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AMMONIUM ETHYL CARBAMOYLPHOSPHONATE
A NEW PLANT GROWTH REGULATOR FOR THE CONTROL OF UNDESIRABLE BRUSH-WOOD SPECIES

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Summary A new growth regulator - ammonium ethyl carbamoyl-phosphonate - is described and its chemical characteristics listed. At rates of around 2.4 kg/ha it gave good control of a number of brushwood species in trials in West German forest areas.

INTRODUCTION

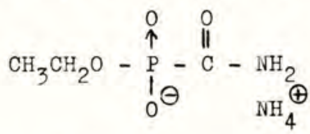
Ammonium ethyl carbamoylphosphonate is a new plant growth regulator developed by Du Pont de Nemours under the code number DPX-1108 and trade name of KRENITE*. It was introduced in West Germany in 1972 and tested at Kassel station of the German Plant Protection Organisation. Results in America are reported by Weed et al, 1974.

DPX-1108 has a novel mode of action plus the following desirable characteristics: favourable toxicological properties, negligible impact upon the environment and versality in application in forestry and non-cropped land.

CHEMICAL AND PHYSICAL CHARACTERISTICS

Chemical name: Ammonium ethyl carbamoylphosphonate

Chemical structure:



Molecular weight: 170.1

*Registered trademark of E.I.Du Pont de Nemours & Co. (Inc.)

Appearance: white, crystalline solid

Odour: negligible

Melting point: $175^{o}C$

Solubility at $25^{o}C$:

Solvent	Gram/100 g Solvent
Chloroform	0.004
N-Hexane	0.02
Acetone	0.03
Benzene	0.04
DMF	0.14
Ethanol	1.2
Methanol	15.8
Water	179.0

Formulation:

DPX-1108 is a water soluble formulation of Ammonium ethyl carbamoyl phosphonate, containing 480 g a.i./litre.

DPX-1108 is non-volatile and non-flammable liquid

TOXICOLOGY

DPX-1108 has a very low acute and chronic oral toxicity. It is not an eye irritant, a skin irritant, nor a skin sensitizer.

The following primary toxicological data refer to the active ingredient.

LD_{50} acute oral rat = 10.200 mg/kg

Subacute oral toxicity:

Groups of male and female rats were fed diets at rates up to 10,000 ppm for 90 days. No clinical and pathological changes attributable to the compound were detected and no adverse effect on the birth of offspring has been noted.

LD_{50} acute dermal rabbit = $>$1683 mg/kg

Wildlife toxicity:

Bobwhite Quail - oral LD_{50} $>$4200 mg/kg
Mallard Duck - oral LD_{50} $>$4200 mg/kg
Rainbow trout - TL_{50}(96 hrs) $>$ 420 mg/l
Fathead minnow - TL_{50}(96 hrs) $>$ 420 mg/l

In addition to low toxicity on aquatic fauna DPX-1108 breaks down rapidly in water.

Fate in soil:

Ammonium ethyl carbamoyl phosphonate is adsorbed by the soil and is rapidly decomposed by soil microorganisms. No problems of run off or leaching into surface or subsurface water are expected. Preliminary studies indicate a half-life in soil of about one week.

GENERAL MODE OF ACTION

Depending on spraying time and brush species, DPX-1108 applied as a cover foliar spray at rates of 5 l and more product per hectare exhibits good control of many woody plants.

Patterns of absorption by buds, foliage, and stems and of translocation in woody plants have not been defined. Additional studies are underway. Test work todate indicates that when spray is applied to one side of a tree, only treated branches are controlled, resulting in "chemical trimming".

MATERIALS AND METHODS

In 1972 and 1973 a total of 20 trials were carried out in the Hessian area. These trials were laid down according to the official guidelines for testing herbicides for the control of undesirable woody plants in forestry (Storch et al, 1966).

DPX-1108 was applied at rates from 1.2 to 7.2 kg a.i./ha with a proposed optimum of 2.4 kg a.i./ha. The plot size used was 200 square metres.

In addition to the treatments above two volume rates of 200 and 500 l/ha were applied and there were also plots in which a surfactant was added to the DPX-1108. Four trials examined the effect of timing on weed control with rates of 2.4, 4.8 and 7.2 kg a.i./ha applied with and without surfactant. Treatments were applied with a Stihl SG 17 mistblower or a Holder FLORA F sprayer.

Results were recorded as percent plants killed the year after treatment.

Standard herbicides used were 2,4,5-T salt or ester formulations or the combination of 2,4-D and 2,4,5-T ester at recommended rates.

TABLE I

Details about time of spraying and treatments applied with DPX-1108 in 1972 and 1973 at Hessian Forestry Area.

location	time of spraying	rates of DPX-1108 kg a.i./ha	rate of water per hectare	equipment
1	9/25/72	4.8	250	mistblower
2	9/25/72	3.84	200	mistblower
3 a	9/25/72	2.4 / 3.0	250	mistblower
3 b	9/25/72	2.4 / 3.0	500	mistblower
4	9/22/72	1.8 / 2.4	500	sprayer
5 a	9/22/72	3.0 / 4.8	250	mistblower
5 b	9/22/72	3.0 / 4.8	500	mistblower
6	9/22/72	3.0 / 4.8 / 5.9	500	sprayer
7	9/22/72	1.8 / 2.4	500	sprayer
8	7/ 9/73	2.4 / 4.8 / 7.2	200	mistblower
	9/ 3/73	2.4 / 4.8 / 7.2	200	mistblower
9	7/ 9/73	2.4 / 4.8 / 7.2	500	mistblower
	9/ 3/73	2.4 / 4.8 / 7.2	500	mistblower
10	7/ 2/73	2.4 / 4.8	200	mistblower
11	8/10/73	2.4 / 4.8 / 7.2	200	mistblower
	9/ 5/73	2.4 / 4.8 / 7.2	200	mistblower
12	8/10/73	2.4 / 4.8 / 7.2	500	mistblower
	9/ 5/73	2.4 / 4.8 / 7.2	500	mistblower
13	9/ 3/73	2.4	400	sprayer
14	9/ 5/73	4.8	250	mistblower
15	9/ 7/73	2.4	400	sprayer
16	9/ 7/73	2.4	400	sprayer
17	9/ 7/73	2.4	400	sprayer
18	9/14/73	4.8	200	mistblower
19	9/24/73	4.8	200	sprayer

The following brush and tree species were treated:

Alnus glutinosa	Alder
Betula pendula	Silver Birch
Carpinus betulus	Hornbeam
Corylus avellana	Hazel
Fagus sylvatica	Beech
Fraxinus excelsior	Ash
Lonicera xylosteum	Fly Honeysuckle
Populus tremula	Aspen
Quercus robur	Pendunculate Oak
Frangula alnus	Alder Buckthorn
Rosa canina	Rose
Rubus fruticosus agg.	Blackberry
Rubus idaeus	Raspberry
Salix caprea	Goat Willow
Sambucus nigra	Elder
Sambucus racemosa	(-no British common name)
Sorbus aucuparia	Rowan

RESULTS

At rates of 2.4 kg a.i./ha DPX-1108 and above no major differences in weed control were recorded. Also no significant difference occurred between the volume rates of 200 l and 500 l or between the plots with or without surfactant. When comparing applications, starting in early July with treatments in early August and early September, the best results were obtained with the latest treatment.

In the year of treatment no apparent visible changes occur following the spray, except on Frangula alnus, Betula pendula and Sorbus aucuparia where some yellowing of the leaves was recorded. Deciduous plants defoliate normally at the end of the season except the three species above where leaf drop was observed earlier than in untreated plants.

The following spring, bud development was either prevented or severely limited on most of the species producing miniature yellow, grey or red coloured spindly atypical leaves. The stem of most of the woody plants remains alive for some time but if in spring a plant shows only leaves with the typical DPX-1108 symptoms, the wood dies towards the end of the year, or is dead in spring of the next year. This effect was recorded in several trials from the 1972 treatment in autumn 1973 or spring 1974 especially on Frangula alnus, Betula pendula, Sorbus aucuparia, Alnus glutinosa, Quercus robur, Fagus sylvatica, Carpinus betula and Rubus fruticosus.

On Rubus idaeus we observed that in the year after treatment new plants were present which had developed from seed.

The year after treatment results on Corylus avellana, Rosa canina, Salix caprea and Sambucus nigra looked promising. In spring 1975 these trials will be scored again because the stems of the species mentioned above were green with severely limited leaf growth.

TABLE II

Efficiency of several rates of DPX-1108 on brush-wood species in percent control year after treatment

CHEMICAL / brush-wood species	DPX-1108 2.4 kg a.i./ hectare	DPX-1108 3.0 kg a.i./ hectare	DPX-1108 4.8 kg a.i./ hectare	DPX-1108 7.2 kg a.i./ hectare
Alnus glutinosa	> 97.5	> 97.5	> 97.5	> 97.5
Betula pendula	100.0	100.0	100.0	100.0
Carpinus betulus	95.0		> 97.5	
Corylus avellana	> 97.5			
Fagus sylvatica	95.0		> 97.5	
Lonicera xylosteum	0.0		35.0	50.0
Quercus robur	> 97.5		> 97.5	
Frangula alnus	> 97.5	> 97.5	> 97.5	> 97.5
Rubus fruticosus agg.	> 97.5	100.0	100.0	100.0
Rubus idaeus	85.0	85.0	85.0	85.0
Salix caprea	95.0			
Sambucus nigra	> 97.5		> 97.5	> 97.5
Sambucus racemosa	60.0		60.0	85.0
Sorbus aucuparia	85.0	95.0	95.0	95.0

After treatment Fraxinus excelsior, Populus tremula and Sambucus racemosa showed limited leaf growth but also leaves without symptoms. Here the control was not sufficient. In the case of Sambucus racemosa normal regrowth was coming from the base of treated plants.

After treatment of Lonicera xylosteum no control could be observed and normal leaves were present in the season after treatment.

From general observations it was seen that best control of most of the species is given if the plants are approximately 1.2 - 1.5 metres high. At this height good cover of all the leaves and green plant parts is readily achieved.

DISCUSSION

DPX-1108 was tested for the control of brushwood species common to forestry in West Germany and from the results obtained it would appear to have considerable promise in this field.

Its initial use would be in land to be planted with forest trees. The use of DPX-1108 in young forest plantations will depend on its selectivity to forest species especially Scots pine (Pinus sylvestris) Norway spruce (Picea abies), Douglas fir (Pseudotsuga menziesii)and Noble fir (Abies procera). Some initial tolerance studies are currently being carried out and preliminary results look quite promising.

From the results 2.4 kg a.i./ha would appear to be the optimum dose. Best results were obtained where treated plants were around 1.2 to 1.5 m high. This would tend to stem from the local action of the material and to indicate the necessity of obtaining good cover with the chemical if complete control is to be obtained.

The appearance of phytotoxic symptoms the year following treatment take the form of distorted, very small leaves. This in no way impairs final results as death ultimately follows.

Variations in results occurred due to timing of application and the species sprayed. There appears to be a critical time in the annual growth cycle of the species treated for the uptake of DPX-1108. From the results this is in late summer and may be associated with the onset of scenescence and a possible negative translocation of DPX-1108 down into the wood of the plant and into the following years buds.

Species difference showed up in the family Caprifoliaceae. Sambucus nigra was moderately susceptible, Sambucus racemosa moderately resistant with normal regrowth from the base of the plant, Lonicera xylosteum resistant only responding to rates of 7.2 kg a.i./ha and Lonicera periclymenum was resistant to all rates tested.

The optimum time of applying DPX-1108 fits in well with coniferous tree growth. These species are tolerant of most herbicides in late summer when the best results were obtained with DPX-1108. Further trials will be carried out to examine this aspect of its use and also to establish the tolerance of other woody weed species and the optimum time for their treatment. Other methods of application will also be examined.

Acknowledgements

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CEREALS AS WEEDS

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Summary The penalties of allowing cereals to grow as weeds on the arable farm are discussed. Volunteer cereals can be a serious source of disease inoculum as well as being competitive weeds. Control of the problem commences with more timely and efficient harvesting followed by judicial post-harvest cultivation treatments and, where possible, selective herbicide treatment preferably early in the life of the subsequent crop.

Céréales comme mauvaise herbes On discute les peines de laisser croitre sur la ferme arable des céréales comme des mauvaises herbes. Des céréales spontanées peuvent étre la source des maladies des plantes autant d'être des rivales. La contrôle due probleme commence avec la moisson opportune et efficace, suivi par des traitements du culture et, òu il est possible, des traitments selectifs herbicides, par préférence au commencement de la vie de la seconde récolte.

INTRODUCTION

A weed is a plant growing where it is not wanted. Cereal plants are often found growing as weeds where their presence is detrimental to the profitable production of sown cereals or other crops. Volunteer cereals appearing in seed crops of the same or other species of cereal can lead to rejection within seed certification schemes resulting in financial penalty to the grower and loss of precious seed stock. The introduction of UK grain quality marketing standards for wheat and barley, akin to those applying to grain sold into EEC Intervention Schemes, have now set a standard of maximum impurities including not more than 3 per cent, by weight, total other cereals. This is currently a fairly lax standard since it allows, for instance, for an admixture of 1½ cwt (75 kg) of barley in a 50 cwt (2.53 tonnes) crop of wheat. On the basis of average grain weight and average number of grain per fertile ear this allows for 21 ears of barley per square metre in the field crop of wheat assuming every grain is harvested. Standards are of course subject to alteration according to market supply and demand and in the event of over-production of cereal grain such standards are likely to be adjusted to allow for much lower levels of contamination with other cereal grain. The presence of other grain in wheat offered for milling or barley for malting can also lead to rejection thus incurring loss of quality premium. Even when accepted for processing the extra cost of further grain separation and the inevitable loss of grain involved infers a financial loss to the grower or the processor.

Cereal plants which arise from shed grain either prior to or following harvest can prove a serious hindrance to the establishment of a subsequent healthy vigorous cereal crop. They act as barriers to efficient seed-bed, cultivation and sowing techniques and can perpetuate soil-borne diseases as well as being host carriers of cereal pests. An excessive amount of other cereals growing in any sown cereal species can result in too high plant population leading to yield depression, a crop micro-climate conducive to the rapid build-up of disease, lodging and problems at harvest due to variation in ripening allied to further difficulties in drying grain.

'Break-crop' influence During the last decade many cereal growers conscious of the limitations of close cropping with cereals, bordering on mono-culture, have been searching for viable alternative short-term break-crops. Field beans, harvest peas, clover leys and other break-crops have been grown but it is only recently that many of these crops have offered high financial output inducements apart from the benefits conferred to the subsequent cereal crops which assume, amongst other advantages, a reduction in carry-over of soil-borne diseases such as Take-all (Ophiobulus graminis*) and soil pests such as cereal cyst eelworm (Heterodera avenae). The mere presence of volunteer cereal weed plants in these crops does however negate such benefits to the detriment of the subsequent cereal crops. This may explain many failures in yield improvement of wheat and barley following short-term break-cropping.

The alternative crops may also suffer from the presence of the cereal weed. Crops such as peas, oil rape and linseed are notoriously sensitive to weed competition during their early growth stages. A combination of cereal and crop plant density can also lead to dense foliage growth conducive to the build-up of disease such as powdery mildew in brassica crops and an increase in slug activity. Dense growth of the cereal weed can also bring about uneven ripening of the crop and provoke mechanical difficulties at harvest resulting in loss of yield and a lowering of produce quality standard.

Carriers of Foliar Disease There is no doubt that the greatest harm caused by cereal weed plants is the harbouring of foliar diseases which can spread to adjoining cereal crops. Volunteer cereals are often the "green bridge" upon which spores of mildew (Erysiphe graminis) and cereal rusts (Puccinia spp) survive during autumn and winter to be transmitted by contact, wind or other agency to newly emerged winter or spring sown cereals of the same species. Other diseases such as glume and leaf blotch of wheat (Septoria spp), leaf blotch (Rhynchosporium secalis) and net blotch (Helminthosporium teres) of barley, which survive initially on straw residues post-harvest, are easily transmitted to nearby seedlings of volunteer cereals of the respective species and these then act as contact sources of innoculum to affect young plants of the sown crop of the same species.

During the autumn of 1966 seven cereal growers in the Arundel area of West Sussex reported that they had experienced a disastrous barley harvest largely due to poorly developed grain with very low specific weight resulting in grain yield below one ton per acre (2.5 t/ha). Agronomists and Plant Pathologists of the National Agricultural Advisory Service (now ADAS) agreed to launch a survey of barley production in the area starting with an examination of crops in May 1967 followed by a full scale survey of disease on the upper two leaves and ears after emergence in late June (Mills 1968). The Survey allowed also for the recording of pests, weeds and any other factors likely to influence yield and quality of grain. A total of 78 barley crops, approximately 3,000 acres, grown by the seven growers were examined that year.

The results of the survey (MAFF South East 1970) showed that mildew and brown rust (P. hordei) together with some of the straw diseases were, in some crops, reducing the effective leaf area of the two upper leaves to below 50 per cent by mid-June and in others causing a considerable reduction in photosynthetic areas of the upper leaves which largely govern the extent of grain filling. Later in July some of the foliar diseases were killing the awns which can sometimes compensate for loss of the flag leaf's role in aiding photosynthesis. There was very clear evidence in the worst affected crops that disease had been perpetuated on self-sown volunteer cereals

* also (Gaeumannomyces graminis)

growing in the same field or in adjoining fields and sometimes on uncropped land in the area. The worst culprit was the winter type barley, particularly six-row winter barley, previously grown in the area and which had become the most common weed. After discussion of the results of the survey the seven farmers concerned agreed to undertake a concerted cleaning operation during the autumn of 1967 in an endeavour to reduce the extent of the cereal weed problem and to assist in attaining this objective it was decided to eliminate winter barley production from the cropping programme for 1968 harvest. Guided by the advisory officers a very effective campaign of cereal weed eradication was carried out during the winter and early spring 1967/68. In some instances this involved a change in management of grass leys substituting grazing or early conservation because of the ingress of weed barley. Further surveys in mid-summer during the next three years revealed that the foliar disease levels, which can also be influenced by weather, had been considerably reduced throughout the remaining barley acreage:-

Table 1 Arundel Foliar Disease Survey - Spring Barley 1967-70.

June	Number of Crops	Total Foliar Disease Severe	Moderate	Low
1967	78	26	33	19
1968	56	nil	9	47
1969	60	nil	8	52
1970	69	1	2	66

Severe - 50% kill of upper two leaves surface area.
Moderate - over 25% kill of upper two leaves ".

The elimination of volunteer cereal weed plants has a very high priority, as an autumn operation, in the Arundel area now and although winter barley cropping has been re-introduced, largely to gain earliness of harvest, there have not been any serious outbreaks of cereal foliar disease in the area in recent years. Where appropriate the use of fungicides has helped to maintain a low incidence of mildew disease and most of the growers have reported barley yields in the region of two tons per acre (5 t/ha) in 1974.

In 1972 many areas of the UK suffered a very serious outbreak of yellow rust (Puccinia striiformis) in winter wheat, the variety Joss Cambier being most severely affected. A survey conducted by plant pathologists of ADAS indicated an average penalty of 7.2 cwt per acre (0.88 t/ha) loss of yield in affected wheat crops which, at todays values, (October 1974) is a financial penalty in the region of £22 per acre. It is interesting to postulate the extent to which this loss of yield, accompanied by penalties for poor grain quality, could have been attributed to the existence of volunteer wheat plants carrying a specific race of yellow rust, in the affected areas, during the autumn of 1971. The pattern of weather in 1971/72 was highly conducive to the rapid development of the disease. There have been many other instances since of yellow rust outbreaks in the South-east region where the source of infection could be traced directly to volunteer cereal plants surviving seed bed cultivations or growing on uncultivated areas of a farm, near gateways, on dung heaps or in areas around the farm buildings where small grain or cleanings have been discarded. Another common source of potential wind-borne cereal disease is the use of cereal straw, carrying small unthreshed grain, fed to animals on pasture land and trodden by animals into the soil. The use of straw for protection of fruit and nursery stock plants constitutes another source of disease carry over on volunteer cereals to affect neighbouring cereal crops.

At present many winter wheat growers in the UK are following official and commercial advice in restricting the acreage of yellow rust susceptible varieties to below 40 per cent of the total acreage of wheat sown in any year. They are doing this knowing that susceptible varieties, such as Maris Huntsman, could outyield other less susceptible varieties by more than 5 cwt per acre (0.62 t/ha) and this can be regarded largely as yet another penalty of the likely existence of volunteer wheat plants (as carriers of yellow rust) on their own farm or other farms in the neighbourhood.

CONTROL OF VOLUNTEER CEREALS

1. In the previous crop

Careful selection of species and variety for the previous cereal crop can minimise pre-harvest shedding of grain. By experience several growers of winter oil rape have learnt that pre-cropping with winter oat, which is notorious for pre-harvest grain loss, provokes a serious cereal weed in the following rape crop. Varieties of most cereal species can be chosen partly on their resistance to shedding and on their slow rate of early growth and vigour should they regenerate as weed plants in the subsequent crop.

Surveys carried out by Mechanisation Advisers NAAS in 1966 (Catt 1967) and later over a three year period 1969-71 (MAFF 1973) revealed the extent of cereal grain loss which occurs at harvest. In the earlier survey (1966), involving 96 samples, the average total grain loss was 74 lb per acre (82 kg/ha) of which 40 lb per acre (45 kg/ha) was lost at the combine cutter-bar. Higher losses were recorded in the subsequent surveys.

Table 2 ADAS Grain Loss Studies - at harvest 1969-71

Grain loss lb/acre

Year	Sample Number	Wheat			Barley		
		Front	End	Threshing Total	Front	End	Threshing Total
1969	178	42	38	80	84	51	135
1970	21	56	26	82	86	27	113
1971	51	29	64	93	138	46	184

A mean loss of 144 lb barley per acre could produce 350 barley grains per square metre and if only 10 per cent of these survive to produce volunteer barley plants the population of weed barley plants would then be in excess of 20 plants per square metre required to produce 3 per cent of barley grains, by weight, in a succeeding wheat crop. A high proportion of the losses in wheat and barley could be attributed to delays in harvesting. The survey showed that many farmers did not start combine harvesting until grain moisture was below 18 per cent and that this could be interpreted as at least seven days, on, average, after the optimum date. Current investigations at ADAS Experimental Husbandry Farms are indicating a maximum 1,000 grain weight of barley at moisture levels of around 24 per cent.

