SOME AGRO-ECONOMICAL ASPECTS OF IMPROVED WEED MANAGEMENT SYSTEMS IN INDIAN SEMI-ARID TROPICS

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Summary Although herbicide use is rapidly increasing the world-over it has become difficult to convince the small farmer of the Indian semi-arid tropics to replace his present system of weed control with the chemicals. The paper describes the resource base and the setting at the peasant farmer level which determines his present weeding system. ICRISAT on-farm studies have shown that the present weed control activity is closely related to the quality of the resource base and is guided by rational considerations. Farmers allocate more effort to crops on more productive areas and to crops with high values per unit area. The interrow cultivation is done primarily by males while hand weeding is primarily done by hired female labour. An ex-ante appraisal of alternative weed control methods has shown that for rainfed crops of the Indian semi-arid tropics, herbicide use cannot at present be advocated because of cost considerations as well as the possible decrease in the income opportunities for the most disadvantaged labour group in India - landless female labourers. On-farm field trials have further shown that the herbicide use is more costly than handweeding and the expected yield increase due to herbicide use is negligible. The farmers' present weed control practices seem to be adequate to obtain optimum yields under the present farming systems. The paper also attempts to identify a few areas of herbicide research and suggests that they should be focussed on and associated with research efforts aimed at achieving substantial changes in the farming system.

INTRODUCTION

All weed control practices give high returns in relation to inputs because of the large increase in crop yields from controlling weeds. Recently weed control has become one of the more efficient areas of agriculture with the adoption of chemicals to replace manual weeding. There is ample evidence to support the position that herbicide use, at least in developed countries, is a profitable capital expenditure. Thus herbicide use has increased more rapidly during the last decade than most other agricultural inputs, including all other types of pesticides (Miller, 1976). Worldwide weed research has therefore been focussed mainly on the use of herbicides, but the advances have not, in general, reached peasant farmers, particularly the small-scale substistence farmers of the semi-arid tropics (SAT). The factors contributing to the limited adoption of herbicide weed control methods, despite their demonstrated efficacy at research stations and in some 'on-farm' evaluations, are described by many authors (Shetty et al, 1977; Haswell, 1972; Okali, 1978; Parker, 1977; Hammerton, 1974) and they include:

a) The limited cash flow and income of the farmers that leaves little or nothing to invest in the farm.

b) The ample supply of both family and hired labour and the fear of labour displacement.

c) The hesitation to accept risks in adopting new practices.

d) Ignorance of the losses caused by weeds, especially during the early crop growth period.

e) The alternate use of weeds, often as fodder or vegetables.

In this paper, ICRISAT's approaches and experiences in analysing the Indian SAT farmers' reluctance to accept improved modern weed control methods are highlighted using information from studies conducted to gather information and understanding of the crops, soil, climate and social circumstances where improved weed management could have a greater impact. Using the results of the studies conducted so far, the implications for future agronomic weed research activities that will help in increasing the agricultural productivity in semi-arid tropical India are also explored.

THE SETTING IN THE SEMI-ARID TROPICS

The climate of the SAT is defined as having 5-10 months in which potential evapotranspiration exceeds precipitation and a total rainfall of between approximately 400 and 1200 mm. The SAT is estimated to cover 19.6 million square kilometres in 49 countries and has a population exceeding 600 million. More than 70% of the cultivated area of India is in the SAT and the area has a population of 350 million persons. Thus India represents 10% of the total SAT area and 56% of its population (Ryan, 1974).

Sorghum, millets, chickpea, pigeonpea and groundnut are the important crops of the semi-arid tropics and the traditional agricultural systems involving these crops have developed over a long period. They do not give high economic returns, but rather give an adequate and secure harvest with the available tools and labour (Kampen et al, 1974). Poor yields of all the major crops are a feature of SAT production; for example, the average sorghum yield is only 800 kg/ha, about 70 percent of the average world yield and only 20 percent that of Europe (Kanwar and Ryan, 1976).

Although average precipitation in many parts of SAT India appears to be sufficient for one or even two good crops per year, the rainfall patterns are erratic and extended droughts are frequent. Within the SAT India, judged by developed country standards, most farmers are small and have limited capital, education and aspirations. They farm their land with few inputs and without the benefits of regular, regional irrigation. Additionally within the villages there are many other people who are dependent on the small farmer; his family, the artisans and the landless labour whom he employs.

The main features which have direct relevance to weed management systems practiced by the farmers are described by Shetty et al (1977) and include the following:

a) Weed problems are more complex than those of temperate zones.

b) The farms are small and divided into a number of fields; in addition almost all fields are surrounded by uncultivated areas or bunds which serve as sources of weed infestation. Mixed or intercropping is the most common cropping system followed.

c) The generally poor soils coupled with erratic amounts and distribution of rainfall makes tillage difficult and crop and weed growth extremely unpredictable.

d) The improved farming systems technology required for crops under rainfed conditions is complex and if available has not yet fully reached the farmer.

e) The farmer owns limited resources and operates with scarce and expensive capital.

f) The supply of farm labour in the villages is generally good.

g) The farmers are unaware of or are fatalistic about the yield losses caused by weeds.

h) There is a lack of trained research and extension personnel.

Presently farmers depend predominantly for weed control on hoeing and hand weeding with traditional equipment - 'Guntaka' or 'Danthe' (hand hoes) and weeding policy is variable. Interrow cultivation is the basic method of weed control but in many cases no weeding is done. Often, either through ignorance or because weeds are used for fodder, weeding may only be done once the weeds are well established. Herbicide use on the crops of the SAT is negligible; about 75% of the presently sold herbicides in India are consumed by tea and coffee plantations and the remainder mostly by rice and wheat (Kanwar, 1978).

METHODOLOGY ADOPTED FOR AGRO-ECONOMICAL ANALYSIS

Since 1975, in addition to agronomic studies within the research center, a series of agro-economic 'on-farm' investigations were conducted by ICRISAT, to develop and evaluate alternate weed management systems. The objectives of this on-farm weed research were:

- to measure the success of the farmers own methods of weed control;
- to investigate whether alternate and improved methods of weed control are feasible under the existing system of the small farmer, and to assess the pay off, if any, of additional weed control by the farmer;
- to observe whether improved methods of weed control are more appropriate under improved farming systems with high levels of inputs.

Three types of investigations were carried out:

1. The ex-ante appraisal of herbicide use in SAT India taking account of both technical and socio-economic effects by using the data from ICRISAT's village level studies. This involved the documentation of the extent and timeliness of weed control activities by farmers in three distinct agro-climatic zones of SAT India (Table 1). Further, alternate weed control methods (involving inter-culture, hand weeding and herbicides alone or in combinations) were developed and budgets compared in order to assess the potential for use of herbicides in these areas at the present time and with the existing resource position. It should be noted that in this cost analysis of alternative weed control methods, though we have tried to draw up the plans in such a way that they give an

equivalent quality of weed control within each crop, any possible yield effect of herbicides was neglected. Also, in the economic evaluation only individual crops (not the cropping system) and only individual farmers (not the community) were considered[1/].

Table 1

Characteristics of the study areas

Particulars	Andhra Pradesh* Mahabubnagar** Aurepalle***	Maharashtra* Akola** Kanzara***	Maharashtra* Sholapur** Shirapur***
Soil type	Shallow to medium Alfisols	Medium deep Vertisols	Deep Vertisols
Average rainfall (mm)	680	818	635
Average farm size (net cultivated area in ha)	3.5	6.0	6.5
Rainfed area to total cropped area (%)	88	95	92
Total house holds (no.)	476	169	297
Landless households (%) in population of village	28	32	24
Bullock pair (no.) per 100 ha of net cultivated area	42	26	17
Family workers (no.) per 100 ha	109	70	71
Distance from ICRISAT Center (km)	100	500	300

* State; ** District; *** Village.

2. Operational field research on the farmers' fields under farmers conditions mainly to observe whether herbicides could be introduced as an additional practice for controlling weeds, in the existing situations. The treatments were:

i) farmers permanent weed control practices only;

ii) i + application of low rate pre-emergence herbicides;

iii) i + frequent hand weedings so as to maintain a weed free situation.

1/ For a more detailed version of the methodology and the results of this study see Binswanger and Shetty (1977).

3. Operational field research on the farmers' fields under the farmers traditional as well as improved (in terms of soil fertility) systems:- in the experiments additional treatments involving low and high fertility levels and low and high herbicide rates, combination of herbicide and other cultural weed control treatments were superimposed on the farmers' fields [1/].

When conducting these 'on-farm' field studies farmers were involved in planning and executing the field trials. This helped us in understanding more about the philosophy and reasoning behind existing traditional practices.

SALIENT RESULTS OF 3 YEAR STUDY

Extent and timeliness of weed control activity: As the three study districts were in very different agro-climatic zones the weed control activities also varied and seemed to be closely related to the quality of the resource base, the value of the crop grown and the condition of the crop growth at the weeding and interculture stages. In the assured rainfall area with medium-deep Vertisols of Akola district, weed control could be described as good, while in the poorer areas at Mahabubnagar (low rainfall and shallow Alfisols) and Sholapur (low rainfall, monsoon fallow on deep Vertisols) much less activity takes place and existing weed control practices appear to be deficient in some crops (for details see Binswanger and Shetty, 1977).

Farmers' weed control activity seems to be guided by quite rational consideration. They allocated more effort to crops on better lands and to crops with high values per unit area. Crops like cotton in Akola and castor (high value) in Mahabubnagar receive more care than crops like sorghum and millet. Hand weeding is not done in Mahabubnagar but is considered desirable in Akola. Where crops are not handweeded, preference for interculture is given to cash crops (like castor or groundnut) rather than the food crop mixture (sorghum/millet). Usually castor and cotton fields look clean without many weeds, whereas in other low value crops as well as in mixed cropping systems, weeds within the row still remain even after intercultivation. Weeds are a severe problem in the rainy season crops in Sholapur. In the post-rainy season the weed problem is less severe because most plots are harrowed several times during the rainy season and most post-rainy season plots look quite weed free. Farmers put in more weeding effort in the rainy season crops than post-rainy season crops, and where crop stands are good more effort is spent than where crops appear to be failing.

Interculture was done primarily by males (family and hired) while hand weeding was done primarily by hired females; generally more than two thirds of all hand weeding hours were performed by hired females (Table 2). Thus labour saving alternate weed control techniques (herbicides) would decrease income opportunities for the most disadvantaged labour groups in India, landless female labourers. Also contrary to earlier expectations, results indicated that primary school age children did not participate substantially in hand weeding. They may, however, be called on more heavily during the harvesting season.

1/ For a more detailed version of the methodology and the results of the operational field research see Davies (1979) and Davies and Shetty (1980).

Table 2

Distribution of weeding and interculture hours by sex (Adopted from Binswanger and Shetty, 1977)

Crops	Total hand weeding hours (by respondent farmers)	% hours by females	% hours by hired females (of total)	Interculture	
				Total hours	% of hours by males
Akola (1975/76)					
Sorghum (K)	5734	96	77	663	95
Cotton (K)	18774	98	91	7710	98
Groundnut (K)	1271	95	83	429	94
Sorghum mixture (K)	5886	98	93	4137	100
Mahabubnagar (1976/77)					
Sorghum mixture (K)	0	-	-	336	100
Castor (K)	72	84	44	1066	100
Sholapur (1975/76)					
Sorghum (R)	2698	100	70	1826	94
Sorghum mixture (R)	0	-	-	509	100
Groundnut (K)	1128	95	63	0	-

K = Kharif (Rainy season), R = Rabi (Post-rainy season)

Cost analysis of alternative weed-control methods: In Table 3 and 4 three alternate plans for weed control are outlined along with costs for a few major crops. Plans were developed to give an equivalent quality of weed control within each crop for that particular season, but possible yield effects of the alternate weed control systems were not considered. In none of the crops considered was it economical to use herbicides under the present system of cultivation. Even doubling of the real wage rates would not have been sufficient to make a herbicide based plan for rainfed crops financially attractive. Further, if we consider mixed cropping, the predominant SAT cropping system, the costs of herbicide based plans rise since it is necessary to use more selective and more costly herbicides.

Possible yield effect of herbicides: As described above, our ex-ante calculations showed that herbicide use was not economic for rainfed dry lands crops in the Indian SAT, but the analysis ignored the possible yield benefit of herbicide use. To test whether the outcome of this analysis could be changed if yield effects of herbicide use were included, operational research trials on the farmers' fields were conducted during 1977 and 1978. The results of these field trials on two major crops, sorghum and groundnut, did not change the analysis. Several of the experiments, both on groundnut and sorghum, resulted in no significant yield differences between various herbicide and no herbicide treatments (Davies & Shetty, 1980). Only in Akola village (deep Vertisol and assured rainfall area), during 1977 in one farmer's field was there a significant increase in sorghum grain yield after using herbicides in addition to the farmer's weed control system (Fig. 1). The additional grain yield of 360 kg/ha was sufficient to offset the cost of the herbicide (atrazine) and its application and leave a net profit of Rs.186. Overall, however, the potential of herbicides in improving the productivity of the crop in a given season was not demonstrated. This was mainly because the farmers practiced

Table 3

Alternative weed control plans and the costs
(adopted from Binswanger and Shetty, 1977)

Method	Groundnuts Herbicide	Groundnuts Cost Rs/ha	Castor Herbicide	Castor Cost Rs/ha	Sorghum Herbicide	Sorghum Cost Rs/ha
Herbicide						
Pre-emergence	alachlor 2.5 kg/ha	210			atrazine 1 kg/ha	138
Post-emergence	-		paraquat 1 kg/ha (2 applns) (Directed)	650	2,4-D	50
Total[b/]		210		650		188
Integrated Methods						
Herbicide-pre	alachlor 1 kg/ha	90	-		atrazine 0.5 kg/ha	74
Herbicide-post	-		paraquat 0.5 kg/ha (Directed)	168	-	
Inter-cultivation[a/]	1	15	2	30	1	15
Handweedings[a/]	1	20	-		1	20
Total		125		198		109
Present Cultivation						
Inter-cultivations[a/]	3	45	4	60	2	30
Handweedings[a/]	2	40	2	40	2	40
Total		85		100		70

a/ Rainfall and soil conditions permitting.

b/ Prices of herbicides -- 2,4-D = Rs. 40/kg; alachlor = Rs. 80/kg; paraquat = Rs.315/kg; atrazine = Rs.128/kg; prometryn = Rs.120/kg; nitrofen = Rs.120/kg

Herbicide application charge = Rs. 10/ha

Cost of handweeding = Rs. 20/ha (10 female labour at the wage rate of Rs. 2/labour)

Cost of intercultivation = Rs. 15/ha (Rs. 12/bullock pair and Rs. 3/operator)

Table 4

Alternative weed control plans and the costs
(adopted from Binswanger and Shetty, 1977)

Method	Pearl Millet Herbicide	Pearl Millet Cost Rs/ha	Chickpea Herbicide	Chickpea Cost Rs/ha	Sorghum/Millet/P.P Mixture Herbicide	Sorghum/Millet/P.P Mixture Cost Rs/ha
Herbicide						
Pre-emergence	atrazine 0.5 kg/ha	74	nitrofen 2 kg/ha	250	prometryn 1 kg/ha	130
Post-emergence	2,4-D 0.5 kg/ha	30			paraquat 0.5 kg/ha (Directed)	168
Total[b]		104		250		298
Integrated Methods						
Herbicide-pre	atrazine 0.4 kg/ha	61	nitrofen 1 kg/ha	130	prometryn 0.75 kg/ha	100
Herbicide-post	-		-		-	
Inter-cultivation[a]	-		-		1	15
Handweedings[a]	1	20	1	20	1	20
Total		81		150		135
Present Cultivation						
Inter-cultivations[a]	1	15	-		2	30
Handweedings[a]	2	40	2	40	2	40
Total		55		40		70

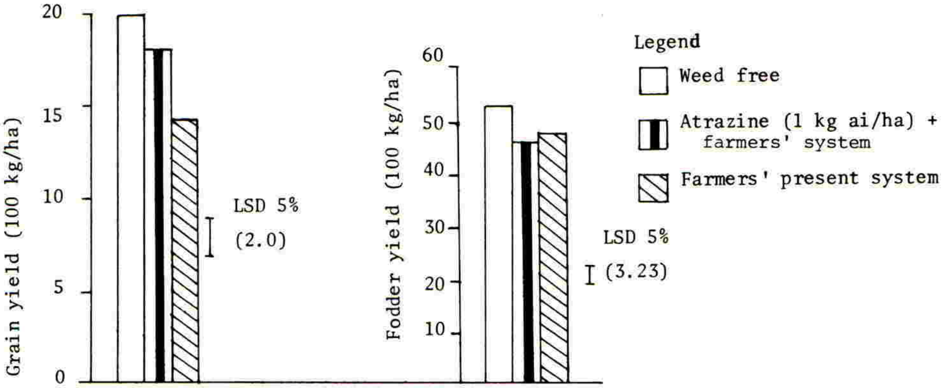
a/ Rainfall and soil conditions permitting.

b/ Prices of herbicides -- 2,4-D = Rs. 40/kg; alachlor = Rs. 80/kg; paraquat = Rs.315/kg; atrazine = Rs.128/kg; prometryn = Rs.120/kg; nitrofen = Rs.120/kg

Herbicide application charge = Rs. 10/ha
Cost of handweeding = Rs. 20/ha (10 female labour at the wage rate of Rs. 2/labour)
Cost of intercultivation = Rs. 15/ha (Rs. 12/bullock pair and Rs. 3/operator)

sufficient and timely weed control. Even under different fertility status no significant differences in net profits were detected between high and low fertility plots. While there were indications that farmers' plots treated with herbicides had higher sorghum grain or groundnut pod yields compared to the farmers' own practice, in experiments where herbicide application resulted in some but not significant yield increase during 1978 (Table 5) the small net profits observed are insufficient to justify the adoption of herbicides under the present traditional farming systems. Thus, the two year field trials on the farmers' fields confirmed our earlier conclusions (ex-ante appraisal) that on the basis of present costs herbicides cannot be advocated in the existing farming systems.

Fig. 1. The effect of three weed control treatments on sorghum grain and fodder yields at Kanzara village on Vertisols, 1977.



IMPLICATIONS FOR FUTURE HERBICIDE RESEARCH

Economic analysis of herbicide use is not simple mainly because it concerns the society as a whole. Social effects of herbicides are both monetary and non-monetary and may be negative or positive (Miller, 1976). Simple economic evaluation does not consider the frequent failure of markets (externalities) to give true indications of future social benefits and costs. If measures were taken to correct externalities by modifying the incentive structure or governmental control, herbicide use could be attractive even under the existing farming systems of the semi-arid tropics. Multi-disciplinary team research by agronomists and economists is necessary to provide policy makers with scientific estimates of herbicide effects.

Further, improvements of herbicide use which may lead to a reduction in costs and hence enhance the utility and acceptability by the farmers should be explored. Can herbicide rate be minimised? Can we simplify the method of application through granules, low volume sprayers, formulation with insecticides, fertilizers, etc? Can present day cropping systems be simplified to facilitate the use of herbicides? However, even if herbicides are used extensively it should not be forgotten that in the Indian semi-arid tropics hand weeding will stay for years to come and therefore it should be regarded as an integral part of herbicide programmes particularly to safeguard against possible weed shifts due to herbicide use.

Table 5

The relative costs and the net profits due to herbicdes use in sorghum and groundnut
(from one experiment out of 18 experiments in 1978, adopted from Davies and Shetty, 1980)

Treatment	Mean yield difference from farm practice (kg/ha)	Rupee value of the yield difference	Herbicide application cost (approx. Rs./ha	Net profit Rs./ha
Sorghum				
Farm practice + atrazine (1 kg/ha)- Low fertility (20 kg/ha)	+ 300	210	138	+ 72
Farm practice + atrazine (1 kg/ha)- High fertility (80 N/ha)	+ 350	245	138	+ 107
Grounnut				
Farm practice + nitrofen (1 kg/ha)- Low fertility (20 N/ha)	+ 123	295	190	+ 105

Value of sorghum grain - Rs. 70/100 kg   Cost of atrazine - Rs. 128/ha
Value of groundnut pods - Rs. 240/100 kg   Cost of nitrofen - Rs. 180/ha
Application charges - Rs. 10/ha

In the existing systems of farming, however, herbicides may be the only solution for treating patches of weeds which are difficult to control manually or mechanically, for example, perennial grasses, sedges and parasitic weeds such as Striga. Consequently a large portion of abandoned areas could again be brought into cultivation.

According to Parker (1977) three problems which embrace most agronomic weed situations in the tropics are peak labour demand, perennials and parasites and if none of these apply, then the small scale farmer with a modest amount of family and other labour available should be able to contain weed populations at tolerable levels and should not be encouraged to depend on chemicals. Such farmers could, however, be helped in various other ways to reduce drudgery by making his weeding easier and more efficient.

Herbicide related studies should be designed to increase productivity of the whole farming system rather than to reduce the cost of handweeding of an individual crop. Herbicide research will be most productive if it is focussed on and associated with research efforts aimed at achieving substantial changes in farming systems via new cultivars or improvements in soil, water and crop management to facilitate multiple cropping. Research should be oriented to identify situations in which herbicides are immediately applicable and/or vital to the success of a new farming system in the long term. For example:[1/]

- Herbicides may have to be used in developing economically viable double cropping systems in some areas of the Indian deep Vertisols. These soils are traditionally fallowed during the rainy season partly because the high probability of prolonged wet spells may make it impossible to control weeds by hand weeding and interculture.

- For post-rainy season crops, the time between harvest of the rainy season crop and planting is very critical. The possibility of minimum tillage using herbicides to reduce the time and tillage costs and to conserve soil moisture for the establishment of a post-rainy season crop in receding soil moisture conditions looks promising at ICRISAT.

- Herbicides could be used to improve production by allowing many agricultural operations to be carried out at an optimum time. A good example is time of planting, which is dictated by rainfall where herbicides could allow a larger area to be planted at the optimum time. Further, as Hammerton (1974) pointed out, selective pre-emergence herbicides can increase the total acreage handled by a single family, or hand work will be greatly eased so that fields not treated with herbicides can be weeded more effectively.

As improved weed management is an integral part of improved farming system and as it concerns many aspects of the system like soil and water management, tillage, crop sequence, variety, crop density, crop residue management, fertility, pest management, crop sequence etc. herbicide research should only be viewed in that perspective. Any future economic analysis of herbicide use must consider the change in farming system as a whole and must include estimates of non-market as well as market costs. Only multi-disciplinary team research by agronomists and economists working together can achieve this goal.

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ECONOMICS OF WEED CONTROL IN AFRICAN TROPICS AND SUB TROPICS

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INTRODUCTION

Tropical and subtropical Africa is defined as the geographical area lying between latitudes 35 N and S of the equator. The agriculturally important parts are characterized by a mean annual rainfall of more than 250 mm and a vegetation that consists of forest, savanna and scrubland. Over 75% of the economically active population in this region is engaged in agriculture (FAO 1976). A review of the traditional cropping system in tropical Africa (Okigbo and Greenland 1976; Okigbo, 1978) indicated that multiple cropping is very important throughout the area especially among the small-holder subsistence farmers. Most of the crop in this region is produced by these farmers and they spend more time weeding than on any other aspect of crop production.

