PRE- AND POST-EMERGENCE WEED CONTROL IN CARROTS

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SUMMARY

A SERIES of field trials conducted under a wide range of soil and environmental conditions in the North Island has led to a promising new development for pre-emergence weed control in carrots. Propazine at 1 to 2 lb a.i. per acre has given extended control of a range of annual broad-leaf and grassy weeds with a wide margin of safety toward several varieties of carrots. Provided soil moisture conditions are adequate after seeding and following the application of propazine, the seedling weeds are controlled as they germinate and do not offer any competition to the young carrots. If thorough cultivation is given following the harvesting of the carrots, no effects from residues of propazine in the soils have been detected in subsequent crops.

A preliminary evaluation has been made on three new substituted anilide herbicides for post-emergence weed control in carrots in comparison with selective oil sprays. In preliminary field studies these compounds appear to be highly selective toward carrots and to offer several advantages over the currently used oil sprays. Further evaluation work is required to assess their full potentiality as post-emergence selective herbicides in umbelliferous crops.

INTRODUCTION

The economic production of vegetable crops in New Zealand seems to depend largely on savings in the amount of hand labour required. Carrots in the seedling and early growth stages are very susceptible to competition from weeds which are difficult to control in this crop by mechanical cultivation. The most widely used method of chemical weed control in carrots has been spraying with light petroleum distillates with an aromatic oil content of between 15 and 25 per cent. These are applied to the young weeds at the rate of 35 to 70 gallons per acre when the carrots are in the 2 to 4 true leaf stage. According to Currier (1951) the basis of the selectivity of unsaturated oils toward carrots and other members of the family *Umbelliferae* is probably due to the particular character of the cell wall or of the outer plasma membrane of this group of plants. However, this selectivity is not absolute and some reduction in vigour of the carrots may result for a period after application of the "carrot oil". Furthermore, environmental conditions at the time of and following spraying partly determine the effectiveness of weed control. Warm, dry windy conditions may increase the damage to the crop, and also the rapid evaporation of the oil under these conditions may result in poor weed control. If spraying has to be delayed because of unsuitable weather conditions, higher rates of application of the selective oil may be required to obtain adequate control of the then larger weeds. Application of excessive rates of the oil or at a stage when the carrots have developed roots thicker than a lead pencil may result in the crop having an oily flavour, particularly if required for the early market. Harvesting may then have to be delayed until the oil flavour and odour have disappeared from the carrots. Furthermore the atomised oil spray from the nozzles is highly inflammable and open flames must be kept away from the spray equipment. Proprietary carrot oil sprays appear to vary widely in their phytotoxicity and often a preliminary test is made to determine the crop tolerance and rate of application required for

satisfactory weed control. The delay required to assess the results of this preliminary treatment may result in less than ideal weather conditions for the main spraying operation.

For the above reasons, therefore, there has been a need for a pre-emergence chemical for weed control in carrots. Up to the present the only chemical used successfully as pre-emergence herbicides in carrots has been chlorpropham. Satisfactory weed control has been obtained with rates up to 8 lb a.i. per acre of chlorpropham under cool, moist soil conditions such as prevail in New Zealand during winter and early spring months. Good weed control has been obtained with 4 lb a.i. per acre on susceptible weeds such as *Poa annua*, spurrey (*Spergula arvensis*), twin cress (*Coronopus didymus*), annual chickweed (*Stellaria media*), annual nettle (*Urtica urens*), shepherd's purse (*Capsella bursa-pastoris*), but other weeds such as couch (*Agropyron repens*), fathen (*Chenopodium album*), clovers (*Trifolium* spp.), groundsel (*Senecio lautus*), and small regrowth sorrel (*Rumex acetosella*) have proved to be rather resistant. However, under warmer weather conditions the weed control ability of chlorpropham is often unsatisfactory for two main reasons. Firstly, the residual life of the chlorpropham is reduced by rapid microbiological breakdown and loss from the soil under warmer temperature conditions (Ogle and Warren, 1954). Secondly, many common summer weeds such as fathen and Prince of Wales feather (*Amaranthus hybridus*) appear to be less susceptible to chlorpropham. Therefore there obviously has been a need for a more residual and less variable pre-emergence herbicide than chlorpropham for reliable weed control in carrots. Initial results from overseas in soil sterilant studies with a range of substituted triazine herbicides had indicated that weed members of the *Umbelliferae*, particularly wild carrot and fennel, show a distinct tolerance to propazine. Early studies in Switzerland by Gast (1959) and by Robertson (1960) in Australia indicated the tolerance of the carrots toward propazine and its effectiveness as a pre-emergence herbicide to a range of annual broad-leaf and grass weeds. This selectivity of propazine toward carrots has been confirmed in a series of field trials carried out in the last 18 months over a wide range of soil types and environmental conditions in the North Island, using several different varieties. Studies on post-emergence weed control in carrots have been restricted to preliminary small plot field evaluation of three new related acetamide herbicides in comparison with selective carrot oils.