2. Post-harvest

Deep tine cultivation of cereal stubbles often aggravates a cereal weed problem in the subsequent crop. There is seldom need to carry out immediate post-harvest cultivations to a depth exceeding three inches (9 cm) of soil from which shed cereal seed can germinate easily after a brief dormancy period. This depth of cultivation is also adequate for mulching other residues, such as straw and chaff, to provide optimum conditions for rapid bacterial decomposition thus removing them as sources of disease infection. It is only when surface soil conditions are excessively dry that problems arise due to delayed germination of the cereal weed. Modern techniques of minimal cultivation, if carried out correctly, blend with this requirement for initial shallow cultivation of cereal stubble. With direct-drilling methods there can be considerable degradation of cereal grain left on stubble surface and adequate moisture can cause the remaining shed grain to germinate freely pre-sowing for subsequent kill using paraquat or glyphosate. Failure to kill volunteer cereal plants with paraquat often results from delayed application allowing the cereal plants to develop to the tillering stage when despite foliar kill, the crown and root of the plants remain and regenerate. No such limitations have hitherto been observed when using glyphosate for the treatment of rhizomatous weed grasses in cereal stubbles.

3. Within crop control

a) Cereals Some post-emergence herbicides introduced for the control monocotyledon weeds in cereals can only be recommended for safe use in specific cereal species. A notable example is benzoyl-prop-ethyl recommended for *Avena fatua* control in wheat only and thus capable of selective control of volunteer barley plans. The main disadvantage of this treatment is the requirement of delaying application well beyond the tillering stage of wheat when the barley weed plant will already have exerted its competitive effect and provided a source of foliage disease spread to neighbouring barley crops over a long period.

Other herbicides available for the control of *A fatua* and *Alopecurus myosuroides* in cereals have limitations of use in specific cereal varieties. Barban, for instance, is not recommended for use in some barley varieties whilst chlortoluron can prove toxic to a limited range of wheat varieties. If therefore volunteer plants of these susceptible varieties appear in crops of non-susceptible sown varieties there is an opportunity for selective control as a bonus to the use of these herbicides for the control of *A fatua* and annual grass weed species.

b) Grassland A search for herbicides to control *Avena fatua* in herbage seed crops has spotlighted the possibility of eliminating volunteer cereal plants growing in these crops. Here again benzoyl-prop-ethyl has shown a potential for the eradication of barley plants surviving in these short-term grass leys. Ethofumesate, which shows promise for the control of annual grass weeds in herbage seed production leys, has also had a severe retarding effect on cereal plants present as weeds.

c) Other crops The use of triazine derivatives in field beans and maize, linuron in linseed and sunflower and trifluralin in brassicae and other vegetables are examples of herbicide use which can eliminate volunteer cereals in these crops as well as many other weed species. In some crops post sowing pre-emergence herbicides prove very effective for the control of cereal weed plants provided there is adequate surface soil moisture. In other crops incorporated pre-sowing herbicides are more effective. Hitherto the most widespread use of herbicides to control volunteer cereals, almost specifically, is in the winter oil rape crop which is often sown very soon after cereal harvest thus preventing a kill of this potential weed before the crop is sown. Until recently sodium trichloracetate and dalapon were the most common herbicides used but new introductions with a wider weed control spectrum and sometimes greater crop tolerance are now being marketed. The results of experiments carried out by ADAS in the south east region provide an indication of their efficiency:-

Table 3 Control of cereal and other weeds in winter oil rape 1971/72

Other weeds mainly stellaria media — Var: Victor

Herbicide	Dose rate ai/ac	Cereal Plants Thousand per acre Nov 71	Cereal Plants Thousand per acre July 72	Total Weed Control Score 9 = max weed	Yield of Seed Cwt/ac	Yield of Seed t/ha	% oil content
Pre-sowing							
TCA sod salt	15 lb	7.3	7.1	6.3	20.8	2.60	44.1
TCA sod salt	30 lb	2.9	nil	6.0	20.1	2.51	44.7
Carbetamide	2.1 lb	4.4	13.1	3.7	22.3	2.78	44.4
Post sowing and pre-emergence							
TCA sod salt	15 lb	2.9	2.9	6.3	20.9	2.62	45.0
Carbetamide	2.1 lb	10.2	4.4	3.6	20.7	2.58	42.9
Napropamid	1.5 lb	18.9	13.1	1.7	23.2	2.90	44.4
Post-emergence							
Carbetamide	2.1 lb	30.5	nil	3.3	22.1	2.76	43.2
Dalapon	3.3 lb	59.5	nil	7.3	19.9	2.48	43.8
Control - no herbicide		42.1	61.0	8.7	16.4	2.05	43.5
Standard Error Dif		10.26	11.99	0.90	1.22	0.15 or 5.9%	

Table 4 Control of cereal and other weeds in winter oil rape, 1973/74

Other weeds mainly stellaria media — Var: Mogul

Herbicide	Dose rate ai lb/ac	Dose rate ai kg/ha	Cereal Plants ,000/acre Nov 1973	Cereal Weed Visual Scores 9 = max March 1974	Cereal Weed Visual Scores 9 = max June	Yield of seed @ 90% DM Cwt/ac	Yield of seed @ 90% DM t/ha	% oil content
Pre-sowing incorporated								
Napropamid	1.25	1.40	279	5.6	4.0	13.7	1.72	41.5
Trifluralin	1.00	1.12	218	5.0	4.0	20.9	2.62	40.4
Dinitramine	0.22	0.26	395	6.3	5.3	14.8	1.86	41.1
Dinitramine	0.28	0.35	354	5.3	6.0	16.2	2.03	39.3
Pre-emergence								
Ethofumesate	1.50	1.68	592	7.3	7.7	5.3	0.67	38.9
Post-emergence-crop 2-3 leaves								
Dalapon	2.50	2.80	375	0.6	nil	27.8	3.49	41.2
Carbetamide	2.10	2.40	308	0.5	0.3	29.6	3.71	41.0
Propyzamide	0.52	0.60	421	nil	1.0	26.2	3.29	42.1
Nitrofen	1.00	1.12	412	4.0	5.3	13.4	1.68	43.2
Control - no herbicide			411	4.9	8.2	15.7	1.97	41.4
SSE means			140.1	1.37	1.09	3.89	0.49	

In 1973 the pre-emergence herbicides were disappointing largely due to dry soil conditions although trifluralin incorporated showed promising results. Dalapon, carbetamide and propyzamide applied post-emergence of crop and weed have generally given consistent good control of the cereal weed.

It could be argued that the volunteer cereal weed plant is the most costly weed in the UK today. With more stringent quality standards being introduced in the marketing of cereals for seed or processing requirements and the value of lost grain increasing steadily, year by year, harbouring cereal weeds on arable farms is becoming an expensive business. But it is the harm done in terms of carry-over of cereal disease on the green leaf of the volunteer cereal plants that merits serious attention. It has been estimated that over 40 per cent of the barley grown in the UK in 1974 merited treatment with a fungicide to control mildew. Estimates from the Plant Pathology Laboratory, Harpenden, show that the 1973 barley crop suffered a national average yield loss of 13 per cent due to mildew alone. Wheat growers are currently pre-occupied with assessing risks in growing certain high yielding varieties with poor resistance to yellow rust knowing that cost of ignoring them is high in terms of loss of yield in the absence of disease attack originating from volunteer cereals. The true cost today of allowing cereals to grow as weeds is very difficult to assess but it is bound to be enormous.

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RESEARCH ON THE CONTROL OF VOLUNTEER POTATOES IN THE NETHERLANDS

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Summary In the Netherlands volunteer-potatoes are one of the most serious problems in crop-rotations including potatoes. In the crop following potatoes more than 100,000 potato-plants/ha can be found. This not only creates a weed problem, it also influences the nematode population, especially in close rotations. Since 1970 research was carried out on several aspects of this subject. Until now there was no effective solution for the problem, however there are now three possibilities: mechanical bruising, killing by chemicals and modified soil-tillage. Modified soil-tillage is now practiced on a large scale. Instead of ploughing a cultivator with fixed tines is used for the main tillage-operation. By cultivating the left over tubers are only slightly transported vertically in the soil. The tubers on the soil surface or in the top 10 cm have a better chance of being killed by frost during the winter.

Résumé En Hollande il considère "les repousses" de pommes de terre comme un des problèmes les plus importants dans la culture. Dans les cultures après des pommes de terre plus de 100.000 plantes de pommes de terre par hectare peuvent être trouvées. Ils provoquent non seulement un problème de désherbage mais ils peuvent être ajoutés à la population du nematode doré. Depuis 1970, on a recherché les différents aspects de ce problème. Jusqu'alors il n'existe pas une solution effective, pourtant il y a des prospectives en trois directions: écraser les tubercules, destructions des repousses avec herbicides et travaux du sol avec un cultivateur. Au lieu d'une charrue on utilise un cultivateur à dents rigides pour les labours d'hiver. De cette façon les tubercules restés sur le champs et ceux dans la couche supérieure du sol, ne sont que transportés très peu verticalement. Ainsi la chance qu'ils seront détruits par la gèle pendant l'hiver est plus grande.

INTRODUCTION

The total arable area in the Netherlands is approx. 675,000 hectares. From this area 156,000 hectares in 1973 were devoted to potatoes (22%). On very heavy soils it is impossible to grow potatoes. On sandy and reworked peat podsol soils in the Northeastern part of the Netherlands potatoes for processing are grown every other year. In other regions crop rotations are practised where potatoes for consumption are grown every third or fourth year. Only by using soil desinfection and varieties resistent to the potato-root eelworm (Heterodera rostochiensis) the farmer is allowed to grow potatoes on non-infested soils more frequently than once in four years (HIJINK, 1972).

The groundkeeper problem has been increasing in importance for a number of years because of changes in agricultural practices, such as the highly mechanized and labour saving harvesting techniques. Using bulk harvesters, a number of mostly small sized tubers fall back on the soil. Also loss of potatoes occur at loading the trailers and during transport. Between 20,000 and 300,000 tubers/ha are left behind on the field (Table 1).

Table 1

Average numbers of tubers left on the field, 1970, 1971, 1972

Year	Numbers of tubers left per hectare		Number of examined fields
	mean	variability	
1970	103,000	22,000 - 220,000	23
1971	134,000	17,500 - 290,000	22
1972	257,000	126,000 - 462,000	9

Other authors give similar figures after potato harvester demonstrations. (DE LINT, et al 1969; ANONYMUS, 1972). Normally after harvest the tubers remain on the surface of the soil or are buried in the top 10 cm. They are usually up to 28 or 35 mm in diameter (∅), depending on the gaps in the webs of the potatoharvester. However, inefficient harvesting also influences the number and the size of the tubers (Table 2).

Table 2

Bintje ware potatoes, grown on a sandy soil. Size of the tubers as a percentage of the total of 254,100 groundkeeper tubers/ha. Autumn 1971

Size in mm		Size of the tubers (%)			
		on the soil		in the soil	
< 10		10.7		5.7	
10 - 25		57.8		54.3	
25 - 35		17.6		23.8	
	< 35		86.1		83.8
35 - 45		7.4		8.4	
> 45		6.5		7.8	
	> 35		13.9		16.2

Thus about 15% of the tubers have market value as their size is over 35 mm ∅. Depending on soil conditions some groundkeepers will die during the winter, others may be frozen. Tubers which survive the winter can raise plants in the subsequent year. These selfsets occur in the Netherlands at a level of over 100,000 plants/ha in the year following potatoes. Ware potatoes are normally planted at 40,000 tubers/ha).

Volunteer potatoes have become an important perennial weed. Farmers have to spend up to 50 h/ha in certain crops, to control this weed mechanically, because these selfsets influence the population-density of pathogenic nematodes, especially the potato-root eelworm (Heterodera rostochiensis). DEN OUDEN, (1964, 1967) showed that on a light soil 4-16 "volunteer plants"/m^2 of tubers planted in oats multiplied the potato-root eelworm population 2 to 3 times. Normally a natural kill of 35% can be expected in a year without potatoes.

METHOD AND MATERIALS

The research reported here was started in 1970 by a working-group representing several institutions. A survey was organized to analyse the problem. Farmers and the regional agricultural advisory service collected the data by investigating fields with selfsets.

In 1970 research was started on chemical control of groundkeepers and volunteer potatoes.

A. The effect of several chemical weedkillers was assessed on tubers on and in the top-soil.
B. To simulate these volunteer potatoes, in the spring small size tubers were planted at the depth of 10 and 20 cm, in autumn sown wheat.
C. On potatoes as a main crop, simulating volunteer plants.
D. On a green manure crop of a cereal stubble.

The systemic effects of the herbicides was controlled by germination trials with tubers in store-houses. Some chemicals were first tested on potatoes in a glass-house, to get a selection for the field-trials. Another subject of research was the influence of different soil-tillage methods and of soil sterilization on the tubers. In model-trials the effect of mechanical bruising and the interaction of this method with the effect of chemicals was studied.

Also the freezing chances of tubers were studied. First in pot trials where tubers were planted in soil at different depths. Then in a climate-room the influence of different temperatures and the moisture contents of the soil on the potato tubers were assessed. These investigations were followed by field-trials in which tubers were planted in autumn up to 20 cm depth. The effect of cultivation methods on freezing chances of groundkeepers was investigated in a model-trial (LUMKES and BEUKEMA, 1973). Afterwards a large number of trials on practical scale were carried out. Different soil-tillage methods were tested in regard to soil structure, crop yield, soil temperature and the number of volunteer plants. Also tests were made with types of fixed tine cultivators. Research was carried out to develop the best construction of the cultivator-tine to achieve; a. a soil-tillage operation by the cultivator which give a soil structure as good as with ploughing. b. to prevent the vertical movement of remaining tubers.

RESULTS AND DISCUSSION

1. The survey in 1970 on farms with an intensive potato cropping system showed that: a. on light sandy and peaty soils and on heavy clay soils in general more tubers are left behind than on light clay soils. b. if the potato-stubble is not ploughed in autumn the number of volunteer-plants are less than with ploughing. c. even tubers of a size of 10 mm Ø at a depth of about 30 cm can be a source of volunteer-plants. d. in cereal crops a volunteer-potato plant developes rather spindly, but forms tubers. In crops of sugarbeet, peas, beans, onions and maize the size of the volunteer plant is almost equivalent to that of a normal potato plant.

2. <u>Research on herbicides</u>

MEIJERS (1968) tested flame cultivation for killing remaining tubers. About 60% of the tubers of the variety Bintje lying on the surface started rotting. On other varieties this method was less effective. No effect was measured on tubers covered by soil. Stimulation of autumn germination was not achieved.

LUMKES and SIJTSMA (1972) found that:

A. In a trial on a potato stubble even tubers lying on the surface were not affected by 5 l/ha diquat, 10 l and 20 l/ha CIPC, 6 l/ha CIPC and 500 kg/ha lime-nitrogen. The results with the other chemicals are given in Table 3. It will be seen that 50 l/ha aminotriazole/ammonium-thiocyanate decreased germination by 50% in the next spring.

The effect of soil sterilizers ((dichloropropene/dichloropropane (D.D.) and metamsodium)) on the rotting of tubers was of some value. A similar effect of these chemicals was found at the normal soil desinfection. However this does not give a practical solution for the problem because in this trial all chemicals tested were sprayed on the surface of the soil. Chemicals such as DD normally work in a gasform and a large amount is then needed to kill a relatively small number of tubers in a large volume of soil.

Table 3

Chemicals sprayed on a potato-stubble with remaining tubers of the variety Bintje. Clay soil 1970/71.

Chemical and dose in kg or l/ha product	Percentage of the tubers, partly or total rotten in autumn	Percentage of the stored tubers that germinated healthy in spring
1) aminotriazole + ammonium-thiocyanate 25 l	3	76
2) as 1., 50 l	0	50
3) DD 250 l	23	90
4) as 3, 500 l	28	78
5) metam-sodium 400 l	17	86
6) as 5, 800 l	23	79
7) combination of 3 and 5, 250 + 400 l	64	36
8) sodium-arsenite, 20 l	2	80
9) non treated	0	98

B. In trials in winterwheat, with small tubers planted in the spring at depths of 10 cm and 20 cm simulating groundkeepers, a range of chemicals were tested. Potato shoots emerge rather late in winterwheat, and herbicide spraying is carried out when the greater part of the volunteer potato plants are not sufficiently developed. Later the cereal-crop covers the volunteer plants, limiting the effect of herbicide-application. Delaying the application often decreases the yield of the crop (Table 4). Some of the tested herbicides checked the growth of the volunteers. Herbicides based on 2,4-D and dicamba deformed a percentage of the tubers. 2,4,5-TP and benazolin decreased germination.

C. To get a better understanding of the effect of the chemical weed-killers on the potato-tuber the trials were continued by using a main crop variety to simulate volunteer-plants (Table 5). 2,4-D/dicamba and benazolin decreased the number of new tubers formed and also the percentage of tubers germinating, confirming previous results in cereals. Diquat and paraquat can be applied for "mowing" volunteer-potatoes chemically. This is now introduced in practice as interrow-spraying, especially in crops of maize, beet, peat and beans, but also in potatoes.

Table 4

Effect of herbicides on planted "remaining" tubers in a winterwheat crop. Planting date March 30, tubers Bintje, size 28/35 mm Ø. Winterwheat Manilla. Clay soil 1971.

	Chemical and dose in kg or l/ha product T1 spraying time May 15th; T2 2 weeks afterwards	Yield winter wheat kg/ha	Number of tubers on 20 planted tubers depth 10 cm depth 20 cm		Percentage of the stored tubers that germinated in spring	
			a	b	a	b
1)	2,4-D 3 l T1 + MCPA 4 l T2	6560	24	15	97	84
2)	2,4-D 2 l + ioxynil-sodium 1 l, T1 MCPA + ioxynil-sodium 3 l T2	6360	11	12	94	100
3)	bromoxynil/MCPA MCCP 5 l T2	6550	28	13	98	92
4)	MCPA/TBA 6 l T1	6440	17	15	94	100
5)	MCPA/TBA 6 l T2	5470	28	12	94	100
6)	ioxynil ester/ bromoxynil ester/ MCPP-ester 4 l T2	6540	19	12	100	94
7)	MCPA + MCPP + dicamba 5 l T2	6160	23	17	88	83
8)	2,4-D + MCPA + benazolin + dicamba 4 l T2	6140	33	21	86	74
9)	2,4,5-TP 4 l T2	6460	18	13	50	60
10)	benazolin 6 l T2	6670	23	16	75	77
11)	2,4,5-TP 2 l + benazolin 3 l T2	6620	25	19	71	52
12)	dinoterb/MCPP 8 l T1	6550	23	23	83	94
13)	non treated	6670	17	18	97	100

A second trial on potatoes, carried out in 1972 with a similar range of chemicals at four application dates. 2,4-D/dicamba, 2,4,5-TP and benazolin as before had limited the germination of newly formed tubers. Ethofumesate applied after the emergence of the potato-shoots only delayed germination. Glyphosate was promising, at a dose of 3 l per hectare. It killed the plants and stimulated the rotting process of the tubers. Aminotriazole/ammonium-thiocyanate killed the potato-plants in the same way as diquat.

In the 1974 trial atrazine at 3 kg/ha sprayed with or without incorporation into the soil at potato planting was not very effective. It delayed germination only as did ethofumesate. Dichlobenil gave, contrary to previous results, an unsatisfactory effect.

Glyphosate (9-12 l/ha) sprayed when the groundkeeper-plants had just formed new tubers, killed the potato-plants, and all the tubers rotted. Using a lower dose of glyphosate with a hormone may give a similar effect.

Table 5

Herbicide-testing-programme on potatoes planted in summer to study the possibilities of killing volunteer-potato plants, sandy soil 1971.

	Chemical and dose in kg or l/ha product	Number of tubers on 15 planted tubers	Percentage of the stored tubers that germinated healthy
1)	MCPA-TBA 6 l	147	85
2)	$DNOC-NH_4$ 12 kg	104	93
3)	ioxynil ester + bromoxynil ester + MCPP-ester 4 l	101	92
4)	benazolin 5 l	91	25
5)	2,4-D + MCPA + benazolin + dicamba	213	44
6)	dinoterb/MCPP 8 l	92	94
7)	bentazon 4 kg	160	93
8)	MCPP + MCPA + bromoxynil 5 l	84	91
9)	2,4-D 3 l T1 + MCPA 4 l T2	131	95
10)	2,4-D 3 l + ioxynil-sodium 1½ l T1	110	92
11)	As 10, T2	106	96
12)	2,4-D + dicamba 5 l	40	11
13)	diquat 4 l	53	95
14)	DNOC (oil) 15 l	115	95
15)	MCPA 4 l	138	96
16)	paraquat 4 l	68	89
17)	lenacil 2 kg	123	96
18)	non treated	135	96

D. The regrowth of potato-plants after harvesting winterwheat undersown by Italian ryegrass was sprayed with several herbicides. In the trial-field 60,000 volunteer-plants per hectare were counted. At the time of application the height of the regrowth was approx. 20 cm, 2,4-D did not kill the potato-plants (Table 6). The best results were obtained with ioxynil-sodium/MCPA/MCPP, followed by dinoterb/MCPP and DNOC-oil. In a test in the climate-room 2,4,5-TP, benazolin and 2,4-D/dicamba limited the germination of the tubers, but was not confirmed in field tests.

From these results herbicide application has not given a practical solution to the problem of potatoes as a weed. Only interrow-spraying of diquat may in crops of maize, beet and beans be of practical value. Glyphosate, or in combination with other herbicides seems promising, but further research is required on rates and timing.

3. Research with bruising e.g. Soil-tillage operations may also destroy tubers which results in a reduction of volunteer-plants. Figure 1 shows the results of various soil-tillage systems on a light sandy soil, and 10-30% of the tubers are damaged depending on the tillage operation.

Trial results comparing the effect of soil-sterilization and soil tillage operations on remaining tubers, are summarized in Table 7.

For soil sterilization the chemical DD was used. Shallow ploughing and rotovation followed by the combination of ploughing and soil-sterilization were effective.

Table 6

Herbicides tested on volunteer potato plants, in Italian Ryegrass for green manure undersown in winterwheat. Sprayed August 25. Clay Soil 1970.