Weed problems in tropical and subtropical Africa were recently reviewed by Akobundu (1980a). Increase in population pressures in all countries of tropical Africa have led to drastically shortened fallow periods, which in turn have increased the population of annual weeds at a time when changes in the cultural and social values in most of these countries are causing a shortage of the once abundant farm labour. In some of these countries such as Nigeria and Zambia, labour is both expensive and scarce (Akobundu 1980a; Vernon 1978) while in other countries such as Mali, Ghana, Uganda and Sierra Leone where labour is still relatively cheap, labour availability is not reliable. Consequently timely weeding is hardly carried out by farmers and yield remains low even when improved cultivars and other production inputs are made available to the farmer. In the semi-arid regions of Africa where labour is still cheap and abundant, perennial and parasitic weeds make handweeding laborious and crop yield is poor.

Although very little data are available on crop yield losses caused by delayed weeding in the major crops of tropical Africa, average yield reduction due to uncontrolled weed growth in field crops range from 50-100% (Akobundu, 1980a). There have been very few innovations in weed control methods in Africa. Handweeding has remained the most common method.

WEED CONTROL METHODS USED IN FIELD CROPS IN AFRICA

Handweeding is the most common method of weed control in tropical Africa. The level of technological advancement, climatic and soil factors, cropping systems, and socio-economic considerations have contributed not only to the level of sophistication of the weed control tools but also to the extent to which the energy for the weeding operation is derived from man, animal, machinery, chemicals or biological systems. In most technologically advanced countries, energy for weed control is derived mostly from chemicals. On the other hand, human energy is used directly for weed removal in most of tropical Africa. While farm sizes were small, fallow periods long, labour abundant and literacy rate was low, handweeding was accepted as the only way to cope with weeds. Changing values and alternative job opportunities have led the educated young people of Africa to associate handweeding with the drudgery characteristic of crop production in the tropics.

Increase in human population in Africa has in recent years, had a destabilizing effect on the traditional food production capabilities in this region, and weed infestation is one of the weak links in the food production chain in this region. Advances in temperate agriculture have shown conclusively that weed control can respond economically to scientific research and extension education. It is conceivable therefore that crop yield can be increased in tropical agriculture through better weed control practices.

Weed control methods presently available to farmers in Africa are limited by level of technological advancement in various parts of Africa, the cropping systems, climatic and soil conditions and by the resource base of farmers in this region. The economics of available weed control methods are closely linked with the available labour pool, cost of labour and production costs of alternative weed control methods. Innovations in weed control in Africa have included improvement in timing and frequency of handweeding, use of tractor-mounted or animal-drawn weeders, chemical weed control, mulching and more recently no-tillage weed control in some crops. The choice of a weed control method will depend on the crop, soil conditions, terrain, and the prevailing climatic and economic conditions in a given area.

Among the widely used cultural methods of weed control are handweeding and use of animal-drawn inter-row weeders. The latter is often supplemented with handweeding of the intra-row spaces. While oxen-drawn weeding supplemented with intra-row handweeding uses about one-third of the labour needs of handweeding in maize (Zambia Dept of Agriculture, 1978), its use is limited to the tse-tse fly-free zones of Africa. Even within these tse-tse fly-free areas, use of draft animals may be handicapped in some countries by severe drought that limit available feed for the draft animals. Handweeding is labour intensive, unattractive and slow. In most countries, the labour is unreliable even where it is cheap. The cost of handweeding will vary from one region to the other. The frequency of weeding will vary with rainfall, soil fertility, land use intensity, cropping system, and preplanting land preparation. Cultural weed control methods are traditional in Africa, and have seen little modification over the years. Weed control innovations are aimed at making cultural weed control methods more efficient and introducing other weed control methods to complement cultural control practices.

Chemical weed control has been shown in temperate agriculture to reduce significantly the time spent weeding. Its advantages in increasing yield and reducing labour cost in the tropics have been demonstrated (Furtick, 1970; Parker, 1972). As population pressure and urbanization put extra demands on food production in the tropics, efficient weed control methods that do not rely heavily on human labour will become necessary. Large scale production of any food crop will require chemical weed control in order to be effective and efficient. Several sole crops and some intercropping systems have been identified as suitable for chemical weed control. One of the advantages of chemical weed control is in eliminating early weed interference in crops, and this is usually at peak labour demand.

No-tillage crop production is an alternative method of land use particularly suited to the humid and subhumid tropics. The success of this crop production technology depends to a large extent on judicious use of herbicides. Where no-tillage crop production is feasible, the weed control package must be economical to make the package attractive to the farmer. In addition, the soil conservation advantages of the no-tillage package must be considered when alternative weed control options are evaluated.

Integrated weed control has been shown to be important for some tropical crops and cropping systems (Akobundu, 1978). Combining a pre-emergence herbicide with a late season handweeding has been shown to be desirable in several long season crops and for herbicides with short residual life in tropical soils. Such a system reduces cost by combining low levels of the chemical and handweeding methods.

LABOUR USE IN FIELD CROPS

Labour use in the farm will vary with the type of crops, climatic conditions and land use systems prevelant in the region. A study by Flinn and Zuckerman (1979) showed that farmers in the forest vegetation zone of Western Nigeria spent 72% of their available farm labour on weeding their various crops while farmers in the derived savanna zone spent only 52% of their farm labour weeding (Table 1).

Table 1

Average labour use per farm in days for various farming operations in Akinlalu and Ilero

Operation	Akinlalu (Forest Reservation) Days	%	Ilero (Derived Savanna) Days	%
Clearing	13	4	7	3
Heap making	13	4	9	3
Planting	13	4	33	13
Weeding	256	72	189	52
Harvesting	44	13	57	22
Spraying Cocoa	13	4	0	0
Others	2	0	20	7
Total	354		265	

Source: Flinn, J.C. and Zuckerman, P.S., 1979.

For specific crops however, marked differences in time spent weeding have been reported. At least 36% and as much as 54% of the labour input in maize production was used for weeding (Table 2). The actual labour use varied with weed pressure, weeding frequency and environmental conditions. Weeding accounted for at least half the labour use (50%) for groundnut production in Senegal while the root and tuber crops tied up more labour during land preparation, planting and harvesting. The high labour input in yam was caused by staking. Weeding accounted for less than 30% of labour use in root and tuber crops. Lagemann (1977) compared the cropping systems in three villages in the forest areas of Eastern Nigeria. In the highly densely populated villages where compound farming with continuous cropping was particularly important, weeding took up most of the field hours followed by planting and clearing. In the less densely populated areas, weeding was important but was not the most time consuming activity. Provided labour is available, farmers will prefer to (a) hire rather than use own labour sources for field work and this includes weeding; (b) hire labour rather than be late for planting or other farm operations; and (c) hire labour rather than buy fertilizer (Table 3). The high opportunity cost of hired labour is supported by the fact that farmers will rather minimize their own labour input than hired labour. According to Nweke and Winch (1980), the smallholder farmers they surveyed hired over 75% of their labour even when these farmers spent an average of 48% of their working time on the farm work. These farmers preferred to send their children to school rather than have them work on the farm.

Table 2

Labour input for selected food crops in Africa (in man days/hectare/crop)[a/]

Crop	MAIZE						SORGHUM	GROUNDNUT	CASSAVA	YAM (*D. rotundata*)	
Country	Ethiopia	Ghana	Malawi	Nigeria	Zambia	Upper Volta	Nigeria	Senegal	Nigeria	Cameroon	Nigeria
Land preparation and planting[b/]	21	54	26	33	38	25	28	28	68	159	195
Weeding	39	43	57	30	65	42	25	63	45	120	70
Harvesting	12	16	36	20	33	11	15	35	70	125	60
Total	72	113	119	83	136	78	68	126	183	404	325
Weeding % of total labour	54%	38%	48%	36%	48%	54%	37%	50%	25%	30%	22%

[a/] Source: Adapted from Ruthenberg, H. 1976; Knipscheer, H.C., 1980, Lyonga, S. 1980.

[b/] Includes planting, transplanting, thinning, and fertilizer application. In yams, it also includes ridging and staking

Table 3

Farmers choosing between paired strategies[a/,b/] (%)

	Strategy	%		Alternative Strategy	%
(a)	Minimize own labour	90	(a)	Minimize hired labour	10
(b)	Buy fertilizer	27	(b)	Buy herbicides	73
(c)	Children go to school	94	(c)	Children go to farm	6
(d)	Hire labour	90	(d)	Be late for farm work	10
(e)	Buy herbicide	92	(e)	Hire labour	8
(f)	Buy fertilizer	17	(f)	Hire labour	83
(g)	Avoid borrowing money	2	(g)	Borrow to invest in farm	98
(h)	Buy motorcycle	4	(h)	Invest in farm	96
(i)	Minimize family labour	44	(i)	Minimize hired labour	56
(j)	Have cash income throughout year	90	(j)	Have max. yearly income even if concentrated in a few months	10

a/ Response to the following question: for a farmer in your situation, is it more important to: (Check one in each row of paired possibilities assuming both cannot be done)

b/ Source: Okali, C.; Oben, D. and Ojo-Atere, T. (1980)

ECONOMICS OF WEED CONTROL

Many parts of the semi-arid tropics still have a large cheap labour pool that can be effectively used for weeding and other farm-related activities. Hand-weeding in these regions has been reported to be economical (Binswanger and Shetty, 1978). However in the semi-arid regions of Mali and Senegal this cheap labour is unreliable and not always available at that early crop growth stage when weed interference generally does the most harm to the crops. In the humid tropics rapid weed growth and increased land use intensity associated with the short fallow periods make increased weeding frequency a necessity. As more youths migrate from rural areas to urban centres and into non-farm occupations following their greater access to education, farm labour will become scarce and expensive. It is to be expected that changes in social values and level of education will with time catch up with the countries of the semi-arid regions. A lasting solution therefore to weed problems in tropical Africa is to identify weed control methods that are economical and attractive, and easy to use by farmers.

Herbicide use has been shown to be an effective weed control tool for many field crops in the tropics especially if thorough preplant vegetation control is practised. In addition to time saving features of chemical weed control, herbicide and application cost have been shown to be lower than two handweedings in Ghana, Cameroon, Nigeria and Zambia for most food crops (Carson, 1978; Vernon, 1978; Akobundu, 1980a). In cassava, Akobundu (1980b) has shown that chemical weed control is over three times cheaper than two timely handweedings in the humid tropical region of Nigeria.

The advantages of chemical weed control have been recognised by smallholder farmers in the tropics. In most countries where a horizontal approach to increasing food production has been adopted, farmers have been encouraged to increase land area under crop production through government or cooperative society tractor-hiring services for land preparation and planting. These farmers can neither afford to pay for the costly handweeding nor rely on its uncertainty. Consequently, these farmers have in recent times in Nigeria, opted for chemical weed control.

The study by Okali et al (1980) shows among other things that 92% of farmers surveyed will rather buy herbicides than hire labour and that 73% of the farmers will prefer to buy herbicides than buy fertilizer (Table 3). These farmers would prefer to invest whatever money they have on the farm rather than purchase household needs such as a motorcycle.

A CASE STUDY ON THE ECONOMICS OF WEED CONTROL METHODS

Various estimates and experimental plot calculations of labour use in field crop are available in Africa. While some of these studies are based on farm surveys (Parker, 1973; Fotzo, 1977; Igwebuike, 1975) other labour inputs are based on estimates (Phillips, 1977; World Bank, 1977). Knipscheer (1980) has pointed out the disparity in labour use estimates from these various sources. For example, while labour use is estimated a 8 man-hours/day by some authors, others have used 6 man-hours/day. Labour for weeding has been variously estimated and is known to vary with weeding frequency, land preparation, land use, ecological zone, degree of weed infestation and cropping system.

An experiment to assess the economics of some weed control methods was set up in 1978 at Ikenne, Nigeria in an alfisol (Alagba sandy loam). In order to make a fairly accurate assessment of labour use, it was determined that two labourers working together will be able to weed a plot of $600m^2$ in one day. A minimum plot size (10m x 15m) in four replications was used to determine labour input for planting, weeding, herbicide application, and other inputs in monocropped maize and cassava and in maize-cassava intercrop. Two hired labourers were assigned to each plot of a given crop and were rotated with respect to crops and replications for a given handweeding treatment. Thus the total labour use for any crop represents a mean value of the labour output by the three different groups of workers. The workers operated a 6-hour working day. Two people were involved in herbicide application; while one person fetched water and mixed the herbicides, the other sprayed.

Results of our study show that labour use for weed control was similar irrespective of the cropping pattern (Table 4). However, sole cassava tended to use up more labour than either maize or maize/cassava intercrop possibly due to more weed growth in the sole cassava treatment. Cost of weeding was higher in all cropping systems where handweeding was practiced. Two properly timed handweedings were enough to reduce loss caused by weeds in all the plots. However this weeding frequency was nearly three times as expensive as the combined cost of herbicide and labour for spraying. The highest gross return was obtained where the crops were weeded three times or where the herbicide 'Primextra' (a formulated mixture of atrazine and metolachlor) was used. Because handweeding costs were so many times higher than chemical weed control, the net return to the farmer was highest in the herbicide treated plots.

CONCLUSION

Use of herbicides for weed control has been demonstrated in many parts of Africa to be effective in reducing cost of crop production. In places where labour is scarce and many farmers work in non-farm occupations use of herbicide is both economical to, and preferred by, a majority of farmers (Winch 1976; Lageman 1977; Nweke and Winch, 1980). As noted by Okali (1978), it is the opportunity cost of the farmers' time that is considered in decision making

Table 4

Economics of some weed control methods in selected cropping systems in the subhumid tropics

Weed control method	Labour input (man-day/ha)			Labour Cost[a] ($/ha)			Gross Return ($/ha)			Net Return ($/ha)		
	M	C	M/C	M	C	M/C	M[b]	C	M/C	M	C	M/C
Hoe weeding (x2)	45	49	47	243	265	254	1713	4663	4911	1470	4398	4657
Hoe weeding (x3)	59	64	62	317	347	334	1675	4973	5064	1358	4626	4730
'Primextra' (2.5 kg PE)	2[c]	2	2	90	90	90	1773	4748	5020	1683	4658	4930

a Based on $5.40/man-day at 6 hours/man-day (for herbicide treatment cost of chemical is included)

b Based on farm price of commodities. Maize value is based on early season maize yield. Where a late season maize is grown a yield of 2.0-2.5 tons/ha is possible at a gross return of $1000.00/ha.

c Herbicide applied with a knapsack sprayer. Time includes mixing herbicides and actual spraying (one spray operator and one assistant).

M = maize; C = cassava; M/C = maize/cassava intercrop

Source: Akobundu, I.O. (unpublished data).

processes involving hiring labour and herbicide use. Using this cost where labour was cheap and capital scarce, Binswanger and Shetty (1978) in India found out that it was uneconomical to use herbicides. On the other hand, herbicide use has been found to be economical in most parts of the humid and subhumid tropics.

Chemical weed control has great potential and will become more attractive as solutions to the major constraints limiting herbicide use in tropical Africa are found. These constraints include (a) inadequate knowledge of which herbicide should be used in a given weed-crop situation, (b) poor timing of application especially for pre-emergence herbicides, (c) poor preplanting control of perennial weeds, (d) unavailability of herbicides in farmer-usable packages, (e) uncertainty of availability of herbicides, (f) limited knowledge of herbicides and their use, (g) lack of extension services, and (h) scarcity of trained personnel in weed science.

In places like Nigeria where labour is both scarce and expensive today, labour was abundant and cheap barely two decades ago. Similarly, cost of labour and availability will change with time in those parts of Africa that at present enjoy cheap labour. A lasting solution to improve agricultural practices that will benefit from use of high yielding crop varieties that are disease and insect pest resistant is to develop appropriate weed management systems that are economical, effective and technically within the farmers' ability to understand and use. The present generation of illiterate farmers is rapidly becoming an endangered species in the wake of advancements in education, changing social values and urbanization. The educated children of these farmers are unlikely to appreciate the virtues of laborious handweeding where alternative job opportunities exist. We must live beyond the present, come to grips with the weed problems of tropical and subtropical Africa and identify weed control strategies that will make farming attractive, less labour intensive and economical.

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ECONOMICS OF WEED CONTROL IN MAIZE, DRY BEANS AND SOYBEANS IN LATIN AMERICA

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Summary Farmers of small land holdings in Latin America produce the bulk of maize and dry beans although some large scale maize production occurs in Argentina, Uruguay, and parts of Mexico. Presently, small farmers rely on family or hired labour for weeding and other farming operations. While peak demand periods and seasonal labour scarcities exist, unemployment and under-employment prevail throughout Central America and most of South America. The resulting low cost labour and relatively low product prices often preclude herbicides as an option to handweeding. By contrast soybean production is concentrated on large farms, mostly in Brazil. These commercial farm operations possess sufficient land and capital to use modern technology, including herbicides. Increased herbicide use can be anticipated similar to that experienced in more developed regions.

INTRODUCTION

Latin America includes 20 countries from Mexico to Chile, plus some of the Caribbean islands including Cuba, and embraces a land mass of approximately 28 million km^2. Much of the land is sparsely inhabited jungle, open plains, deserts or mountains. Cropped land per person averages 0.32 ha, but varies from a high of 1.4 ha/person in Argentina to a low of 0.1 ha/person in Mauritius. With the exception of the southern portions of Brazil, Uruguay, Argentina, and Chile, a sub-tropical or tropical climate prevails. Over 300 million people inhabit the region and the annual population increase is 2.5%. More than a third of the population is rural and dependent on agriculture for subsistence, with extremes ranging from a low of 5% in Puerto Rico to a high of 69% in Haiti. Ranking of national average income per person finds the region between 51st and 156th out of 213 countries worldwide (Anon., 1978).

The Committee for Development Planning of the Economic and Social Council of the United Nations in 1971 classified 25 countries as "Least Developed". It included only one in Latin America, Haiti. Honduras, El Salvador, and Haiti are found on the World Food Council list classifying 43 countries as "Food Priority Countries" (Anon., 1980).

In 1974 the United Nations Emergency Operations was established to assist countries affected by the economic crisis resulting from petroleum's sudden price rise. Countries with per capita income less than US$450 in 1971 for which projections showed the likelihood of an overall balance of payment deficit in 1974 equivalent to 5% or more of imports, were classified as "Most Seriously Affected". The list currently includes 45 countries, four of which, Honduras, Guatemala, El Salvador and Haiti, are in Latin America. The remainder were African and Asian countries.

Latin America's agriculture roughly falls into two categories: (1) cash crops such as sugarcane, coffee, bananas, oil crops, cacao, cotton and, in Brazil and Argentina, soybeans, grown both for export and for local markets; and (2) subsistence food crops grown predominatly by small farmers for home consumption and local markets. Major crops in this category are cassava, maize, wheat, rice, dry beans, potatoes, and various kinds of fruits and vegetables.

Maize is by far the most important and widespread food crop with an annual production of 39 million metric tons. Root crops - primarily cassava - rank ahead of maize in total annual production at 47 million tons per year. Though dry bean production totals only 4 million tons per year, the crop is grown throughout Latin America and forms an important dietary staple in many countries.

The purpose of this paper is to discuss the economics of weed control of maize, dry beans, and soybeans as they are grown in Latin America. In so doing we will not only describe the present weed control practices but attempt to indicate how economic influences will affect future weed control techniques on both subsistence and commercial farms.

PRODUCTION STATISTICS AND SYSTEMS

Maize, overwhelmingly the most important cereal crop in Latin America, grows throughout the region, but only Brazil, Mexico, and Argentina stand among the world's ten top producing nations. Latin America's 39 million metric ton annual production accounts for about 11% of the world's 365 million metric tons. The 1530 kg/ha average production in Latin America fails to match the world average of 3082 kg/ha and pales beside the 6350 kg/ha averaged in North America. Over 5 million tons of maize were imported by various Latin American countries during 1978.

With the exception of Argentina, Uruguay and parts of Mexico, maize can be characterized as a "small farm" crop. A fair share of it is grown in tiny patches on steep, rocky hillsides and amongst logs and stumps of newly cleared forests. As a preferred crop, maize receives better treatment than some other crops. It is often grown in a monoculture. Maize production in Argentina, Uruguay and portions of Mexico is a mechanized enterprise not dissimilar to that found in Europe and North America.

Dry Beans. As mentioned, Latin America produces approximately 4 million metric tons of dry beans compared to total world production of 18 million tons. Brazil and Mexico account for three quarters of the Latin American production. Latin America production averages 550 kg/ha compared to 580 kg/ha for the world and 1416 kg/ha in North America. Nearly every country in Latin America imported beans in 1978, a typical year.

Beans are grown almost totally as a small farm crop and usually in association with another crop, often maize. In spite of their importance, farmers usually consider beans as a secondary crop. This view may be due to the high probability of crop failure. Beans often fall prey to insects, diseases, and weather extremes far more than other crops. Small farmers have learned that investments in fertilizer, weeding, and pesticides will probably not yield a profitable return.

Handweeding, the most common weed control method, in dry beans is often complicated by the presence of mature maize. The most time consuming weeding may actually occur prior to planting beans as late season weeds are removed from the maize. However, in several countries beans and maize or beans and cassava are planted simultaneously. Weeds are usually less of a problem in these situations.

Few herbicides are applied to dry beans in Latin America. Aside from the economic and distributional factors limiting herbicide use by small farmers, very few common "bean" herbicides are sufficiently effective or safe to be used under small farm conditions.

Soybeans are not a major crop in Latin America with the exception of Brazil which ranks third behind the United States and China in world production. Out of a world production of 80 million tons in 1978, 50 million tons were produced in the United States while China produced 13 million tons and Brazil 10 million tons. Argentina, at 2 million tons, and Mexico, at 300,000 tons, also are among the top ten world producers. Significant tonnages are produced in Ecuador and Colombia as well.

Soybean production in Brazil is a relatively new and rapidly expanding enterprise and occurs on large farms with cultural practices as mechanized and contemporary as in North America. Specialists from the United States are consulted regularly, thus expediting rapid transfer of modern technology. Weed control practices reflect those found in the United States, including heavy reliance on herbicides such as trifluralin and alachlor. Cultivation is common and some handweeding is still performed but field labour increasingly becomes difficult to obtain.

CROP PRODUCTION AND WEEDING PRACTICES

In assessing weed control practices in Latin America several points must be kept in mind. First, Latin America is not homogeneous; climates, topography, farm size, cropping systems and economic and social conditions vary from one area to another. Second, maize and dry beans are grown in virtually all countries. Production of these commodities, however, is usually confined to small farmers. Only in the more temperate areas of the south are they commercially grown. Third, soybeans are a cash crop, grown on commercial farms with production systems similar to those used by European and U.S farms. Brazil is the world's second largest (after the United States) exporter of soybeans and dominates Latin American production.

Production on small farms in Latin America is characterized by relatively cheap and abundant labour although seasonal scarcity does exist. Capital is expensive and relatively unavailable and land is scarce at least within the confines of the farm. In these conditions it is very doubtful that widespread herbicide use will soon replace manual weeding. Presently manual methods are economically efficient and little change is expected in the future. This is true even when serious price distortions favouring modern inputs exist. There are simply insufficient market incentives for a wholesale switch from manual weed control. It should also be obvious that many non-economic factors such as education and transportation will also slow the adoption of modern weed control methods in Latin America (Doll, 1976).