MATERIALS AND METHODS

An Oxford Precision sprayer was used to apply the chemicals in the small scale 1/200th acre plots. In all treatments the equivalent of 46 gallons of spray liquid per acre was applied, using 37 solid cone nozzles at a pressure of 40 lb p.s.i. and with the operator travelling at 3 m.p.h. In the larger-scale field tests of up to $\frac{1}{4}$ acre plot size a "Landrover" unit with a 15 ft articulated boom fitted with 37 solid cone nozzles was used. The same application conditions and the same volume of spray liquid per acre were used as in the 1/200th acre plots.

In all tests the carrots were planted in raised beds 5 ft wide and were either sown broadcast or drilled in rows 10 in. apart. The seeding rate was normally 2 lb a.i. per acre. The variety of carrots tested included Manchester Table, Chantenay, Chantenay Long, Topweight, Touchon, and Nantes Stump Rooted. The soil types involved in the various tests included a fine sandy loam, a silt loam, clay loam, and a volcanic ash. Weather conditions following applications ranged from extremely moist to dry periods without rain for four weeks after application. All small-scale field tests were replicated three times and the larger $\frac{1}{4}$ acre blocks two times where possible.

The following compounds were evaluated in all or some of eight

different trials to assess their herbicidal activity and selectivity toward carrots.

Treatments	lb a.i. per acre
Simazine	2 and 3
Atrazine	2 and 3
Propazine	1, 1.5, 2, and 3
Trietazine	1, 2, and 3
Ipazine	2 and 4
Chlorpropham	2 and 4
Amiben	2, 4, and 8
Carrot oil	30, 60, and 100 gallons
Dicryl	2 and 4
Karsil	2, 4, and 6
Solan	2 and 4

The following weed species were present in some or all of the trial areas: black nightshade (*Solanum nigrum*) fathen, broad-leaf dock (*Rumex obtusifolius*), *Poa annua*, lady's thumb (*Polygonum persicaria*), sheep sorrel, twin cress, spurrey, storksbill (*Erodium cicutarium*), yarrow (*Achillea millefolium*), chickweed, speedwell (*Veronica persica*), annual nettle, wireweed, creeping buttercup (*Ranunculus repens*), groundsel, mallow (*Malva* weed (*Polygonum aviculare*), creeping buttercup (*Ranunculus repens*), groundsel, mallow (*Malva parviflora*), purslane (*Portulaca oleracea*), Prince of Wales feather, shepherd's purse, narrow leaf plantain (*Plantago lanceolata*), and perennial ryegrass (*Lolium perenne*).

RESULTS AND DISCUSSION

The first trial was laid in March 1960 in a Taranaki market garden, Manchester Table variety of carrots being sown in a coarse, sandy loam soil. These were treated post-emergence when in the 2 to 4 true leaf stage and when the weeds were 2 to 3 in. high. These consisted principally of black nightshade, broad-leaf dock, creeping buttercup, fathen, narrow-leaf plantain, and perennial ryegrass.

Treatments	lb a.i. per acre
Propazine	2 and 3
Simazine	2 and 3
Atrazine	2 and 3
Trietazine	2 and 3
Carrot oil	30 gallons

Almost complete weed control was obtained with all the triazine treatments right up to harvest time 12 weeks later. The selective oil gave a rapid knockdown of the weeds and an excellent total kill. The carrots showed slight leaf scorching and some chlorosis was evident 10 days after application. However, fresh weed infestation followed, and subsequent oil sprayings would have been necessary for continued weed control. Simazine and atrazine at both rates eliminated the carrots. Propazine and trietazine at both rates had no retarding effect on the carrots, while yields and quality of the crop were quite comparable to the carrot oil treated plot.