	Chemical and dose in kg or l/ha product	Effect 2/10 on It. Ryegrass 10 = no effect in killing the crop	on vol. pot. plants 10 = totally killed	Percentage of tubers rotten at harvest time samples 27/10	germinated in spring after storage	Number of volunteer plants/ha from remaining tubers. Subsequent crop sugarbeet
1)	MCPA/TBA 9 l	9.75	1.5	-	90	30,400
2)	2,4-D/dicamba 6 l	10.0	5.5	11.5	50	30,000
3)	ioxynil-sodium/MCPA/MCPP 1½/4½/4½ l	9.0	9.5	-	84	37,100
4)	benazolin 3 l	10.0	1.0	-	49	40,100
5)	2,4-D 6 l	10.0	2.0	-	97	34,200
6)	2,4,5-TP 5 l	9.5	2.5	-	15	32,300
7)	DNCO-oil 20 l	9.0	8.5	-	96	47,600
8)	sodium-arsenite 15 l	4.5	9.0	2.3	96	47,600
9)	diquat 5 l	3.0	9.75	-	100	38,600
10)	dinoterb/MCPP 10 l	8.5	9.75	4.0	96	37,800
11)	aminotriazole + ammonium thiocyanate 12½ l	1.0	9.5	31.8	79	34.200
12)	as 11, 25 l	0.0	9.0	7.5	63	38,200
13)	non treated	10.0	0.0	-	96	38,200

Figure 1. The effect of soil-tillage systems in eliminating tubers in a seed-potato field, sandy soil, autumn 1971.

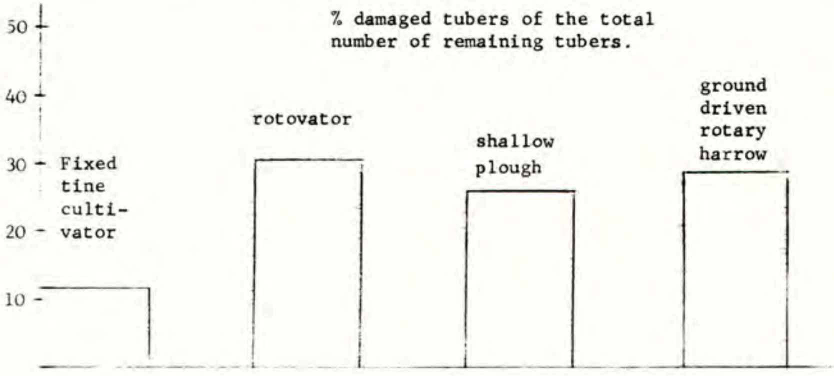


Table 7

Clay soil tillage methods and sterilization after seed-potatoes 1971/72

Trial A. Crop in 1972 winterwheat.

Treatment	Numbers of remaining tubers/ha summer 1971	Numbers of volunteer plants/ha summer 1972	Numbers of new tubers/ha on the vol. plants summer 1972
a) cultivating (fixed tines)	274,100	10,000	7,000
b) shallow ploughing	305,600	82,200	246,600
c) ploughing + sterilization	223,900	87,200	218,000
d) rotovation followed by c)	117,800	39,300	86,500
Trial B. Crop in 1972 sugarbeet.			
a) as in trial A	131,100	18,900	79,400
b) as in trial A	193,300	2,200	12,100
c) as in trial A	191,100	20,000	78,100
d) as in trial A	131,900	6,700	18,100
e) shallow then deep ploughing	127,400	82,200	197,300

4. Cultivation methods. The number of volunteer potatoes can be influenced by different factors. In winterwheat following potatoes (Table 8) less volunteers occur than in sugarbeet. This effect seems to be related to the time of seedbed preparation and to soil-physical properties.

As is mentioned before most tubers remaining on the field at harvest, are on the soil or in the top 10 cm. In the Netherlands the soil temperatures in winter are not low enough to kill tubers which are buried by a 10 cm layer of soil. 50 frost hours are required to kill potato tubers if the temperature falls below $-2^{\circ}C$, (e.g. 25 hours at -2° or 12½ hours at $-4^{\circ}C$, but 50 hours at $-1^{\circ}C$ will not be effective).

Table 8

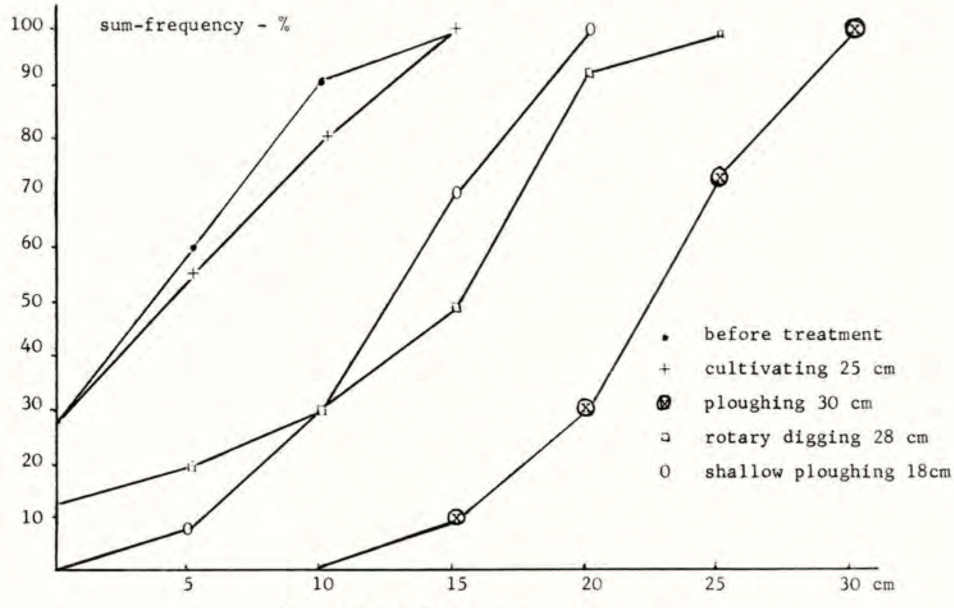
Number of volunteer potato plants/ha in two rotations (Clay soil).

Crop in sequence to potatoes	Number of volunteer plants per hectare 1971	1972	1973*
Rotation A			
1st year winterwheat	7,400	35,000	500
2nd year sugarbeet	4,400	7,000	8,000
3rd year summer barley	-	1,000	2,000
4th year potatoes	-	-	-
Rotation B			
1st year sugarbeet	25,000	45,000	19,000
2nd year summer barley	40	2,000	1,000
3rd year potatoes	-	-	-

* Cultivated with a fixed tine cultivator instead of ploughing, but no frost during the winter.

The effect of the soil tillage method on the transport of the tubers in the soil has been studied (fig. 2).

Figure 2. Position of volunteer potatoes on a clay soil.



By using a cultivator with fixed tines the tubers are only slightly transported vertically. Turning the soil transports the tubers to a greater depth, where the freezing chances decrease. The effect of ploughing and cultivating on the number of volunteer potato plants is shown in Table 9.

Table 9

Number of volunteer potato plants ha as a percentage of the remaining tubers 1971,72,73.

Year	No. of fields	Treatment	No. of volunteers/ha mean	No. of volunteers/ha variability	Fields - volunteers	Fields + <500 plants/ha
1971	23	ploughing	19257 (19)	260 - 93200	0	1
	23	cultivating	5600 (5)	0 - 53300	7	10
1972	22	ploughing	7860 (6)	0 - 84500	5	5
	22	cultivating	2450 (2)	0 - 22900	10	17
1973	15	ploughing	17260 (9)	0 - 42800	1	1
	15	cultivating	9910 (5)	0 - 19500	2	5

By using the fixed tine cultivator instead of the plough, it is necessary to reach a working depth of at least 20 cm in one operation for soil-physical reasons. By repeating the operation there is more chance that an unstable layer of soil will arise at a working depth of about 10-20 cm, and also of too much crumbling. To reach a depth of 20 cm in one operation a power of 5-10 hp per tine is required.

Tines should be mounted at an angle of 50-60° to the frame of fixed tine cultivators.

In general there were no significant differences in the yield of the following crops (winterwheat, winterrye, spring barley, sugarbeet, flax), when a well built type of a fixed tine cultivator was used compared to ploughing, while the chances of freezing for groundkeepers are better.

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DEVELOPMENTS IN DIRECT DRILLING IN THE UNITED KINGDOM

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In opening a conference at Rothamsted on the art and science of cultivation in 1927, Sir Daniel Hall used the increased cost of labour in relation to the price of wheat as a reason for suggesting changes in methods of cultivation (Hall, 1927). The journal of the Royal Agricultural Society of 1937 contained an article entitled "are cultivation standards wastefully high?" (Keen and Russell, 1937). These and other publications show that an interest in economy of cultivation is not new. They have in common an appreciation of the overriding need of cultivation for weed control and therefore of weeds as a barrier to economy of cultivation.

The discovery and development of modern herbicides coming as they did from 1942 onwards were bound to add momentum to the quest for economy of cultivation, because of their ability to control weeds largely independent of soil disturbance. Yet for some 20 years the chemicals made no impact on arable cultivation, probably because the rapid change from horses to tractors in the 1950's had temporarily alleviated the pressures of labour shortage and cost. But by the 1960's the need for economy in land preparation for sowing was again outrunning what tractors could provide. Hence the developments in minimum cultivation during the 1950's and 1960's which have been described elsewhere and need not be enlarged on here (Elliott, 1973). Direct drilling and reduced cultivation have now made the break-through into systems for cereals and fodder crops: the resources of both commercial and official R & D are increasingly supporting the new trend and those in the forefront of this new technology have to adjust to the fact that what a year or two ago was a research possibility is turning rapidly into a widespread commercial reality with all that that entails.

The experiences of 1974 in reduced cultivation are an episode in a train of events stretching over the past 50 years and probably into the next 50 years as well. Assessments of what is known or unknown, what has been achieved or has failed need to be considered on that long-term basis.

The purpose of this paper is to consider the present state of the technology of direct drilling and reduced cultivation, and to suggest some approaches to the future.

Current usage in the United Kingdom

The most up-to-date figures for the extent of direct drilling in the United Kingdom are those provided by Plant Protection Ltd (Denning, 1974).

A number of points about the figures are of interest. The very much greater area of winter cereal than of spring cereal may be simply a reflection of where the emphasis of development has been placed; or does it indicate that farmers have encountered difficulty or failure in direct drilling spring cereal? The general experience in the field investigations being financed by the Agricultural Research Council in various institutes would not support such a view, indeed their experience indicates that spring barley can be grown successfully by this technique.

Table 1

Area of Direct Drilled Crops in the United Kingdom during 1973

Winter cereals	30,600
Spring cereals	3,700
Kale and rape into grass	27,200
Swedes and turnips into grass	2,750
Catch crops into stubble	13,600
Oilseed rape	8,050
Fodder rape	1,400
Grass into grass	5,280
Grass into stubble	8,530
Miscellaneous	590
	98,700 hectares

The area of Kale and Rape sown into Grass at 27,200 ha represents 27% of the national crop - a substantial use of the technique: while the area of grass sown into grass (5,280 ha) amounts to less than 5% of the total area of grass sown without cover crop each year. Bearing in mind that the direct drilling of kale and grass made their initial impact at about the same time and in similar farm situations, the reasons for the disparity in their development merit enquiry.

Certainly the most striking figure is that for oil seed rape: it reveals that about 67% of the crop was direct drilled in 1973.

Figures for the extent of reduced cultivation are not available on the same scale. A survey of cereal practice undertaken in 1968 showed that at the time in Northumberland and in the Midlands 22% of the fields going from cereal into cereal did not receive mouldboard ploughing but were cultivated by tined implements or rotary cultivators: 7% received no cultivations and were direct drilled (Phillipson et al, 1972). The figures imply a much more widespread use of reduced cultivation for cereals than of direct drilling, and this would agree with field observations. There are possibly areas of light soil in the southern half of England where mouldboard ploughing is now the minority approach to land preparation for cereals. That it is unfortunately necessary to speculate in this way is an indication of the need for a monitoring of cultural techniques on a national scale.

The General State of the Technology

In Crop Sequences

In assessing the relevance of direct drilling, it has become the practice to distinguish between surface harvested crops and those which form their produce in the soil, all the former being potentially suitable for direct drilling but the latter being of low priority for research because the need of a deep loose seedbed and of powerful traction for harvesting dictate a continued use of ploughing. At the present time this distinction appears to provide a reasonable basis for R & D priorities but it should not be assumed to continue in the long-term. Work in Europe with sugar beet has pointed to the technical feasibility of growing this crop by direct drilling, and a few pioneering farmers have direct drilled sugar beet in Britain with some success.

In any case of the 11 m hectares cropped area of British agriculture only 0.4 m hectares are used for crops that form their harvest in the soil: there is thus plenty of scope for the expansion of the technique within surface harvested crops. The crops for which direct drilling is potentially relevant are: cereals, annual and perennial legumes, brassicae and grasses; and it is likely that farmers will require freedom to progress from any one of these crops to another without resort to cultivation. Two notable crop sequences are grass to cereal and grass to grass. Throughout the broad acres of Britain grass occurs on so many farms and in so many crop sequences that any new cultural technique must be usable into and out of grass if it is to be adopted on wide scale: yet it is precisely in these sequences that direct drilling is lagging. Apart from the current project at WRO there appears to be little detailed research in progress on this important aspect of the subject (Anon, 1974).

Soils and Soil Conditions

Which are the soil conditions on which direct drilling may succeed consistently? An answer is provided in the guidelines issued by Plant Protection Ltd which state "fields should be well drained ..... For winter cereals in particular it is important to ensure that there is no compaction or panning and that the surface water drains freely". The key words are "drainage" and "compaction" when identifying suitable soils. In practice the technique in respect of cereals has settled on top soils in the textural range of sand to medium loam and has avoided silts, clays and clay loams: but fodder crops are sown on a wider range of soils. In spite of these restrictions it is possible to find farmers direct drilling cereals successfully on soils that might be regarded as heavier than the guidelines allow. Official research is also suggesting a widening of the limits of soil type: the joint WRO/Letcombe Laboratory tillage project has an experiment on clay loam over Oxford clay on which after two years experience the indications are that direct drilling can be made to succeed on such soil with both winter wheat and spring barley (Elliott et al, 1974).

The truth is that at the moment we don't know what are the limitations to direct drilling imposed by soil type. Some soils may be inherently unsuitable but much of what is unsuitable in soil conditions is commonly caused by man's activities and these can be changed. Until the agronomy of direct drilling reaches a high standard (which it has not at the moment) who can say what will be the inherent limitations of soil?

So far as crop growth in relation to soil physical and mechanical conditions is concerned, considerable and detailed research is in progress at at least six centres in Britain and elsewhere in the world. This research may be expected in time to produce many answers relevant to direct drilled cereals but it suffers the limitation of not including other crops which may exhibit different reactions to those of cereals.

An aspect of soil condition not receiving attention is that of the maintenance of a natural surface tilth. Agronomists have observed that some soils on which cereals have been grown without cultivation form a surface layer of natural tilth perhaps no more than 3 cm deep. For many crops this layer may provide the loose soil in which the seed may be placed. What are the factors contributing to its creation and maintenance? One may speculate that organic matter, frost, and earthworms may encourage the formation of this layer and that heavy rain and heavy wheels may destroy it but at the moment this is no more than speculation. Since this tilth may be a key factor in the establishment of crops, and therefore of successive direct drilling, it must be a subject worthy of research.

Machinery for Direct Drilling

When in the 1940's farming turned from horses to tractors it suffered a period during which much of the attendant equipment was still based on that for horses. Direct drilling is in a somewhat similar situation to-day; although special drills have been developed, the tractors that draw them and all the remainder of the equipment used to grow and harvest the crop is that designed for work on conventionally cultivated soil. The important differences are twofold.

1. Traction requirements in direct drilled systems should be small compared with those of conventional cultivation.

2. Uncultivated soil is firm, not loose - and it should not be compacted.

Traction requires weight on wheels and strength in the attached machinery which in turn implies weight. All too often weight is associated with soil compaction. In direct drilling, where much of this can be avoided, there should be a premium on lightness. It is therefore a sad reflection that the special drills weigh up to 2 tonnes. Now that the existence of natural tilth is known should not steps be taken to preserve it and allow light drills to be designed to work in it?

The standard tyre used on most field machinery is that based on chevrons, which are the ridges to be seen on the circumference of the tyre. Such tyres are specifically designed to work on soil that can and will be deformed. Furthermore they are all expected to slip in the soil. Slip occurs, not between tyre and surface, but within the soil itself. So such tyres must penetrate the harder foundation. The assumptions in the design of these tyres admirable though they are for conventionally cultivated soil are inconsistent with the preservation of surface tilth on direct drilled fields. Tyre manufacturers do cater for different surfaces, for example there are designs of low inflation pressure and a block type pattern which provide good flotation to avoid damage to ornamental or recreational grassland. It is clearly necessary to open communication with tyre designers so as to obtain suitable tyres for the special surface conditions of direct drilling.

One further aspect of machinery is worthy of mention. Of all the operations carried out on a direct drilled field, the most crucial and the one most likely to go wrong is the act of sowing. Since a great deal hinges on the precision, efficiency and absence of side effects with which that task is accomplished, research should be interested in the continued improvement of the devices used for sowing. In fact the most commonly used design was produced some 7 years ago and before the major expansion of the technique (Koronka, 1973). It is encouraging to learn that NIAE Scottish Station is starting a new project on this subject to complement that already under way in the University of Newcastle.

Nutrients, Pests and Diseases

I have grouped these three aspects together because they have in common that there is a lack of knowledge about the impact of direct drilling on them in relation to crop production. What has happened is that the assumptions in respect of them used in plough cultivation have been applied to direct drilling and reduced cultivation. Although the results have not been unsatisfactory, there is a need for more research to ensure that undesirable happenings do not occur in the future.

In respect of nitrogen fertilizer early work suggested that more nitrogen was required by direct drilled crops to obtain an optimal yield compared with similar crops growing on ploughed land.

However more recent work has indicated with cereals that given an adequate level of nitrogen direct drilled cereals will yield as well as those on deeply cultivated soil. It could be that the difference between early and recent experience arises from the improved standard of agronomy now current in direct drilling, which ensures equal opportunities for crop growth. It is well known that phosphate and potash are less mobile in soil than is nitrogen and it could in consequence be argued that nutrient gradients would build up in the absence of soil mixing: indeed some evidence in support of this has been published. However the generality of agronomic experience has not so far pointed to nutrient gradients as a disturbing factor in the growth of direct drilled cereals. A scientific basis for estimating the nutrient requirements of direct drilled crops is lacking and in the meantime farmers can only continue to base their fertilizer applications on what their past experience tells them to be sensible.

The situation with regard to diseases is even more vague. In respect of soil borne diseases which may be spread by implements there are grounds for believing that direct drilling might reduce their incidence; and early work at Jealotts Hill supported this view but little more is known than that. Perhaps the greatest danger is in respect of splash borne diseases transferred from the debris of the last cereal crop to the next: and it is a common experience that direct drilled fields are more prone to this type of surface litter. The problems are likely to arise from Cercosporella, Rhynchosporium and Septoria and may be worse in Southern and Western parts of Britain than elsewhere. The foliar diseases depend on the proximity of green leaves such as for example between over wintering volunteer barley and spring sown barley: such happenings can and must be prevented by good weed control. Research on diseases in relation to reduced cultivation is in progress at Rothamsted and elsewhere but it will take many years for the problems to be resolved. In the meantime agronomists and farmers can only pursue the objectives of crop hygiene even more vigorously with direct drilled crops than has occurred with those that are cultivated.

The Agronomy of Direct Drilling

Living as we do in the shadow of centuries of the cult of plough husbandry it is not surprising that many find it difficult to shake off the almost religious assumption that crop plants will not grow without the prior ploughing of the soil. Yet gradually the truth is coming out: how wise was the gentleman who wrote in 1852 "it is not ploughing, it is not digging, it is not harrowing . . . that we want: all these are time honoured, time bothered means to a certain result. That result is - a seed-bed" (Hoskyns, 1852). Give the seed cover from predators, the requirements for germination and rooting, a freedom from weeds, diseases and pests, and the crop plant will do very well in uncultivated soil, just as do wild plants in nature.

Of course these are no more than a set of objectives for the farmer or agronomist wishing to succeed at direct drilling; and the important rule for success is to avoid making mistakes. One of the strengths of plough cultivation was that it allowed the opportunity to correct past mistakes in the handling of the soil: without cultivation correction must be left to nature. Implicit in successful direct drilling is therefore the avoidance of unacceptable soil conditions. The man on the spot has therefore two challenges.

1. To bring the field to a condition appropriate for direct drilling.
2. To keep it that way.

Both involve the avoidance of all the adverse factors mentioned so far in this paper and those to be mentioned in the next section.

The most reliable approach to direct drilling from ploughing is a progressive one through deep and shallow tine cultivation. Such a progression allows for the break-up of plough pans, causes the land to become progressively firmer, provides continuing experience of how to handle the changed situations of weeds, trash, wheelmarks etc. It allows an understanding of how rainfall affects the soil surface in relation to acceptance of traffic and when on the day of drilling the soil will crumble to a tilth or turn into plasticine.

Once the soil condition is achieved its retention requires thought all through the year: any wheel on the ground in wet conditions can destroy the surface tilth, be it sprayer, combine, trailer or baler. The importance of this tilth cannot be over-estimated: in the early days of the technique reference was made to 'slitseeding', now the placing of seeds in slits uncovered by soil is regarded as hazardous.

To sum up, the agronomy of successful direct drilling requires all the conventional attention to variety, nutrients etc., and, in addition, the avoidance of:

1. unkilled weeds
2. quantities of straw or other plant material on the surface
3. surface compaction by wheels or implements
4. the creation of impervious layers in the soil

Consideration of these requirements will lead to an appreciation that direct drilling is a very demanding and skillful technique of crop production and furthermore one that has to be learnt by each farmer on his own farm over a period of years.

Unwanted Plant Material - Knowledge and Ignorance

In direct drilling there is a necessary interest in the problems posed by weeds, cereal straw and mat and trash in grassland: all these apparently disassociated subjects are in fact part of one problem - unwanted plant material (UPM) which can occur in two forms, live or dead. It is necessary to think of them collectively because the disposal of one of them may affect the form and the disposal of another: for example, the use of a herbicide does little more than convert weeds which are unwanted plant material in the live form into the dead form which may also cause a problem in crop establishment. Similarly the disposal of straw (UPM, dead) by burning is likely to have considerable effect on the subsequent growth of weeds (UPM, live). Thus a co-ordinated approach to the whole subject of unwanted plant material is necessary.