Having said that, let us hasten to say that there are niches where herbicides can play a role on small farms and areas within several countries where small farmers are using herbicides. Manual weed control methods are generally impractical for certain cereal crops such as wheat, and rice. Doll (1974) found that 99, 92 and 75% of Colombia's drilled crops of irrigated rice, barley and wheat respectively were treated with herbicides while only 40 and 28% of the soybeans and maize, respectively, were treated. Special weed species, ie certain perennial grasses and Cyperus rotundus are difficult to control by manual methods. In these situations, alternative control measures may be feasible in spite of prevailing economic and social conditions.

Table 1

General information on maize, dry beans and soybean production, and labour and herbicide costs for five Latin American countries*

	Peru	Colombia	Ecuador	Brazil	Costa Rica
Area planted to maize	Coast 120,000 ha Mountain 160,000 ha Jungle 40,000 ha	619,000 ha	Coast 160,000 ha Mountain 80,000 ha	12,359,352 ha	50,000 ha
Maize Yields	Coast 3-4 t/ha Mountain 1.5 t/ha Jungle 2.0 t/ha	1.5 t/ha	1 t/ha	1.2 t/ha	1.8-2.5 t/ha
How is maize grown?	Planted twice a year on coast and in jungle about 60% in association with beans Once per year in mountains about 20% in association with quinoa	Two crops below 1200m One crop above 1200m flat areas monoculture hills maize & beans coast maize with cassava	With dry beans castor beans, lima beans 2 crops/year on coast one in mountains	One crop per year in south monoculture one crop per year in north with beans, cassava, etc.	In association with other crops
Price of maize/ton	Coast $160** Mountain $114 Jungle $214 Price is controlled on the coast	$253 open market	$280 open market	$595 Government sets minimum price	$283
Area planted to soybeans	None	71,000 ha	28,000 ha	8,702,635 ha	None
Soybean yields	-	2 t/ha	2.2 t/ha	1.3 t/ha	None
How are soybeans grown	-	2 crops/year monoculture	2 crops/year monoculture	1 crop/year monoculture	None
Price of soybeans/ton	-	$383	$320	$466	None

* Source: Personal communication with Latin American weed scientists.
** All prices are in U.S. dollars.

Table 1 continued...

	Peru	Colombia	Ecuador	Brazil	Costa Rica
Major weeds of maize and soybeans		Rottboellia exaltata Eleusine indica Digitaria sanguinalis Leptochloa filiformis Sorghum halepense Echinochloa spp. Cyperus rotundus Amaranthus spp. Ipomoea spp. Euphorbia spp. Portulaca oleracea Sida spp. Bidens pilosa	Panicum fasculatum Eleusine indica Cucumis spp. Leptochloa filiformis Echinochloa colonum Amaranthus spp. Ipomoea spp. Luffa operculatata Portulaca oleracea	Ricardia scabra Euphorbia spp. Acanthospermum hispidum Amaranthus spp. Sida spp.	perennial grasses
Salary for labour	Coast $4.28/day Mountain $1.78/day Jungle $1.78/day	$6-7/day increase about 20%/year	$3-4/day 5-8% increase	$4-8/day	$3.50-5.00/day 5-10% year increase
Labour taxes	Grower pays 5% for Social Security	Social Security Meals are included in some areas	None	None	Larger producers are to pay 51.5% Social Security
Is labour available?	Yes	Short supply	Short supply	South/usually short supply; North/short supply during peak periods	Atlantic Zone/ scarce Others/normally available
Herbicide costs:					
Atrazine	$10.27/kg	$6.14/kg	$7.00/kg	$14.14/kg	$9.80/kg
Alachlor	-	$4.58/l	$8.30/l	$ 5.42/l	$7.61/l
Paraquat	$11.22/l	$6.16/l	$6.40/l	$11.00/l	$5-6/l
2,4-D	$ 5.23/l	-	$3.60/l	$ 3.33/l	$2.58/l of 4 lb/gal.
Trifluralin	$ 8.93/l	$ 6.42/l	$13.00/l	$ 8.25/l	
Government subsidy for herbicides	No	No	No	Yes	No
Area planted to dry beans	73,000 ha	112,000 ha	59,000 ha	4,568,000 ha	30,000 ha
Dry bean yields	.8 t/ha	.72 t/ha	.5 t/ha	.48 t/ha	.53 t/ha

There is also evidence that, by using low rates of selective soil applied herbicides, it may be possible to reduce time requirements of handweeding while simultaneously delaying the initiation of handweeding until there is less demand on available labour. The partial control given by low rates occurs during the critical period of weed competition, the time when it is most needed. This approach also reduces the risk of crop injury due to inaccurate calibration or non-uniform application. Research on this and other techniques to reduce herbicide costs should be encouraged.

Also, where land is not limiting, seasonal peak labour demand for land clearing and weeding can be relaxed by appropriate use of herbicides. The International Plant Protection Center is presently conducting research on no-till farming systems in Costa Rica. Herbicides are being used prior to planting to control the heavy grass cover and form a thick mulch. The point remains, however, that in Latin American societies with problems of unemployment, a predominance of small farmers, limited capital, limited education, and mixed cropping systems, manual weed control is likely to be economically efficient and, hence, dominate for many more years.

Some examples of the economic efficiency of manual weed control are shown in Table 2. Research by the International Plant Protection Center has shown that yields of maize and beans are generally the same when manual, mechanical, and chemical weed control is well executed and timely. Without a yield difference, the question of farm efficiency degenerate to determining the least cost method. Studies in Latin America have shown this to most often be manual weeding.

Table 2

Comparison of manual, mechanical and herbicide costs in selected Latin American countries

Area	Cropping Systems	Cost as percentage of manual weed control costs
N.E. Brazil	Intercropped maize and beans	
	Manual	100
	Mechanical (animal)	122
	Herbicide	144
El Salvador	Intercropped maize and beans	
	Manual	100
	Herbicide	141
	Single cropped maize	
	Manual	100
	Herbicide	169
	Single cropped beans	
	Manual	100
	Herbicide	161

Farmers' unwillingness to buy herbicides is also strong evidence of the low profitability and inadequate benefits arising from their use. Table 3 shows the use of herbicides in Brazil by crop over time.

As noted, herbicides are not commonly applied to the subsistence crops of maize and beans. Herbicides, however, are increasingly used in the South and Central Zones of Brazil with its large farms and higher labour costs. On the other hand, willingness to pay for herbicides is quite evident in soybeans. The use of herbicides in soybeans has mushroomed as acreage has expanded, increasing 630 percent during the period 1973-1979 (Table 3). As previously noted, soybeans are grown on large commercial farms.

Table 3

Use of herbicides (t) by crop in Brazil (1973-1979)

	1973	1976	1979
maize	0	809	1,336
beans,dry	0	0	0
soybeans	1,732	7,776	12,643
sugarcane	2,235	5,217	7,549

As implied from the above, the economic situation of large, commercial farms is different from small farms. Generally, the former have more resources at their disposition (both capital and land) and their labour costs are higher. Most of their labour is hired, often at regulated wages, with accompanying increased indirect costs like employer payroll taxes and social security. Alternatively they often have lower input costs, at least for selected inputs which the government wishes to encourage in its quest to "modernize" agriculture. These reduced costs often stem from direct input subsidies, including low interest production loans, exemption from domestic taxes and import tariffs, and preferential exchange rates. Herbicides are often recipients of favourable government treatment.

For example, in a recent study conducted in Brazil on sugarcane, governmental policies reduced the private cost of chemical weed control an estimated 37% below the social cost (Miller and Burrill, 1978). Payroll taxes on labour on the other hand increased private costs of labour to employers by approximately 40%. Together these policies reduced the herbicide/labour price ratio approximately 55% below what it would have been under open market conditions. This led to the adoption of chemical weed control through a distortion of relative factors costs. Without government intervention the least cost weed control choice would have been traditional labour intensive manual methods. Table 3 indicates the rapid increase in herbicide use on sugarcane in Brazil in recent years[1/].

Since soybeans are produced on commercial farms it is assumed that weed control in Latin America will follow the American model where mechanical and chemical methods dominate. All evidence supports this assumption. It follows, then, that energy requirements and associated increased prices of energy will increase pressure on producers to switch to chemical weed control methods. While we were unable to find price data for a Latin American country, if it is assumed that price trends are similar to those of the United States, it is observed that pesticide prices (herbicides constitute 60% of the market) have increased much less during the seventies than other farm inputs, and less than the prices of products farmers sell. Pesticide prices rose 54% between 1970 and 1979 compared with average for all purchased inputs of 128% (Table 4). Prices received by U.S farmers for their crops rose an average of 124% during the same period (Erickers, 1980).

1/ It should be noted that Brazil in 1979 embarked on a major project to produce 10.7 billion litres of alcohol by 1985. With a projected yield of 70 litres of alcohol per ton of sugarcane and approximate yield of 50 tons of cane per cultivated hectare, the total area required to meet the objective is approximately 3 million hectares. Increased production per hectare will help to reduce this enormous requirement.

Table 4

Trends in prices paid for farm inputs and prices received for farm commodities, 1970-79

Input item	Price index (1967=100) 1970	1979	Percent change 1970-1979
Pesticides	98	151	54
Fertilizer	80	211	140
Machinery	116	305	163
Fuel and energy	104	318	206
All purchased inputs	112	255	128
Prices received for crops	100	224	124

These price trends will encourage in the U.S., and subsequently the commercial farms of Latin America, a continued substitution of chemicals for manual and mechanical weed control where inputs are purchased and produce is sold in open markets. Miranowski (1980) recently verified this condition in the U.S. He evaluated the relationship between pest management and energy prices in corn production and concluded that chemical "weed and insect control will be substituted for fuel inputs".

The chemical industry also sees a large expansion in herbicide use. In a recent survey by Farm Chemicals magazine (Anon., 1979) an estimated $3,716 million dollars was spent for herbicides in 1978 (Table 5). World herbicide use was expected to increase 29%, at 4.8% per year, on constant dollar basis between 1978 and 1984. Brazil is expected to have the most rapid growth rate in the early eighties. Other areas of projected rapid growth include several Latin American countries, China, the USSR, South Korea, Nigeria and France.

Table 5

World pesticide use in 1978 and projected use in 1984

Other pesticides	Estimated use (million dollars)	Projected increases (%) 1978-84	Annual increase
Herbicides	3,716	29	4.8
Insecticides	3,028	11	1.8
Fungicides	1,539	28	4.7
Other pesticides	387	38	6.3
Total	8,670	28	4.7

As yet we have said little about growing public concern over the possible health and environmental hazards of herbicides. While herbicides are generally less toxic than insecticides, their safety is increasingly being challenged. Current U.S legislation grants authority to the Environmental Protection Agency (EPA) to cancel or limit the registration of pesticides. It is recognized that the actions in the U.S. and other industrialized countries have major impact on the availability of chemicals in other countries, as well as on the pesticide regulations themselves. The future position of EPA on herbicides is difficulty to forecast. However, in the U.S. a considerable amount of research is being conducted to determine the impact of cancelling registrations of specific pesticides.

It is safe to say, however, that increasing restriction and higher research and development costs will cause a reduction in new product registration, particularly for minor uses which lack sufficient market to justify development costs [1/].

In summary, it appears that small farmers in Latin America will continue to use traditional manual weed control methods in the production of maize and dry beans. Herbicides will be used selectively as factor prices allow in periods of peak labour demand or where problem weeds occur. Opportunity for manual mechanization will continue. However, fuel costs will limit the use of motorized mechanization. Commercial production of maize and soybeans will expand the use of herbicides through government action as well as the impetus of factor price relations.

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1/ In one study banning of herbicides in the U.S. would have resulted in a 5% an 20% reduction in the 1976 production of maize and soybeans with a corresponding increase of 14% and 16% in their respective prices.

NOTES

ECONOMICS OF WEED CONTROL IN TROPICAL AND SUB-TROPICAL RICE GROWING REGIONS WITH EMPHASIS ON REDUCED TILLAGE

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Summary In irrigated transplanted rice fields in Asia, farmers generally do an adequate job of weed control. The weed control method used depends on the resources available to the farmer. Weeding labour in Laguna province, Philippines almost tripled between 1965 and 1975 as a result of the introduction of modern cultivars and a high rate of fertiliser application. Between 1975 and 1978 weeding labour decreased due to an increase in the use of herbicides and increased efficiency of herbicide use. In addition, real agricultural wages increased and herbicide prices stabilised. Reduced tillage techniques have resulted in considerable savings in time, labour, water, power, and capital without yield loss under varying ecological conditions. However, usage of such techniques may be limited to areas where perennial weeds are absent. Acceptance of reduced tillage systems in tropical Asia has been slow but they are expected to become more acceptable in the future with changing economic and social conditions.

GENERAL CONSIDERATIONS

The literature is replete with papers that indicate the losses that can be caused by weeds in rice in the absence of any weed control. Such figures are unrealistic as most farmers attempt to do some weed control. Therefore, a comparison between weeded and unweeded plots overstates the additional benefits of weed control. A more realistic approach is to compare the added benefit from additional weeding compared to the farmers weed control method.

Assuming that yields could be increased 10% by improved weed control practices the increase in rice production throughout the world would be a staggering figure of 3.4 million tons or 0.25 t/ha. Such increases mean little unless they can be achieved economically. Maximisation of crop yield unless it concurrently maximises net revenue is rarely the objective of any producer.

Herdt (1979) reported that the increase in yield of irrigated transplanted rice due to improved weed control practices in 169 dry season trials and 229 wet season trials in six Asian countries averaged only 0.2 and 0.1 t/ha, respectively. This indicates that the farmers generally did an adequate job of controlling weeds in the test sites. The author notes that farmers are unlikely to be impressed by these small yield gains (<5% of their yield levels) and says it is obvious why farmers do not increase their level of weed control. However, Gomez et al (1979) state that even though the yield increase due to improved weed control averages only 0.2 t/ha, net returns could be increased by over $13.33/ha in the dry season and $20.00/ha in the wet season. Benefits from additional weeding over the farmers weeding practices would probably be greater in other types of rice culture.

The data of Smith and Gascon (1979) give an indication as to why farmers in irrigated transplanted rice areas may not be obtaining much benefit from an increased level of weed control. The total labour per hectare in Laguna province, Philippines rose from 86 days/ha in 1965 before the introduction of the modern cultivars to 112 in 1975. From the mid-1970's, chemicals and machinery gradually replaced labour. As a result, in 1978 labour use fell back to pre-modern cultivar levels. During the period, land preparation labour declined steadily. This was more than offset by tbe increase in weeding labour, which almost tripled from 11.6 days/ha in 1965 to 31.6 days in 1975 (Table 1) as a result of the introduction of modern cultivars and a high rate of fertiliser application, factors which invariably increase the need for weed control inputs. In 1978, weeding labour decreased to 84% of its 1975 level. This was accompanied by an increase in the use of herbicides and increased efficiency of herbicide use as farmers shifted from post-emergence to pre-emergence application (Smith and Gascon, 1979). Thus, the weed control method selected appears to reflect relative costs rather than an inherent technical advantage of one method over another. For the period between 1966 and 1975 hand weeding increased despite the expanded use of herbicides (De Datta and Barker, 1977; Barker and Cordova, 1978). According to Barker and Cordova (1978) this is indicative that herbicides are used more as a supplement to, rather than as a substitute for, hand weeding.

Table 1

Changes in labour use in rice production, Laguna, Philippines, 1965-1978 wet seasons
(Smith and Gascon, 1979)

Farming Operation	Total labour (man-days/ha) 1965	1970	1975	1978
Land preparation	19.2	11.4	10.6	9.2
Repair and cleaning of levees	4.2	4.9	4.7	5.2
Transplanting	9.8	10.7	11.3	10.0
Weeding	11.1	19.1	31.6	26.6
Fertilising and spraying	0.9	1.6	3.0	2.6
Other preharvest operations	4.5	9.1	14.7	4.2
Total preharvest labour	49.7	56.8	75.9	57.8
Harvesting, threshing and other postharvest activities	35.8	37.3	35.8	27.8
Total labour	85.5	94.1	111.7	85.6

A similar relationship has been observed for rotary weeding. The increase in hand weeding could have been brought about by any combination of three factors: the high yielding cultivars made intensified hand weeding profitable; increased fertiliser use made increased weeding necessary or the efficiency of rotary weeding increased marginal returns to weeding labour (Barker et al, 1974).

The drop in weeding labour between 1975 and 1978 was apparently an attempt by the farmer to adapt to changing relative factor prices. From 1970 to 1975 as herbicide prices increased and real agricultural wages fell farmers' weed control was mainly by hand weeding. From 1975 to 1978 real wages increased and herbicide prices stabilised due to government control and farmers increased their use of herbicides. In 1979, herbicides worth $7.6 million were applied to 1.1 million hectares of rice land in the Philippines; 2,4-D was applied to 54% of the treated area and butachlor to 33% of the area compared to a total importation of only $0.6 million in 1970.

For rice production throughout the tropics a large portion of the total labour required during crop growth has been devoted to weeding. Manual weeding methods are still the most common methods of weed control in rice in the tropics. However, the method of weed control used depends not only on the method of rice production but also on the combination of resources - land, labour and capital - available to the farmer (De Datta and Barker, 1977). For example, in India butachlor is extensively used in areas where there is a labour shortage such as in Punjab state where sales exceed $1 million but in areas of surplus labour and poor water control, such as in northeast India, herbicides are seldom used (De Datta, 1980). One of the best guides for choosing the appropriate method of weed control is the relative cost of labour and herbicides. Knowing the daily wage rate in a given area and the approximate time for one hand weeding, the cost of hand weeding one hectare can be determined and compared with the cost of the herbicide (De Datta and Barker, 1977). Selection of an appropriate weed control technology should be based not only on degree of weed control or cost of yield alone. All these factors should be used to determine the weed control method that provides the highest returns per unit invested.

Mercado and Arceo (1980) concluded on the basis of 17 field trials that butachlor + 2,4-D gave commercially acceptable weed control in transplanted rice growing regions in the Philippines and the highest incremental gains over 2,4-D or hand weeding. For India, Arceo et al (1979) determined that the rate of butachlor giving the highest economic return in transplanted rice was 1.5 kg/ha. Shahi et al (1979) reported that the application of herbicides such as butachlor are an economically viable proposition compared with traditional hand weeding. Returns per unit invested on weed control were greater with butachlor than hand weeding even though the yields obtained were greater with hand weeding.

The economic advantage of herbicides becomes even more significant in areas where a labour shortage exists or there is a relative increase in the cost of labour compared to chemicals. Under Thai conditions, Schiller and Indhaphun (1979) note that the use of herbicide would be an economically attractive alternative to employing non-family labour for manual weed control in upland rice even when herbicides have to be supplemented with a manual weeding. Similar results have been reported by Sabio et al (1980) for the Philippines.

REDUCED TILLAGE SYSTEMS

Minimum and zero tillage techniques have resulted in considerable savings in time, labour, water, power and capital without loss in rice yield under widely varying ecological conditions (Mabbayad and Buenacosa, 1967; Mabbayad et al, 1968; Mittra and Pieris, 1968; Novero, 1968; Elias, 1969; Seth et al, 1971; Croon, 1978). In other instances especially where perennial weeds were present, weed growth was greater and yields were less with reduced tillage systems than with conventional tillage systems (IRRI, 1971, 1979; De Datta et al, 1979). This indicates that reduced tillage techniques may be limited to areas where perennial weeds are not present.

Moomaw et al (1968) note that minimum tillage techniques using herbicides have resulted in reduced tillage operations and occasionally made zero tillage feasible for transplanted rice. In the absence of perennial grasses, land preparation may also be replaced by chemicals in wet-seeded rice. In Malaysian trials, Seth et al (1971) observed that the incidence of weeds in the growing crop was generally less following the use of minimum tillage techniques than after conventional tillage. In the absence of perennial weeds a similar trend was noted in the zero tillage treatment. However, where perennial grasses were present, continued use of zero tillage resulted in rapid regeneration and an increased incidence of these weeds.

Mittra and Pieris (1968) noted that where perennial grasses were present a sequential treatment of dalapon followed by paraquat was superior for weed control than paraquat alone in the absence of cultivation but when one cultivation was carried out subsequent to spraying, control given by paraquat alone was as good as that given by dalapon followed by paraquat. The authors concluded that the relative roles of preplant herbicides, cultivation and flooding were complementary and to a limited extent compensatory in obtaining good preplant weed control. De Datta et al (1979) showed that a preplant treatment of dalapon followed by paraquat which was comparable in cost to conventional tillage failed to give satisfactory control of Paspalum distichum, Frimbristylis littoralis, and Scirpus maritimus and yields were significantly lower than those from the conventionally-tilled plots. When the herbicide treatment was followed or preceded by tillage or reduced tillage was used alone control of these weeds was improved and the rice yield did not differ significantly from that with conventional tillage (Table 2).

Table 2

Effect of combinations of preplant herbicides, tillage and flooding on grain yield of rice
(Adapted from De Datta et al 1979)

Treatment	Weed wt. (g/m^2)	Grain yield (t/ha)
Herbicide-tillage	174[a]	4.2[a]
Herbicide-tillage-flooding	138[a]	4.1[a]
Tillage-flooding	239[ab]	3.7[a]
Conventional tillage	268[ab]	3.2[a]
Tillage-herbicide	271[ab]	3.0[a]
Tillage	257[ab]	3.0[a]
Herbicide-flooding	411[bc]	0.8[b]
Herbicide	784[c]	0.4[b]
Flooding	635[bc]	0[b]

In a column, means with common superscripts are not significantly different at the 5% level.

Minimum and zero tillage techniques imply that the combined effect of herbicide and tillage leads to better weed control than tillage alone. The data of De Datta et al (1979) does not demonstrate that. They point out that the advantage of herbicides need to be more convincingly demonstrated to be included in such systems because herbicide treatments constitute a considerable risk and expense in comparison with tillage and are more weather dependent.

LONG-TERM EFFECTS OF REDUCED TILLAGE

In continuous cropping trials in Sri Lanka the use of minimum cultivation increased grain production over conventional cultivation from 13 to 17 kg/ha/day in the wet zone and from 18 to 22 kg/ha/day in the dry zone (Mittra and Pieris 1968).

Elias (1969) noted that after several seasons of continuous usage of minimum tillage, no major problems have arisen. However, De Datta et al (1979) reported that after two crops without tillage, perennial weeds became dominant because of ineffective control by the dalapon/paraquat preplant treatment. For the third crop, the zero tillage treatment was discontinued and the plots were thoroughly tilled prior to planting. When zero tillage was reinstated prior to planting the fourth crop P. distichum and other weeds were virtually absent. Generally, in the fifth and succeeding years, as tillage was reduced from conventional to zero, weed weight increased and the perennials became more dominant in the weed flora. Due to the inability of the minimum and zero tillage techniques to control perennial weeds, the minimum and zero tillage plots were thoroughly cultivated prior to the eighth and eleventh crops. The virtual absence of weeds in these crops was mainly due to the recultivation which completely controlled the perennial weeds and the effective control of annuals with the pre-emergence herbicide.

In areas that are infested with P. distichum, minimum and zero tillage techniques may not be feasible for more than two successive crops because of the inadequacy of minimum tillage for thorough incorporation of this weed and the inability of preplant herbicides to substitute for tillage in controlling this weed.

