary (Agricultural Engineers, Soil Scientists, Agronomists, Weed Scientists, Economists) approach to reduced tillage. This need only be done at a few selected locations. The objectives of such work should be simple - the development of sustainable cropping systems which reduce soil loss whilst maintaining or improving productivity.
- A national or state multi-discipline team needs to be established to identify ways of reducing herbicide inputs. This will necessitate consideration of the following:-
- various control options.
- weed thresholds
- whole farm management
- herbicide formulations
- application efficiency
- floristic changes
- The objectives of the team should be to "identify ways of providing a system which will enable a reduction in current herbicide dose rates of 15% in five years and 50% in ten years whilst maintaining or improving productivity". This could be funded by generating a levy of 1% against all herbicide sold.
- The review revealed that biological control of weeds projects with grazing animals, whilst poorly resourced, have been generally more successful than the classical approach. Consideration should be given to redeploying resources from the classical area to that of grazing animals. Also the biological control fraternity should recognize the value of the grazing animal as a biological control approach; this has hitherto not been the practice.
- Much rhetoric has been generated about environmental weed control. It remains a poorly understood science, is devoid of resources and is in desperate need of rec-

ognition. It is recommended that a panel of experts be convened to identify better how this enormous problem can be approached. It should have as minimum terms of reference:-

*identification of available resources
*determination of current control methods
*review of current literature
*identification of needs
*development of a proposal which will identify resource needs, location of needs, funding arrangements and a time scale to carry out identified needs.

vi Whilst generating the information for this review it became apparent that research direction is increasingly driven by consumer derived funding. It is recognized that policy makers believe this to be beneficial and encourage their managers to attract as many funds as possible. This approach to research is not supported for the following reasons:-

* it generally funds short term, at the expense of long term, projects
* it necessitates that scientists be engaged on short term contracts which when expired often means the developed expertise is lost
* often the funded research determines the direction of other government research
* it consumes an inordinate amount of the researcher's time drawing up submissions and writing reports.
* there are invariably restrictions on reporting the results

The following changes to the present system are recommended:

* The commonwealth and states develop a priority list of project areas. (This could be done through the present standing committees providing relevant outside bodies were included.) The States/Commonwealth to establish a body to represent all interests. These bodies would then redirect funds to relevant institutions. This would submit applications for the States/Commonwealth and reduce the number of submissions and more accurately direct project work.

vi Manufacturing industry and relevant government departments should be encouraged to work together. This could be achieved in one of two ways (i) direct funding or (ii) placement of staff at government or higher education establishments. Co-operation between industry, government, user and the consumer must be a priority objective. The "them" and "us" syndrome must be overcome.

viii The review confirmed the complexity of weed control. It is imperative that more trained advisers are available to users if more complicated weed control strategies, such as further developments in integrated weed management, are to be implemented. Trained weed scientists are scarce; advisers even more so.

The statement by Julian Huxley summarizes the reason for the present dilemma *"Whenever the lag in communication between science and general thought grows considerable, whenever science through laziness, pride or pedantry, fails to make herself understood and whenever the public, through laziness, stupidity or prejudice, fails to understand, then we shall proceed to a lamentable divorce".*

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