Live Material - Weeds

In a paper to this Conference some eight years ago Cussans described how it was anticipated that changes in cultural practice would bring changes in the performance of weeds, and therefore changes in the species regarded as problems requiring control (Cussans, 1966). Events are now bringing reality to those early forecasts. Somewhat paradoxically the use of herbicides which made direct drilling possible is going to be changed in face of a changing weed flora brought about by changes in cultivation. The research at WRO and elsewhere on arable weed control is starting to produce a flow of information which may be summarised as follows.

Annual broad-leaved weeds: the less does soil disturbance occur the less are the numbers of these weeds that emerge but a sufficient number do so in cereals to necessitate the use of a selective herbicide. The species react differently to lack of soil disturbance; and *Stellaria media* (chickweed), *Matricaria* spp (mayweed) and *Aphanes arvensis* (parsley piert) have been observed to show an ability to increase with direct drilling.

Perennial grasses: the only species about which much is known is *Agropyron repens* (couch grass), there is little doubt that this species increases rapidly in direct drilled cereals and it has not been clear whether its spread can be adequately controlled by the existing range of herbicides. Thus the presence of *A. repens* in a field has been a barrier to the adoption of direct drilling as a technique of growing cereals. However the situation appears likely to be changed by the development of glyphosate currently coming available on the British market because this herbicide has shown an ability to kill couch rhizome without the need for soil disturbance before or after application.

Annual grasses: as a result of recent research on *Avena* spp (wild oat) much is known about its reaction to changes in cultural practice. In cereal systems direct drilling appears to allow an easier control of the weed than does cultivation because of the death of wild oat seeds left exposed on the surface in the autumn as compared with their preservation when cultivated into the soil. There now exists a sufficient range of selective herbicides to ensure wild oat control regardless of cultural system.

While this extent of knowledge may be sufficient to allow the continued extension of direct drilling in cereals, it leaves major areas of ignorance which should be subjects of research, as follows:

1. What are the long-term effects of changes in tillage on weed seed populations in different soils and climates?

2. How do Arrhenatherum elatius, Agrostis stolonifera, Agrostis gigantea and Poa trivialis respond to lack of cultivation and how should they be controlled?

3. There is a need for improved methods for the control of Alopecurus myosuroides, Poa spp and volunteer cereals.

4. What effect will changes in tillage practice have on the phytotoxicity and residual activity of commonly used cereal herbicides?

5. Are there consequences for any of the above weeds arising from changes in systems for the disposal of straw (UPM dead).

At the present time direct drilling of grassland follows the overall application of paraquat and there is very little distinction between the species as to their reactions in different circumstances: the true potential for herbicides in grassland is more varied and more sophisticated. In the case of crops to be sown in rows it may only be necessary to spray a band of the old turf in the row where the seed is to be sown with perhaps a suppression of growth between the rows or the use of grazing animals to prevent grass competition. For overall spraying we have now such a range of herbicides that we should be able to match the chemical to the situation. Dalapon, paraquat, glyphosate, amino-triazole, 2,4-D, MCPA, mecoprop, asulam and ethofumesate offer such a varied catalogue of properties, speed of action, residual effect in soil, weed susceptibility and crop resistance. Research can and should now produce proper species susceptibility tables from which herbicides singly or in mixture can be selected according to the species community to be killed or suppressed and the circumstances surrounding the application (Elliott and Squires, 1974).

Dead Material - Straw, trash and mat

From the early days dead material in its various forms has been regarded as a nuisance and an obstruction to the easy passage of implements, now research and experience has shown it to be in addition, a danger to the germination and establishment of direct drilled crops.

Experiments created specifically to study the problem on killed grass swards have shown that the presence of dead material resulting from the use of a herbicide reduced the establishment of Italian ryegrass and clover in comparison with identical sowings in the absence of such material (Squires, 1974). Similarly field experience of sowing cereal into land covered by straw has shown how crop seed may be placed on straw which has been pushed down into the soil by the drill: in consequence the seeds may not germinate uniformly. Straw overlying sown crop seed may prevent emergence of the growing shoot or slugs encouraged by the straw may attack the crop. All these situations are obviously adverse to the healthy and reliable establishment of a crop.

Awareness of the dangers of UPM (dead) in grassland has led to the development at WRO of a technique for its removal from the vicinity of seed which is placed in killed swards (Squires, 1974). In cereal land straw burning is regarded as a pre-requisite of direct drilling, an unfortunate association from the environmental point of view. Burning reduces the return of organic matter to the soil thus reducing its protection from de-structuring by wheels. In the long-term ways have to be found of assimilating straw and other remains into an organic cycle which does not prevent drills working or increase the risks from pests and diseases. How to accelerate the breakdown of straw in the field is a major undertaking for research from which the prize could be superior crops to those grown by conventional cultivation.

Straw breakdown is the subject of the only research report that it is my duty to review; the paper is by my colleagues Erna Grossbard and S L Cooper of WRO entitled "The decay of cereal straw after spraying with paraquat and glyphosate" (Vol 1. p. 337). In their introduction the authors draw attention to evidence that herbicide treatment may influence the activity of micro-organisms and therefore of straw breakdown. The paper reports a study of paraquat and glyphosate in this connection. They report that neither herbicide influenced the decay of leaves of rye lying on the soil surface but that paraquat delayed the decay of barley straw covered by a shallow layer of soil. After 16 weeks the control and the glyphosate treated samples had lost 55% of their initial weight, but those treated with paraquat had lost only 26% The addition of ammonium nitrate reduced but did not eliminate the difference due to paraquat.

These findings which, I suggest, require following up, support the need to approach the control of both live and dead plant material on a unified basis.

What of the Future?

That direct drilling of surface harvested crops will continue to expand appears a safe prediction: the combined effects of labour shortage and fuel price will ensure this: the questions are how far and how fast will the expansion occur?

The answer depends on how certain major issues are resolved. In a paper to this conference 8 years ago E W Russell said " ..., If it were possible to sow and harvest a crop without ever going on the land, the crops themselves would maintain the sort of tilth and pore space distribution needed for a seedbed and for seedling growth" (Russell, 1966). Field experience points continually to the wisdom of Russell's words. Here is a clear challenge to engineering research: can it provide the means of growing crops without in effect 'going on the land'?

Hanging over the technique is the issue of the disposal of straw and other plant material. Will burning be banned or restricted? Will means be found of growing crops in the presence of surface debris of the previous crop? Upon the answers to these questions depends the future hygiene and healthy growth of direct drilled crops.

Direct drilling was born of herbicides and its further development rests on the omnipotence of chemical weed control. The more the technique expands and the longer is it used the greater will be the requirements of chemical performance. The future can be assured, but only by continuing research.

Certainly the greatest scope for expansion is in the sowing of grass and fodder crops. The revolutionary possibilities are enormous but their adoption requires a major change in the attitudes of grassland farmers and research workers, and this may come slowly.

Given a favourable outcome to these issues it appears a reasonable forecast that direct drilling will be the majority approach to the production of surface harvested crops ten years from now.

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MOTIVATION AND RESPONSE IN THE DEVELOPMENT OF MINIMAL TILLAGE TECHNIQUES OUTSIDE THE UNITED KINGDOM

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In discussing minimal tillage techniques let us first be quite clear about the meaning of "minimal tillage". The phrase could cover any system of cultivation involving less mechanical movement of the soil than is locally the tradition. Stubble and trash farming systems developed to counter erosion under prairie conditions fall into this general category, but in the context of this Conference we will restrict usage of the term to describing only those techniques in which herbicides are used to replace all or part of the mechanical cultivations normally used for weed control.

Within this category there are many different systems. They vary from true no-till systems, where only a seeding slot is cut into the uncultivated soil surface, and where herbicides may be applied before or after seeding, to systems using overall cultivation but where the operation is made easier, quicker and more effective by herbicide treatment before cultivation.

Let us also be clear that these chemically assisted techniques are not necessarily appropriate to all cropping situations. There must first of all be a definite motivation on the part of the farmer to use them, be it a need to minimise soil erosion and/or weather dependence; speed the change from pasture, crop, or fallow to crop; minimise labour; or simply to cut costs. Secondly, to be practicable, any minimal tillage technique must be suited to local cropping conditions. In general, for instance, it would be inadvisable to use a no-tillage technique in an area affected by a perennial grass weed problem, and on a heavy clay soil a minimal tillage technique might be preferred to one of no-tillage. In pasture improvement situations band spraying followed by no-till seeding of legumes could be a more profitable technique, based on stock carrying capacity, than one involving a complete kill of the old pasture and its replacement using a minimal tillage technique.

Some of the earliest work on use of chemically assisted methods of cultivation involved the use of dalapon and aminotriazole, but the real breakthrough began with the discovery of paraquat in the 1960's (Boon, 1966). This herbicide, inactivated on contact with the soil, permitted the rapid switch from pasture, fallow or stubble to crop that has been the key to today's world-wide developments. Some of the earliest work with paraquat took place in the Canadian prairies, in attempts to replace mechanical cultivation used in fallow periods with methods of chemical weed control using paraquat on its own and in mixture with other herbicides. The chemical system improved moisture conservation, particularly by increasing snow catch, and minimised winter damage and wind erosion, with yields of both spring and winter wheat being increased (Palmer, J.R., and Ford, D.O., 1968; Palmer, J.R., 1968). The chemical system proved, however, to be more expensive than the normal methods of mechnical weed control, and no commercial development has yet taken place. This position is by no means final, however, as instanced by current work on atrazine - fallow techniques by Eckert et al (1974) in Nevada, and by Unger's (1974) promising work in Texas on conservation of soil moisture by chemical fallow techniques.

Other early work in Canada concerned the renovation of roughland pastures in Ontario, where shallow, rocky soils precluded the use of normal mechanical systems (Winch et al, 1971). Suppression of the native pasture with paraquat followed by broadcast seeding and fertilizing enabled the successful establishment of pasture based on birdsfoot trefoil. However, the productive value of these roughlands is so low that no commercial development is likely to take place until national priorities indicate otherwise.

It was in a more intensive, productive situation in the corn/stock farms of the Eastern States of America, with soil erosion a problem, where the partnership of paraquat with atrazine triggered off the general acceptance of no-tillage techniques (Shear, 1968). Here, the ability to plant maize without cultivation into erosion-prone land normally kept under permanent pasture, immediately improved the farmers' crop options and consequently his profitability. The advantages of switching quickly from pasture to crop, or crop to crop, without time consuming cultivations lent flexibility to his entire operation, and gave great impetus to the whole development of minimal tillage techniques. A wide range of contact and residual herbicide mixtures has since become available that are now permitting the further extension of no-till techniques to sorghum, soya bean, cereals, cotton, fodder crops and vegetables (Young, 1973; Wiese, 1974).

Over the last ten years the tempo of development in the United States has progressively increased until in 1973 1.0 million hectares of no-till maize were planted. There were 440,000 hectares of no-till soya beans and 67,000 hectares of no-till grain sorghum. Eleven states each raised over 40,000 hectares of no-till crops this last year, led by Kentucky with 380,000 hectares (Lessiter, 1974a). The same authority suggests that some 2.2 million hectares of no-till crops will be planted in the United States in 1974; some 16 million hectares will be planted using a variety of minimal tillage techniques, as compared with conventionally planted crops of some 80 million hectares (Lessiter, 1974b). Naturally, herbicide usage is greatest in the no-till systems, but there are also situations where herbicides are used to supplement cultivation in the minimal tillage situation.

The above figures are impressive, but they represent only the beginning of the story in North America. Powerful new motivations towards use of the techniques now exist: problems of world population and food shortage increasingly dominate the scene, and demands on the American farmer as exemplified by the 1972/73 crop area extension are increasing. At the same time increased labour, equipment, fuel and fertilizer prices are squeezing him, while a heightened environmental awareness is calling for decreased soil erosion and its attendant risks of pollution. Allen (1974) suggests that no-tillage techniques on irrigated land can cut fuel usage from 200 litres per hectare down to 22 litres, and on a more conservative level Green and McCulloch (1974) quote UK and US data showing that no-tillage systems can offer direct diesel fuel savings of between 30 and 50 litres per hectare when compared with traditional cultivation. Quantifying the actual energy content of fuel and herbicide inputs, they find an energy saving offered by no-tillage compared with traditional of approximately 1 GJ/hectare (Table 1). Naturally, fuel savings will be less with minimal than with no-tillage, but still represent a useful bonus over the other advantages offered by the technique, and nationally will total many score millions of litres.

The use of reduced tillage techniques is one of the farmer's main responses to these mounting pressures. Their main advantage is that they enable the farmer to step up his cropping intensity without increasing labour requirements. They also cut his fuel and equipment costs, they practically eliminate soil erosion (Gard and

McKibben, 1973) and can improve fertilizer utilization by minimising soil fixation of applied phosphates.

Table 1

Energy used in conventional cultivation and direct drilling (U.K.)

Ploughing and cultivating			Direct drilling		
Operation	Diesel fuel litres/hectare	Energy GJ/ha	Operation	Diesel fuel litres/hectare	Energy GJ/ha
Ploughing	22.5	0.75	Spraying	1.7	0.06
Heavy cultivating	22.5	0.75	Drilling	11.2	0.38
Light harrowing	5.6	0.19	Harrowing	5.6	0.19
Drilling	11.2	0.38			
Light harrowing	5.6	0.19	Paraquat		0.39
Total	67.4	2.26		18.5	1.02

In developing these techniques American farmers are not only increasing use of the familiar pre-crop emergence herbicidal mixtures, but are also developing directed inter-row spray systems for post crop emergence use. Bentazon has become available to permit overall selective spraying in soya (Thompson and Daniel, 1974), and glyphosate offers the possibility of controlling perennial grass weeds (Lee, 1973; Worsham & Lewis, 1973; Chappell, 1974; Kerr & Royster, 1974). New surface applied soil residual herbicides, oryzalin and metribuzin may remove the need for incorporation of such materials as trifluralin (Talbert & Frans, 1972; Harvey, 1973; Herron et al, 1973; McKibben, 1974).

Another breakthrough that may possibly have significant implications for the development of no-till techniques is the discovery of "safeners", materials which by use as a seed dressing or in mixture with soil residual herbicides, can protect the crop plant from phytotoxic effects without affecting herbicidal efficiency (Heiks & Swink, 1973; Schmer et al, 1973). Use of these materials, may permit the use of higher than normal levels of residual herbicide to control particularly bad perennial weed infestations that can develop where no-tillage is continuously practiced.

In Europe there is also considerable activity in the development of no-tillage and minimal tillage techniques. Elliott (1974) has given an up-to-date summary of the position in the United Kingdom while on the European mainland the principal developments are taking place in Holland and France, where rising costs particularly are placing pressure on the farmer. In Holland, some 10% of the 700,000 hectares of arable land is susceptible to blowing, and a technique has been developed using rye and brassicae winter cover crops to protect the soil. This cover crop is killed off with paraquat in the spring, and then the crop seeded into the dead mulch with a no-till or minimal tillage technique (Lumkes & de Velde, 1974). This technique is now being used over some 1,200 hectares of sugar beet, and usage is likely to extend much further to peas and, in modified form, to the potato crop.

Several minimal tillage systems are being developed in France. In different parts of the country some 5,000 Semavator rotovator drills are being used to sow winter wheat into wheat or maize stubble, using paraquat where post-harvest weeds present a problem. In the "Western marshes" area south of Nantes on the west coast, an area of poorly drained soils that are difficult to cultivate, no-tillage systems of cultivation using pre-seeding applications of aminotriazole and paraquat show good promise (Damour et al, 1973), and work has progressed to the stage where some 50 no-till maize planters are in action.

In the south-west of France, around Toulouse, an area where mild wet springs can make early cultivation difficult, a "spring cleaning" technique has been developed where the ground is ploughed in the autumn, then weeds killed by a paraquat spray in spring before seeding. The time saved by this technique has been studied by Roques (1974) with the conclusion that the spring cleaning technique is profitable where the farms are larger than 35 hectares per unit of manpower, and only rarely profitable when the farm size is below this figure. In this area some 50,000 hectares of land are now planted with this technique, sufficient proof of the benefits to the farmers concerned.

This system of "spring cleaning" also finds a place in Italy where Bonciarelli & Cardinali (1974) report that on clay soils seeding with minimal disturbance into an autumn prepared seedbed cleared of weeds with paraquat, results in better crop stands and fewer weeds. Their work highlights the advantages of keeping the surface soil tilth developed over the winter, and the fact that tilling before seeding can adversely affect soil structure and promote, by disturbance, the germination of weed seed.

From Germany come details of minimal tillage investigations in situations involving problems with <u>Agropyron repens</u>. When glyphosate and other perennial grass weedkillers become more available they may present a ready solution to the problem, but in the meantime Bachthaler (1974) concludes that minimal tillage techniques must be preferred to no-till, since the former permits use of soil-acting herbicides. Tiedau et al, (1974) have approached the problem in a slightly different way, and they conclude that autumn application of aminotriazole and paraquat, followed by the winter cultivation of a competitive green crop such as fodder radish, followed in the spring by applications of paraquat and atrazine can permit the cultivation of a no-till maize crop. For the present, however, the perennial grass weed problem is not one that lends itself to no-tillage techniques.

In a different approach to weed problems in no-till techniques, Stecko (1974) reports from Sweden laboratory experiments showing that under some conditions paraquat and diquat may adversely affect weed seed germination.

In Eastern Europe, with large co-operative farms and, as elsewhere, a movement of labour from land to city, there is considerable motivation towards chemical methods of weed control and no-tillage techniques (Hill, 1974). No-till triple disc drills are known to be in action in Bulgaria and Romania, and their use could follow earlier work on the use of paraquat and atrazine mixtures in the no-tillage cultivation of corn, by Sarpe et al (1969) and Kovachev et al (1971). In Russia, Filev et al (1970) have worked with simazine and atrazine and reduced the number of cultivations required for maize planting in the Ukraine.

In the Southern Hemisphere development proceeds apace. In the western wheat belt of Australia, urged particularly by the need to maximise pasture usage at a time of feed shortage, then to switch quickly from pasture to crop, farmers are rapidly developing use of the 'Spray-Seed' technique (Stonebridge et al, 1973). By this method, killing annual pasture species with a paraquat/diquat spray mixture then seeding the crop with a one-pass cultivation drill, paddocks can be switched from pasture to crop in a matter of days. One farmer, indeed, has quoted a reduction of from 1,250 to 350 tractor hours in the establishment of a crop of 400 hectares using the 'Spray-Seed' system, as compared with conventional cultivation. First demonstrated on a large scale in 1970, some 100,000 hectares of crop were planted with this technique in 1974.

On a smaller scale, in the Murrumbidgee irrigation area of New South Wales where land is valuable and labour short, a no-tillage rotation of pasture, rice and wheat has been used for a number of years; traditionally pasture has been eliminated by a combination of sheep grazing and flooding (Boerema & McDonald, 1967). In 1973, with a shortage of sheep, this elimination was satisfactorily carried out with paraquat, and it would not be surprising to find further herbicide developments in this area.

When considering future developments in Australia, Anderson & Whan (1974) suggest that with land values rising together with costs of production, multiple cropping systems involving minimal cultivation will develop, and bring about an increase in production with little change in fixed costs.

In New Zealand no-tillage renovation of pasture and sowing of cereals and fodder crops has been practiced for a number of years (Leonard, 1973). These techniques were particularly appropriate for farmers traditionally concerned with management of permanent pasture management, and so with little cultivation expertise. First developed commercially by contractors, results have been sufficiently impressive to lead eventually to the purchase and use of no-tillage seeding drills by farmers themselves. A new development is now reported by Palmer et al (1974) where overall cultivation is still carried out but where the use of paraquat to kill pasture swards prior to cultivation and sowing of maize, can eliminate the need for a 4-6 weeks period of fallow. This is important on farms where livestock demands on the pasture available are high, and the technique is now finding rapid acceptance in North Island with some 25,000 hectares of crop established in this way, in 1974. This paper by Palmer leads to suppositions that the prior kill of pasture by paraquat leads to a more rapid mineralisation of plant residues; this interaction of minimal and no-tillage techniques with subsequent re-cycling of plant nutrient appears time and again in consideration of these techniques, and needs perhaps more study than has been the case so far.

New Zealand practice illustrates two points of perhaps general application. Traditionally the country has relied on the clover component of its pastures for the provision of nitrogen, but during the late 1960's and early 70's there was a trend towards greater use of synthetic fertilizer. With the current increase in price of fertilizers the pendulum is likely to swing again to dependence on legumes, and here the no-tillage incorporation of legume species into pastures, or the manipulation of legume/grass balance by application of low doses of paraquat (Williams, 1968) will find application. Concomitantly with increased dependence on the legume component of its pastures will come a need for better clover killers prior to cropping, and dicamba will be important in this respect (Leonard, 1973).

With regard to phosphate, New Zealand soils are predominantly of volcanic origin and with a high fixation capacity for phosphate. Under these conditions normal methods of cultivation can only lead to a dilution and subsequent fixation of surface applied phosphate, while with no-tillage techniques US work shows that such phosphate will be held in the upper surface layers at a relatively high level of availability (Larson, 1970; Gard & McKibben, 1973).

In South Africa, in extensive situations on wind-blow soils there has been some technical interest, but as yield potentials are low there has been insufficient motivation to lead to any significant development.

A similar situation exists in drier areas of the grain belt of Argentina, but as yet economic pressures are not sufficiently great to stimulate development of no-tillage techniques. More interest is seen in Chile where pasture situations similar to those in New Zealand exist, but it is in Brasil where most activity in South America is taking place.

In Brasil there is a combination of circumstances which promises to lead to a massive development of no-till techniques, in the states of Parana, São Paulo and Rio Grande do Sul. In the first place the land, often sited on "terra roxas" and related soils of volcanic origin, has been practically clean cleared of natural cover. With mechanical cultivation, and a seasonal rainfall pattern that can include intense rain storms, widespread and serious soil erosion has taken place, amounting to a national problem. The farmers are progressive, with incentives to crop the maximum land area, rotating wheat with soya in a tight cropping schedule, and yet with only limited labour available to meet peak demands at harvest/sowing times. No-tillage techniques are the answer to the situation, and farmers, co-operatives, local authorities and the suppliers of machinery and herbicides are co-operating in their development, with herbicide use following the North American pattern. Several hundreds of no-tillage seeders will be available in 1975, and the eventual treated area could total millions of hectares.