DRYLAND RICE

Wijewardene (1980) reported that the number of man-hours required for growing a hectare of dryland rice in Nigeria decreased from 930 for conventional tillage to 44 for zero tillage. At the same time the number of tractor hours was reduced from 4 to 0. The conventional systems of land preparation and hoe weeding were replaced by herbicides. Herbicide application consisted of glyphosate applied preplant followed 2 weeks later by fluorodifen pre-emergence plus paraquat if any green vegetation was present at the time of application of the pre-emergence herbicide (Wijewardene, pers. comm.). Yields exceeded 5 t/ha with the highest yield (7 t/ha) being obtained from the zero tillage field.

Other researchers have not been as successful in growing dryland rice under zero tillage. Failures to successfully establish and control weeds in dryland rice in Nigeria and the Philippines have been reported by Moody and Mukhopadhyay (1980). Lacsina (1980) reported that rice in reduced tillage plots that were treated preplant with pendimethalin failed to produce any grain yield due to heavy weed infestation whereas conventionally-tilled plots that were hand weeded twice yielded between 1.0 and 2.4 t/ha.

Control of grasses in a zero tillage system using paraquat preplant and butachlor pre-emergence was so poor that hand weeding had to be substituted 21 days after seeding for the intended treatment of 2,4-D (Olofintoye, 1980). When the plots were harrowed once following paraquat application, there was no need to substitute the hand weeding for the 2,4-D application. However, in the reduced tillage plots weed growth at harvest was significantly higher than in the conventionally-tilled plots that were hand weeded twice while yields were significantly lower (Olofintoye, 1980). The yield differences were attributed primarily to the toxic effects of butachlor.

The costs of land preparation and postplanting weed control were 34% lower under zero tillage and 66% lower under minimum tillage compared to the conventionally tilled plot (Table 3) making them economically attractive. However, because yields were lower under the reduced tillage systems returns were also lower.

Unless better weed control and better stand establishment can be achieved in dryland rice grown under zero tillage resulting in yields comparable to those obtained with conventional tillage it is unlikely that such a system will gain much acceptance even though the input costs might be less than for conventional tillage.

Table 3

Partial cost and return analysis for dryland rice grown under different land preparation methods
(Adapted from Olofintoye, 1980)

Cost of postplant weed control ($)	Conventional tillage	zero tillage	Minimum tillage
Yield (t/ha)	3.2	1.9	2.0
Gross value ($) At $0.18/kg	576.00	342.00	360.00
Cost of land preparation ($)			
Ploughing	28.00	0	0
Harrowing	36.00	0	12.00
Paraquat (1 kg ai/ha)	0	29.59	0
Paraquat (0.8 kg ai/ha)	0	0	23.69
Spraying of herbicide	0	1.80	1.80
Cost of postplant weed control ($)			
Hand weeding	140.80	70.20	0
Butachlor (2 kg ai/ha)	0	23.49	23.49
2,4-D (0.5 kg ai/ha)	0	0	4.16
Spraying of herbicide	0	1.80	3.60
Total cost	204.80	126.88	68.74
Partial net returns	371.20	215.12	291.26

SEQUENTIAL RICE CROPPING

The use of minimum and zero tillage has also been evaluated as a possible way to reduce the turnaround time (the time between harvesting of one crop and the planting of the next in a cropping sequence) between rice crops. In rainfed areas, long turnaround periods result in crops being planted too late in the wet season for dependable production. For example in Iloilo province, Philippines when two wet-seeded (pre-germinated rice seed broadcast on puddled soil) rice crops were grown in sequence there was a yield loss of 0.7 t/ha for each 10-day delay in planting the second rice crop (Roxas et al, 1978).

In Iloilo province, the turnaround period between two rice crops averages 21 days but there is considerable variation ranging from as little as 5 days to as long as 37 days (Magbanua et al, 1977). Farmers in the area regard traction power as the most important constraint to timely crop establishment with labour and cash availability of equal second importance (Price et al, 1980). The use of power tillers and machine threshers could shorten the turnaround period by 1 week (McMennamy and Zandstra, 1978). Further reduction in turnaround time is possible if the number of tillage operations are reduced or chemicals are substituted for the standard tillage treatments of one ploughing followed by two or three harrowings. Bolton (1980) reported that it was possible to reduce the number of harrowings following an initial ploughing for a second crop of rice in rainfed or irrigated areas from three to one without a serious reduction in yield (Table 4). Further reduction in tillage by elimination of the ploughing operation led to an increase in weed weight and the time required for weeding. Except when there were few weeds at harvest of the first crop and adequate water was present for weed suppression in the early growth stages of the second crop, yields from these treatments were significantly lower than that from the standard tillage treatment. Ploughing followed on the same day by a single harrowing was the most promising reduced tillage treatment. The lowest total costs for tillage and hand weeding were obtained when the plots received only a harrowing. Yields though were lower than those from the plots that were ploughed and as a result returns were lower.

Table 4

Effects of land preparation treatments on grain yield, costs of tillage and hand weeding and returns to land preparation and weeding operations[1]
(Adapted from Bolton 1980)

Treatment	Yield (t/ha)	Cost ($/ha) Tillage[2]	Hand weeding[3]	Output[4] ($)	Return ($)
1 ploughing + 3 harrowings	3.1	50.13	14.00	465.00	400.87
1 ploughing + 1 harrowing	2.9	21.60	21.60	435.00	391.80
Harrowing alone	2.4	9.20	24.40	360.00	326.40
No tillage	2.0	3.07[5]	39.60	300.00	257.33

[1]Average of 5 experiments; [2]costed $ 2/day; [3]costed at $ 1.07/day; [4]costed at $ 0.15/kg; [5]paraquat applied at 0.6 kg ai/ha to one field.

In a trial conducted under irrigated conditions at IRRI eliminating the ploughing operation for land preparation for a second crop of transplanted rice following a first crop that had been weeded twice resulted in a significant increase in weed weight (Table 5). However, there was no decrease in yield as a result of the reduction in tillage or the increase in weed weight.

Table 5

Effect of land preparation and weed control method on weed weight at harvest and yield of transplanted IR46 rice

Degree of tillage	Weed weight ($g/0.5\ m^2$) Hand weeded 15 and 45 DAT	2,4-D (0.8 kg ai/ha)	No weeding	Yield (t/ha) Hand weeded 15 and 45 DAT	2,4-D (0.8 kg ai/ha)	No weeding
1 ploughing + 3 harrowings	0.4^a	4.2^b	7.8^b	3.3^a	3.3^a	3.0^a
1 ploughing + 1 harrowing	1.4^a	5.2^b	10.7^b	2.9^a	2.6^a	2.6^a
Harrow only	0.6^a	60.4^a	66.3^a	3.3^a	3.1^a	3.1^a
Zero tillage (paraquat 0.75 kg ai/ha)	0.9^a	44.6^a	50.1^a	2.8^a	2.7^a	3.1^a

In a column, means with common superscripts are not significantly different at the 5% level.

Minimum tillage has been used successfully for the establishment of a second crop of transplanted rice in Cavite province, Philippines (Anon. 1979). The time required for land preparation was reduced from 3 or 4 weeks using the conventional system of two or three ploughings to less than 1 week when a non-selective herbicide was followed by a light cultivation. Hoque and Akanda (1980) reduced the turnaround time between crops from 15 days for the farmers land preparation of ploughing seven times and laddering four times to 1 day using zero tillage without reducing grain yields.

The weed flora growing in association with the rice crop may also be affected by the degree of land preparation used. Perennial weeds would be expected to increase as the number of cultivations is reduced. The long term effects of reduced tillage for the second crop of rice following conventional tillage for the first rice crop on the weed flora needs to be studied in detail.

Despite the benefits obtained from reduced tillage systems acceptance in tropical Asia has been slow. The reasons are summarised by Brown and Quantrill (1973). Nevertheless, Brown and Quantrill (1973) feel that minimum tillage can offer substantial benefits to rice producers in the tropics and in the long term, with changing economic and social conditions and improving standards the technique will undoubtedly become much more acceptable in the future. De Datta et al (1979) conclude that minimum tillage is a dependable alternative to conventional tillage for transplanted rice production. However, zero tillage, needs to be treated with caution, being a more radical departure from the conventional and time tested methods of land preparation.

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ECOLOGICAL ASPECTS OF CHEMICAL WEED CONTROL IN SUGAR BEET

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Summary Changes in crop production practices in Poland have led to both an increase in weed numbers and in the range of weed species occuring in sugar beet, including several grass weeds. Herbicide systems have been devised to deal with four weed associations:

1. Broad leaved weeds only
2. Broad leaved weeds + *Agropyron repens*
3. Broad leaved weeds + *Echinochloa crus-galli*
4. Broad leaved weeds + *Avena fatua*

Echinochloa crus-galli is particularly troublesome and unless controlled seriously reduces the yield of sugar beet. It has been most effectively controlled by diclofop methyl, alloxidim sodium and acetanilide, with root yield increases of 25-30 t/ha. Work is in progress on the control of *Avena fatua*, and on the influence of weather and soil conditions on the dynamics of weed populations.

INTRODUCTION

An area of 550,000 hectares of sugar beet is grown in Poland. In the rotation sugar beet usually follows cereals, which are harvested very late due to difficult and variable weather conditions. This causes shedding of grain before and during harvesting and reduces the time available for good soil preparation for the sugar beet. Consequently a high level of weed infestation in the spring has to be expected.

Further factors exert selection pressure on certain weed species:

simplification of crop rotation (monoculture)

increased proportion of cereals in the rotation

new short-strawed cereal varieties providing less competition to weeds

mechanisation of harvest

selective action of herbicides

About forty different weed species occur on sugar beet farms in Poland. The most prominent ones are:

Chenopodium album	*Lamium purpureum*
Stellaria media	*Veronica sp.*

Polygonum sp.   Viola tricolor
Thlaspi arvense   Anthemideae
Galium aparine

In addition to these, Amaranthus retroflexus occurs in some parts of our country. The most troublesome grass weeds are Agropyron repens, Echinochloa crus-galli and Avena fatua. More recently several other species, such as Sinapis arvense, Papaver rhoeas, Cirsium arvense and Centaurea cyanus have increased but they can be successfully controlled by the use of appropriate herbicides in cereals and now do not present much of a problem in sugar beet.

Long spells of cold weather and dry conditions in summer tend to weaken the sugar beet plants and decrease their ability to compete against weeds. This often causes late infestation by Echinochloa crus-galli, Polygonum sp., and Anthemideae. These ecological factors directly influence the mechanical cultivation methods for sugar beet.

The traditional method of weed control for this crop - handweeding - has disappeared because of manpower shortage, and consequently chemical methods of weed control are developing rapidly. Herbicide systems based on the degree and type of weed infestation have been devised to deal with the following four groups of weeds:

A. broad-leaved weeds only
B. broad-leaved weeds + Agropyron repens
C. broad-leaved weeds + Echinochloa crus-galli
D. broad-leaved weeds + Avena fatua

The weeds in Group A are to be found on practically all farms, the species present varying according to soil type and climatic conditions. Groups B to D each represent one species of a grass weed and are specific to certain areas. Only Agropyron repens occurs over the whole country, its incidence depending mainly on the standard of husbandry of the specific farm.

METHOD AND MATERIALS

The basic weed control systems using herbicides which have been developed and recommended to deal with these situations, are described in Table 1. These systems can be modified in response to local needs and conditions to achieve optimal control.

RESULTS AND DISCUSSION

By selecting the appropriate herbicide group and by using the correct husbandry practice we are able to produce sugar beet under weed-free conditions for all circumstances relating to Group A, broad-leaved weeds only.

For the control of problem weeds in Groups B to D, Agropyron, Echinochloa, Amaranthus, Avena and certain additional weeds now appearing in sugar beet as a consequence of the widespread use of selective herbicides, other systems are currently under development at our Institute in Poland. A good example is the group having Panicoideae and Echinochloa crus-galli as the prominent species. Under Polish conditions these species germinate over a long period from about the middle of May to the end of June. The rate of infestation is influenced by the increased frequency of corn and sugar beet in the crop rotation, and the type of selective herbicides used in these crops (lenacil, phenmedipham, chloridazon, triazine derivatives). Echinochloa crus-galli competes strongly with the sugar beet crop and, when not adequately controlled greatly decreases yield (table 2).

Table 1

Systems of weed control
in sugar beet in Poland

group	pre-sowing	pre-emergence	post-emergence
A	-	chloridazon/lenacil, metabenzthiazuron + lenacil	phenmedipham
B	TCA	chloridazon/lenacil	phenmedipham
C1	cycloate	chloridazon/lenacil	phenmedipham + oil
C2	-	chloridazon/lenacil	phenmedipham + ethofumesate
C3	-	chloridazon/lenacil	phenmedipham + alloxidim sodium/ diclofop methyl
C4	-	chloridazon/lenacil + acetanilide	phenmedipham + oil
D1	chloridazon + triallate	acetanilide/thiobencarb	phenmedipham + oil
D2	-	chloridazon/lenacil	phenmedipham + diclofop methyl

groups: A = Broad Leaved weeds
B = " " " + *Agropyron repens*
C = " " " + *Echinochloa crus-galli*
D = " " " + *Avena fatua*

Table 2

The interrelationship between density of *Echinochloa crus-galli* and crop yield of sugar beet

(ZD.Czechnica 1978 J.Rola)

Echinochloa crus-galli number/m^2	crop yield t/ha
57	37.0
234	30.6
676	21.3
1100	20.8

Controlling *Echinochloa crus-galli* by mechanical and/or hand-weeding is expensive, the cost being up to 25-30% of the total crop value. Farmers therefore show considerable interest in effective methods of chemical control (table 3 and 4).

Table 3

Control of Echinochloa crus galli and Stellaria spp. in sugar beet
Mean of 8 trials (WOPR 1976-77)

Treatment	Rate kg/ai/ha	Yield t/ha	Index of density at harvest time	
			Echinochloa c.g	Broadleaf weeds
TCA + lenacil	7.6 + 0.6	47.0	6	5
TCA + chloridazon	7.6 + 3.2	48.4	3	4
ethofumesate + phenme- dipham	1.5 + 1.0	50.5	2	1
chloridazon + etho- fumesate + phenme- dipham	4.0+8.0+0.8	50.0	1	3
cycloate + chloridazon + phenmediphan	3.66+2.4+1.0	51.0	2	2
acetanilide + chlor- idazon	2.16 + 3.2	53.0	2	6

Table 4

Evaluation of herbicides for control of Echinochloa crus-galli in sugar beet
(South-west part of Poland, 1976-78)

Herbicide	Number of trials	Yield increase %	Assessment of weed control (number of trials)	
			Excellent	Good
acetanilide	23	12-26	18	5
cycloate	23	8-38	12	11
thiobencarb	5	17-24	3	2
ethofumesate	9	5-11	1	8
diclofop methyl	2	24	2	-

In our 1978-79 experimental programme we tested many different herbicides against E. crus-galli. The most effective ones were acetanilide, dichlofop methyl and alloxidim sodium. Their use increased root yields of sugar beet by about 25-30 tonne per hectare without showing phytotoxicity, demonstrating their suitability; the yield increase more than compensated for their cost.

Similar experiments are in progress for the control of Avena fatua, dichlofop methyl and alloxidim sodium so far having proved to be the most effective. Further test programmes are under way to evaluate the influence of weather and soil conditions (1979 was unusually dry in May and the first half of June) on the dynamics of the weed population, and the selection of the most effective herbicide programmes under given circumstances. This problem is not yet fully solved, but results of our work will be reported at a future Conference.

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SURVIVAL VERSUS YIELD IN CEREALS. THE PROBLEMS AND CONTROL OF APICAL DOMINANCE

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INTRODUCTION

Since its introduction in the early 1960s, the growth regulator, chlormequat, has made a major contribution towards checking yield losses in wheat that result from lodging. Under traditional application schedules, the capacity of standard chlormequat formulations to restrict lodging has become closely associated with its most obvious visual effect, inhibition of stem elongation.

This association has led to undue emphasis on 'straw shortening', to a search for new growth regulators by the chemical industry based on this criterion, and to a restricted concept of the value of chlormequat, embodied in the oft-quoted statement that it 'enables the farmer to make the best possible use of the optimum level of nitrogen'. It is our opinion that dependence on these approaches has resulted in a less than full appraisal of the benefits obtainable from use of the compound; in particular, a valuable effect, reduction in apical dominance, has been largely overlooked. This effect becomes all the more important in the context of recent 'growing systems', into which 'straw shorteners' fit less well. In addition, dwarf and semi-dwarf wheat varieties, with the exception of Maris Hobbit, are far less prone to lodging.

APICAL DOMINANCE

Apical dominance is the phenomenon by which the terminal meristem suppresses development of axillaries. In cereals, it is manifest, in the vegetative plant by suppression of tillering, and in the reproductive plant by abortion and only partial filling of some seed. In a typical winter barley, less than half of the initiated shoots survive to produce ears, and from these surviving ears less than half of the potential grains survive, many of which are reduced in weight. Thus more than three quarters of the genetic potential is lost. The phenomenon is clearly of survival value to a plant, permitting development of further tillers to replace the main shoot in the event of its untimely demise. Seen in this light, apical dominance is not a mechanism working in favour of high yields in a crop growing under "favourable" conditions, free from many of the restraints (e.g. nutritional) of a natural ecosystem. Chlormequat, applied in an appropriate formulation (we have developed four for specific purposes - see below) and at an early growth stage, is beneficial to yield, even in the absence of lodging of the untreated crop, principally through increase in numbers of uniform tillers and in grains per ear, manifestations of an induced reduction in apical dominance.

OTHER BENEFITS WHICH NEW CHLORMEQUAT FORMULATIONS MAY CONFER

1. Control of lodging is still achievable by early applications of our

formulations. It is a function of stem strength, rather than plant height.

2. There is a tendency for early-treated cereals to adopt an erect, as opposed to a more lax, growth habit, based on leaf posture. Treated and control plants bear a striking resemblance to the two basic wheat genotypes, erect and lax, studied by Austin et al. (1976). These authors found that the erect habit was more efficient with respect to light trapping and yield production. The possible implication here is clear enough.

3. We believe that early good root and tiller development resulting from early application of chlormequat enables the plant to utilize nitrogen that might otherwise be lost, and that the nitrogen response of treated plants is reduced with respect to optimum levels. This is under investigation.

4. Finally, we hold that chlormequat may, by interference with the plant's hormonal system, lower response to the phytochrome-mediated drive to secure production of some seed at the expense of yield, under pressure of competition through high crop density. The environmental factor here is a high far red/red light ratio received by the crop canopy at high planting density (Holmes and Smith, 1975). The implication is that chlormequat treatment may permit considerably higher seed rates without a proportionate decrease in yield per plant. This, too, is under investigation.

THE NEW FORMULATIONS

Bettaquat has been developed for early spring application to wheat, to function during the tillering stage under cold conditions that are likely to be met at this time. Barleyquat is a related formulation to which barley, in contrast with standard chlormequat formulations, is similarly responsive. Additionally, formulations which include persistent coating agents have been developed to permit application to winter cereals in the autumn; these are Halloween (winter wheat and oats) and Hele Stone (winter barley and rye).

All of these products are relatively new, and work on their further development is proceeding. Results available to date, mainly of field trial work, will be presented in substantiation of most of the views expressed above.

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PREVENTION OF LODGING IN WINTER BARLEY

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Summary Effects of growth regulators on yield and components of yield of winter barley were investigated. Reduction in straw length and in lodging of both 2 row and 6 row varieties was obtained. In the absence of lodging growth regulators had only a small effect on yield but where early lodging was controlled yield increases of 8-10% were typical. Improvements in components of yield were more dependent on lodging prevention than on the individual chemical used.

INTRODUCTION

Growth regulators, as their name implies, have the ability to modify the growth pattern of cereal plants, predominantly in the degree and rate of cell elongation. The most obvious effects are in a reduction in straw length, which may be retained through to harvest or may be followed by compensatory growth by the upper internodes giving no net reduction in straw length at harvest.

While the effects of the growth regulator, chlormequat, have been well documented for wheat (Humphries 1968) showing stem shortening and thickening, increased root growth and increased grains per ear, results with barley have generally been less reliable. Early investigations on winter barley (Cyanamid 1966) looked at chlormequat as both a foliar spray and a seed dressing. Reduction in straw length and lodging was not reliable from spray treatments. Seed treatment reduced straw length and lodging and increased yields by up to 20% but germination of treated seed was delayed. Improved winter hardiness was found with seed treatment.

The mixture of ethephon and mepiquat chloride was first used in ADAS trials in 1978 and reduced lodging from 21% down to 9% with a yield increase of 11% (Rosemaund 1978) and delayed early lodging with a resultant yield increase of 20% (South East Region 1978). With the introduction of ethephon and a further formulation of chlormequat, ADAS initiated a series of trials beginning in spring 1979 to investigate the effects of growth regulators on yield and other growth parameters of winter barley. A report on the first year's results (ADAS 1979) indicated a small positive, but in most cases not significant, yield increase in the absence of lodging on 2 row winter barley. Prevention of early lodging gave significant yield increases in a 6 row winter barley.

METHOD AND MATERIALS

16 field experiments were carried out in 1979 and 23 in 1980. Experiment layout was a randomised block design with 3 replicates. Each chemical treatment was applied at 2 nitrogen levels:

N1 = ADAS recommended rate

N2 = ADAS recommended rate + 25%

Chemical application was by hand precision sprayer based on Oxford Precision sprays, van der Weij, or modified farm sprayer according to site limitations. Harvesting was carried out by plot combines or by breadknife technique. Chemicals were applied in accordance with manufacturers' recommendations (Table 1).

Table 1
Treatment details

Active Ingredients	Product Name	Growth Stage (Zadoks)	Product Dose (l/ha)	Water Volume (l/ha)
1979				
Primary treatments				
chlormequat	Barleyquat*	31-32	3.5	225
ethephon + mepiquat chloride	Terpal	32	2.5	200-450
ethephon + mepiquat chloride	Terpal	37	2.5	200-450
ethephon	AHM 79/1 (Cerone)	37	1.0	200-400
ethephon	AHM 79/1 (Cerone)	49	1.0	200-400
Secondary treatments				
ethephon + mepiquat chloride	Terpal	32	2.0	200-450
ethephon	AHM 79/1 (Cerone)	37	1.25	200-400
1980				
Additional primary treatment				
chlormequat	Barleyquat-B	30	2.3	180-220
Secondary treatment				
chlormequat	Cycocel ≁	30	3.5	200-400

* Identified as chlormequat(B) in text

≁ Identified as chlormequat(C) in text

In 1979 GS Zadoks 31/32, 1 to 2 nodes detectable, ranged from 12 May in Wales to 2 June in the northern region - a reflection of the cold late spring. GS.49, awn emergence, was reached by late May - early June on most sites. In 1980 GS.30, pseudosten erect, was recorded between 14 March, south east, and 15 April East Anglia GS.31/32 occurred between 3 April and 1 May, and GS.49 between 14-22 May.

RESULTS

Statistical analyses have been carried out on individual trial results though these have not been completed for 1980 data. Information referred to in the tables relates to mean results from a number of trials and these accumulated results will not be statistically analysed until the trial series ends in 1981.