We thus have in the above countries, with a temperate/Mediterranean climate, an active scene of rapid development. What of the countries in the tropics and sub-tropics, where population pressures are high, and yet where crop production is limited by poor soil, climatic interference with cultivation, vigorous weed competition and low mechanical inputs? National motivations here are high and increasing, with elevated costs of imported mechanical equipment and fuel, and the need to reduce dependence on imported foods. On the other hand, in many cases, the personal motivation of the smaller farmer is low: he can exist at a subsistence level with traditional systems of agriculture, and even if he were to produce significantly greater quantities of food this achievement would need to be accompanied by improvements in marketing facilities before he could benefit.

Without a doubt all the cereals, row and vegetable crops he produces are susceptible to the use of reduced tillage methods. In Taiwan, mung beans and other crops have been directly sown into standing rice, without use of any herbicide. In Salvador, beans are sown directly into maize crops before harvest, after elimination of weeds by the directed inter-row spraying of paraquat. In Malaysia vegetables are repeatedly cropped on raised beds, with no cultivation but weeds kept under control by between-crop sprays of paraquat.

However, wet paddy is probably the tropical crop which comes most generally to mind as suitable for reduced tillage techniques for here, in many areas, the farmer faces a most formidable combination of vigorous weed growth and difficult soil conditions, with only limited mechanical or draught animal assistance. Japan has shown the way where, even with small farmers, the existence of local skills and finance complemented by the availability of alternative sources of employment, has led to the development of minimal tillage techniques in rice on a large scale (Brown & Quantrill, 1973). These Japanese techniques involve the pre-cultivation spraying of paraquat to kill over-wintering annual grasses, so facilitating cultivation and improving soil conditions at planting. Other useful developments involving the pre-planting application of paraquat or dalapon/paraquat sequential sprays have taken place in Malaysia and Ceylon (Mittra & Pieris, 1968; Seth et al, 1971), and from the Philippines Moomaw et al (1968) have pointed out that substantially more economic justification for the use of herbicidal chemicals in rice cultivation can be made if the chemical performs a part of the tillage requirement, in addition to its function as a simple herbicide. In these countries several scores of thousands of hectares of crop are currently planted using minimal tillage techniques, but development now seems to have "plateaued". Reasons for this are several: there is a limit to the degree to which individual small farmers can co-operate to obtain uniform irrigation and hence control their field operations. They have only limited funds for purchase of herbicides and spray equipment, and the sheer numbers of farmers involved impose major difficulties in the supply of materials and dissemination of technical advice (Lewis & Watson, 1972).

Possibilities also exist for the use of reduced tillage techniques in semi-wet and dry paddy. This is where, because of limitations on the area of land available for irrigation, it might be thought the greatest potential for development of the rice crop would lie. However, it is also where adverse soil conditions and weed growth present the greatest limitations, and where the leap from traditional to reduced tillage systems presents what may be an insurmountable obstacle to the farmer on his own. Glyphosate could be a very useful tool in this field, perhaps linked with a stale seedbed technique, because of its ability to control the perennial grasses which are such a problem. It could well be, however, that a revision of thinking is required in the cropping of these lands traditionally sown to dry rice, with paddy being concentrated in the truly irrigable areas, and these drier areas being used for other crops.

Minimal tillage techniques present the possibility of significantly raising the cropping intensity of the existing wet paddy areas in particular by conserving available water and by facilitating multi-cropping (Elias, 1969). If this can be accepted, and then implemented by proper organisation of the irrigation and cropping schedules of these areas, then perhaps the drier lands would be better cropped with maize, sorghum and others, taking advantage of no-till techniques developed elsewhere for these crops. Such a policy could only be brought about by government intervention: first by optimising cropping of the lowland wet paddy areas, by integrated systems such as those described by Smith (1974) supplemented by the use of minimal tillage techniques where appropriate, then by introducing appropriate cropping schedules to the upland areas, with adequate mechanical, herbicide and crop inputs. One step in this latter direction has been observed in Ecuador, where small farmers growing cotton with only the minimum of equipment available, have organised co-operatively the pre-plant spraying of their land with paraquat using helicopters. After spraying, the cotton is hand planted and then subsequently kept free of weeds by directed inter-row application of paraquat. Such a technique needs refinement to obtain optimum efficiency. However, the farmers had a motivation in that cotton was the only large scale crop they could grow, they had little mechanical assistance to help, and together they devised a no-tillage method of overcoming their problems.

Suggestions have been made in Africa for the use of minimal tillage techniques in dry land cropping (Gordon, 1968) and increasing interest in this subject is reflected in a recent detailed paper by Rockwood & Lal (1974). These authors have worked in Nigeria with a number of dry land crops using mulch tillage techniques, in which weeds are kept under control with paraquat and the soil surface maintained cool and moist by the mulch of dead plant material. Positive advantages have been quantified, among the more striking being a 40 times reduction in weed incidence in no-tillage plots compared with ploughed. This work lends confidence in the potential for this technique in the tropical environment, and is being extended to Ghana and Liberia.

With pressures now bearing down on countries, co-operatives and individual farmers to produce more crops, against counter pressures restricting the availability to them of mechanical inputs, one response must inevitably be towards the greater use of reduced tillage techniques. These techniques will not be developed easily, for conditions are not as in North America. Here there is a highly developed system of liaison between universities, state extension authorities, commercial organisations and highly motivated owner-farmers selling their crops for cash. These conditions do not generally pertain to the tropics, and the difficulties involved in developing these new techniques there should not be underestimated. In the first place those areas must be identified where the farmers have a direct motivation to see that minimal tillage techniques can be made to work. A detailed assessment of the field situation will then be required to determine which tillage/cropping system can be introduced, and finally a period of 2-3 years of development in the field must be expected before proven techniques will be ready for handing over to the farmer. For the programme to succeed, close liaison between the farmer, the agronomist, and the suppliers of herbicides and machinery must be established, and Governments must establish adequate credit and crop marketing facilities; as success offers an incentive to all, the difficulties should not be insurmountable.

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THE DEVELOPMENT OF THE WEED FLORA AFTER SEVERAL YEARS' DIRECT DRILLING IN CEREAL ROTATIONS ON DIFFERENT SOILS

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Summary In one 6-years and in four 4-years field trials the effects of the direct drilling method of sowing was tested under different climatic and soil conditions, in particular the development of the weed flora was studied in different crops in comparison to conventional ploughing. The "no ploughing" over several years and the periodical application of different herbicides (Bipyridyls, hormone herbicides and contact herbicides) has decreased the population of dicotyledon weed species on the direct drilling plots. On the contrary the population of grass weeds has increased. This paper highlights the different composition of the weed flora at the trial sites as a result of different planting methods. At all trial sites the very large increase in *Agropyron repens* after direct drilling in the cereal rotations caused a big decrease in yield.

INTRODUCTION

Different aspects of direct drilling as the most extreme possibility of minimum cultivation have been tested in the Federal Republic of Germany for several years in field trials (BACHTHALER 1967, 1971; BAEUMER et.al. 1971; CZERATZKI and RUHM 1971; DEBRUCK 1971; KAHNT 1969, 1972; MUSHTAQ 1973; SCHWERDTLE 1971 and TEUTEBERG 1971). Concerning the reaction of weeds within direct drilling of cereals, corn and beans there are only a few comprehensive experiments over several years (SCHWERDTLE and KOCH 1967, SCHWERDTLE 1971). In many experiments there are only passing references to weed species and their reaction to different field cultivation methods. In the field trials here described one lasting 6-years and four 4-years, the effects of direct drilling under different climate and soil conditions was tested. In particular the development of the weed flora was studied in different crops in comparison to conventional ploughing

Local conditions

Table 1

Soil conditions and rainfall at the experimental sites

place	soil texture	soil type	rainfall mm (average measures over many years)	highth above sea level m
Brandhof	loamy clay	pelosol	596	430
Duerrnhof	loamy clay	brown earth	568	345
Herbststadt	loamy clay	pelosol	549	290
Mantlach	clayey loam	rendzina	741	535
Untermaxfeld	moor	lowmoor	664	380

At the experimental site at Duerrnhof the stone fraction of the soil was 22 % and at Mantlach 26 %.

METHOD AND MATERIALS

The direct drilling at the experimental site at Brandhof was done for two years with a "Rotaseeder" manufactured by HOWARD-ROTAVATOR LTD., West Horndon/England. In the following years at Duerrnhof as well as at Herbstadt a one pass rotavating drilling combination made by EBERHARDT-Ulm/W-Germany was used. For the rendzina soil type at Mantlach and for the moor soil type at Untermaxfeld a three-disc-drill made by Nodet-Monterau/France was used.
At the experimental fields on mineral soils a maize cereal rotation was followed; at Untermaxfeld, on organic soil, a green crop cereal rotation was followed.
The plots planted with the direct drilling method were treated about one week before sowing, in autumn or spring, with 3 to 4 L/ha Paraquat (trade-formulation) to kill the vegetation. On the control plots the planting was done in the traditional way after ploughing in autumn. For controlling the dicotyledonous weeds in the cereals, hormone herbicides were used based on 2,4-D + MCPA, a preparation with the active ingredient Flurenol + MCPA, and a contact herbicide containing Dinoseb acetat. Against the strong growing Avena fatua in same trials a special post-emergence herbicide application Chlorphenpropmethyl was used. For the control of Agropyron repens, at same sites autumn spraying of stubbles with Dalapon was done for several years.

RESULTS

Development of the weed flora   In order to find out the in-

fluence of the planting method, on the weed flora in the different cultures, a detailed recording of the weed population was made at all stations before finishing the trials. As a result the weed covering rating after BRAUN-BLANQET (1954) for all weed species was recorded. Because of lack of space results of the listed weed plants are shown in an abbreviated way in the following tables 2 and 3.
The 3-4 years continuous cereal rotation where direct drilling was practised brought on average an increasing number of Agropyron repens (table 2) at three places with mineral soil cropped with wheat, springbarley and oats. After direct drilling, among annual grass weeds, Avena fatua increased in spring barley and particulary in oats. As far as the perennial broad-leaved weeds were concerned there was no difference due to the different planting methods. In contrast the drilling after conventional ploughing increased the annual broad-leaved weeds in the weed flora.

Table 2

Structure of the weed flora in the 4th experimental year
average results of three mineral soils
(Locations Duerrnhof, Herbstadt and Mantlach)

	winter wheat spring wheat		spring barley		oats	
	sown after ploughing	direct drilling	sown after ploughing	direct drilling	sown after ploughing	direct drilling
broad-leaved annual weeds	2	+	1	+	+	+
broad-leaved perennial weeds	+	+	+	+	1	1
annual grass weeds	+	+	+	1	1	2-3
perennial grass weeds (Agropyron repens)	1	3	+	2-3	1	2
number of weed species	16	16	17	13	16	13

The same tendency is partly seen in the experiment on moor soil (table 3). Here the increase of perennial broad-leaved weeds after direct drilling in maize and sugarbeet is remarkable. The very high population of annual grass weeds (Avena fatua and Poa annua) occurred only in sugarbeet.
For all weed species, the average of all trials with the cereal rotation showed that direct drilling gave a reduced number of weeds.
A comparison of the development of the different annual broad-leaved species in the weed cover, under the influence of different planting methods in the 4th and 6th experimental year at the Brandhof site showed only a noticable difference for a few species. Polygonum convolvulus, Stellaria media and Thlaspi arvense showed an increase in number on the continually ploughed plot with the increasing number of

years of the experiment for all crops. In comparison there was not an increased population on the plots after direct drilling. As far as the perennial broad-leaved weeds are concerned there was no essential change within these species. Within the grass weeds the average population of Avena fatua in the 5th and 6th trial year was decreased by a special herbicide use. In contrast the results for A. repens showed a significant increase when cropped with cereals and beans on the direct drilled plot.

Table 3

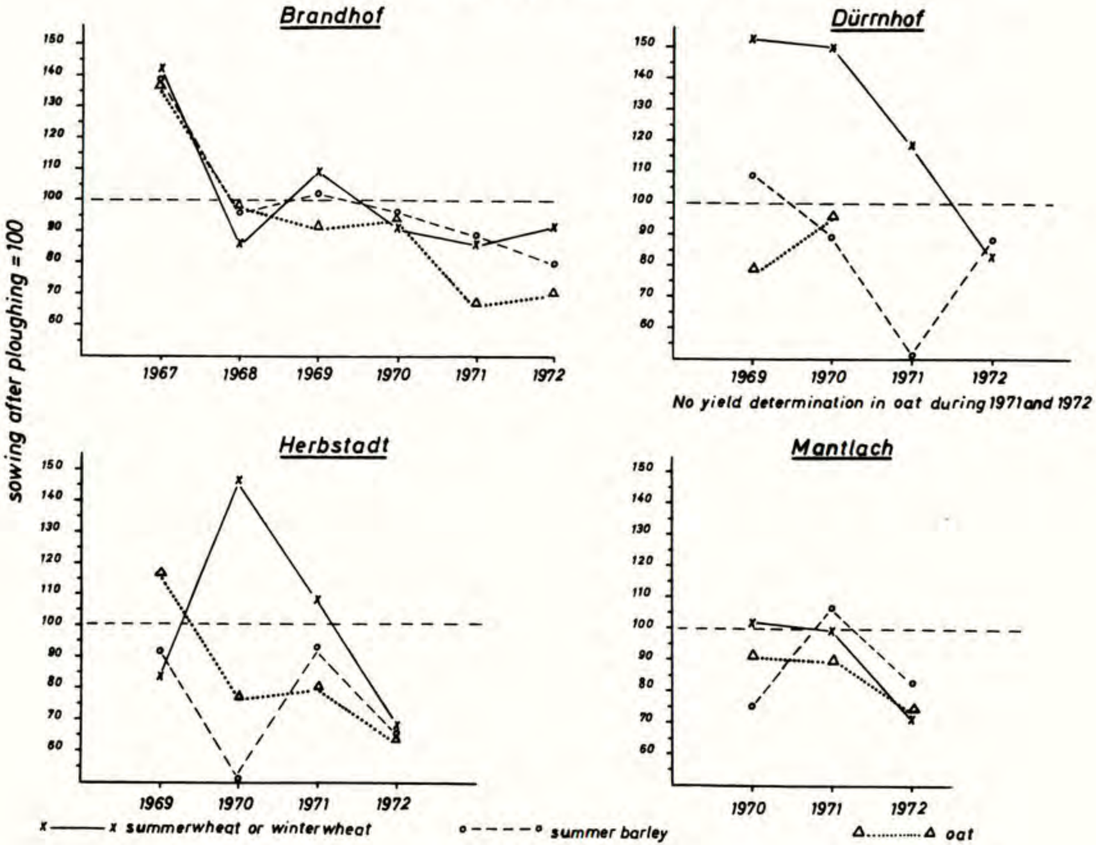
Structure of the weed flora in the 4th experimental year results on the moor soil (location Untermaxfeld)

	beans		corn		sugar-beet		rye		oats		wheat	
	I	II	I	II	I	II	I	II	I	II	I	II
broad-leaved annual weeds	1-2	+	+	1	+	1	1	1-2	1	+	1	1
broad-leaved perennial weeds	1	+	+	1	+	2	3	2	2	1	1	1
annual grass weeds	r	r	2	+	1	2	-	-	-	-	1	+
perennial grass weeds (A.repens)	+	5	+	4	-	1	-	4	1	5	+	4
number of weed species	14	11	19	17	11	25	14	10	12	7	14	15

Key: I = seed after ploughing; II = direct drilling
Suggest: % Weed Cover
+ = below 1 %
1 = 1-5 %
2 = 5 % - 25 %
3 = 25 % - 50 %
4 = 50 % +
r = single occurence only

Yield results During the 3-6 years, mainly decreased yields were recorded at all sites after direct drilling. Actually the yields at the four trial stations with mineral soil cropped with oats and spring barley were more unfavourable than when cropped with winter wheat and summer wheat. Almost in every case the 4th and 6th trial year gave the worst yield, though on the heavy loam- and clay-soils the first direct drilling sometime gave better results. This yield loss is closely related to the number of A. repens and A. fatua, present on the sites, and reflects the competition from the weeds which suppressed the development of the crops considerably (Fig. 1). The tendency to decreasing yields without ploughing at all places over many years, could not be corrected until an extra 50 % nitrogen was applied reflecting the severe competition of the weed flora in the direct drilled plots.

Fig.1 Yield (development) in cereals over a period of several years after direct drilling
4 locations with mineral soils



In autumn 1972 in all field experiments the direct drilled plot was ploughed in the same way as the control plot. The first step was an intensive chemical control of A. repens by application of sodium trichloracetate on the stubble followed by soil cultivation by rotovator. In spring 1973 mainly spring cereals and beans were cultivated.

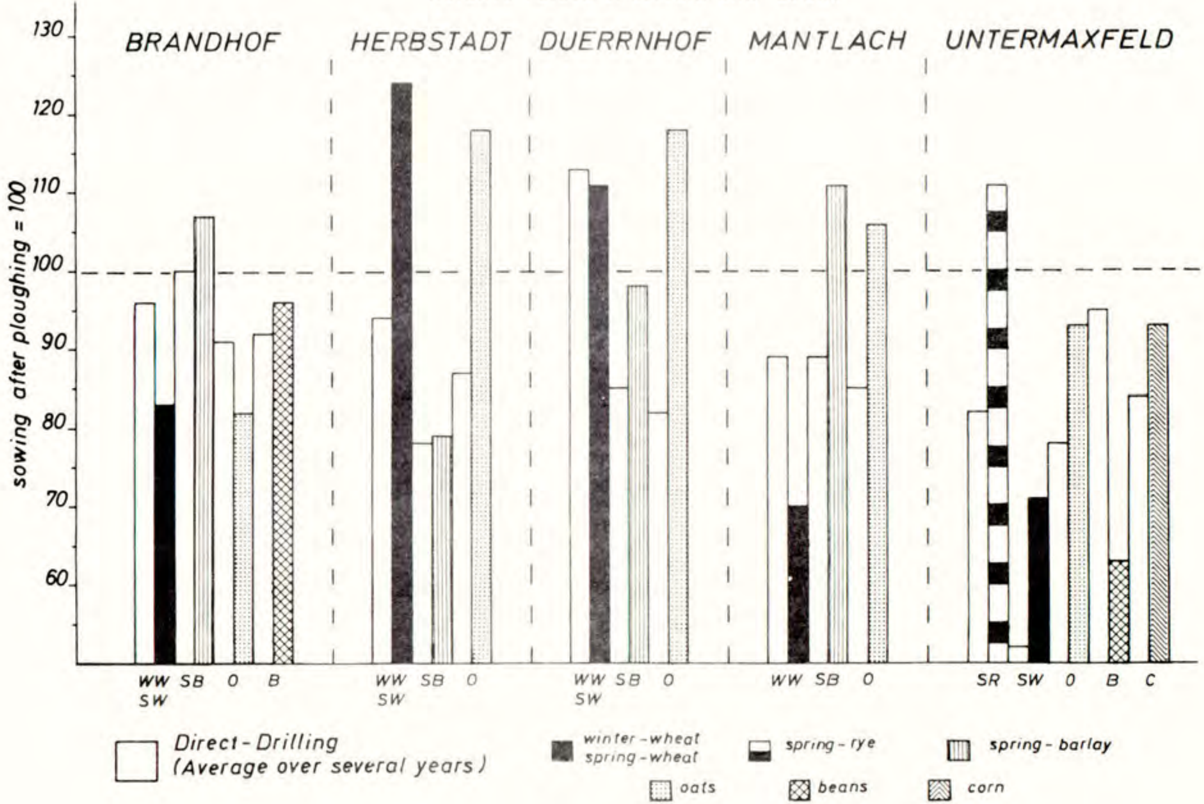
Figure 2 shows the average yield over several years of the direct drilled plots for cereals, beans and maize. The 1973 results on the same areas after the ploughing and A. repens treatment showed at all sites specially for spring barley and oats, a large increase in yield by one ploughing, which slightly surpassed the results from the continuously ploughed standard plots.

DISCUSSION

The results for annual broad-leaved weeds found in the majority of the trials after direct drilling for several years, in comparison to traditional field cultivation is confirmed by SCHWERDTLE (1971). KOCH (1969) found the germination of broad-leaved weed seeds is promoted by traditional soil cultivation.
Even though table 2 which showed the population of perennial broad-leaved weeds on the four mineral soils indicated no differences by planting method, the direct drilling for several years showdid a local increase in Convolvulus arvensis, Rumex crispus, Sonchus arvensis and Taraxacum officinale. However these species could be eliminated in the cereals by use of herbicides so that they need not decrease the yield. Only in beans after repeated direct drilling was a higher population of Taraxacum officinale, Cirsium arvense and Sonchus arvensis unfavourable for the development of the plants. An increasing weed population of perennial broad-leaved weeds in direct drilled areas after pre sowing-applications of Paraquat and Diquat is mentioned by DEBRUCK (1971) and TEUTEBERG (1971).
At the Duerrnhof, Herbstadt and Mantlach sites the direct drilling led to an increase in Avena fatua in the plots with spring cereals. Although in spring wheat and -barley a periodical postemergence-application with 6-8 L/ha of the Chlorphenpropmethyl (Bidisin) showed a satisfactory effect, the very large population of Avena fatua in the oat crop made necessary a premature cut as forage.
On buth the four mineral soils and on the moor soil the explosive multiplying of A. repens is seen as the main reason for the decreasing yields in cereals after direct drilling over several years. This agrees with the experimental results from CZERATZKI and RUHM (1971), KHANT (1971) and SCHWERDTLE (1971) who showed that the population of A. repens, after several years use of bipyridyl and hormone herbicides, was the limiting factor for continuous direct drilling in a cereal rotation.
The complete avoidance of soil cultivation in the direct drilling method has also prevented the effective control of A. repens by use of Sodium trichloracetate. The autumn application of 15 kg/ha Dalapon was insufficient. The lack of soil cultivation and the selective control of broad-leaved weeds by herbicides have encouraged the increase of A. repens. It is interesting to note that only the Brandhof site was completely free of A. repens at the start of the experiment. During the following three years direct drilling the increase of A. repens was small but in increased badly in the following experi-

Fig. 2 Yield after several years direct-drilling and ploughing at the end of the test-programmC

Relative values of cereals and beans



mental years.

After the 3-6 years experimental treatments the control with Sodium trichloracetate against A. repens, used in conjunction with ploughing, produced at all sites a large increase in the yield of cereals. Also affecting the trial results, it should be said that the use of the direct drilling machines caused a lower germination of seed. This was due partly to mechanical difficultes and partly to soil problems.

CONCLUSIONS

At 5 out of 6 trial sites the decrease in yield, caused by the large population of A. repens within the cereal rotation forced a premature stop to the direct drilling method. The omission of soil cultivation prevented the use of Sodium trichloracetate due to the risk to the following cereal. For the effective control of annual grass weeds and dicotyledonous weeds, additional to the presowing-application of bipyridyls it is always necessary to have a planned herbicide programme. After the current trial experiences in the Federal Republic of Germany, because of difficulties with the weed flora, minimal cultivation seems to be preferred method because it provided for the effective use of soil herbicides which require incorporation.

ACKNOWLEDGEMENTS

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PROTECTION OF WIND EROSION (MINIMUM CULTIVATION TECHNIQUES ON SOILS SUSCEPTIBLE TO BLOWING WHEN GROWING SUGARBEET, POTATO, ETC. IN RYE AS A COVER CROP

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Summary. A farming system to control wind erosion of soils and crops on arable farms on sand and reworked peaty podsol soils in the Netherlands is described. Sugarbeet, potato, maize etc. can be grown with less risk on these soils by using methods to diminish wind erosion. Methods of minimum cultivation, the use of a cover crop and of soil stabilizers are discussed.

Résumé. Pour prévenir l'érosion par le vent en sols susceptibles, des façons culturales sont développés pour un plan d'assolement avec 50% des pommes de terre et 25% des betteraves. En périodes sans culture principale une culture dérobée, le plus souvent du seigle, est sémée, qui peut être detruite chimiquement à tout moment que l'on vent. Avec un sémoir adapté des betteraves, du maïs, des haricots etc. sont semés directement dans le mulch vegètale... Aprés avoir éclaircit le seigle par un cultivateur à dents élastiques les pommes de terre sont plantés. Le seigle est détruit par pulvèration de Gramoxone, 4 à 5 l/ha, quand les premières plantes des pommes de terre viennent de se lever. Les traveaux du sol doivent être limités au minimum nécessaire.

INTRODUCTION

Erosion of land by wind has destroyed many hectares of agricultural land in the world. The measures which can be taken to control wind erosion depend on the crop te be grown, the cultivation methods to be carried out and on a number of other conditions. Van Dooren et al (1945), Woodruff et al (1972), Phillipsand Young (1973) described methods preventing wind erosion of soils in the U.S.A. Davies and Harrod (1970), Williams (1972) Davies et al (1972) have done so for conditions in England.

In the Netherlands approx. 10% of the 700.000 hectare of arable land is susceptible to blowing. Sand soils with an organic matter content of less than 7%, and reworked peaty podsol soils (R.P.P.-soils) with a content of less than 15%, are classified as blowing soils (KNOTTNERUS, 1971).
The factors which cause wind to be such a problem to these soils are for the Netherlands described by PEERLKAMP (1971) and KNOTTNERUS (1971). KNOTTNERUS and PEERLKAMP (1972) distinguish three kinds of soil blowing based on the coherence and on the size of the soil particles.

a. The finest and lightest particles, mostly organic material, form a dust cloud which may be carried for miles.
b. The middle-sized particles (minerals of 100-500 mu and aggragates of 180-1200 mu) jump and bounce just above the soil surface.
c. The larger particles roll along the soil surface.

The middle-sized particles are the greatest risk to growing plants. These jumping particles may have a damaging effect on plants, especially on the fresh parts. Small plants may be covered by soil and are often killed this way. Crops can be considered to be at risk until they have sufficient foliage to be self protecting.

At winds speeds of more than 8 meters per second at 10 meters above ground level, blowing may start on susceptible soils. In a short time tons of soil can be transported; at a wind speed of 10 m.p.s. 15 tons per hectare may be blown away, at a speed of 15 m.p.s. even up to 50 tons per hectare in one hour. In the most vulnerable period of the year, March to May, also seeds, fertilizer, herbicide and diseases may be removed and carried to adjoining fields. In autumn there is a blowing risk of bare soil.

The methods to diminish or avoid the effects of wind erosion include

- minimum cultivations techniques
- reduction of wind speed at the soil surface (wind breaks, cover crops, etc.)
- the use of soil stabilizers (artificial products, liquid manure)

The research carried out in the Netherlands include all three methods.

For economical reasons the cropping pattern of the arable farms on R.P.P. soils in the north eastern part of Holland is 50% potatoes for processing, 20% sugarbeet and 30% cereals. On the sand soil in the south-eastern part approx. 60% cereals, 10% potatoes for consumption, 15% sugarbeet and 15% maize for silage are grown. In both regions sugarbeet in general gives the best financial results; in the north followed by potatoes. Soil blowing however is one of the major hazards of the beet and maize crop and to a lesser content also of the potatoe crop.

METHODS AND MATERIALS

The work is carried out in a number of trials and experiments, also on a practical scale. Minimum cultivation techniques in relation to wind erosion are tested. Covercrops are used in strips as well as on the whole surface. Seed rate and sowing time are also tested. The optimum stage of destruction of the cover crop so that they provide the necessary shelter without reducing crop yield is determined. Existing machines are adapted to sow or plant the covercrop and the sugarbeet, maize, potatoe in the rye mulch.

The work started seven years ago by I.C.I. - Holland in conjunction with BAKERMANS of IBS[1]), PEERLKAMP and KNOTTNERUS of IB[2]) and TE VELDE and LUMKES of PA[3]). Also the extension service, farmers and machinery manufacturers are concerned in this project. The experiments in the field were supported by windtunnel work carries out by KNOTTNERUS (1973).

RESULTS

Minimum Cultivation

The careful selection of type and frequency of cultivations can be very effective in controlling winderosion.

In a rotation, in which every other year potatoes are grown, soilsterilization has to be carried out by law every fourth year. This process goes along with a deep cultivation.

Research on the frequency of cultivation on a soil susceptable to wind erosion, is now being carried out for four years in the rotation potatoe, cereals, potatoe, sugarbeet, potatoe etc. So far no differences in crop yield emerge at the objects ploughing every year, every other year, every fourth year and no ploughing but cultivating every fourth year. The differences in air content and other soil properties between the objects are small. There are no differences in weed vegetation. If possible shallow cultivation is carried out. The crop residues mixed with the toplayer of the soil reduce the risk of wind erosion. If a deep cultivation is necessary, for instance when soilsterilization has to be carried out, a tined implement is preferred. In this system rye is used as a crop to cover the soil during autumn and winter up to the next crop is sown. As far as possible the soil tillage and the broadcasting of rye are combined.

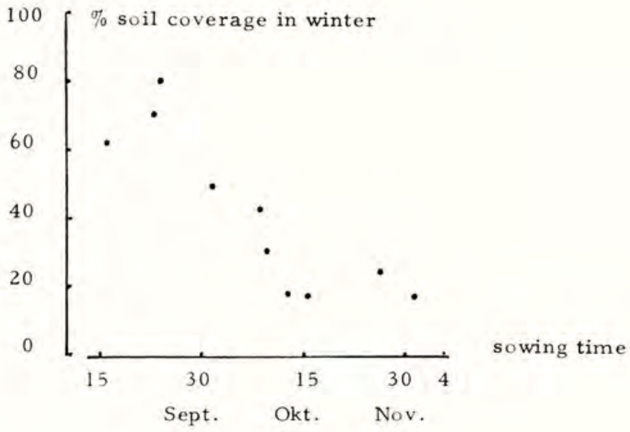
1) Institute for Biological and Chemical Research on Field Crops and Herbage
2) Institute for Soil Fertility
3) Research Station for Arable Farming

Reduction of wind speed by using a cover-crop.

Spring-cereals are not suitable as a cover-crop as they are killed by frost. Winter-rye is a better crop as winter-wheat or winter-barley in this system, as it grows faster in autumn and gives a better cover in spring.

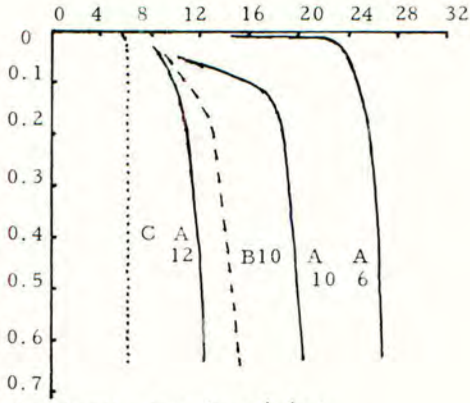
The windtunnel work by KNOTTNERUS (1973) suggests that soil blowing can still occur when the rye is sown in rows. The crop should therefore under Dutch conditions, preferably be broadcasted at 125 kg per ha before the middle of September. If sowing is delayed the seed rate should be increased up to 225 kg per ha in the first half of November. But the increased seed rate at the later sowing time will in general give less soil coverage in the winter than when using less seed at an early sowing date (fig. 1)

Figure 1. Percentage of soil coverage in winter and time of sowing rye.



In some cases very susceptible soils, for approx. 20% covered by the rye, did blow in the winter and many ryeplants were killed. The value of the soil coverage is also illustrated by windtunnel results of KNOTTNERUS (1973). Experiments carried out with plastic plants (simulating rye plants) of different height show that resistance to soil blowing not only depends on the soil coverage, but also on the height of the rye plants (fig. 2)

Figure 2. Relation between wind velocity and rate of soil loss for two heights different densities of a plastic model crop (simulating broadcast winter rye, KNOTTNERUS, 1973)



A = crop, height 8 - $8\frac{1}{2}$ cm
B = crop, height 5 - $5\frac{1}{2}$ cm
C = no crop, level dry loose sand
The numbers 6, 10 and 12 indicate spacing (cm) between neighbouring plants.

The last opportunity to carry out the main soil-tillage operation is before the broadcasting of the rye, when also the seedbed for the crop to be sown in spring should be prepared.

Which tillage-method is chosen, a flat seedbed for the rye should always be prepared. Rutty wheel tracks should therefore be avoided. The spring-crops should be drilled without any further tillage-operation to make a good use of the rye-mulch in preventing the soil from blowing. This is also a minimum cultivation technique because only a tillage operation is carried out in the autumn. To prevent fertilizer-application-wheelings the P and K must be given in the autumn before broadcasting rye or, if this is impossible, the fertilizer should be applied during winter on a frozen soil. Sprayer-wheelings are unavoidable, but the N is applied after the beet has been drilled in spring.
Direct drilling beet into the rye-mulch is carried out by existing machines adapted for this job.

The required modifications of the drill are
a. a disc coulter which is able to cut a slot through the mulch
b. a sharped drill coulter which can make a furrow of the right form and depth without smearing
c. a press-wheel to close the furrow without compacting the soil to much
d. the possibility to put weights on the front and on the back of each drill unit. The pressure springs often have less effect by sowing in a rye mulch in sand or in R.P.P. soil.
e. the ability of indepent working of each drill unit with separate weights to get the right working depth of each unit.

A rye-cover is also used to prevent blowing in potatoes. There is no worry about wheelings because the planting-bed is produced at the normal tine Before planting potatoes the rye is thinned out with a springtime cultivator to limit water withdrawal by the rye-plants. In one or two passes (cross-wise) a great deal of the rye is mixed with the soil and loose soil is formed in which potato-ridges can easely be prepared. After potato-planting the rye is allowed to grow away again to provide continuing blowing protection until approx. 50% of the tubers planted have emerged.

After plantings the rye mixed with the soil protects the soil. Dying plants stimulate the formation of a crust, even after potato-planting.

The modification introduced on the planting machine necessary to plant in the rye mulch are :

a. spring tine in front of the plant unit. The tine moves the rye plants away from the plant unit, so that it cannot disturb the planting process.
b. a press-wheel which goes over the middle of the ridge at the back of the plant unit. So the ridge is pressed somewhat to prevent the soil drying up to soon. The potato ridges are built up partly with planting.

If couch-grass (Agropyron repens) has to be controlled, rye is normally not used as a cover-crop. A system has been developed in which TCA is sprayed and immediately afterwards a cruciferous plant is drilled. Perko, a cross of tetraploid Chinese cabbage (Brassica campestris subsp. pekinensis) and tetraploid winterturniprape (Brassica campestris subsp. oleifera f.biennis), at a seed-rate of 10 kg/ha, may give good results if drilled in August of the beginning of September.

The method of preparing a seedbed for sugar-beet in March and drilling mustard which is killed-off by Betanal, is in a testing-stage. The drawback of this system is that the soil is left uncovered during the winter. It is likely that mustard will only be used when other systems have failed.

Killing-off the cover crop and weed control afterwards.

So far the best chemical to destroy rye is paraquat, trade name Gramoxone to which a wetting agent is added. To kill-off rye 4 litres per hectare of Gramoxone in 600 litres water is normally sufficient. In stages 5 to 7 (Feekes' scale) it is better to use 5 litres of Gramoxone per hectare. If the rye-plants are covered by soil or fertilizers, the effect is generally rather poor.
It is better to postpone spraying for a few days.

Time of spraying for beet, maize, peas and bean is being determined by the development of the reye; 3 to 5 days before drilling with a light crop, up to 4 to 6 weeks before drilling with a heavy crop. If the rye is rather small (stage 3-4) it may be killed-off after drilling but before emergence of the sugar-beet plants. The disadvantage is, that the rye-plants may then be covered by dust as an effect of the drilling operation.

The official recommendation for weed control in sugar-beet growing in a rye mulch are

a1. on light sandy soils with 4-5% humus 4 - 5 kg/ha Pyramin should be applied.
a2. on soil susceptible to drought and on sandy soils with 5% humus it is advised to use I.P.C., instead of Pyramin, in a rate according to the humus-content.
   5% 3-4 kg./ha I.P.C.
   6-8% 5-6 kg/ha I.P.C.
   8% 7 kg/ha I.P.C.
b1. after the emergence of the sugarbeet 6-7½ l/ha Betanal is practised
b2. after the mergence of the beet 6 l/ha Betanal + 2 kg/ha Pyramin is advised.
   If necessary an interrow sprayer should be used.
   In most cases method a2 and b2 is practised.

c. in fields with much camomile (Matricária Chamomilla) the application of 3-5 kg/ha Pyramin combined with 3 kg/ha I.P.C. directly after drilling the sugarbeet is recommanded.

If vegetables are grown, Gramoxone can be sprayed as with beet. Afterwards the normal chemical weed killing is practised.

Rye followed by maize can be killed-off up to 4 days before the emergence of the maize. The rye may have reached stage 7; the result of the Gramoxone-application may than leave something to be desired. Rye plants that are left will be destroyed by the Atrazin-application in maize.

The rye in a potatoe crop is sprayed off with 4 l/ ha Gramoxone when approx 50% of the tubers planted have emerged. This application also deals with germinated weeds and the overground portion of the couch-grass. No further chemical weed control is practised. The ridges are build up in one or two passes, which will also control weeds.

A cruciferus cover crop e.g. Perko, is killed off by diquat ; trade name Reglone, to which a wetting agent is added. 4 l/ ha Reglone, and 3 l/ ha of the wetting agent Citowet in 600 l/ ha wateris normally sufficient. It is sprayed approx. 2 weeks before drilling the beet crop.

Soil stabilizers

A few large scale trials were carried out with soil stabilizers. The industry produce materials which will bind the soil surface against movement of high velocity winds. In the trials strip stabilizing and stabilizing the whole surface was carried out. One of the disadvantages of this system in the trials was, that heavy rainfall disturbed the layer in such a way that blowing could not any longer be prevented.

None of the stabilizers used in the trials was regarded as effective as the use of a rye cover in conditions where blowing protection is needed from October to the beginning of June. Some of the stabilizers were only effective at rates which would be uneconomic.

Also liquid manure will bind the soil surface, 20 to 30 ton/ ha is sprayed soon after drilling or planting. However after heavy rainfall this cheap material can only prevent blowing for a short time. This method is practised on a large scale on mixed farms. If there is a surplus, manure may also be incorporated into the soil before sowing.

DISCUSSION

The system of using a cover crop to protect the soil from blowing has now been accepted by farmers on a rather large scale. Using the temporary shelter of a rye cover crop is a cheap and effective method of reducing the damage caused by wind erosion. The costs are on average ƒ 250,-- per hectare higher than with the traditional system. However depending on the following crop the number of passes are reduced, the cost of which should be deducted. The great advantage of this new farming system is that if it is carried out properly, the blowing risk is avoided and no damage, often followed by re-drilling the crop, will occur. The costs of re-drilling and yield reduction are as much as ƒ 400,-- per hectare and for sugarbeet even higher. The costs of soil deterioration, loss of organic matter etc., are not counted.

Yields of the crops are in general at least at the same level, but in many cases higher as a result of preventing the soils from blowing. The system is therefore of high value to arable farming on soils susceptible to blowing.

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WEED CONTROL IN LETTUCE ON ORGANIC SOIL

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Summary The results of trials carried out on fen peat during 1971 - 73 showed that the application of paraquat in combination with the standard pre-emergence herbicides to a stale seed bed gave excellent weed control compared with standard herbicides applied to a fresh seed bed. The most effective combinations with paraquat were propyzamide at 2.2 kg + sulfallate at 4.4 kg and chlorpropham at 3.3 kg + sulfallate at 4.4 kg. Propyzamide at 1.1 kg + sulfallate at 2.2 kg applied post-emergence in 90 l/ha synthetic oil provided more prolonged weed control than propyzamide at 4.4 kg + sulfallate at 4.4 kg in 450 l water.

INTRODUCTION

Due to its habit of growth lettuce is among the least competitive of vegetable crops and one of the major limiting factors for the successful production of this crop on peat soil is weed control. In preliminary trials carried out on peat soil at Lullymore in 1969 and 1970 propyzamide and chlorpropham gave promising results (MacNaeidhe & Cassidy, 1970). Propyzamide had the added advantage of being highly selective when applied as a post-emergence spray. These materials however, had a relatively short lived period of residual activity and the spectrum of weed control was small. In trials carried out from 1971 - 1973 an attempt was made to widen the spectrum of weed control using these materials on a stale seed bed in combination with paraquat and sulfallate. To provide more prolonged weed control the effectiveness of post-emergence applications of propyzamide/sulfallate and chlorpropham/sulfallate mixtures was also investigated.

METHOD AND MATERIALS

All experiments were carried out on fen peat at the Lullymore Peatland Experimental Station. In the 1972 and 1973 pre-emergence trials a split plot design was used. In the remaining trials a randomized block design with 5 replications and a standard plot size of 4.6 m x 1.8 m was used. Herbicides were applied in a volume of 450 l/ha water carrier. Some of the treatments in 1971 and 1972 were applied in 90 l/ha TVO or 90 l/ha of a crop tolerant synthetic oil (No 3408). All doses are given in kg/ha a.i. Weed density was recorded either by counts from whole plots or from 6 x 0.3 m^2 random quadrats per plot. Assessments of crop and weed growth were made regularly during the growing season. The standard 1 - 10 rating was used in 1971. The European Weed Control Council (ERWC) rating scale was used in 1972 and 1973. The crop was drilled in early June in 1971 and 1973 and in the second week of July in 1972.

RESULTS

Pre-emergence application - 1971 The effectiveness of paraquat at 0.6 kg applied pre-emergence in combination with propyzamide and a propyzamide/sulfallate mixture to a seed bed prepared 3 weeks in advance of sowing was tested. None of the treatments applied caused crop damage. The main weed species in the trial were *S. media*, *P. annua* and *S. vulgaris*.

The weeds were in the 4 - 6 true leaf stage at the time of spraying. Chlorpropham at 6.6 kg in TVO 90 l gave good control of *S. media* but failed to control *P. annua* and *S. vulgaris*. Paraquat at 0.6 kg gave excellent control of *S. media* but seedlings of *P. annua* and *S. vulgaris* began to emerge in the plots treated with this herbicide two weeks later. Paraquat at 0.6 kg + propyzamide at 2.2 kg + sulfallate at 4.4 kg gave excellent control of *S. media* and *P. annua* (Table 1). Paraquat at 0.6 kg + propyzamide at 2.2 kg was slightly less effective against these weed species. None of the treatments applied gave satisfactory control of *S. vulgaris*. Seeds of this species were carried into the trial area by wind and these emerged 2 - 3 weeks after the sprays were applied.

In 1972 and 1973 the effectiveness of a number of herbicides applied in combination with paraquat to a seedbed prepared 3 weeks prior to sowing was compared with the effectiveness of these herbicides applied to a freshly prepared seedbed without paraquat.

Table 1

The effect of pre-emergence herbicide application on weeds and crop - lettuce 1971

Treatment	Dose kg/ha	Carrier	Plant stand as % of control	Assessments Crop	Assessments Weeds	% Weed kill SV	% Weed kill PA	% Weed kill SM
*Paraquat	0.6	Water 450 l	115	10.0	9.9	62	67	98
*Paraquat + Propyzamide	0.6 2.2	" " "	127	10.0	9.9	69	89	91
*Paraquat + Propyzamide + Sulfallate	0.6 2.2 4.4	" " "	130	10.0	10.0	79	94	99
Chlorpropham	6.6	TVO 90 l	109	10.0	3.7	0	41	89
Control			100	10.0	4.3	0	0	0
Weed No/ft^2 in control plots						5	19	7
S.E. of treatment mean (df = 30)			9.2					

Rating scale : Crop : 0 (complete kill) - 10 (no damage)
Weeds : 0 (dense cover of weeds)- 10 (no weeds)

*Application to a stale seedbed prepared 3 weeks in advance of sowing

SV = *Senecio vulgaris*. PA = *P. annua*. SM = *Stellaria media*.

Pre-emergence application - 1972 The herbicides were applied 4 days after sowing. The crop emerged on the following day but the plant stand was reduced in the stale seedbed (Table 2). No reduction in crop vigour occurred. The plots treated with paraquat remained weed free for a period of 2 - 3 weeks after spraying.
Propyzamide at 2.2 kg + sulfallate at 4.4 kg, sulfallate at 4.4 kg + chlorpropham at 3.3 kg and sulfallate at 8.8 kg gave good control of *S. media*, *S. vulgaris* and *P. annua* in the stale seed bed. Propyzamide at 2.2 kg was only slightly less

effective against these weeds. Sulfallate at 4.4 kg gave good control of S. vulgaris and P. annua but poor control of S. media. Propyzamide at 1.1 kg gave satisfactory control only of P. annua.

Chlorpropham at 3.3 kg gave good control of S. media and P. annua but was less effective against S. vulgaris. The 9.9 kg dose of this chemical gave more effective control of S. media but did not give improved control of the other two species.