Table 2
Straw length as % of untreated control

	Nitrogen treatment	chlormequat(B)		ethephon + mepiquat chloride		ethephon		Straw length of control (cm)
		GS.30	31/32	GS.31/32	37	GS37	49	
1979								
East Anglia (4 sites)	mean	-	98	91	87	88	87	106
1980								
Igri - no lodging (1 site)	1	94	97	84	83	87	90	77
	2	100	99	89	86	91	94	79
1980								
Igri - lodged sites (4 sites)	1	99	101	94	85	90	94	91
	2	92	103	87	86	87	88	97

Table 3
Proportion of crop lodged, %

Type of barley	Date of lodging	Nitrogen treatment	Control	chlormequat(B) GS.30	31/32	ethephon + mepiquat chloride GS.31/32	37	ethephon GS37	49
1979									
6 row (1 site)	18.6.79	1	42	-	42	0	2	8	37
		2	42	-	53	3	40	28	35
1980									
2 row (7 sites)	1. to 14.7.80	1	20	4	12	6	2	2	4
		2	53	20	46	21	3	4	13
6 row (1 site)	1.8.80	1	60	47	36	0	2	2	0
		2	60	50	48	10	0	0	2

Table 4
Crop yield as % of untreated control

Type of barley	Nitrogen treatment	chlormequat(B) GS.30	chlormequat(B) 31/32	ethephon + mepiquat chloride GS.31/32	ethephon + mepiquat chloride 37	ethephon GS37	ethephon 49	Yield of control (t/ha)
Sites where no lodging occurred - 1979								
2 row	1	-	104	104	102	99	102	5.92
(14 sites)	2	-	103	103	99	100	99	6.34
Sites where no lodging occurred - 1980								
2 row	1	101	103	105	103	103	102	6.76
(12 sites)	2	101	102	106	103	103	101	7.06
6 row	1	98	103	100	-	-	-	6.94
(1 site)	2	97	98	98	-	-	-	7.16
Sites where lodging occurred - 1979								
6 row	1	-	122	138	155	140	123	6.24
(1 site)	2	-	107	129	106	114	99	7.85
Sites where lodging occurred - 1980								
2 row	1	103	102	104	102	103	102	7.47
(6 sites)	2	108	105	106	111	108	107	7.38
6 row	1	103	102	108	108	107	108	9.47
(1 site)	2	100	95	104	100	102	103	10.01

Table 5
Crop yield as % of untreated control, sites where chlormequat(C) used

Type of barley	Nitrogen treatment	chlormequat(B) GS.30	chlormequat(B) 31/32	ethephon + mepiquat chloride GS31/32	ethephon + mepiquat chloride 37	ethephon GS37	ethephon 49	chlormequat(C) GS.30	Yield of control (t/ha)
Sites where no lodging occurred - 1980									
2 row	1	103	104	109	104	105	103	104	6.96
(6 sites)	2	102	103	108	105	104	102	105	7.28
Sites where lodging occurred - 1980									
2 row	1	105	103	105	103	104	105	103	6.75
(2 sites)	2	111	111	105	114	110	110	110	6.51

Table 6

Fertile tillers at harvest - as % of untreated control

Type of barley	Nitrogen treatment	chlormequat(B) GS.30	chlormequat(B) 31/32	ethephon + mepiquat chloride GS.31/32	ethephon + mepiquat chloride 37	ethephon GS37	ethephon 49	Control heads/m^2
Sites with no lodging - 1979								
2 row	1	-	99	101	100	103	93	682
(6 sites)	2	-	107	104	113	113	103	667
Sites with no lodging - 1980								
2 row	1	97	97	96	98	95	98	802
(5 sites)	2	98	98	99	101	101	98	822
Sites with lodging - 1979								
6 row	1	-	110	111	107	119	109	410
(1 site)	2	-	103	92	90	110	100	432
Sites with lodging - 1980								
2 row	1	106	99	106	101	111	99	848
(2 sites)	2	111	-	111	107	107	112	824

Table 7

Grains per ear - as % of untreated control

Type of barley	Nitrogen treatment	chlormequat(B) GS.30	chlormequat(B) 31/32	ethephon + mepiquat chloride GS.31/32	ethephon + mepiquat chloride 37	ethephon GS37	ethephon 49	Control grains per ear
Sites with no lodging - 1979								
2 row	1	-	98	97	92	93	95	24.3
(6 sites)	2	-	99	96	93	94	92	24.1
Sites with no lodging - 1980								
2 row	1	102	105	96	99	98	103	22.0
(3 sites)	2	99	97	94	95	103	100	22.8
Sites with lodging - 1979								
6 row	1	-	89	150	156	110	111	26.3
(1 site)	2	-	100	182	140	149	107	22.9
Sites with lodging - 1980								
2 row	1	112	104	104	112	112	108	24.0
(1 site)	2	100	104	96	96	108	96	26.0

Table 8
Thousand grain weight - % of untreated control

Type of barley	Nitrogen treatment	chlormequat(B) GS.30	chlormequat(B) 31/32	ethephon + mepiquat chloride GS.31/32	ethephon + mepiquat chloride 37	ethephon GS37	ethephon 49	Control thousand grain weight (g)
Sites with no lodging - 1979								
2 row	1	-	100	98	98	99	99	51.6
(6 sites)	2	-	99	99	96	99	97	51.5
Sites with no lodging - 1980								
2 row	1	104	101	94	101	96	99	48.5
(1 site)	2	102	103	99	103	99	103	47.8
Sites with lodging - 1979								
6 row	1	-	97	84	93	90	99	33.9
(1 site)	2	-	83	98	104	104	96	34.4
Sites with lodging - 1980								
2 row	1	100	100	104	104	98	103	51.6
(1 site)	2	101	103	102	105	103	102	48.9

DISCUSSION

Formulation and recommended timing for chlormequat(B) has changed during the course of the trial series and results for this chemical in 1979 must be treated with caution. Application at GS(Zadoks)30 reduced straw length initially but this was not carried through to harvest on most sites (Table 2). Application at GS30 reduced lodging more effectively than at GS31/32 (Table 3) but differences in yield between the two times of application were small (Table 4). Fertile tiller number appeared higher where the chemical was applied at GS30 in lodging sites (Table 6).

Ethephon + mepiquat chloride reduced straw length by 10-15% and gave marked reduction in lodging at both GS31/32 and 37 with a tendency to better lodging prevention at GS37 (Table 3). In the absence of lodging, applications at GS31/32 produced greater yield benefit than at GS37, while the later application tended to produce higher yield on lodging sites (Table 4). On lodging sites tiller number tended to be increased by application at GS31/32. Grain number per ear tended to be reduced at GS37 applications in the absence of lodging but was increased considerably at both GS31/32 and GS37 where early lodging was prevented (Table 7).

Ethephon reduced straw length by 10-13% with satisfactory prevention of lodging on most sites at both GS37 and GS49. The lower control of lodging on the 6 row site in 1979 (Table 3) was attributed to rain following application. Effects on grain yield were variable in the absence of lodging with little benefit in 1979 but a small increase in 1980 (Table 4). On lodging sites satisfactory yield responses were obtained in both years. Tiller number tended to be increased by application at GS37 more than at GS49. Grain number per ear was reduced in 1979 in the absence of lodging but was not affected in 1980. Where lodging was controlled grain number per ear was increased. Incidence of incomplete ear emergence (one or two grains) was more frequently recorded for this material particularly when applied at the latest growth stage. Presence of immature secondary tillers was also more often reported from the later growth stage applications.

Chlormequat(C) applied at GS30 was placed in some trials in 1980 and although having little effect on lodging prevention, yield response was similar to other growth regulators (Table 5).

Yield response from the use of growth regulators has been greatest when early lodging in June or early July has been prevented or delayed. Lodging prevention near to harvest has not necessarily resulted in yield increases. Activity of growth regulators in increasing fertile tiller number and grain number per ear has generally been more marked in lodging than in non-lodging situations. This suggests that increases in components of yield may be associated more with the ability of the plant to maintain these components where lodging is prevented than with direct chemical effect.

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SESSION 8A

The paper by P. E. Schott and F. R. Rittig, B.A.S.F., Federal Republic of Germany was withdrawn.

THE 1980 NOTTINGHAM FOREST WEED CONTROL CONFERENCE

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Held at Nottingham University in April under the auspices of the Association of Applied Biologists and the Institute of Foresters of Great Britain, the conference on Weed Control in Forestry was undoubtedly a success. The first of its kind to be held in the UK, the far-ranging interest that it stimulated was made very clear from a study of the list of registered delegates, nearly 200 in number.

The steadily increasing awareness of forestry, trees in general and their establishment in particular, over recent years has highlighted a need for an examination and dissemination of knowledge and experience in the many aspects of forest weed control. The use of chemicals in the wide range of forest situations has now become a specialised field and the selection of the correct method and material to be as effective and economic as possible, now requires a considerable degree of expertise. It is important therefore to set aside the time and create the opportunity to pool information, exchange experiences and thus lead to a better understanding of the problems involved.

This was ably demonstrated in the first session on Weed and Crop Biology which dealt with the effect of weeds on trees in both nursery and forest sites and the subsequent effect of weed removal. Several papers confirmed the importance of vegetation in a competition for moisture and nutrients and not just in a physical suppression of young trees. Complete control of vegetation by chemicals leads to faster early growth and greater production. Horticulturists and Agriculturists have long appreciated this. But they are dealing with an annual crop situation, which is quite different to forestry in economic terms. Foresters must treat the "evidence" of growth gains with caution, relating it to financial input. Small, but statistically significant gains in early growth there are and even large gains are possible with "scorched earth" inputs. But it could be misleading expressing such benefits in long term crop production terms. It may be more meaningful to emphasise such benefits in the shorter term, such as a greater potential for crop trees to growth out of any browsing pressure zone or to keep ahead of any competitive woody weeds.

Another important aspect for foresters to note is the timing of weeding in relation to maximising the benefit:input ratio. Vegetation control early in the season is much more beneficial than later, and first year control appears to be more important than in later years.

For foresters who practice the more extensive, large scale type of forestry in the upland areas of the north and the west of the country, two significant points emerged. Firstly tree survival, at least on ploughed sites, is not markedly affected by the vegetation normally found on these areas, despite the stimuli of removal of grazing pressure and site improvements, both physically and chemically by drainage and standard forest fertiliser input. This confirms a fact that foresters already well appreciate that ploughing is a useful extensive way of minimising any effects of ground vegetation on the planted tree crop. Secondly the positive effect on tree growth of chemical weed control is not so evident on peaty soil types. This is particularly important, as on such site types chemical weed control has proved to be unreliable and these site types form the major proportion of upland areas.

All foresters, but particularly upland foresters, must therefore always be asking themselves the question "Is it necessary and economic for me to weed?" in order to get the best value for input in the wide range of situations that can occur. Further work is required in the field of chemical weed control in order to determine the maximum levels of various types of weed growth that can be tolerated by young trees before they are adversely affected. Information is also required in order to determine the minimum level and frequency of weed control that will result in the maximum cost effectiveness of the treatment used.

As a natural follow-on the second session on Weed Control and Forest Management dealt with different aspects of actual application. Once it is accepted that weeding is necessary, chemical weeding gives greater outputs than hand weeding and when mechanical methods of application are employed even greater outputs can be achieved. However it is not always so obvious and straightforward in upland areas, where the bulk of forestry occurs. Here there is a more selective occurrence of "weedy" areas and mechanical methods are less able to be selective. In certain circumstances hand weeding therefore may still be a feasible, if uneconomic option. This aspect was rarely mentioned during the conference, although it was one on "Weed Control" and not "Chemical Control of Weeds".

It appears that in order to allow approval of large scale herbicide application which may be more beneficial to forest managers, more dissemination of information on properties and residues is required to get the co-operation of Water Authorities and Local Government departments. An excellent example of such overall co-operation and planning was noted from experience in Norway, where the usefulness of glyphosate in its spectrum and potential for woody weed control by helicopter was very well demonstrated. The importance of careful planning was highlighted in this instance because for foliage application, the technique, timing, rate of chemical and climatic conditions can be critical.

The value of careful pre-planning by the forest manager was further demonstrated in the consideration and evaluation of options for rhododendron control in Ireland and in maximising efficiency of herbicide usage at Thetford.

For efficient use of available labour, application of herbicide in less busy times in the forest year must be very advantageous to the manager. This is where propyzamide scores with its October to January application period.

In this session there was an interesting reminder of the problems of rhododendron control in Ireland. Although we are very well aware of this locally in this country, it has tended to get ignored on grounds of high cost. However with the increase in land values over recent years and the fact that rhododendron usually occupies the better forest site types, the problem is well worth a fresh look, particularly with the advent of promising new herbicides, such as glyphosate and triclopyr.

The third session which covered weed control in specific forest situations, served to provide some useful reminders and pointers. Firstly for the control of bracken, asulam continues to be an important chemical showing good crop tolerance in post planting applications. It is a pity that there has been little in the way of follow up reports on the period of control after 10 years of usage. Although perhaps considered not so important for forestry, it is quite relevant for the forest manager to have this information for pre-planting application, which is the most cost effective time with no subsequent hand cutting required. Although some additives for increasing effectiveness of control are not recommended, it was interesting to note that mixing asulam with an emulsifiable oil, Dessipron, appears to increase reliability and effective swathe width, as well as allowing lower rates of chemical to be sufficiently effective. This is of important practical significance and approved recommendations will be awaited with great interest, particularly to note whether there is any change in crop tolerance. In the wetter parts of the country, any improvements in reliability will be useful to enable programmes to be achieved.

There were useful reminders of the importance of Calluna vulgaris as a spruce growth inhibitor and that 2,4-D ester is still the most effective post planting chemical to apply. However the mention of fertiliser as an alternative option is important, as in certain upland areas the achievement of hand application herbicide programmes is proving difficult and there are current restrictions on aerial application of 2,4-D.

Cut stump treatment using glyphosate indicated the herbicide's promising versatility, and the mention of clearing saw and chainsaw accessory equipment for its application was an interesting feature to note for future availability and trial work in this country.

The revival of fosamine as another possible alternative to 2,4,5-T for woody weed control was also interesting to note. However it may have limitations for widespread practice owing to the apparent minimal translocation of the herbicide in the plant and the fact that adequate spray cover and penetration is important for good control. Results of existing field trials will be anticipated with great interest, particularly as the longer term effects are apparently more dramatic. Perhaps new techniques or equipment will improve reliability.

The use of special formulations of oils to increase the effectiveness of forest herbicides by reducing evaporation and drift must be a step in the right direction from the environmental point of view, as the amount of active ingredient may well be able to be reduced for equally effective results. At the same time however, what must be watched is any change in crop tolerance with any increased effectiveness.

Finally there was a reminder that the use of some normally useful herbicides can be detrimental in artificially created soil conditions, such as reclaimed open cast mining sites. Furthermore, useful practical experiences such as the observation that the herbicide cyanazine/atrazine was more effective when soil conditions were moist, was useful to pass on.

The fourth session was an extension of specific aspects of weed control, this time covering two specialist areas namely the well established forest nursery situation and also the developing field of amenity.

The use of herbicides in forest nurseries is tricky because crop safety is all important. But at the same time, the rewards for any success are substantial from cost benefits. On the one hand there is a labour intensive alternative at high cost these days and on the other there is a high value crop grown in a concentrated area, thus maximising efficient use of any herbicides.

A major point arising from this session was the immense value of the WRO's pot experiment techniques for the screening work required in forest nursery herbicide usage. The margin of safety is much more critical than in the forest situation and the composition and balance of weed populations is locally important. Not only single herbicides, but mixtures too, can be treated quickly to provide "best bets" for further study in the nursery situation. The choice of chemical for further testing cannot always be easy with combinations of the best spectra of crop tolerance and weed control, as well as length of control, being the main aspects to unravel. With a wide range of chemicals on the market and coming on to the market, there must be a limit to the amount of work which can be done, bearing in mind the fairly restricted use for forest nursery herbicides, compared with horticulture and agriculture.

The problems of post emergent sprays for hardwoods are to be noted in relation to the increasing, albeit limited, interest in hardwood species, both for commercial and for conservation/amenity reasons. Continued seedbed work with the nitro-phenyl ether group would appear to be a promising line. Also to promote a better understanding of the mode of action of certain herbicides, which in turn should lead to more efficient usage, a parallel line of research into factors affecting successful usage, such as soil type, irrigation, pH etc would seem logical.

The use of Diphenamid as both pre and post emergent application on a wide range of conifer and broadleaved species was a success story. The effect of repeated application was useful to note, with pre and one post application looking justified. Its use in larch transplant lines as an alternative to simazine was also interesting.

The importance of applying treatments timeously in transplant situations was stressed to prevent the build up of perennial weed populations. Simazine is still as good as any for this purpose, but where a problem has got out of hand, the use of certain "forest" herbicides, such as glyphosate, propyzamide and MCPA, has been successful in specific situations, where the state of weed infestation justifies the risk of crop damage.

A useful resumé of the relatively new work being done in the field of amenity planting on man made sites was to be noted. Concentrating on motorway planting, which has a notoriously variable degree of successful establishment throughout the country, the problems associated with physical soil conditions and a man made weed problem (rye grass) were highlighted. Similar to findings from the first session the competitive aspect of the ground vegetation was important and among the factors of equal interest in the "forest" situation were size of area controlled and timing of control. The effectiveness of black polythene was noted, as was the effect on bigger plants of mowing to reduce biomass competition. It was interesting that this was the first report of a method of weed control other than chemical.

The fifth session on new herbicides once again highlighted the valuable screening work of the W.R.O., with the techniques employed being particularly useful in the field of surfactant or refined oil additions to increase herbicide effectiveness. Several pointers emerged pertinent to specific forest weed situations.

For grass, summer application of triazine compounds, especially terbuthylazine, look useful. Although this timing might not be so effective from the competitive aspect, it might have an application for pre-planting in unploughed conditions to identify spots for back end planting. It could also have a use in hill areas where winter access is difficult, if the weed problem merited it. Application of terbuthylazine or cyanazine in March looked promising for hardwoods, as these compounds appear less phytotoxic than atrazine. Also the autumn application of glyphosate for Calamagrostis control was interesting to note.

For heather, triazines again, particularly atrazine plus a refined oil, look to provide an alternative to 2,4-D should one ever be required.

For woody weeds the effects of glyphosate on different hardwood species, from different application timings, was of interest and served to indicate that we have to feel our way carefully with this useful broad control spectrum chemical to avoid possible disappointments.

Hexazinone looks to be a very promising herbicide for the foresters' armoury due to its control spectrum of the more troublesome grasses on a wide range of sites and the reasonable crop tolerance of the normally sensitive species such as Western Hemlock, Douglas Fir and Norway Spruce. Its effect on other forest situations, such as bracken, birch and perennial herbaceous weeds is useful to note. In upland areas however, the March-May application period may limit its usage, coinciding with the main planting season. Although to compensate, application at this time is when vegetation competition is most important.

The review of continental experience with hexazinone was very useful and dissemination of similar information with other herbicides would, I'm sure, be welcomed by UK foresters.

Another forest situation herbicide, triclopyr, in its ester formulation, looks an interesting alternative to 2,4,5-T for woody weed control, confirming W.R.O's indications. It appears particularly effective against gorse and broom and with its potential for rhododendron control, it seems a useful herbicide to watch for further trial results.

Oxyfluorfen, one of the promising nitro-phenyl ether herbicides for nursery use proves to be so in its crop tolerance and broad spectrum of weed control in seedbeds. Its only drawback is its lack of control of chickweed, an important nursery weed. However, used in mixture with other herbicides, it should become as useful an option as a seedbed herbicide.

The granule formulation of atrazine plus dalapon looks a promising addition to the grass control herbicide range, and it will be interesting to note how competitive it will be when marketed. However one wonders at the future for "mixtures" in forestry, bearing in mind the extra cost of manufacture and the less critical standard of control needed compared with horticulture and agriculture.

The sixth and final session on the Safety and Approval of Herbicides was an important session in view of the ever increasing interest and pressure from the environmentalist lobby today. And rightly so that there should be such pressure to remind user and manufacturer of their responsibilities, although it would appear that sometimes critics do not always seem to be aware of the approval Schemes in operation. Those Schemes were very usefully outlined and the papers will form a valuable way of disseminating this information. The latest Scheme, BASIS, will cover an area which causes much concern amongst users, namely information on storage and disposal of pesticides.

The Norwegian approval scheme, a statutory one compared to our voluntary or optional ones, raised some interesting debatable issues. For example " product must be at least as effective, or displays essential advantages over other approved preparations used for the same purpose" or "products are reviewed after 5 years and re-evaluated for further registration". Also, as well as the expected information on physical, chemical, toxiological and ecological data being required, it was interesting to note that methods of disposal and information on registration in other countries was requested by their Pesticides Board.

Included in the Norwegian paper was an example of the co-operation between different authorities and involved parties in the application of pesticides from helicopters. This seemingly enlightened approach could perhaps be copied in this country as far as some forest weed control applications are concerned. An encouraging step in this direction was obvious from a paper by Clyde River Purification Board staff, in which factual evidence on the effects on water supplies of field scale application of herbicides was presented. It is only by co-operation such as this that data can be built up to allay suspicions and build up confidence all round, to prove that most herbicides used in a responsible way have no harmful effect on the environment.

As a final comment I feel that to maintain the dialogue and exchange of information achieved at this first Forest Weed Control conference, it certainly could be repeated, possibly on a four year cycle, at which interval "meaty" information should always be available. The forest side tends to move more slowly than its sister disciplines.

Furthermore to put forest weed control in the right perspective compared with these other disciplines, I feel that one cannot generalise. It should be remembered that there are different approaches involved when considering the silvicultural and economic impact of forest herbicides. Firstly, there are the more intensive fragmented, lowland forest practices where growth rates are good, timber prices are generally high and access is reasonable. To offset these advantages for maximising economic benefits weed problems in these areas are usually much more critical. However land prices are very high in comparison with upland areas, and there is a necessity, for amenity reasons, to plant mixed plantations of often uneconomic species.

In the uplands a more extensive view is applied. Here the logistic problems of herbicide application, because of accessibility and often scattered distribution of weed problem areas, the slower growth and the standard ground preparation techniques employed, lead to a more selective usage. The bigger scale does not necessarily mean a large potential market, but where financial benefits will be less, a more careful reasoning behind the need to weed has to be applied, to maximise economic and silvicultural benefits.

SAFETY IMPLICATIONS OF RECENT CHANGES OF HERBICIDE USE AND METHODS OF APPLICATION

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Summary Recent trends in the extent and timing of herbicide use in agriculture are reviewed together with changes in application technology. The implications of these changes for the safety of the spray operator, the consumer of treated produce and the environment are considered and areas are delineated where further work is required or improvements could be made based on existing knowledge.

Resume On passe en revue l'évolution récente de l'emploi des herbicides dans l'agriculture, considéré du point de vue de son importance et de la sélection des temps convenables d'application, ainsi que les changements intervenus dans la technologie de l'application. On considère l'incidence éventuelle de ces changements sur la sécurité de l'opérateur de l'appareil de pulvérisation, sur le consommateur des produits traités et sur l'environnement, et on précise des domaines où des travaux ultérieurs sont nécessaires ou dans lesquels on pourrait effectuer des améliorations à la base des connaissances actuelles.