In the freshly prepared seedbed weed emergence occurred in the control plots 7 days after spraying. Chlorpropham at 9.9 kg gave excellent control of S. media. Although chlorpropham at 3.3 kg + sulfallate at 4.4 kg gave good initial control of this weed, further seedlings emerged 5 weeks after the application of this mixture. Sulfallate at 8.8 kg gave good control of S. vulgaris but poor control of P. annua and S. media.

Table 2

Effect of pre-emergence herbicide application on weeds and crop - lettuce 1972

Treatment	Dose kg/ha	Plant stand % control		Assessments				% Weed kill					
				Crop		Weeds		SM		PA		SV	
		Fresh	Stale	F	S	F	S	F	S	F	S	F	S
Propyzamide	1.1	96	79	1	1	6	2	0	78	54	87	17	29
"	2.2	100	82	1	1	6	2	0	90	77	90	39	84
Chlorpropham	3.3	88	80	1	1	5	2	81	94	50	89	20	79
"	9.9	107	80	1	1	5	2	98	99	51	87	39	79
Sulfallate	4.4	88	84	1	1	6	2	0	74	48	90	57	91
"	8.8	95	66	1	1	5	1	75	97	70	93	89	93
Sulfallate + Propyzamide	4.4 2.2	101	80	1	1	4	1	76	98	83	96	50	90
Sulfallate + Chlorpropham	4.4 3.3	108	83	1	1	5	1	85	99	71	93	66	90
Control		100	75	1	1	61	1	0	83	0	81	0	75
Weed No/ft^2 in control plots								7		9		8	

S.E. of treatment mean:
(a) Treatments (df = 24) 7.5
(b) Fresh v stale (df = 27) 0.4

Rating Scale : Crop : 1 (no damage) - 9 (complete kill)
Weeds : 1 (no weeds) - 9 (dense cover of weeds)

F = Fresh seedbed. S = Stale seedbed.

Pre-emergence application - 1973 The herbicides were applied one day after sowing and the crop emerged 4 days later. No reduction in crop stand occurred but the vigour was reduced in plots treated with paraquat following heavy rainfall which occurred 12 days after application. The crop was fully recovered 6 weeks later and the number of marketable heads per plot was unaffected (Table 3).

The main weeds in the trial were S. media and P. annua. Of the herbicides applied in combination with paraquat at 0.6 kg, chlorpropham at 9.9 kg and chlorpropham at 3.3 kg + sulfallate at 4.4 kg gave excellent control of S. media. Propyzamide at 2.2 kg + sulfallate at 4.4 kg also gave good control of this weed but the control provided by propyzamide at 2.2 kg, sulfallate at 4.4 kg and

Table 3

Effect of pre-emergence herbicides application on weeds and crop - lettuce 1973

Treatment	Dose kg/ha	Wt. of thinnings (kg) F	Wt. of thinnings (kg) S	Number of marketable heads/plot F	Number of marketable heads/plot S	Assessments Crop F	Assessments Crop S	Assessments Weeds F	Assessments Weeds S	% Weed kill SM F	% Weed kill SM S	% Weed kill PA F	% Weed kill PA S
Propyzamide	2.2	2.6	3.0	55	56	4	3	8	6	41	75	63	78
Sulfallate	4.4	2.3	1.9	55	57	5	5	9	7	3	45	53	79
Sulfallate	8.8	2.7	1.6	55	56	5	6	8	7	32	69	51	84
Propyzamide + Sulfallate	4.4 + 4.4	2.4	1.8	54	56	4	5	7	6	60	83	59	76
Sulfallate + Chlorpropham	4.4 + 3.3	2.0	2.6	56	57	4	4	6	5	78	92	68	77
Chlorpropham	3.3	2.0	2.6	55	54	4	5	7	7	51	78	18	71
Chlorpropham	9.9	2.9	3.2	55	56	3	5	7	6	95	100	61	72
Propyzamide + Glyphosate	2.2 + 2.2	2.7	1.5	55	56	4	6	7	6	64	67	42	84
Propyzamide + Glyphosate	2.2 + 4.4	3.0	1.5	55	56	5	6	7	5	44	85	36	82
Control		3.5	2.6	55	54	4	6	9	8	0	59	0	68
Weed No/ft^2 in control plots										2		3	
S.E. of treatment mean													
(a) Treatments (df = 27)		0.5		0.9									
(b) Fresh x stale (df = 30)		0.4		0.6									

Rating Scale : as in Table 2.

*Glyphosate applied to stale seed bed instead of paraquat.

S = Stale seed bed. F = Fresh seed bed.

chlorpropham at 3.3 kg was unsatisfactory.

Glyphosate at 2.2 kg used in combination with propyzamide instead of paraquat gave moderate control of S. media and good control of P. annua. Glyphosate at 4.4 kg + propyzamide at 2.2 kg gave good control of S. media and P. annua.

Of the herbicides applied to the freshly cultivated seed bed only chlorpropham at 9.9 kg gave satisfactory control of S. media. All the herbicides applied gave poor control of P. annua.

Post-emergence application - 1972 Propyzamide at 2.2 kg was applied pre-emergence to the trial area. The post-emergence herbicides were applied at the 5-true leaf stage of the crop. The use of oil as a carrier caused wilting of the lettuce leaf margins. The wilting was more severe in plots treated with the sulfallate/chlorpropham mixture but the crop had fully recovered two days after application in all cases. The main weed species S. media, P. annua and S. vulgaris were in the 4 - 5 true leaf stage at the time of spraying. Propyzamide at 1.1 kg + sulfallate at 2.2 kg applied in oil gave good control of S. media (Table 4). This mixture gave only a moderate kill of P. annua and S. vulgaris but caused severe stunting in both species and only a few plants of S. vulgaris had regained full vigour when the crop was harvested. Less weeds were killed with sulfallate at 2.2 kg + chlorpropham at 3.3 kg in oil but severe stunting of all three weed species occurred. Propyzamide at 1.1 kg and sulfallate at 2.2 kg in oil and propyzamide at 1.1 kg in water gave unsatisfactory weed control.

Table 4

The effect of post-emergence herbicide application in lettuce - 1972

Treatment	Dose kg/ha	Carrier	Assessments Crop	Weeds	% Weed kill SM	PA	SV
Sulfallate	2.2	Oil 90 l	1	6	17	26	77
Propyzamide	1.1	" " "	1	4	71	53	65
Propyzamide + Sulfallate	2.2 1.1	" " "	1	4	87	56	75
Propyzamide + Chlorpropham	2.2 3.3	" " "	1	4	69	31	79
Propyzamide	1.0	Water 450 l	1	5	43	46	54
Control			1	6	0	0	0
Weed No/ft^2 in control plots			-		2	6	2

Rating scale : as in Table 2.

Post-emergence application - 1973 The seed bed was prepared 3 weeks in advance of sowing and paraquat at 0.6 kg was applied pre-emergence. The herbicides applied at the 6 true leaf stage of the crop were highly selective (Table 5).

S. media and S. vulgaris had emerged shortly after the paraquat spray and were in the 4 to 8 true leaf stage when the post-emergence treatments were applied. P. annua was in the 1 to 5 true leaf stage.

Propyzamide at 2.2 kg, sulfallate at 8.8 kg and propyzamide at 2.2 kg + sulfallate at 4.4 kg gave good control of P. annua but further emergence of this weed occurred after two weeks. Propyzamide at 2.2 kg + sulfallate at 4.4 kg gave excellent control of S. media. Propyzamide at 2.2 kg and sulfallate at 8.8 kg also gave good control of this weed. Only sulfallate at 8.8 kg gave good control of S. vulgaris.

Table 5

Effect of post-emergence herbicide application on weeds and crop - lettuce 1973

Treatment	Dose kg/ha	Yield Marketable heads/plot	Assessments 21/8/73 Crop	Weeds	% Weed kill 2/8/73 SM	PA	SV
Propyzamide	2.2	55	4	7	89	56	0
Propyzamide + Sulfallate	2.2 4.4	55	4	7	100	42	68
Sulfallate	4.4	54	4	8	72	25	60
Sulfallate	8.8	54	4	7	87	60	86
Control		54	5	8	0	0	0
Weed No/ft^2					5	3	3
S.E. of treatment mean (df = 12)		0.4					

Rating Scale: as in Table 2

DISCUSSION

The weed control obtained with the pre-emergence application of paraquat in combination with the standard herbicides to a seed bed prepared three weeks in advance of sowing was superior to that obtained with application of these herbicides to a freshly prepared seedbed. This technique is most effective against weeds with a flush type emergence pattern. In 1971 and 1972 S. media emerged in a definite flush and was well controlled by the paraquat but in 1973 a period of heavy rain occurred four weeks after spraying and a new flush of S. media emerged shortly afterwards. On the other hand the emergence of P. annua was more gradual in all three seasons and with the exception of 1972 when the trial was carried out late in the season, was not well controlled. Although S. vulgaris has a flush pattern similar to S. media and the first generation was well controlled, more seeds of this weed were blown into the trial area giving rise to further flushes in July and August. Plots with a dense weed cover were protected against the fresh infestation and the numbers of seedlings emerging were highest in the plots with the least weeds.

In 1972 the paraquat was applied one day prior to crop emergence and the crop stand was reduced by 25%. The paraquat was applied immediately after sowing in 1973, and the vigour of the crop was noticably reduced. The depth of sowing in 1972 and 1973 was 1.0 cm. In 1971 the paraquat was applied immediately after sowing. The depth of sowing was 1.5 cm and although heavy rain occurred after application no crop damage occurred. Trials carried out under glass showed that doses of from 0.6 - 6.6 kg of paraquat penetrated to a depth of only 0.5 mm in peat after the application of 40 mm irrigation. Approximately 96% of the applied paraquat was adsorbed a few days after application (MacNaeidhe, 1973). Due to the greater availability of moisture emergence is more even and growth is more rapid in freshly cultivated peat. In summer the surface 3 cm of the seedbed becomes progressively more dry with time and the crop injury which occurred in 1972 and

1973 was most likely, due to the dry conditions in the stale seedbed than to the application of the paraquat.

Glyphosate at 2.2 kg applied instead of paraquat to the stale seedbed gave equally effective results. Trials carried out under controlled conditions showed that this chemical was less persistent than paraquat in the peat and caused less growth inhibition in lettuce (MacNaeidhe, 1973). This material has the added advantage of being more effective against perennial weeds. In the 1971 and 1973 trials propyzamide had a definite advantage over chlorpropham because of the more effective control of P. annua. These materials were highly effective against S. media but gave poor control of S. vulgaris.

In 1972 however, the trial was carried out late in the season. The majority of the Poa seedlings emerged simultaneously and the superior residual activity of the propyzamide was not so evident due to the good kill obtained with the paraquat.

Sulfallate at 4.4 kg gave consistently good control of S. vulgaris but the residual activity of this herbicide was short lived and the tendency of S. vulgaris to recolonize weed free areas in late summer greatly reduced its effectiveness. Sulfallate at 8.8 kg was highly effective against P. annua but the selectivity of this high dose when applied pre-emergence was only marginal.

With the stale seedbed, the use of sulfallate in combination with propyzamide or chlorpropham successfully widened the spectrum of weeds controlled to include S. vulgaris. These mixtures gave the most effective weed control and also showed good crop selectivity.

In the post-emergence trials sulfallate at 8.8 kg gave good control of S. media and S. vulgaris. The standard propyzamide/sulfallate mixture gave more effective control of S. media but the control of S. vulgaris was unsatisfactory. Although this mixture applied at half the standard dose in 90 l/ha of the crop tolerant synthetic oil gave a somewhat similar overall kill, the injury to the remaining weeds was more severe and competition with the crop was reduced to a minimum up to the time of harvesting.

The results in this paper provide a suitable basis for an effective weed control programme in lettuce in peat soil. The pre-emergence application of paraquat in combination with the propyzamide/sulfallate mixture has given good weed control in the stale seedbed. Further investigation are needed on the post-emergence application of the propyzamide/sulfallate mixture.

Acknowledgements

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NEW USES OF TRIFLURALIN IN VEGETABLE CROPS

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Summary Advances in mechanical harvesting and the increasing use of 'bed' systems in the growing of certain vegetable crops, has lead to an increasing need for more reliable and improved weed control. Many herbicides, especially during the last two to three years, have lost activity due to the dry conditions and the late sowing of crops: Phaseolus vulgaris varieties have especially suffered in this respect.

During the last three years, replicated trials have been carried out in carrots, parsnips, dwarf French and navy beans, where herbicide programmes based on trifluralin, have been examined for reliability and weed control.

Trifluralin at 1.0 lb a.i./ac followed by linuron at 0.5 lb a.i./ac, or metoxuron at 3.2 lb a.i./ac has given improved weed control in carrots and parsnips over linuron or metoxuron alone where adverse conditions or tolerant weeds were found. Similarly trifluralin at 0.75 lb a.i./ac followed by bentazone at 1.26 or 0.9 lb a.i./ac or dinoseb acetate plus monlinuron at 4.0 lbs formulated product per acre has given excellent results in dwarf French and navy beans.

INTRODUCTION

Trifluralin has now been used commercially in the United Kingdom for seven years, and its early development for use on animal feed and human food brassica crops is well recorded; Tyson and Smith (1966), Lawson (1968), Bartlett, Handy and Darge (1970).

The increased use of mechanical harvesters and the modified growing techniques associated with them, has increased the need for improved weed control in certain vegetable crops. Many of the herbicides at present used on these crops, particularly in carrots, parsnips and Phaseolus vulgaris have proved unreliable in the dry conditions of the last few seasons, and have not controlled some species of Polygonum and Veronica and certain other annual weeds.

Because of three important tolerant weeds, Capsella bursa-pastoris, Matricaria spp. and Senecio vulgaris, trifluralin does not provide sufficient weed control when used alone. However, because it requires incorporation and is reliable under most climatic conditions, and because it controls the weeds tolerant to other compounds, trifluralin forms an ideal base on which to build a weed control programme.

Trials during the last three years have examined the use of trifluralin in herbicide programmes with linuron, metoxuron and chlorbromuron on carrots and parsnips, and with bentazone and dinoseb acetate plus monolinuron on dwarf French and navy beans.

METHOD AND MATERIALS

Experiments were of a randomized block design with four replications and an average plot size of 15 yd^2. Nearly all the trials were situated within commercial crops and applications were made with a van der Weij propane sprayer fitted with Teejet fan nozzles. All doses are expressed in lb a.i./ac, and were applied in 30 gallons of water per acre. Formulations used were:

carrots and parsnips	- trifluralin 48% e.c., linuron 50% w.p., metoxuron 80% w.p., Chlorbromuron 50% w.p.
dwarf French and navy beans	- trifluralin 48% e.c., bentazone 48% a.s., dinoseb acetate plus monolinuron 50% w.p.

Trifluralin treatments were incorporated before drilling (ppi) by a hand rotovator to a depth of 2-3 inches. Pre-emergence (pre-em) and post-emergence (post-em) treatments were all applied at the recommended stage.

Trials were assessed for emergence, crop vigour, weed control at different stages and some for yield. Yield figures were taken by hand lifting 3 x 6 feet lengths of row and weighing the roots or pods obtained.

Crop stand figures were obtained by counting the number of emerged plants in 2 x 5 yards of row. The crop vigour ratings were taken by assessing the crop on a 0-10 scale where 10 represented the vigour of the best plot. Weed control in all trials was assessed using the Barratt-Horsfall rating system (Barratt and Horsfall 1945, and Brown et. al. 1966) and the data are expressed as percentage of controls. Where possible the level of weeds in the non-weeded control plots is given underneath in brackets. The means in the tables followed by the same letters are not different at the 5% significance level according to Duncan's Multiple Range Test.

Samples of carrots, parsnips and beans have been submitted for taint testing and residue analysis, and further samples are being taken from this year's trials.

Specific information for all trials is given below:

<u>Carrots and Parsnips</u>

Year	Code	Location	Soil	Variety
1972	GB72-4	Holbeach	Silt loam	Amsterdam
1972	GB72-6	Godalming	Sandy loam	Ideal
1973	GB73-13	Godalming	Sandy loam	Ideal

Dwarf French Beans

Year	Code	Location	Soil	Variety
1974	GB74-9	St. Germains	Clay loam	Blue Bush Lake
1974	GB74-10	Hollesley	Loamy clay	Tenderette
1974	GB74-11	Goldhanger	Clay loam	Provider
1974	GB74-19	Shripney	Sandy loam	Provider

Navy Beans

1974	GB74-13	Chislet	Sandy loam	Purley King

RESULTS

Carrots

Linuron when applied alone at 0.75 lb/ac on a sandy loam soil in GB72-6 was the only treatment to significantly reduce emergence and vigour of the crop (Table 1). Trifluralin at 1 or 2 lb/ac showed no adverse effect. Neither did any of the combination treatments of trifluralin and linuron except one treatment in GB72-4, and the 1.0 + 0.75 lb/ac treatment in GB72-6 where 0.75 lb/ac of linuron alone had affected the crop. The drop in vigour of the metoxuron and control treatments in GB73-13, shown in Table 1, was due to weed competition as the carrots were delayed by a cold spell in May, and a high weed infestation (49%) developed before the metoxuron could be applied at the three true leaf stage.

Where *Matricaria* spp., *Capsella bursa-pastoris* and *Senecio vulgaris* were present in fairly large numbers, which was particularly evident in the intensive horticultural areas in GB72-4, 6 and 13, trifluralin alone gave very poor control, but where these were not the predominant species control was good.

Consistently good and almost complete weed control was obtained with a programme of trifluralin at 1.0 lb/ac followed by linuron at 0.5 lb/ac applied pre-emergence. A combination with linuron applied post-emergence at the same rate in other trials also worked well, but did not give as complete control of *Matricaria* spp. as the pre-emergence treatment.

The combination treatment of trifluralin plus metoxuron gave equivalent weed control to the trifluralin-linuron treatments, even when the amount of metoxuron was reduced to 2.4 and 1.6 lb/ac. With this particular combination, competition from trifluralin tolerant weeds appeared to reduce the crop where the growth of the carrots was held back by cold weather and the application of the metoxuron had to be delayed.

In experiments GB72-6 and GB73-13 the weed spectrum was such that all weeds were susceptible to one application of linuron at 0.75 lb/ac, and control was equivalent to the trifluralin-linuron combination. At the East Anglian site (GB72-4) and in other trials however, even two applications of linuron at 0.5 lb/ac gave poor weed control due to the presence of *Fumaria officinalis*, *Polygonum aviculare*, *Veronica* spp. and *Polygonum convolvulus*.

TABLE 1

Crop vigour ratings and percent weed control in experiments where carrots were treated with trifluralin, alone and in combination with linuron and metoxuron

	Treatment and dosage 1/ (lb a.i./ac)	Crop vigour rating 2/			% weed control		
		GB72-4	GB72-6	GB73-13	GB72-4	GB72-6	GB73-13
1.	trifluralin 1.0	9.5 abc	9.8 a	9.5 ab	0 abc	4 bc	2a
2.	trifluralin 2.0	9.8 ab	9.3 a	-	58 bcd	20 e	-
3.	trifluralin 0.75 + linuron 0.5	8.8 d	8.8 a	10.0 a	85 d	98 f	81 de
4.	trifluralin 1.0 + linuron 0.5	9.3 bcd	8.5 a	-	89 de	98 f	-
5.	trifluralin 1.0 + linuron 0.75	9.8 ab	7.7 b	-	88 d	100 f	-
6.	trifluralin 1.0 + metoxuron 3.2	9.5 abc	-	-	94 e	-	-
7.	trifluralin 1.0 + metoxuron 2.4	-	-	9.3 abc	-	-	94 ef
8.	trifluralin 1.0 + metoxuron 1.6	9.8 ab	-	9.3 abc	89 de	-	92 ef
9.	linuron 0.5	10.0 a	6.5 b	9.0 abc	0 a	98 f	95 f
10.	metoxuron 3.2	9.8 ab	-	8.3 bc	65 cd	-	15 abc
11.	control 0.0	9.9 a	8.8 a	8.1 c	0 abc	0 a	0 a
	Coefficient of variation - %	4.44	10.4	9.3	44.4	96.7	22.2

1/ Trifluralin applied pre-plant incorporated, linuron pre-emergence and metoxuron post-emergence

2/ Crop vigour rating - mean result based on a 0-10 scale where 0 = death, 10 = vigour of best plot.

Metoxuron alone at 3.2 lb/ac gave good control of most weeds, but in GB72-4 Veronica agrestis was not controlled and Polygonum persicaria, which was 12 to 18 inches tall at application, was only partially controlled. In GB73-13 metoxuron controlled all the broadleaf weeds present, but gave only 14% control of a high infestation of annual grasses, probably due to the fact that the plants were beyond the susceptible stage when the metoxuron was applied.

Trials carried out on parsnips have given similar results to those shown here on carrots.

Dwarf French and navy beans

Crop emergence and vigour (Tables 2 and 3) were reduced by application of 1.5 lb/ac trifluralin in several of the trials on dwarf French beans, and although emergence was not significantly affected on navy beans, vigour was also reduced by the 1.5 lb/ac rate. At harvest the dwarf French bean plants were smaller, and the pods had curved due to the lack of growing space.

Conditions were overcast when bentazone was applied at the two to three trifoliate leaf stage, but temperatures were high (between 14 and 18^{o}C), and some scorching of the leaves still occurred, especially at the higher rate of 1.88 lb/ac. This rate, following 1.5 lb/ac trifluralin, also reduced general plant growth. Bentazone phytotoxicity was seen as yellowing of the leaf margins, but these symptoms disappeared in two to three weeks.

The weed control results from applications of trifluralin followed by bentazone or dinoseb acetate + monolinuron are shown in Table 4. Trifluralin alone did not give sufficient weed control, particularly where tolerant weeds were present as in GB74-9, 10, 13 and 19. Bentazone at 1.26 lb and dinoseb acetate plus monolinuron at the recommended rate gave good weed control where susceptible weeds were present, but did not control Veronica spp. or Polygonum aviculare, particularly in trials GB74-10 and 11. Dinoseb acetate plus monolinuron alone was particularly poor in GB74-9 and 12 where dry weather conditions prevailed for one to two weeks after planting.

Both navy beans and dwarf French beans were held back by dry weather in the spring, and bentazone could not be applied till mid-July when the plants had reached the correct leaf stage. By this time several of the weeds, particularly Chenopodium album and Urtica urens were quite large and complete kill was not obtained, especially with the 0.9 lb rate.

The combination treatments of trifluralin followed by bentazone or dinoseb acetate plus monolinuron gave excellent weed control. In general, however, the follow-up treatment of bentazone gave more reliable control than dinoseb acetate plus monolinuron.

Yields from the navy beans were not available at the time this paper was written, but yields from four of the French bean trials are shown in Table 5. In general there were few significant differences between treatments at the 5% level which must reflect variability within the trial areas or the size of area sampled. In all the trials, however, increases in yield of up to 34% over control plots were found. Trifluralin plus bentazone at 0.75 +

TABLE 2

Effects of trifluralin, trifluralin-bentazone and trifluralin-dinoseb acetate + monolinuron treatments on stand of Phaseolus vulgaris

	treatment and dosage (lb. a.i./ac)	Crop stand count - No. plants/10 yds of row				
		GB74-9	GB74-10	GB74-11	GB74-13	GB74-19
1.	trifluralin 0.75	132 a	129 a	90 b	145 a	216 ab
2.	trifluralin 1.5	92 b	104 c	97 ab	145 a	186 bc
3.	trifluralin 0.75 + bentazone 0.94	127 a	126 ab	94 abc	141 a	218 a
4.	trifluralin 0.75 + bentazone 1.26	125 a	137 a	97 ab	147 a	179 c
5.	trifluralin 1.5 + bentazone 1.88	108 ab	113 bc	91 bc	147 a	192 abc
6.	trifluralin 0.75 + dinoseb acetate monolinuron 4.0 formulated product	128 a	128 a	88 c	143 a	199 abc
7.	*dsa-monlin 5.0 formulated product	113 ab	124 ab	94 abc	145 a	202 abc
8.	bentazone 1.26	129 a	136 a	95 abc	148 a	198 abc
9.	control 0.0	134 a	133 a	95 abc	146 a	189 abc
	Coefficient of variation - %	7.7	3.8	2.2	6.3	4.6

1/ Trifluralin applied pre-plant incorporated, bentazone and dinoseb acetate-monolinuron applied post-emergence.

* dinoseb acetate plus monolinuron.

TABLE 3

Effects of trifluralin, trifluralin-bentazone and trifluralin-dinoseb acetate + monolinuron on vigour of *Phaseolus vulgaris*

Treatment and dosage 1/ (lb a.i./ac)	crop vigour rating 2/ GB 74-9 22.7.74	GB 74-10 25.7.74	GB74-11 25.7.74	GB74-13 1.8.74	GB74-19 7.8.74
1. trifluralin 0.75	9.5 a	10.0 a	10.0 a	10.0 a	10.0 a
2. trifluralin 1.5	8.5 a	9.0 bc	9.5 ab	10.0 a	9.7 a
3. trifluralin 0.75 + bentazone 0.94	9.1 a	9.5 ab	10.0 a	10.0 a	10.0 a
4. trifluralin 0.75 + bentazone 1.26	9.1 a	9.3 abc	9.8 ab	9.9 a	9.5 a
5. trifluralin 1.5 + bentazone 1.88	8.6 a	8.5 c	8.9 b	9.4 b	9.5 a
6. trifluralin 0.75 + dsa-monolin* 4.0 formulated product	9.5 a	10.0 a	10.0 a	10.0 a	10.0 a
7. *dsa-monolin 5.0 formulated product	8.8 a	9.8 ab	10.0 a	10.0 a	10.0 a
8. bentazone 1.26	9.3 a	9.5 ab	9.8 ab	10.0 a	10.0 a
9. control 0.0	9.8 a	10.0 a	10.0 a	10.0 a	10.0 a
Coefficient of variation - %	8.9	5.9	5.9	1.6	4.7

1/ Trifluralin applied pre-plant incorporated, bentazone and dinoseb acetate applied post-emergence.

2/ Crop vigour rating - mean result based on 0-10 scale where 0 = death, 10 = vigour of best plot.

* Dinoseb acetate plus monolinuron.

TABLE 4

Percent weed control in *Phaseolus vulgaris* with trifluralin, trifluralin-bentazone and trifluralin-dinoseb acetate + monolinuron

Treatment and dosage 1/ (lb a.i./ac)	% control - all weeds				
	GB74-9 22.7.74	GB74-10 25.7.74	GB 74-11 25.7.74	GB74-13 1.8.74	GB74-19 7.8.74
1. trifluralin 0.75	68 b	85 b	93 cd	9 a	4 ab
2. trifluralin 1.5	89 c	91 bc	94 d	0 a	45 bc
3. trifluralin 0.75 + bentazone 0.94	100 d	98 d	90 cd	80 b	97 d
4. trifluralin 0.75 + bentazone 1.26	100 d	97 cd	94 cd	80 b	97 d
5. trifluralin 1.5 + bentazone 1.88	100 d	98 d	94 d	92 b	98 d
6. trifluralin 0.75 + dinoseb acetate-monolinuron 4.0 formulated product	85 c	95 bcd	94 cd	88 b	98 d
7. dinoseb acetate-monolinuron 5.0 formulated product	29 a	88 b	85 bc	86 b	97 d
8. bentazone 1.26	89 c	34 a	75 b	67 b	98 d
9. control 0 2/	0 a (17.7)	0 a (74.7)	0 a (23.7)	0 a (95.3)	0 a (90.6)
Coefficient of variation - %	26.8	43.0	60.9	26.0	48.0

1/ Trifluralin applied pre-plant incorporated, bentazone and dinoseb acetate-monolinuron applied post-emergence.

2/ Figures in brackets represent % groundcover by weeds in control plots.

TABLE 5

Effects of trifluralin, trifluralin-bentazone and trifluralin-dinoseb acetate + monolinuron on yield of Phaseolus vulgaris

treatment and dosage (lb. a.i./ac)	yield - % of control			
	GB74-9	GB74-10	GB74-11	GB74-19
1. trifluralin 0.75	102 a	122 a	110 ab	105 bc
2. trifluralin 1.5	88 a	107 a	95 bc	105 bc
3. trifluralin 0.75 + bentazone 0.94	104 a	130 a	98 abc	128 a
4. trifluralin 0.75 + bentazone 1.26	107 a	116 a	103 abc	120 ab
5. trifluralin 1.5 + bentazone 1.88	98 a	112 a	106 abc	127 a
6. trifluralin 0.75 + dsa-monolin 4.0 formulated product	98 a	133 a	113 a	129 a
7. *dsa-monolin 5.0 formulated product	100 a	112 a	106 abc	135 a
8. bentazone 1.26	100 a	111 a	105 abc	125 a
9. control 0.0	100 a (6.3)	100 a (4.2)	100 abc (5.2)	100 c (5.0)
Coefficient of variations - %	15.7	17.2	10.2	9.3

yield shown as % of control. Figures in brackets show mean yield in tons per acre in the control plots.

* dinoseb-acetate plus monolinuron

1.26 and 1.5 + 1.88 lb/ac gave consistent increases in all the trials, but in GB74-10 and 11 trifluralin and dinoseb acetate plus monolinuron at 0.75 + 4.0 lb formulated product/ac gave the highest increase. Both bentazone and dinoseb acetate plus monolinuron alone gave good increases in yield over controls in GB74-11 and 19, but yields were not as high as for the combination treatments in GB74-10 where the weed spectrum included a high percentage of tolerant weeds.

GB74-14 was the only trial where a significant amount of Solanum nigrum was present, and the trifluralin-bentazone treatment gave excellent control of this particular weed.

Taint tests and residue analyses carried out so far have shown no detectable taints or detectable residues in the samples.

DISCUSSION

Many herbicides on the market today are limited in their use by tolerant weed species and/or by unreliability under dry conditions. The use of individual herbicides in vegetable crops also means that mechanical or hand weedings often have to be made to control tolerant weeds between the rows, and this, apart from leaving weeds in the rows, often leads to ridging of the soil around the base of the crop (King, 1968 and 1972). In a dry year such as this last one, where dwarf French beans in particular were shorter than usual, this leads to dirty crops and difficulties in mechanically harvesting the crop with the new machines now available.

In carrots and parsnips, trifluralin at 1.0 lb followed by linuron applied pre-emergence at 0.5 lb, gave excellent weed control without any deleterious effects on the crop. Metoxuron at 3.2 lbs also gave excellent results following trifluralin, but in dry conditions where the crop was held back, it was felt that competition from resistant weeds might affect the crop before metoxuron could be applied. In certain trials no advantage from combination treatments could be seen over linuron alone, and their use will obviously depend on the weed flora present, providing sufficient moisture is available for activity.

Trials in dwarf French and navy beans have shown that a programme of trifluralin at 0.75 lb/ac followed by dinoseb acetate plus monolinuron at 4.0 lb formulated product/ac or bentazone at 0.9 or 1.26 lb/ac will also give reliable and almost complete weed control. Bentazone appeared to be the more reliable follow-up herbicide in the trials, and the rate of use would appear to depend on weed stage, but trifluralin followed by dinoseb acetate plus monolinuron gave good results in certain trials. In 1974 where the crop was delayed and weeds were large at the stage of bentazone application, the 1.26 lb/ac rate was required to control trifluralin tolerant weeds, but in more normal seasons the 0.9 lb rate would be sufficient. Further work is needed to determine if bentazone can be applied to Phaseolus vulgaris at a slightly earlier stage without affecting the crop.

The trials have demonstrated that trifluralin which is soil incorporated and therefore provides reliable control under wet or dry conditions of many weeds, including _Polygonum_ spp. and _Veronica_ spp. in combination with a suitable pre- or post-emergence herbicide gives virtually complete and reliable weed control in certain vegetable crops.

The development of herbicide programmes in many small acreage crops would seem to be an answer to the need for improved weed control in the face of new mechanical harvesting methods, the shortage of hand labour, and the scarcity and cost of developing new compounds. If these programmes are to be made readily available to the farmer, then there must be co-operation between the companies concerned with the various products in terms of development and label recommendations, the government P.S.P.S. and 'Approval' schemes and the advisory services.

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INFLUENCE OF HERBICIDES ON THE DEVELOPMENT OF NODULE BACTERIA ON THE ROOTS OF SOYBEANS

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Summary The influence of different herbicide treatments on the development of nodule bacteria on soybean roots was investigated.Number of nodules per m^2 of cropping area,average size and volume of nodules per m^2 of cropping area were evaluated at 3 different dates during the growing period.Some herbicide treatments investigated reduced the number of nodules per m^2 of cropping area.The total volume of nodule bacteria per m^2 of cropping area was however not influenced by any of the treatments investigated.The reduction in number of nodule bacteria observed in some treatments was therefore compensated by an increased average size of the nodules in these treatments.

Resumé: L'influence de divers traitements herbicides sur le développement des nodosités bactériennes des racines du soja a été étudiée. On a évalué le nombre de nodosités par mètre carré de culture,leur taille moyenne et leur volume par m^2de culture,à trois dates différentes de la période de végétation .Certains herbicides ont réduit le nombre de nodositiés par m^2 mais le volume total n'a jamais été influencé par l'un quelconque des produits étudiés.La réduction du nombre de nodositiés observée dans quelques cas a donc alors été compenśe par une augmentation de leur taille moyenne.

INTRODUCTION

Many researchers from Romania and from other countries have reported that herbicides applied for weed control in soybeans and leguminous crops in general have a negative effect on the development of nodule bacteria and therefore on their capacity for symbiotic nitrogen fixation.

METHOD AND MATERIALS

Field trials applying various herbicides to soybeans(variety Amsoy) were conducted during 197o-1973.The trials were conducted on plots of 50.4 m^2 replicated 5 times.Herbicide treatments were compared to two control treatments.

The first control was weeded mechanically between the rows and manually within the rows three times each.The second control was left without any weed control.The natural of the weed population was represented by following :Amaranthus retroflexus,Chenopodium album,Cirsium arvense,Sinapis arvensis,Convolvulus arvensis,Sonchus arvensis,Hibiscus,Echinochloa crus galli,Sorghum halepense,Setaria spp,Poligonum convolvulus.

Soybeans followed winter wheat in crop rotation.Autumn ploughing to a depth of 20-23 cm was followed by seedbed preparation with a disk harrow in spring.Seed was inoculated each year with virulent strains of Rhizobium japonicum.

Number of nodules per m^2 of cropping area and average size of nodules was evaluated three times during the growing period.The first evaluation was made at the beginning of the flowering period,the second during full flowering and the third after flowering,at the pod setting stage.For further comparison of nodule formation in various treatments,the volume of nodules produced per m^2 of cropping area was calculated for each evaluation.

RESULTS

Table 1 shows number/m^2,size and volume/m^2 of nodules on soybeans roots at the beginning of the flowering period of the soybeans for the various herbicide treatments. The number of nodules per/m^2 varied between 520 when treated with prometryne at 3.5 kg a.i./ha incorporated in the soil before seeding and 1410 when treated with chloramben at 1.7 kg a.i./ha surface applied as band treatment.In this latter treatment 3 mechanical cultivations were carried out for weed control between rows. Comparing the different herbicide treatments with the mechanically and manually weeded control,the following can be observedIn the treatment with prometryne at 3.5 kg a.i./ha,the number of nodules per m^2 was reduced by 730.In the treatment with trifluralin +prometryne at 0.7+1.5 a.i./ha the reduction was 690.In the treatment with trifluralin at 1.2 kg a.i./ha the reduction was 600 nodules per m^2. A reduction of 580 nodules per m^2 was observed in the treatment with trifluralin+prometryne at 0.7+1.0 kg a.i./ha.In the control left without weed control the number of nodules per m^2 was 260 nodules less than in the weeded control.

In a few treatments the number of nodules per m^2 was greater than in

the weeded control,namely in the treatments with chloramben at 1.7 kg a.i./ha(band treatment),chloramben at 4.8 kg a.i./ha(broadcast application)and alachlor at 3.0 kg a.i./ha(surface application,broadcast)
Using the data given in Table 1,a negative correlation was found between the number of nodules per m^2 and the average size of the nodules for the various herbicide treatments.The correlation coefficient is r= -0.695 significant at 0.01%.This indicates that the various herbicides are selecting the larger and more vigorous nodules but do not destroy nodule bacteria in general.
This can be confirmed by comparing the total volume of nodule bacteria per m^2 for the various herbicide treatments.In only one treatment triflüralin + prometryne at 1.0+1.0 kg/a.i./ha,was the total volume of nodules per m^2 significantly smaller than in the weeded control.
In all other treatments the smaller number of nodules was compensated for by the increased average size of the nodules.
The selection of larger size nodules by herbicide treatments was observed especially in treatments where the herbicides were incorporated into the soil and where herbicides of the triazine group were applied.
Table 2 shows the same parameters characterizing the nodule development during full flowering of the soybeans.
By comparing Table 1 and Table 2 it can be clearly seen that on average the number of nodules per m^2 was much higher at the full flowering stage. The number of nodules per m^2 in the weeded control was increased from 1250 to 2420. Only in the control left without weed control was the number of nodules per m^2 decreased,from 990 to 830.
The total volume of nodules per m^2 was increased by 1 cm^3/m^2.
Comparing the various treatments with the weeded control the following treatments showed a significantly smaller total volume of nodules : control without weed control,trifluralin + terbutryne at 0.7 + 1.5 kg a.i./ha, chloramben + terbutryne at 1.2 + 2.5 and prometryne at 3.5 kg a.i./ha. In all other treatments the total volume of nodules was not significantly different from the weeded control.
The largest average size of nodules was obtained in the treatments : trifluralin + prometryne at 1.0 + 1.0 kg a.i./ha, chloramben + alachlor at 1.2 + 2.2 kg a.i./ha,and prometryne at 3.5 kg a.i./ha.
Table 3 shows number/m^2 size and volume/m^2 of nodules after flowering at the pod setting stage.
On the average of all treatments the number of nodules has decreased

by 100 nodules per m^2 from the previous evaluation(Table 2).The total volume of the nodules per m^2 has however increased by 1.5 cm^3/m^2. The average size of the nodules has on the average increased by 1.04 mm^3 from the last evaluation(Table). Among the different treatments only the control left without weed control had a significantly smaller total volume of nodules than the weeded control.

A negative correlation could be established between size and number of nodules using the data in Table 3.

The number of nodules/m^2 increased sharply between start of flowering and maximum flowering; thereafter the number of nodules decreased. The average size of the nodules stayed fairly constant during July, but started to increase later in the growing season.As for the different herbicide treatments,it can be seen that the treatments with the biggest number of nodules per m^2 had the smallest average nodule size. This reflects the negative correlation between number and size of nodules as mentioned earlier.As a result,the total volume of nodules/m^2 was slowly increasing with time and not significantly different between the four herbicide treatments and the weeded control.

Especially at the last evaluation the total volume of nodules per m^2 was almost identical for all treatments.

Table 1

Number/m^2, size and volume/m^2 of nodules on soybean roots when treated with different herbicides. Evaluation at the beginning of the flowering period of soybeans

Treatment	Rate kg a.i./ha	mode of application	number of nodules per m^2	average size of nodules mm^3	total volume of nodules cm^3/m^2
Control I (mech. weed control)			1250	1.04	1.3
Control II (no weed control)			990	0.80	0.8
Chloramben	4.8	post-em	1390	1.07	1.5
Trifluralin	1.0	pre-em	780	1.28	1.0
Trifluralin	1.2	pre-em	650	1.38	0.9
Chloroxuron	4.0	post-em	970	1.23	1.2
Trifluralin + Prometryne	0.7 1.5	pre-em	560	1.61	0.9
Trifluralin + Prometryne	1.0 1.0	pre-em	670	1.04	0.7
Trifluralin + Terbutryne	0.7 1.5	pre-em	930	0.97	0.9
Trifluralin + Terbutryne	0.7 1.0	pre-em	1010	1.18	1.2
Chloramben	1.7	post-em	1410	1.00	1.4
Chloramben + Alachlor	1.2 2.2	pre-em	1360	0.80	1.1
Chloramben + Prometryne	1.2 2.5	pre-em	1010	0.89	0.9
Cnloramben + Alachlor	1.2 2.2	post-em	1230	1.06	1.3
Chloramben + Prometryne	1.2 2.5	post-em	820	1.46	1.2
Chloramben + Terbutryne	1.2 2.5	post-em	670	1.49	1.0
Fluorodifen	3.0	post-em	1110	1.90	1.0
Prometryne	3.5	post-em	520	1.53	0.8
Terbutryne	3.5	post-em	910	1.20	1.1
Alachlor	3.0	post-em	1320	0.91	1.2
Average			978	1.12	1.1

Table 2

Number/m², size and volume/m² of nodules on soybean roots when treated with different herbicides. Evaluation at full blooming

Treatment	Rate kg a.i./ha	mode of application	number of nodules per m^2	average size of nodules mm^3	total vol. of nodules cm^2/m^2
Control I (mech. weed control)			2420	1.19	2.9
Control II (no weed control)			830	1.20	1.0
Chloramben	4.8	post-em	2730	1.20	3.3
Trifluralin	1.0	pre-em	1830	1.42	2.6
Trifluralin	1.2	pre-em	1.650	1.39	2.3
Chloroxuron	4.0	post-em	1.790	1.06	1.9
Trifluralin + Prometryne	0.7 1.5	pre-em	920	1.30	1.2
Trifluralin + Prometryne	1.0 1.0	pre-em	1020	1.67	1.7
Trifluralin + Terbutryne	0.7 1.5	pre-em	1260	1.27	1.6
Trifluralin + Terbutryne	0.7 1.0	pre-em	1473	1.28	1.9
Chloramben	1.7	pre-em	2670	1.20	3.2
Chloramben + Alachlor	1.2 1.2	pre-em	2110	1.28	2.7
Chloramben + Prometryne	1.2 2.5	pre-em	1450	1.24	1.8
Chloramben + Alachlor	1.2 2.2	post-em	1918	1.52	2.2
Chloramben + Prometryne	1.2 2.5	post-em	1425	1.26	1.8
Chloramben + Terbutryne	1.2 2.5	post-em	990	1.41	1.4
Fluorodifen	3.0	post-em	1340	1.34	1.8
Prometryne	3.5	post-em	925	1.51	1.4
Terbutryne	3.5	post-em	1410	1.20	1.7
Alachlor	3.0	post-em	2850	1.19	3.4
Average			1650	1.27	2.1

Table 3

Number/m^2 size and volume/m^2 of nodules on soybean roots when treated with different herbicides. Evaluation after flowering at pod setting

Treatment	rate kg a.i./ha	mode of application	number of nodules per/m^2	total vol. of nodules cm^3/m^2	average size of nodules mm^3
Control I (mech. weed control)			2110	1.80	3.8
Control II (no weed control)			1710	1.57	2.7
Chloramben	4.8	post-em	2120	1.76	3.7
Trifluralin	1.0	pre-em	1786	2.18	3.9
Trifluralin	1.2	pre-em	1812	2.26	4.1
Chloroxuron	4.0	post-em	1626	2.21	3.6
Trifluralin + Prometryne	0.7 1.5	pre-em	1250	2.56	3.2
Trifluralin + Prometryne	1.0 1.0	pre-em	990	3.13	3.4
Trifluralin + Terbutryne	0.7 1.5	pre-em	1015	2.85	2.9
Trifluralin + Terbutryne	0.7 1.0	pre-em	1625	2.27	3.7
Chloramben	1.7	post-em	2530	1.74	4.4
Chloramben + Alachlor	1.2 2.2	pre-em	1810	1.69	4.1
Chloramben + Prometryne	1.2 2.5	pre-em	1255	2.78	3.5
Chloramben + Alachlor	1.2 2.2	post-em	2125	1.93	4,1
Chloramben + Prometryne	1.2 2.5	post-em	1530	2.35	3.6
Chloramben + Terbutryne	1.2 2.5	post-em	830	3.85	3.2
Fluorodifen	3.0	post-em	990	3.43	3.4
Prometryne	3.5	post-em	815	3.68	3.0
Terbutryne	3.5	post-em	1017	3.44	3.5
Alachlor	3.0	post-em	2200	1.77	3.9
Average			1557	2.31	3.6

DISCUSSION

In conclusion the data presented indicate that some herbicides can affect the less virulent nodule bacteria and therefore reduce the number of nodules per m^2. The remaining nodule bacteria however become more active and develop to a larger size. As a result, there is practically no influence of the herbicide treatments investigated on the total volume of nodule bacteria per m^2, and therefore on the symbiotic nitrogen fixing capacity of the soybean plant.

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