INTRODUCTION

Although the herbicide DNOC was one of the first synthetic organic pesticides to cause safety problems due to its toxicity, herbicides are generally of low acute mammalian toxicity and have traditionally been viewed as extremely safe. However, changes in both the scale and method of use during the last few years give rise to some concern over the safety of herbicide application and a re-examination of the hazards of current patterns of use for the operator, the consumer and the environment is probably timely. This review attempts to highlight the major changes which have occurred recently, to point out problems in the few instances where these have been documented and to draw out potential problems which may need some attention. Unlike insecticides, herbicides seem to have attracted relatively little safety evaluation outside the normal package of animal tests required for registration purposes so that many of the points raised in this review are inevitably speculative especially when considering the environmental hazards which herbicides pose. They are nevertheless in the view of the authors, worthy of further investigation.

EVALUATION OF THE TOXICITY OF HERBICIDES

Registration procedures, which rely heavily on the laboratory assessment of toxicity by animal tests, are often considered to guarantee the safety of commercially used pesticides. This can only be true as far as toxicological knowledge current at the time of registration allows and there must always be a margin of error. Many of the herbicides currently in widespread use have been registered for a considerable period of time. For instance the phenoxyalkanoic acid group mostly date from the late 1940's and many of the substituted urea group from the 1950's. Advances in toxicology make it inevitable that these compounds were not subjected to as full a toxicological assessment as more modern compounds although the important gaps have now been filled by independent investigators, especially for the common compounds most of which have a long record of use without obvious problems to the operator. Modern chemical analysis has also revealed the presence of small amounts of undesirable high toxic impurities in some of the older compounds. For instance, 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) has been found in compounds such as 2,4,5-T made from 2,4,5-trichlorophenol and the isosteric chlorinated azobenzenes in herbicides made from chlorinated anilines. Although such impurities are kept to acceptable levels in commercial formulations as soon as their hazards are recognised, the continuing discovery of such materials certainly suggests that it is generally unwise to expose anyone unnecessarily to crop protection chemicals. Further, it appears desirable to use chemicals from reputable sources where correct quality control is assured.

Registration procedures assess safety for each product independently since neither existing techniques nor available resources allow the testing of mixtures of products which may be used in practice. It follows that the use of experimental mixtures may carry safety problems in addition to the occasional more obvious problems of compatability or phytotoxicity, some of which have been documented.

ASSESSMENT OF THE SAFETY OF HERBICIDES IN USE

The hazard presented by a pesticide to man or the environment is a function both of the inherent toxicity and the extent to which exposure occurs. Assessment of the former is made during registration by using laboratory animal tests. In practice, the latter is a function both of the amount used and the way it is applied, which vary considerably with the current agricultural practices and problems. It is these variables which often cannot be gauged when the first clearances are given and which make hazard difficult to assess in practice. A continuing indication of the current exposure of the three major groups at risk, namely the operator, the consumer of treated produce and the environment, must be obtained if we are to be assured of the safety of existing practices even with compounds of low inherent toxicity such as most herbicides. Furthermore, registration authorities will need to ensure that more guidance on the machinery through which a cleared pesticide may be applied, is given to the operator on the label. This requires clearance to be much more closely linked with the method of application than has hitherto proved possible. It is on these problems that this review focuses and most attention is given to the large use crops.

HERBICIDE USAGE

The extent of herbicide use is an important feature for the assessment of their safety. Annual figures for the total use of pesticides in the United Kingdom are difficult to obtain because the most reliable surveys which are carried out by ADAS have been conducted on a cyclical basis in which the various major areas of agriculture and horticulture are examined approximately every 3 to 5 years. However, there is no doubt that herbicides form by far the greatest part of pesticides used on both a weight and a sales basis and their use has grown steadily on most crops during the last two decades. For instance, in 1979 the value of sales increased by 35 per cent (BAA, 1980). Although a significant proportion of all important agricultural crops except fodder and forage now receive herbicide treatments, the largest quantity and greatest variety are applied to cereals, partly because of the size of the crop and partly because of the diversity of the problems encountered. The most recent estimate (MAFF, 1977) suggested that 142 per cent of the national crop of 3.2 million hectares of cereals is treated with herbicides (ie most is treated and much is treated more than once). About two-thirds of the treatments are for broadleaf weeds mainly with older herbicides and the rest for the increasing problem of grass weeds mainly with newly developed sophisticated selective chemicals. Although these figures show little overall change in the three years since the previous survey the use of paraquat for stubble clearance and glyphosate for pre-drilling weed control had increased significantly. Other crops, in particular vegetables, arable crops, orchards and soft fruit have shown considerable growth of herbicide use and appear to receive proportionally more treatments than cereals, but are grown on much smaller areas. Although grass and fodder occupy a larger area than cereals only approximately 30 per cent receives herbicide application.

RECENT DEVELOPMENTS IN HERBICIDE APPLICATION

The second half of the 1970's has seen a variety of developments of importance when considering the safety of herbicides although the long-term agricultural significance of many has yet to be properly assessed, especially for large-scale users such as cereal farmers. Cultural practices and the use of herbicides have encouraged the development of grass weeds in cereals and a new generation of expensive selective herbicides has appeared for their control, accounting for part of the overall increase in use. The timing of herbicide application has also changed. Earlier drilling of cereals, particularly of the increasing area of winter barley, has encouraged the development of grass weeds and has led to the introduction of autumn herbicide applications. The development of low ground pressure vehicles will accentuate this trend. Overall this may lead to an increase of herbicide use since such applications may still require 'topping up' in the spring. The introduction of a herbicide application to cereals just pre-harvest to clean up the ground for subsequent sowing is another recent development.

The increasing cost of labour, chemicals and energy has prompted considerable changes in application techniques. The use of tank mixes in order to shorten application time has increased and a recent publication (Farmers Weekly, 1980) listed a very large number of tank mixes recommended by manufacturers with a range of products. Few mixtures containing chemicals from more than one manufacturer were recommended. The recommendations are generally made primarily on compatability and efficacy and it must be noted that although each component of every mixture has been cleared individually for safety and that there is no evidence of potentation of toxic effects, few of the mixtures have been subjected to a safety evaluation in the same way as their components.

Developments in spray technology have mainly been concerned with reducing spray volumes and are aimed primarily to shorten the application time. In some instances there is also an increase in the efficiency of placement of the chemicals. Of some potential importance are the moves to replace the hydraulic nozzle with rotary atomisers or some other form of droplet production. Ultra low volume applications (1-10 l/ha) which rely on drift of small droplets (<70μ) for their effect should not be considered for weed control because of their potential for crop damage, their variability in penetration of standing crops and the difficulties of calibration and achievement of selectivity between weed and crop, although some hand-held machines have however found moderate use in special situations such as over rough ground. Controlled drop application, the use of spinning discs to produce a narrow range of drop size coupled with very low volumes (10-50 l/ha), is of more interest for herbicide application (Byass and Lawrence, 1976). In particular the production of aqueous droplets around 250 μ is attractive and may decrease drift although the technique still has problems of crop penetration. Although some herbicide formulations are cleared for this use, the technique is unlikely to progress further in the absence of a reliable wide-boom sprayer coupled to a sprung vehicle. Of considerably more current importance is the increasing move away from the use of conventional spray volumes (>200 l/ha) and towards the application of existing formulations at the recommended rate but in low volumes (50-100 l/ha). These applications, carried out through conventional hydraulic nozzles with smaller orifices, sometimes at higher pressures, invariably produce a wider spectrum of droplet size with lowered volume median diameters (VMD) and associated drift and safety problems. Aerial spraying, usually carried out at around 20 l/ha through conventional nozzles should for the same reasons be attractive, but the even greater drift problems have generally kept aerial application of herbicides in the United Kingdom to a minimum. Although 22 herbicides are cleared for aerial application, they account for less than 2 per cent of the 4 x 10^5 ha treated aerially in 1978 (MAFF, 1980).

Several other long-term developments may prove significant for the safety of herbicides. The direct drilling of cereals is expected to increase and it has been estimated (Phillips et al., 1980) that resultant herbicide use is increased by about 50 per cent. On the other hand successful development of the electrostatic sprayer might be expected to lower dose rates and to apply chemicals with less drift, whilst developments such as the wick and the roller applicator for the treatment of tall standing weeds and the 'recycling' sprayer, could also significantly increase the efficiency of placement of herbicides on their target. Interest continues to be shown in granular and slow-release formulations of pesticides which can also significantly reduce unwanted operator and environmental exposure, but developments with herbicides are so far disappointingly low.

HERBICIDE DRIFT

A proportion of any applied pesticide drifts away from its immediate target. The magnitude of this drift depends on many factors some of which have been discussed above. The most important are probably the mode of application, particularly the spectrum of drop size which it produces and the prevailing weather conditions. Tottman and Phillipson (1974) have estimated that drift can be a hazard using conventional machinery on more than three days out of four during the period when post-emergence herbicides are applied to cereals in the spring. The extent of drift is of considerable importance in assessing the hazard of spray applications to the operator and to the environment generally. Although much has been done to characterise the kinetics and physics of drift spray particles the work has so far failed to solve the practical problems.

Observations in the field have concentrated on herbicides because herbicide drift causes obvious and often economic damage. It is the avoidance of damage rather than the safety aspects which has generally prompted investigations, but even so much of the work has severe limitations. Firm data on the magnitude and the effects of the drift under different operational circumstances, as well as the effectiveness of drift control measures, are hard to find. Few studies account for the fate of all the applied chemicals (Renne and Wolf, 1979) whilst other ignore significant differences in droplet collection and retention by artificial targets used to study drift and by crops and other herbage exposed to drift (Lawson and Uk, 1979). Few reports appear to take into account the dimensions, shape and orientation of the target area and their influence on an observed level of drift. Identical applications in the same direction to two equal rectangular areas, orientated at right-angles to each other, lead to very different drift levels simply because incremental deposition of drift from each successive spray track could take place chiefly within the target area in one case and outside it in the other. Recent work (Renne and Wolfe, 1979; Lewis and Lee, 1976; Cooper, 1977 and Maybank et al., 1978) suggests a very wide range of drift levels in practical spraying operations. This is predictable in view of the plethora of application equipment (Matthews, 1979), variable operational conditions and the variety of procedures used to measure drift. Insufficient data are available to be able to assign precise drift potential factors to specified types of spray equipment but broadly it appears that from about 15 to > 50 per cent of an aircraft's spray is liable to drift away from a target area and from < 1 to > 40 per cent of a ground spray. Conventional hydraulic boom and nozzle systems fitted to tractors are used most widely in the United Kingdom for herbicide application. For these, drift levels can rise from just over 1 per cent of the applied spray, under ideal operation conditions, up to 37 per cent in windy conditions and with incorrect settings for pressure and boom height (Nordby and Skuterud, 1974). Controlled-droplet application of certain herbicide sprays may be expected to have relatively low drift potentials but other forms of CDA equipment, that rely on wind and gravity for placement of the spray, have very high potentials due to the presence of many drift-prone particles (Matthews, 1975). It is apparent due to the additive nature of droplet drift coming off successive swaths even a small fraction of initially drifting material may present a hazard. It has been suggested (Maybank et al., 1978) that under certain conditions even if only 1 per cent initially moves off from each swath the drift density at the down wind field edge may well exceed the deposit density within the field. The distance which such drift may carry is also difficult to estimate. Most results suggest that the bulk is deposited within 500 m (Table 1) but drift of 10-50 miles has been suggested in certain circumstances (Robinson and Fox, 1978).

TABLE 1

The variability of drift deposits

Distance downwind from target area m	Percentage of applied dose deposited	
	ground-based spraying	aerial spraying
0 - 30	0.1 - 60	1 - >100
30 - 100	<0.1 - 20	0.1 - 25
100 - 500	<0.05 - 2	<0.1 - 4

A high proportion of the drift of applied herbicides is attributable to the movement of fine air-borne particles. However, evaporation from the leaves of sprayed vegetation can add appreciably to the initial loss. The lower molecular weight members of the phenoxyalkanoic esters are exceptionally volatile and concentration of 2,4-D in vapour form in air of up to 0.01 mg/m^3 have been found in areas of the USA subject to regular crop damage (Grover et al., 1972; Farwell et al., 1976). These workers estimate that 30-40 per cent of the initial deposit of the butyl ester is liable to evaporate within two hours of spraying in contrast with only 10-15 per cent of the octyl ester and 4-6 per cent for the relatively non-volatile amine salts. Although the hazard of crop damage by vapour from both 2,4-D and dicamba has been recognised for some time in North America, especially when air and/or leaf temperatures are high (> 24°C) it has not until recently been considered a problem in the United Kingdom. Recent reports of damage (Harvey, 1979) in England have, however, been consistent with damage by the vapour of the iso-octyl ester formulation of mecoprop, although air temperatures were not high. Eagle (1980) has demonstrated that vapour damage to brassica can be reproduced experimentally in conditions similar to those observed in the field. It may be that these observations are a function of decreased volume spraying which may lead to a greater deposition on leaf surfaces from which evaporation is known to occur more readily (Behrens and Lueschen, 1979) and also to deposited droplets with a much greater surface area which can also aid evaporation. The relationship between the nature and extent of the initial deposit and the dilution, when a formulation is applied through conventional sprayers has not been investigated for herbicides in arable crops. However, Carmen et al., (1972) demonstrated that up to twenty times the initial deposit was obtained on the leaves of fruit trees when emulsifiable concentrate formulations of insecticides were sprayed at volumes between five and twenty times less than those normally used.

RISK TO HUMANS DURING HERBICIDE APPLICATIONS

Most herbicides fall into the low risk category so that they would not be expected to cause acute affects even at moderate exposure levels. The major route by which operators are exposed is dermal adsorption and the dispensing and mixing of liquid products carries the greatest risk. Recent changes in the application of herbicides have not generally affected this hazard although the use of tank mixes probably increases the risk. Protective clothing, especially for hands and eyes are usually recommended for these operations.

Dermal adsorption and inhalation of drift particles and contact with recently sprayed vegetation are the other potential exposure hazards. Since the operator is generally nearer the source of any drift, higher exposure levels are to be expected than in bystanders downwind. Observations made by one of the authors (Lloyd) suggest that exposure of the casual bystander by these routes is likely to be insignificant although slight irritant effects sometimes occur and these can often generate alarm and lead to complaints. For the operator, respiratory exposure tends to be low, whatever the spray method (< 1 mg/h), but dermal exposure varies considerably (Lloyd, 1979). It tends to be highest in the use of hand-held sprayers, where even particles drifting short distances can reach the operator. Because these machines are often used over rough terrain this exposure can be compounded by contact with sprayed vegetation. The much more widely used tractor-mounted sprayers can also give rise to considerable operator exposure from short distance drift unless, as is increasingly the position, a cab with suitable air intake filters is fitted. The latter of course must be properly used in order to afford protection. Clearly, moves towards spraying lower volumes through conventional hydraulic nozzles tends to increase drift and concentration in the drifting droplets and hence operator exposure. Raising the boom height, spraying in strong winds and using hollow cone in preference to flat fan nozzles also all increase drift and dermal exposure. Further, since reduced volume spraying through hydraulic nozzles probably leads to higher initial deposits it may also increase exposure by subsequent contact with vegetation.

The regulatory authority in the United Kingdom does not demand the wearing of specialised protective clothing in spraying operations with the majority of herbicides because of their low-risk rating. Normal working clothes afford a considerable measure of protection. Nevertheless, where drift is high or adverse conditions prevail and no other form of protection is afforded it appears prudent to consider the use of minimal specialised protective clothing which can subsequently be removed and decontaminated when using the majority of plant protection chemicals professionally. Work is required to make available good comfortable protective clothing.

Accurate statistics of incidents involving undesirable human exposure to pesticides are impossible to collect. It is difficult to define an incident. Where an investigation is undertaken, opinions on the significance often vary widely. Many minor incidents are not reported and conversely trivial incidents often are. Subjective presentation of the statistics also adds to the confusion. Nevertheless records are kept and herbicides regularly account for about 20-30 of the approximately 100 incidents each year in which pesticide involvement is confirmed. The greater proportion of these involve complaints of drift, but more complaints are received for insecticide and fungicide drift presumably reflecting the larger aerial use. Within limitations these figures confirm that acute poisoning is not a hazard when using herbicides but that drift is an unsatisfactory feature even for ground-based spraying operations and must be considered hazardous to unprotected operators chronically exposed over long periods. More work is required to provide advice to minimise drift from all forms of spraying and in particular to provide guidance on the influence which the weather has on drift.

HERBICIDE RESIDUES

Herbicides, which are usually applied long before harvest, normally present few residue problems. No reports are available comparing initial and harvested residues when herbicides are applied either by different types of machine, or at different concentrations through the same machinery and there are few results available for other pesticides. A recent ADAS trial suggested that HCH applied to rape by ULV (112 g ai/ha) and conventional machinery (560 g ai/ha) gave initial residues approximately proportional to the application rate. Carmen et al. (1972) suggested that for a variety of insecticides, the same application rate in reduced volumes through conventional machinery leads to higher initial deposits and higher residues at harvest in orchard spraying. No general conclusions can be drawn but, from small amounts of evidence gained with other chemicals, it seems that recent changes in herbicide applications are unlikely to cause unacceptable residues at harvest, although regulatory authorities must be assured on this point when new formulations and new practices are notified. This is particularly important where pre-harvest intervals are decreased as in the application of translocated herbicides just prior to the harvesting of cereals in order to clean up the soil for subsequent sowing.

ENVIRONMENTAL HAZARDS FROM HERBICIDES

A number of environmental problems have been traced to the use of insecticides. These have occurred either because of their acute toxicity or through their propensity to be transported in various physical or biological systems and cause chronic effects in certain species or ecosystems often far removed temporally and spatially from the site of action. Because of their generally low acute toxicity herbicides have received little comparable attention, but they undoubtedly have the potential to cause changes in the environment and there is some evidence that they do so. The work required to demonstrate the often subtle effects which occur after pesticide application is both time-consuming and difficult, but the present scale of herbicide use and the degree of drift and volatility which can occur suggests that continuing vigilance is important.

Direct effects Herbicides have generally not been implicated in the deaths of birds or mammals in the field. The outstanding exception has been the death of brown hares immediately after the application of paraquat, apparently by contact with wet vegetation. The increased use of paraquat for stubble clearance may pose some hazard for this species. Herbicides are hazardous for fish. Many are classified either as dangerous (96 hr $LC_{50} < 1$ mg/1) or harmful (96 hr LC_{50} 1-100 mg/1) to fish. Certain herbicides are approved for application direct to water, but the majority are not. Making reasonable assumptions concerning application rates and drift potential (Table 1) reveals that fish kills are possible up to 500 m downwind of applications of herbicides classified as dangerous to fish, so that operations near water courses must be undertaken with extreme caution and attention to drift. The majority of herbicides are strongly absorbed by most soil types so that leaching into water does not generally present a hazard, but spillage and disposal of unwanted containers into water obviously do. Herbicides do not appear to be toxic to bees and only a few are classified as dangerous (contact $LD_{50} < 2$ μg/bee) or harmful (contact LD_{50} 2-11 μg/bee) so that foraging in recently treated fields or surroundings contaminated by drift is unlikely to lead to bee kills and none have been confirmed (Stevenson, 1980). However, making reasonable assumptions on application rates and drift potential (Table 1) suggests that individual flying insects could pick up lethal quantities up to 100 m downwind of many herbicide applications, especially since significant quantities of drift can be found in air over 10 m above the ground. Our knowledge of the toxicity of herbicides to other insects including pests and pest predators is virtually non-existent but it is likely to vary widely and it seems reasonable to suppose that herbicides will cause some direct kills both on the field and in the drift area. Such effects have been suggested but it is difficult to differentiate them from induced changes in habitat or food supply.

Indirect effects The use of herbicides in forestry and on rangeland can cause significant changes in habitat which may be either beneficial or harmful to various species. A number of examples have been reported from North America in which populations of vertebrates, particularly birds have declined as a result of large-scale scrub clearance by herbicides and consequent loss of cover and nesting sites. Use on this scale seems unlikely in the United Kingdom but the likely environmental effects of any new proposals must be examined carefully.

Of much greater potential significance are the changes which may occur as the result of herbicide use on farmland and its environs. Eighty-five per cent of the land in the United Kingdom is used agriculturally so that farmland is a major wildlife habitat. A large part receives herbicide treatment and this alone must reduce the diversity of species over large areas through its contribution to the intensification of agriculture on the better land (Moore, 1971). Methods for studying the effects that pesticide treatments may have are still relatively primitive and often the most painstaking work leads to equivocal results. Moreover baseline data on which to make judgements are frequently not available. However, some examples of the subtle interactions which can occur are now authenticated and point to the need for the development of better methods and more studies.

A long and detailed study initiated by the Game Conservancy on 62 km^2 of cereal farmland in West Sussex has demonstrated that insect pest species in cereals have remained stable or increased in numbers whilst many non-pest species have declined. Whilst much of this effect is attributed to interference with predator-prey relationships by the use of insecticides and also fungicides, which often have insecticidal action, many insects associated with weeds have declined substantially (Vickermann, 1980). The essential interrelationships which occur in this ecosystem were illustrated in the same study by Potts (1977). He demonstrated that the removal of dicotyledonous weeds by herbicides has resulted in a significant decrease in the density of saw fly larvae (Tenethredinidae) over a number of years. Since the survival of grey partridge chicks (Perdix perdix) can be related directly to the abundance of saw fly larvae and cereal aphids, Potts has suggested that this is the link which explains the correlation between the decline in partridge survival rate first observed in the mid-1950's and the widespread introduction of herbicides during the same period. The same considerations may apply to the pheasant (Phasianus colchicus) and the red-legged partridge (Alectoris rufa). In another elegant study, Green (1978) has demonstrated the use of herbicides in cereals has so depleted the weed seed density on ploughed land in late winter that the skylark (Alanda arvensis) ceases to forage for seeds and adopts a less favourable feeding strategy of grazing young cereals and sugarbeet. In areas of low herbicide use this does not happen. Not only does this disadvantage the species but also causes it to become a pest. A similar phenomenon has been observed with linnets (Acanthis cannabina) which have also recently caused damage by removing seeds from strawberries, especially from the early crop grown under polythene tunnel cloches, because the increased use of herbicides in local orchards has seriously reduced the density of available weed seeds (Flegg, 1980). Since a number of common farmland bird species employ a similar feeding strategy it seems likely that they may also be subject to the same constraints.

The demonstration of herbicide interference with complex interrelationships such as those above, suggest that it would be prudent to undertake further work for the benefit forboth agriculture and conservation. The increased use of herbicides especially with direct drilling and reduced cultivations and the tendency to autumn application are new pressures on the farmland ecosystem which is now receiving herbicides all the year round. The move toward lower volume spraying through hydraulic nozzles with some increase in drift and the recent demonstration of herbicide volatility in certain situations in the United Kingdom will both tend to spread any effects wider, whilst the use of tank mixes leads to a broader spectrum of activity. The well known variation in sensitivity of cultivated plants to herbicides suggests that some species in natural plant communities will also be ultra-sensitive. The removal of individual species of plants from the hedgerows and other wildlife shelter areas could have serious consequences for insect fauna. This in turn could cause pest problems for the farmer and food problems for other species.

Resistance to herbicides might also be expected, and weeds resistant to triazine herbicides are becoming quite widespread in North America (Bandeen *et al*., 1979) although no resistance has been reported in the United Kingdom. One species to develop resistance is the groundsel, *Senecio vulgaris* and the susceptibility of populations in the United Kingdom to simazine has been investigated. Although it was shown (Holliday and Putwain, 1980) that there is a genetic basis for variation in susceptibility in United Kingdom populations, the most interesting observation was in orchards. Under pressure of simazine, groundsel switched completely to a winter annual life cycle, thus avoiding phytoxic concentrations of simazine in the spring and consequently flowered much later in the summer. With the complex relationships which occur in ecosystems, changes such as this can be expected to have significant consequences. Little data are currently available to assess such problems and sustained monitoring programmes will be required if the effects of the widespread use of herbicides are to be extracted from normal background variation in natural systems.

CONCLUSIONS

Although the safety record of herbicides has been reasonable, there is no cause for complacency. Increasing use and changing application methods suggest that continuing thought must be given to minimising non-target exposure. More studies are required to monitor the effects of selected chemicals applied by a variety of existing techniques. The aim should be to achieve a better mass balance in order to produce reliable and meaningful exposure data for the operator, consumer and the environment. The further development of methods to assess the safety for man and the environment of mixtures and sequences of chemicals applied in current agricultural practice is also required. This would allow better advice to be given on the safety and improvement of existing spray equipment and on the desirability of current herbicide application practice.

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NOTES

THE IMPLICATIONS OF HIGH SPEED LOW VOLUME SPRAYING FOR THE EFFICIENCY OF HERBICIDES USED IN WINTER CEREALS

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Summary The use of lightweight low ground pressure spraying vehicles has created the opportunity of applying herbicides in winter cereals at low volume rates and high forward speeds.

This paper reports on the influence of volume rate, forward speed, nozzle size and pressure on the activity of isoproturon for control of black-grass (*Alopecurus myosuroides*) and a commercial mixture of ioxynil, bromoxynil and mecoprop for broad-leaved weed control. Data is taken from previously published papers and from new studies conducted during the winter of 1979/80.

Weed control was not reduced when forward speed was increased to 20 km/h or spray volume rate reduced to 60 l/ha. Potential drift hazard was minimised using larger drop sizes with no loss of weed control from either herbicide. Implications of the results are discussed together with other aspects relating to the use of this technique.

INTRODUCTION

Since the early 1970's the pattern of cereal production in the United Kingdom has changed primarily as a result of the widespread move from spring barley to the more profitable winter varieties. This has been accompanied by a trend towards earlier planting and an increase in minimum tillage techniques which has led to a peak labour demand in early autumn. The early germination and growth of many autumn weeds is favoured by these changes in husbandry and early competitive effects on the crop represents a big threat to cereal yields. Removal of these weeds as soon as possible has become important both to guarantee yields and because certain herbicides are more effective when applied at this time of year.

Autumn herbicide applications have until recently been hampered by slow work rates caused by spray volume rates in excess of 200 l/ha and the inability to get onto the land with heavy equipment once the soil becomes too wet to carry traffic. Both these barriers can now be overcome with the introduction of low volume spraying systems and the use of lightweight low ground pressure vehicles. The progress of low volume spraying techniques and efficacy is well documented and is now reflected in current commercial recommendations. Similarly, the considerable commercial interest and development in alternative vehicles from which these applications can be made, and the logistics and opportunities offered by these systems has also recently been published (Nation, 1978; Elliott, 1980; Rutherford, 1980). The use of this type of vehicle with improved boom design has allowed higher spraying speeds to be used without the problems of excessive boom bounce. Higher forward speeds can be used to reduce spray volume rates and the relationship between these two factors is another variable which can influence the effective transfer of herbicide from spray tank to target weed.

The opportunity to gain access to wet land and the possibility of spraying at low volumes and high forward speeds has created a new approach to cereal crop protection in the UK. However the successful development of this new approach depends on the ability to maintain high levels of herbicide performance and reliability without increasing the potential drift hazard. Early studies (Cussans and Ayres, 1978; Ayres and Cussans, 1980) indicated that high speed low volume application was of considerable practical promise and further work has sought to establish the limits of its effectiveness.

The influence of forward speed, volume rate, nozzle size and pressure on two herbicides used for the control of two major groups of weeds in winter cereals is described in this paper. These herbicides, isoproturon active against black-grass (Alopecurus myosuroides) and a mixture of ioxynil, bromoxynil and mecoprop for broad-leaved weed control also have contrasting modes of action. Data is drawn from previously published papers and some new studies conducted during the winter and spring of 1979/80. The implications of the results will be discussed together with other aspects relating to the use of the technique. The methods used in these studies will be briefly described in the following section.

Experimental details

All herbicide treatments were applied using an 'Argocat 8' with either a sprayer and conventional boom as described by Cussans and Ayres (1978) or pressurized chemical containers attached to two sections of the modified boom. The nozzles used in these experiments (Table 1) were Spraying Systems 'Tee-Jets' and the spray solution was always delivered from each nozzle directed in a vertical plane. The herbicides were applied at their recommended dose rate and each experiment was replicated three or four times.

Table 1

Volume mean diameter (µm) for a range of Spraying Systems 'Tee-Jets'

Nozzle size	Pressure bars	*Volume mean diameter µm
80015	2.11	390
80015LP	1.05	410
8003	2.11	430
8006	2.11	520
8003LP	1.05	540
8010	2.11	630

Although the precise values of these data have been questioned by information gained from modern techniques using laser based devices it is still useful for its comparative value.

The influence of forward speed and volume rate

With conventional hydraulic nozzles, spray volume rates can be reduced either by using a nozzle with a smaller aperture or by increasing forward speed. The use of a smaller nozzle aperture results in the production of a drop spectrum with a lower v.m.d. and therefore an increased drift potential. One approach to this problem has been to use low pressure nozzles. These reduce output, without the disadvantage of increasing the number of small drops, and still enable a forward speed of 7-8 km/h to be used. This system which maintains a drop spectrum with a fairly large v.m.d. has been shown to be well suited for pre- and early post-emergence applications of soil-acting herbicides.

*Source Spraying Systems Co. 50% of the volume of liquid in drops less than the diameter given, spraying water at room temperature under laboratory conditions.

Results from field experiments using isoproturon (Table 2) and the ioxynil mixture (Table 3) show that the degree of weed control was not influenced by increased forward speed with consequent reduced spray volume.

Table 2

The effect of forward speed and volume rate on the efficacy of isoproturon for the control of A. myosuroides (heads/m^2) in winter cereals (Mean of three sites)

Nozzle size	Forward speed km/h	Pressure bars	Volume rate l/ha	% control
8003	5.3	2.11	220	98.7
"	10.0	2.11	115	98.4
"	19.3	2.11	60	98.8

Table 3

The effect of forward speed and volume rate on the efficacy of a mixture of ioxynil, bromoxynil and mecoprop for the control of broad-leaved weeds (total number/m^2) in winter cereals (Mean of two sites)

Nozzle size	Forward speed km/h	Pressure bars	Volume rate l/ha	% control
8003	5.3	2.11	220	95.0
"	10.0	2.11	115	96.2
"	19.3	2.11	60	95.3

The results obtained with isoproturon are perhaps not surprising as there is evidence of successful applications of soil acting herbicides at controlled drop volume rates as low as 20-30 l/ha (May and Ayres, 1978; Ayres, 1978). The control achieved from the ioxynil mixture which is partially contact in effect is better than some previous evidence from low volume controlled drop applications would have suggested(Ayres, 1976; Ayres and Merritt, 1978).

The absence of any substantial crop canopy at this time of year may have influenced the degree of control, for there was no lack of deposit on the small weeds. In addition the weeds were slow growing thus giving time for the translocated properties of the herbicide to be more effective.

The influence of drop size

Table 4a shows that from applications at 220 l/ha there was very little effect on the performance of isoproturon due to drop size. In subsequent work (Table 4b) other nozzles were used, including low pressure types, to achieve a range of drop sizes from applications at 60 l/ha and these results confirmed the previous findings.

Table 4

The influence of drop size on the efficacy of isoproturon for the control of A. myosuroides (heads/m^2) in winter cereals

	Nozzle size	Volume mean diameter µm	Pressure bars	Volume rate l/ha	% control
a)	8003	430	2.11	220	98.7
	8006	520	2.11	"	99.3
	8010	630	2.11	"	98.9
b)	80015	390	2.11	60	97.1
	80015LP	410	1.05	"	98.3
	8003	430	2.11	"	97.2
	8003LP	540	1.05	"	97.4

a) Mean of three experiments 1978/79
b) " " two " 1979/80

Additional support for this is given in Table 5 which shows no difference in black-grass control between controlled drop applications at 30 and 60 l/ha using either 150 or 250 µm drops.

Table 5

The influence of drop size and volume rate on the efficacy of isoproturon for the control of A. myosuroides (heads/m^2) in winter cereals (Mean of three sites)

Volume rate l/ha	Drop size µm	% control
30	150	90.3
	250	88.2
60	150	88.3
	250	87.9

The results obtained in the first series of experiments with the ioxynil mixture (Table 6a) also indicated that there may be scope for using larger drop sizes. The degree of control achieved from these applications using nozzles producing a drop spectrum with a v.m.d. greater than 400 µm is of considerable interest particularly for herbicides that are semi or wholly contact in action and where droplet movement away from the target zone is extremely undesirable.

More recent work (Table 6b) has also tended to support this although results have been less consistent. The range of drop sizes produced by using a variety of nozzle sizes, forward speeds and volume rates was thought to be sufficiently extreme to produce a point at which herbicide performance would deteriorate. The absence of any marked fall off indicates a degree of latitude in performance of both herbicide and application method.

Table 6

The influence of drop size on the efficacy of a mixture of ioxynil, bromoxynil and mecoprop for the control* of broad-leaved weeds in winter cereals

	Nozzle size	Volume mean diameter µm	Pressure bars	Volume rate l/ha	% control	
a)	8003	430	2.11	220	95.0	
	8006	520	2.11	"	96.7	
	8010	630	2.11	"	96.2	
					i	ii
b)	80015	390	2.11	60	79.8	94.1
	80015LP	410	1.05	"	71.0	95.7
	8003	430	2.11	"	74.9	88.9
	8003LP	540	1.05	"	70.3	92.2

a) Mean of two experiments 1978/79 (*total number/m^2)
b) Two experiments 1979/80 (*dry weight g/m^2)

The implications of high speed low volume application

The results presented in this paper establish that good control of both black-grass and broad-leaved weeds can be achieved from high speed low volume application and that large drop sizes with a lower drift potential can also be used without reducing herbicide performance. The successful combination of these three factors raise a number of logistic, environmental and technological implications.

For herbicide applications the greatest increase in rates of work are gained when high forward speeds are associated with lower volumes together with boom widths matched to the size of tank and adequate water supplies in the field (Nation, 1978). In addition the number of potential spraying days can also be increased if larger drop sizes can be used (Adams, 1978).

The timeliness of application can have a profound effect on the safety of the crop and on its final yield. The value of early weed removal to ensure maximum crop yield (Hubbard et al., 1976; Wilson and Cussans, 1978; Wilson, 1980) and the danger of spraying before or beyond certain growth stages (Tottman, 1977) are prime examples of this. Access onto wet land allows greater precision in timing but herbicides applied through suitable 'climatic windows' may be required to perform in conditions they were not originally intended for. In three seasons the experience gained from 14 experiments covering 32 ha has not suggested that the herbicides were any less safe or effective. However, this experience is limited and in commercial practice where a range of wider conditions exist such operations should still be treated with caution. Risk of herbicide damage to the crop is a possibility but in the event of crop failure, due to other factors, then there could also be a danger of extending residual damage into a subsequent spring crop. Further field research to examine these conditions and to re-evaluate herbicides is therefore required. However the subject is complex and it would also involve chemical industry in additional work if current herbicide label recommendations were to be extended.

In the process of seeking greater efficiency and precision in herbicide application we have witnessed over the last decade the development of other application methods designed to achieve this goal. These methods are capable of successfully applying spray volumes at very much lower rates than is currently used with hydraulic nozzles and they also offer greater control over drop size. The use of rotary atomisers at high speed could effectively double the area covered in a day now claimed for low volume hydraulic nozzle applications. However this is not possible because of limitations of the spinning discs currently available. The high flow rates required to match forward speed and the type of spinning disc used in both the Micron 'Herbi' and Horstine Farmery 'Microdrop' only produce uniform drops at low rates (80 ml/min) of flow. Unshrouded discs stacked vertically in groups of five and mounted on a boom at 60 cm spacing have been used at the Weed Research Organization to achieve a volume rate of 20 l/ha applied with 250 μm drops at a speed of 20 km/h. Distribution at this speed was poor but at 10 km/h a more uniform result was produced and this was used successfully to apply difenzoquat to control wild-oats in winter wheat (Taylor, Ayres and Turner, in press). The development of discs designed to cope with higher flow rates have resulted in the production of a narrow drop spectrum, but variations in swath width caused by increasing forward speed may make even distribution difficult in practice.

Using a single line of multiple pulsed jets may offer a possible solution. (Yates and Akesson, 1978). These have advantage of no moving parts, narrow drop spectrum and drops that can be directed vertically downwards into the crop. However with any system that involves using small orifices attention must be paid to adequate filtration and flow monitoring. Electrostatics is also currently receiving renewed attention and the development of a new device (Coffee 1979) has stimulated interest. Further reductions in volume rates would seem possible, but its main attraction for high speed application could be an ability to control drop size and flow.

CONCLUSION

In the last five years there has been much comment and discussion on the opportunities offered by new spray technology. The implications raised in this paper are a reflection of that interest as it applies to low volume high speed application but they inevitably overlap with ideas that have previously been expressed. Nevertheless the evidence reported in this paper does reinforce these views. Since the first reports on the feasibility of using fast lightweight vehicles for low volume application (Cussans and Ayres, 1978; Elliott, 1978) the technique has gained wide acceptance in the farming community. The speed at which the findings of a research project were taken up in practice, is indicative of the need that farmers have for this technique. There is no doubt that soil acting herbicides used in winter cereal production are suitable candidates for application by this method. The consistency of black-grass control that has been achieved in the range of application experiments conducted since 1975 offers ample evidence of the efficiency of these herbicides.

The limited work with broad-leaved weed herbicides also suggests that they too may significantly increase the options open to farmers. The success of the low volume high speed applications of a semi-contact herbicide is intriguing for it does not entirely agree with previous evidence. Why this should be so is a subject of continuing research. Other compounds, different formulations and additives also require further attention and there is clearly much work to be done if we are to keep pace with this development.

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NOTES

AUTUMN APPLICATION WITH LOW GROUND PRESSURE VEHICLES

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Summary Changes in arable cropping patterns are forcing farmers to reconsider the effect of pesticide application systems on their soils. Alternative methods of extending the spraying season are discussed. The relative merits of modified agricultural tractors, cross country vehicles and special purpose agrochemical application systems are compared.

INTRODUCTION

Changing patterns of arable cropping are leading to a complete reappraisal of the design criteria for pesticide application systems, Rutherford (1980).

Table 1 shows the swing towards autumn sown barley in England and Wales during the last 3 years. In 1979, for example, the area of winter barley increased by 28%. Oil seed rape is also increasing rapidly, and most of this is drilled in the autumn.

Table 1

The increase in winter sown barley and rape

	1978 ha	1979 ha	1980 ha
Spring barley	1416	1229	1065
Winter barley	449	566	722
Oil seed rape	64	71	92

Weather conditions will, of course, influence the area planted from year to year, but the trend has been firmly upwards. Farmers have invested heavily in power and machinery to maximise the area of winter sown crops which have shown significant financial advantage over spring crops.

Changing cropping patterns have led not only to different and more challenging weed problems but also to new difficulties in pesticide application. How are the chemicals to be applied in the winter when, by all accepted agricultural criteria, no tractor or machine should be on the soil lest the soil structure be compacted or even permanently damaged?

FIELD AND SOIL CONDITIONS

A great deal has been said about the need for a vehicle to travel over very wet soils with the minimum of damage to the crop and the structure of the soil. There is, however, very little information on what ground pressure is acceptable before the growing medium becomes impaired to the extent of reducing crop yield. The problem here is the interaction between soil particle size and moisture content. A coarse sandy soil not only drains more easily, but is also less easily compacted. Field observation of a number of wheelings of different tyres would suggest that a ground pressure exceeding about 30 kPa (4 psi) is likely to cause permanent deformation of most soils at field capacity. This ground pressure relates to the footprint area of the tyre and is not the inflation pressure which may well be 30-50% higher, depending on a number of factors such as soil moisture content, bulk density, tyre ply rating and method of tyre wall construction. It may be helpful to relate the ground pressure and footprint area of a man to 30 kPa. In fact, it is roughly equal, and the sinkage of the farmer's own Wellington boot may provide a useful guide for comparing the effect of alternative ground drive systems in an empirical way.

EXTENDING THE SPRAYING SEASON - THE ALTERNATIVES

The farmer or spraying contractor is now faced with a number of alternative methods of extending the spraying season.

1. Modify existing tractors on the farm
2. Modify other vehicles already available
3. Purchase a special-purpose vehicle.

1. The Agricultural Tractor

Tractors were primarily designed for draught operations and as such they need to be heavy to achieve adhesion and traction. Even with all the ballast removed, the normal tyre pressure is about 100 kPa on the rear tyres and approaching double that on the front. Although a long way from the target 30 kPa, the fact remains that there are large numbers of farmers whose cereal acreage will not justify costly new equipment. As a compromise they should consider distributing the load of the tractor on larger or more tyres.

Larger tyres Some combine harvesters are fitted with very large section tyres which remain unused for eleven months of the year. Wheel hubs may require modification, but for a modest sum an agricultural engineer will be able to carry out this work. Oversize tyres fitted to a 40 kW tractor carrying a mounted 500 litre sprayer have reduced ground pressure to below 50 kPa. With a mounted sprayer, weight on the front axle is reduced. Further improvement is possible by fitting wide rims and tyres on the front wheels. This will result in extra steering forces, making power assisted steering essential. The disadvantage of using oversize tyres is that they are very expensive and are often not available off the shelf. The utmost care must be taken to ensure that tyre deflection does not exceed that recommended by the manufacturer.

Dual wheels A much cheaper method of reducing ground pressure is to fit dual wheels. It may be possible to obtain secondhand wheels, and quick release couplings are available to maintain the flexibility of the tractor for other tasks. Since the tractive pull required is low, worn tyres with little or no tread are preferable. With old tyres which are otherwise destined for scrap, some farmers may be prepared to accept even lower pressures and the possibility of tyre wall damage. An additional problem at pressure below the manufacturer's recommended minimum is the risk of movement on the rims. This occurs when torque on the tyre overcomes the rim to casing friction, and will result in damage to the valve. A painted mark across the rim and tyre simplifies the frequent checks needed to avoid this problem.

2. Other Vehicles

There is a very wide range of vehicles which have been designed for other purposes but which, with more or less modification, may be used for pesticide application. It is difficult to categorise them due to the fact that some are by definition multi-purpose vehicles. In broad terms, however, they have been primarily designed to carry either personnel or loads.

Personnel carriers i. Four wheel drive. Most farms will have a vehicle in this category. The 4 WD Landrover has dominated this market but is now threatened by an increasing number of similar imported vehicles and increasingly versatile pickup trucks. Provided attention is paid to ground and mudguard clearanges, oversize rims and tyres enable ground pressures to be substantially reduced.

ii. Multi-wheel. Several 6 and 8 wheel vehicles are now available which were primarily designed to carry personnel and small loads over difficult terrain. Using small diameter low pressure tyres, they are able to travel over the worst surfaces, and indeed some are amphibious.

Problems have arisen when attempting to carry excessive loads on sticky heavy clays at high speeds. One solution is to add a semi-mounted trailer to increase the load carrying capacity while reducing the stress on individual components of the original vehicle.

Load carriers Vehicles capable of loads of 1000-5000 kg are included in this group. i. Four wheel drive trucks. The traditional vehicle in this group is the 4 x 4 of military origin. The problem with this type of vehicle is to achieve a compromise between the weight of the bare chassis, the payload, and the tyres required to provide traction at an acceptable ground pressure. A vehicle designed to carry 3 tonnes on the road weighs about 2 tonnes in cab and bare chassis form. It seems likely that apart from very large farms and contractors, this type of vehicle is too big and heavy, and the special tyres required to reduce the ground pressure to below 30 kPa suggested earlier add considerably to the cost.

ii. Tracked vehicles. Most of the vehicles in this group were primarily designed for snow. While the need for low ground pressure is the same as for the spraying operation in the winter, the traction forces are very different. Slipping of the tracks in snow acts as a protection device against excessive torque, but on Essex clay, for example, the adhesion of the large contact area will minimise slip. Stronger components or additional overload protection may therefore be required to ensure trouble-free operation on the arable farm.

3. Special-purpose Agricultural Vehicles

Agri-systems In recognising the limitations of the agricultural tractor, some manufacturers have designed a vehicle which is able to carry out a whole range of tasks in addition to the original one of producing tractive effort.

The Mercedes Unimog was probably the first and most sophisticated attempt based on the 4 x 4 military vehicle mentioned in the previous section. The American New Idea system took the concept right through to harvesting using detachable modules. Somewhere inbetween these two extremes are the Mercedes MB-Trac and the Deutz Intrac systems. In all cases these systems offer the capability to carry out a wide range of operations of which spraying is only one.

Special-purpose agrochemical applicators The self-propelled sprayer was first of all based on a large trailed sprayer built onto a tractor skid unit. For the large acreage holding and contractor, this type of machine serves a very useful purpose but it lacks versatility. The trend towards reduced volumes of diluent and autumn application is casting doubt on the need for huge payloads, wide booms and slow moving machines.

The first lightweight vehicle designed exclusively for spraying was probably the American Spra-coupe which is now available in the UK. There are now several machines of UK manufacture available and the interest in this area is such that the choice is likely to increase. The specification of these machines is impressive, with ground pressures well below 30 kPa in some cases. With relatively small payloads, good field organisation is vital, but they have the potential for very high rates of work.

CONCLUSIONS

The outline specification for the 'ideal' machine given earlier, Rutherford (1980) is summarized below:-

Brief specification for a pesticide applicator for the 100-200 ha enterprise

Forward speed:	10-20 km/h; design operating speed: 15 km/h
Transmission:	4 well-chosen gear ratios - cheaper than automatic/ hydrostatics
Suspension:	All wheel independent + isolation of the 12 m boom
Wheels & tyres:	At least 4 WD, low pressure Terra tyres. Row crop wheels for summer use optional.
Steering:	Pivot or all wheel steering preferable to skid steering
Ground clearance:	Minimum of 30 cm. High clearance with row crop option.
Carrying capacity:	500 litres
Power unit:	Lightweight diesel
Cab:	Fully suspended and air conditioned
Price:	Not to exceed cost of 50 kW agricultural tractor

Having studied the requirements for a suitable vehicle for autumn spraying and having considered the range of machines available, the following conclusions may be drawn:-

1. A cost effective solution for the medium size cereal enterprises of 50-100 ha is to consider using dual wheels on an agricultural tractor.

2. Vehicles originally designed for other purposes may be modified and will provide an interim solution for 2-3 years.

3. Special purpose low ground pressure vehicles are already emerging to fill an important gap in the equipment used by professional cereal growers and contractors.

4. The British agricultural engineering industry is reacting quickly to develop entirely new machines required for this significant change in agricultural practice.

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NOTES

ELECTROSTATIC SPRAYING - SOME BASIC PRINCIPLES

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Summary This paper sets out to explain some of the basic principles of electrostatics, as applied to charged agricultural sprays, to the layman. Using these principles it is shown how charged sprays are produced by equipment reported previously, and how the presence of a charge on a drop can help to modify its trajectory in a desirable manner. Reference is made to some of the unknown factors which need to be investigated before full use can be made of the concept.

INTRODUCTION

Work has been carried out at N.I.A.E. to measure the retention of different sized drops of spray liquid on plant surfaces (Lake, 1977). It was concluded that small drops were retained well whereas larger drops often bounced off. On this evidence, pesticides would be applied more efficiently in smaller rather than larger drops. Added to this, elementary calculations show that more drops are produced from a given volume of liquid if the drops are small. This would tend to increase the uniformity of cover and, especially in the case of small targets such as emerging weed seedlings would increase the chance of at least some pesticide reaching the target. Some workers (e.g. Lake and Taylor, 1974) have shown that smaller drops can lead to better biological control. This could well be due to the better coverage mentioned above but may also be caused by differences in the complex processes which determine the uptake of the chemical by the plant or pest.

It seems therefore that if small drops can be used then they should be. However, the major drawback is that small drops drift. For instance, the terminal velocity of a 50 µm diameter drop is only about 0.1 m/s whereas that of a 400 µm drop is over 1 m/s (Yeo, 1959). The smaller drop would therefore drift about ten times further than the larger one in a laminar air stream and is likely to be more affected by turbulence.

As will be seen in this paper, electrostatic spraying results in extra forces acting on spray drops which opens up the possibility of using smaller drops than would otherwise be acceptable. These extra forces can be used to help resist the effects of air drag and to modify the drop trajectories in a desirable manner. The forces can even be used to overcome gravity so giving a wrap around effect and achieving under as well as top leaf cover.

Electrostatics does not usually form part of the training of crop protection specialists yet an understanding of the basic principles is essential if the possibilities are to be exploited fully. In this paper, the author attempts to clarify some of the points relevant to agricultural spraying, however it must be stressed that only a very brief introduction is given here. For a more complete treatment the reader is referred to one of the standard texts (e.g. Moore, 1973).

METHODS OF PRODUCING CHARGED DROPS

1.1 Some basic principles

To understand how charged drops can be produced we must first discuss the basic components of matter. For the purpose of this paper, matter can be considered as being made up of elementary particles, some of which are charged negatively (electrons), some charged positively (protons) and some not charged at all (neutrons). Protons (and also neutrons) are relatively massive compared with electrons, about 2000 times as heavy, and each one carries a charge equal to that of an electron but opposite in sign. Normally matter is electrically neutral, this state being attained by having an equal number of electrons and protons. The positive charges thus "cancel out" the negative ones.

If a body, for instance a drop of spray liquid, is to be charged, it is necessary to disturb the normal balance of electrons and protons, for instance removing a number of electrons from an electrically neutral body will leave it with a positive charge.

Charged bodies react with others mechanically. Bodies with the same sign of charge repel while those with opposite charges attract. The force of attraction or repulsion is proportional to the product of the charges and inversely proportional to the square of the distance between them. The electric force is therefore greatest for high charge levels and short distances.

A charged body also experiences a force when placed in an electric field. One way of producing an electric field is to connect a source of voltage between two parallel conducting plates (Fig. 1). The electric field strength between the plates (neglecting effects near the edges) is the voltage divided by the distance between the plates. A positively charged body placed in the field will be attracted towards the negative plate (cathode) and a negatively charged body will be attracted towards the positive plate (anode). The magnitude of the electric force will be proportional to the charge on the body and also to the field strength.

To visualize an electric field, lines of force are often used. These lines extend from the positive electrode to the negative one and their closeness determines the strength of the field. The force on a positive charge placed in the field is always along a line of force in the direction given by an arrow placed on the line. The arrowheads are therefore towards the negative electrode. Because the electric field between the plates in Fig. 1 is uniform (neglecting edge effects) the lines of force are straight, uniformly spaced parallel lines.

1.2 Corona charging

The field strength between the two electrodes is determined not only by the spacing but also by the electrode geometry. In particular, a sharp point gives rise to a high field strength in its vicinity. The high field rapidly accelerates the few free electrons which are always present causing them to collide with the electrons in electrically neutral atoms. The collisions result in electrons being displaced from their parent atoms and becoming free to take part in an avalanche process. The depleted atoms (known as ions) are left with a positive charge.

A practical method of charging liquid drops by this process is to direct a stream of liquid past the end of a needle held at a positive high voltage (Fig. 2). Electrons are strongly attracted to the needle point leaving the relatively massive and slow moving ions to be picked up by the liquid on its passage through the ion cloud. The charge imparted to the drops is therefore of the same polarity as that of the high voltage needle.

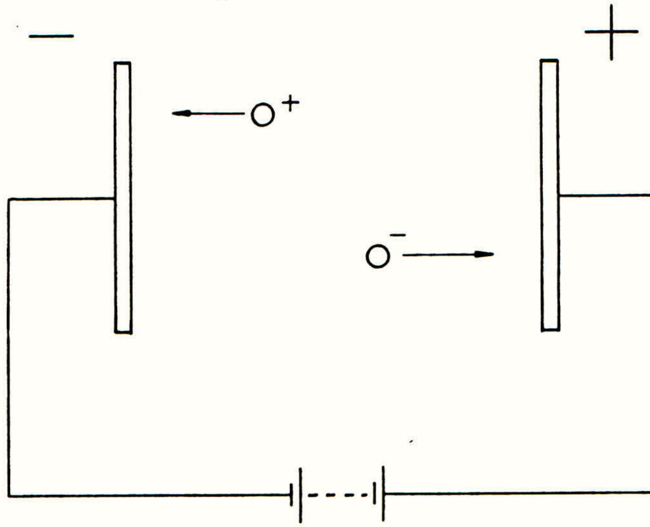

Fig. 1. Forces on charged drops in an electric field.

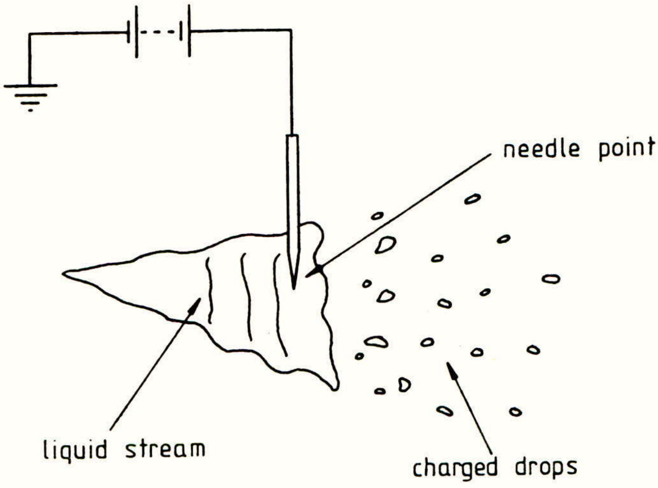

Fig. 2. Corona charging.

This method of charging is often used in paint spraying guns and has also been used for agricultural sprays produced from spinning discs (Arnold and Pye, 1979) and from hydraulic nozzles (Ganzelmeier and Moser, 1980). It is possible to charge liquids having a wide range of conductivities by this method but one disadvantage of using good conductors (e.g. water based sprays) is that the bulk of the liquids, as well as the spray drops, become charged and attains a potential close to that of the needle. With voltages between 30 kV (Arnold and Pye, 1979) and 70 kV (Ganzelmeier and Moser, 1980) the isolation of the liquid in the tank from the sprayer frame presents a problem.

1.3 Induction charging

A consequence of Gauss's law (Moore, 1973) is that lines of force must start and end on charges. Thus positive charge will be stored on the anode of Fig. 1 and negative charge on the cathode. Even if the cathode is earthed, the charge will not leak off, the mutual attraction between the positive charges on the anode and the negative charge on the earthed cathode will maintain the charges in position. These attractive forces would also bring negative charges to the earthed cathode if this were initially uncharged, the process being known as "induction". Of course, the process also works with the anode earthed whereupon positive charges will be induced onto it. The important point is that charges of the opposite sign from the high voltage electrode are induced onto the earthed one.

This phenomenon can be put to use in a practical charging system. Fig. 3 shows an arrangement developed by Law (1978) in which a high voltage electrode (about 2 kV) surrounds a liquid jet. Because the liquid is a good conductor it remains at earth potential while charges are induced from earth onto its surface by the electric field between the jet and the electrode. When the jet is disrupted by the high velocity air stream, drops are formed which carry away some of this charge. In order for the system to work satisfactorily there must be enough time for the charge to transfer from earth to the liquid jet during the passage past the electrode. The major determinant of the charge transfer time is the conductivity of the liquid but in general terms the system will work for good conductors (e.g. water based sprays) but not for poor conductors (e.g. oil based sprays).

As well as forming the drops, the air stream is necessary to keep the high voltage electrode dry and so to avoid short circuiting the power supply. Unfortunately this means that an air compressor becomes a necessary part of the system and because the air requirement of the nozzles is quite large the compressor is bulky and consumes rather a large amount of power (about 300 W per nozzle).

1.4 Electrostatic atomisation

If charge is constantly injected into a liquid, the mutual repulsion between different portions will eventually overcome the surface tension and the liquid will break up. A spherical drop will split at a charge level that depends on its surface tension and diameter. This charge level represents a maximum that a drop can attain and is called the Rayleigh limit following the classic paper on the subject by Lord Rayleigh (1879).

The production of drops from a liquid body by this method is known as electrohydrodynamic (EHD) atomisation and a modern application of the technique is ink spray printing (Moore, 1973) where the charged drops that result from the process are deflected by electric fields to form characters on paper. Recently Coffee (1979a) has applied the technique to agricultural spraying with the invention of the "Electrodyn" system. The nozzle (Fig. 4) consists of a high voltage (about 20 - 25 kV) electrode with an annular gap through which the spray liquid flows. The

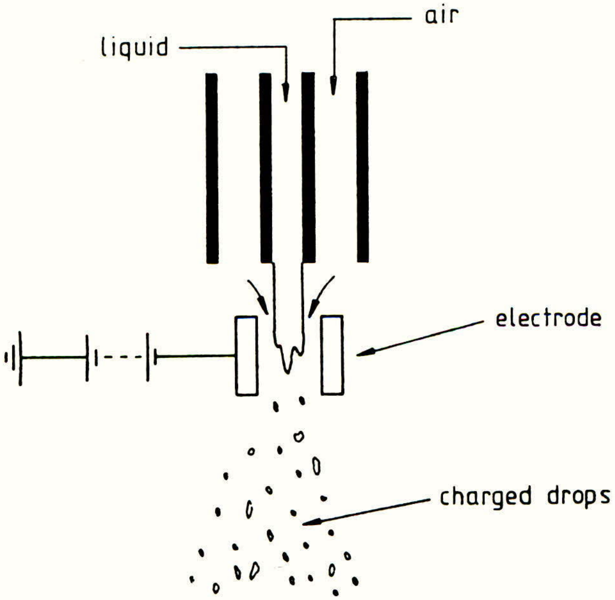

Fig. 3. Induction charger (S.E. Law).

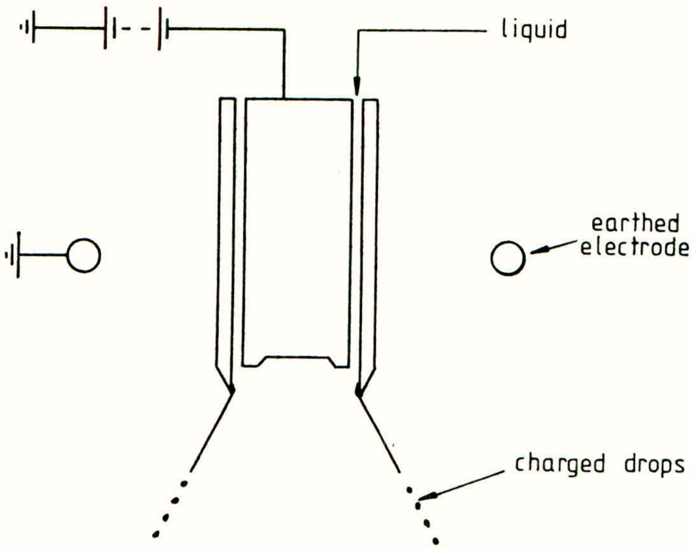

Fig. 4. Electrohydrodynamic atomiser (R.A. Coffee).

proximity of the earthed electrode to the nozzle serves to increase the electric field, which is especially intense near the sharp nozzle tip. This intense field must (by Gauss's law) have large charges at its start and end points, i.e. at the earthed electrode and at the nozzle tip. Some of the free charge at the tip enters the liquid and results in atomisation by EHD forces.

The design of the Electrodyn nozzle is certainly an elegant one. The system contains no moving parts and consumes very little power, about 100 mW per nozzle (Coffee, 1979a). This means that four dry batteries should last about 60 hours which makes the system ideal for hand-held use. However, the charging and atomisation process is a complex interaction of electrical, viscous and surface tension forces which means that the conductivity and viscosity of the liquid must fall within a certain range. This restricts the types of liquid that can practically be used with the Electrodyn nozzle to oils which must be seen as a disadvantage of the system.

In addition to the circular nozzle, it is possible to design a similar device in a linear form. It may be possible to mount such a nozzle on a spray boom so giving a uniform distribution of drop producing sites along its length.

2. Transport of charged drops to the target

2.1 Application of an electric field

As suggested in Fig. 1, an electric field presents one method by which charged drops can be actively propelled to their target. The force resulting from the electric field must compete with (or to be assisted by) air drag forces and gravity and it is helpful to examine the relative magnitudes of these forces. Coffee (1979b) calculated the electric field below an Electrodyn nozzle by dividing the nozzle voltage (25 kV) by the distance from the ground (0.4m). In reality the electric field is nonuniform being higher near the nozzle and lower near the ground, however the approximation will serve to illustrate the point. Coffee showed that a 100 µm diameter drop produced with a charge level typical of the device (about 75% of the Rayleigh limit) would have a downwards electric force acting on it about 50 times the gravitational force. It is not surprising therefore that charging a drop has a dramatic effect on its trajectory and flight time in still air. In fact calculations with a computer simulation (Marchant, 1977) show that the terminal velocity would be increased by about 16 times to approximately 5 m/s. As well as showing the effect in still air these simple calculations suggest that the electric force could compete with air drag forces caused by wind speeds of the same order as the increased terminal velocity. For instance, with an air velocity of 4 m/s the electric force would be about 20% greater than the air drag force.

Two factors which frustrate these simple calculations are

a) the non-uniform fields caused by small high voltage electrodes and

b) the screening effect of the targets themselves.

Fig. 5 shows the electric field between an electrode 0.6 m above the ground, a standing plant, and the ground. The calculation was carried out using a computer program (Marchant, 1976) based on the finite element method. The field is represented by equipotentials (lines of equal electric potential or voltage) which are rather like contour lines on a map. The electric field is in the direction of the downward slope of the contours (i.e. at right angles to the equipotentials) and the field strength is proportional to the slope. Because the electrode is small and so has a relatively high curvature, the field strength near it is large, an average of about 140 kV/m for the first 10 cm away from the electrode. This results in most of the potential being lost in the region close to the nozzle and so near the ground,

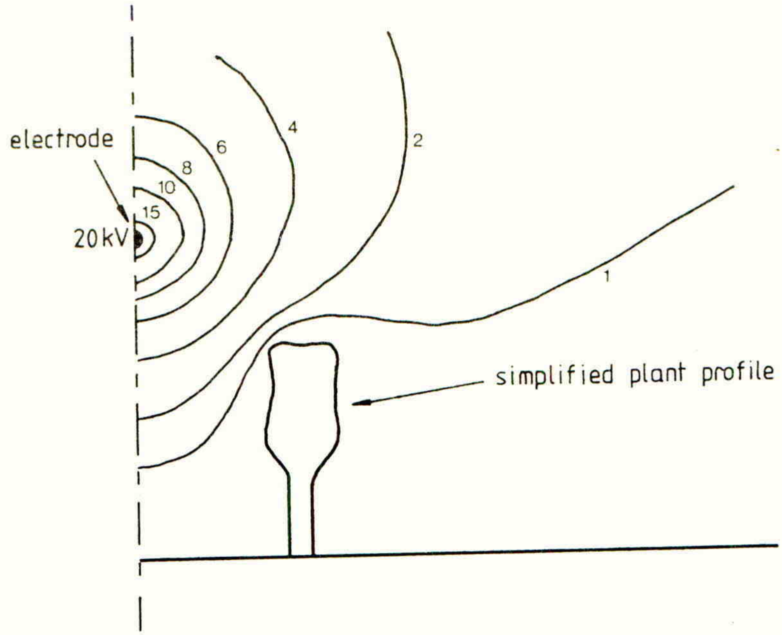

Fig. 5. Electric field around a high voltage electrode. The numbers on the lines are the potentials in kV.

underneath the electrode, the electric field is much lower, about 6 kV/m. In the region of the plant, on the side away from the electrode, the shielding effect of the plant reduces the field strength still further to about 2 kV/m. This contrasts with the figure of 33 kV/m obtained by dividing the elctrode voltage by the distance above the ground and upsets the relative values of forces calculated above. For instance, the air drag force near the ground for a wind speed of 4 m/s would be about nine times the electric force which means that the tendency to drift would hardly be resisted. Once drift had started and the drops had moved out of the electric field they would be lost. Fig. 5 shows the case with one standing plant only. When plants are in close proximity, the electric field is very much more reduced and, for instance, inside a canopy of standing cereals, the electric field would be virtually non-existant.

In the case of earth induction chargers (e.g. Law's device) field calculations based on electrode potential lead, at first sight, to rather surprising results. Because the drops are charged with the opposite polarity to the electrode, the electric field acts to return the drops to the nozzle rather than to propel them to the target. How then can charging by this method lead to increased deposition? Fortunately there are other agencies which supply attractive forces and these are known as the "image" and "space charge" effects.

2.2 Image charges and space charge

Section 2.3 showed that the electric field between a high voltage electrode and an earth induces charges on the earthed electrode. Exactly the same effect is caused when a charged body is placed near an earthed one. Charges of the opposite polarity are drawn up from earth and are induced onto the surface of the earthed body. For a flat plane, the force with which the charged body is attracted to the charges on the earth is equal to that between the body and a similar one of opposite polarity (the "image") placed an equal distance the other side of the plane. Thus a charged drop will be attracted to any earthed object, even in the absence of an externally applied electric field. Because of the inverse square relationship of force to distance, the image force is only effective over comparatively short distances. For instance, the 100 μm drop charged to 75% of the Rayleigh limit used in the previous section would experience an electric force equal to its weight at a distance of about 2.5 mm.

So far, only isolated drops have been discussed. In reality there are many drops present in a spray each of which experiences repulsive forces from all the other drops in the cloud and attractive forces from their images in earthed surfaces. This means that even if all the drops are charged to a similar level, the force experienced by any one drop is not just a function of the charge. It also depends on the total number of drops in the cloud and their density, i.e. the number per unit volume. This is one reason why charging systems cannot be compared solely on the basis of percentage of the Rayleigh limit achieved. The net force on the drop can be described in terms of an equivalent electric field by simply dividing the force by the charge on the drop. If the charge per unit volume were known throughout the cloud, the magnitude of this field could be calculated and compared with that produced by strategically placed electrodes. In a practical case this knowledge would be difficult to obtain but, according to Law (1979) the field may be sufficiently high to ionise the air in the vicinity of the cloud.

2.3 Targets underneath crop canopies

The way in which an electrostatic spraying system might work on an isolated target is comparatively clear. In contrast to this, the performance when directed at a target underneath a crop canopy raises many questions. It has already been stated that there will be a negligible electric field resulting from any electrodes placed above a canopy and so any beneficial effect must result from the space charge and/or the image forces. Before these forces can become effective it is necessary to get the drops down into a canopy. Here a high charge level, such as that produced by the Electrodyn could be detrimental. The drops could be so powerfully attracted by the top of the canopy (i.e. the nearest earthed object) that they would never penetrate it. It is possible to partially discharge the drops (Coffee, 1979a) which may improve penetration. However, this would increase the susceptibility of the small drop, which the device produces, to drifting in the wind.

The solution proposed by Law is to give the drops a significant downward momentum by the compressed air blast. This will certainly propel the drops into the canopy but the large volume of air produced by the compressor must go somewhere If it is not dispersed in the canopy, for instance if the crop is too dense or the air flow rate is too high, the air could escape upwards (rather like spraying into a bucket) carrying drops with it.

It would seem that charged drops produced by spinning discs are less likely to penetrate a crop canopy than those produced from the compressed air type atomiser. The reasons for this are:-

a) No initial downward velocity is imparted to the drops as they are ejected radially.

b) Because the drops are directed outwards, through 360°, the cloud is more dispersed than that from a nozzle in which all the drops are projected in the same direction. This reduces the space charge field compared with a nozzle that keeps the cloud relatively dense and so reduces the force of attraction towards the canopy.

Both these points reduce the capability of the electrostatic forces to counteract air drag forces arising from wind. However, if the crop canopy could be penetrated the drops would be almost certain to stay inside it because the air disturbance produced by the spinning disc is much lower than that produced by the compressed air type atomiser.

It seems therefore that all the charging devices currently developed would have problems when dealing with targets underneath crop canopies. It is probable that the charge level and the initial momentum given to the drops will need to be matched to the crop. What is certain is that the processes involved need to be further investigated and more fully understood before proper progress can be made.

CONCLUSIONS

Up to now agricultural sprays have been produced by three methods, corona charging, induction charging onto an earthed liquid, and electrostatic atomisation. Corona charging and electrostatic atomisation produce a charge on the drops with the same sign as the high voltage electrode whereas induction charging produces a charge with the opposite sign. Present designs limit the liquid to a good electrical conductor (water based sprays) for induction charging and a good insulator (oil based sprays) for electrostatic atomisation. Corona charging is effective for both types of liquid, although the charge levels may be different, but its use with good conductors causes problems in isolating the bulk of the liquid from earth.

When placed in an electric field, forces act on charged drops which help to propel them towards their target. This field can be produced by high voltage electrodes or by the drops themselves. Simple calculations on highly charged drops in a field produced by an electrode suggest that the extra forces are commensurate with air drag forces at moderate wind speeds. However, more realistic calculations show that the extra forces can be much lower near the ground, especially in regions that are shielded by standing plants.

The electric field caused by a cloud of charged drops (the space charge field) acts independently of any field produced by high voltage electrodes. The magnitude of this field is difficult to calculate but it is likely to be at least as important as that from high voltage electrodes.

In the absence of these two sources of electric field, a single charged drop is still attracted towards an earthed target by the force between itself and an oppositely charged "image" in the target. This force however only acts over short distances.

At present, little is known about the benefits of charging where the target is shielded by a crop canopy. In order to be effective it seems likely that some other means will have to be used to get the drops down into the crop, electrostatic forces being used to reduce drift in the flight between the nozzle and the canopy and to aid impaction and retention once the drops are nearer to the target.

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