The next small-scale plot trial was laid in July 1960 in a Rukuhia market garden, Waikato, on alluvial loam silt. The carrots were Chantenay. The following treatments were made pre-emergence to both weeds and crops:

Treatments	lb a.i. per acre
Propazine	1 and 2
Trietazine	1 and 2
Amiben	2, 4, and 8

The principal weeds present at the first evaluation one month after treatment were twin cress, shepherd's purse, *Poa annua*, and annual chickweed. Evaluations 12 weeks after planting indicated that propazine at both rates gave excellent weed control with no suppression of carrots.

TABLE 1—MEAN EVALUATIONS OF PRE- AND POST-EMERGENCE TREATMENTS TO CARROTS

Chemical	lb a.i. per acre	Weed control	Weed counts (per sq. ft.)	Crop survival	Crop vigour	Selectivity index
Propazine (pre)	2	9.0	7	9.8	9.7	9.5
Propazine (post)	2	8.3	—	10	10	9.4
Propazine (pre)	1	6.8	12	9.5	9.3	8.5
Propazine (post)	1	3.3	—	10	10	7.8
Amiben (pre)	8	7.0	7	9.0	9.0	8.3
Amiben (pre)	4	5.5	16	9.5	9.0	8.0
Amiben (post)	4	3.5	—	10	10	7.8
Amiben (pre)	2	4.0	15	10	8.5	7.8
Trietazine (pre)	2	6.0	13	4.8	5.5	5.4
Trietazine (post)	2	3.5	—	9.5	9.5	7.5
Trietazine (pre)	1	1.5	12	8.3	8.0	5.9
Trietazine (post)	1	2.3	—	9.3	10	7.2
Carrot oil	70 gal.	9.0	—	10	9.0	9.0
Control	—	0	61	10	10	6.7

(Subsequent rainfall: 14.59 in. fell during the 12 weeks following the pre-emergent treatments)

*Counts made five weeks after treatment

However, there was a noticeable difference in the degree of weed control obtained with propazine at the 1 and 2 lb a.i. per acre rate. Though there was no difference evident in crop survival and vigour ratings, trietazine was inferior to propazine at both rates in its weed control and at 2 lb a.i. per acre appeared to reduce their germination slightly and suppress the carrots. Amiben was quite selective toward the carrots at all rates, but it was less effective than propazine in its weed control.

As a further test of the post-emergence activity of the above chemicals a treatment was made to the carrots in the same planting when in the 2 to 4 true leaf stage and when the weeds were up to 2 in. in height and growing vigorously. Only propazine at 2 lb a.i. per acre gave acceptable weed control, though in contrast to the pre-emergence applications the effect was often more that of a suppression of the weeds rather than a complete kill. It was concluded that post-emergence treatments of the above compounds were much less effective even when applied to young weeds. Furthermore, it appeared that the fully pre-emergence application required less than half the dosage rate for acceptable weed control compared with even early post-emergence treatments. Amiben at 4 lb a.i. per acre caused severe leaf twisting of twin cress and plants smaller than 1 in. were killed, but larger plants recovered though stunted compared with those in the control plots. Trietazine gave poor control, though some chlorosis of leaves was still evident six weeks after application, but the weed density was barely reduced. Trietazine at 2 lb a.i. per acre appeared to cause some reduction in vigour of the carrot seedlings. In comparison propazine at 2 lb a.i. per acre appeared to be quite selective toward the carrots, while among the weeds twin cress was most susceptible and wireweed the most tolerant. Carrot oil applied at 70 gallons per acre on weeds at the same stage of development gave excellent control of twin cress, shepherd's purse, *Poa annua*, and fair control of wireweed. Though slight chlorosis of the carrots was evident from the oil treatment, weed control was in general superior to that of any of the post-emergence applications of the above chemicals.

A further pre-and post-emergence small plot trial was laid down in August 1960 in a market garden at Wanganui. The soil type was a fine alluvial sandy loam and the carrot variety tested was Topweight. The pre-emergence application was made on the same day of the sowing while the post-emergence application was made five weeks after planting, when the carrots were in the 2 to 4 true leaf stage. The principal weeds present

at this time were twin cress, annual chickweed, annual nettle, and lady's thumb.

TABLE 2—RESULTS OF THE RATINGS MADE 16 WEEKS AFTER PLANTING AND 10 WEEKS AFTER THE POST-EMERGENCE APPLICATIONS

Chemical	lb a.i. per acre	Weed control	Crop vigour	Crop survival	Selectivity index
Pre					
Propazine	2	9.8	8.7	9.1	9.2
Propazine	1	8.8	8.8	9.1	8.9
Trietazine	2	9.4	4.8	3.7	6.0
Trietazine	1	6.6	8.3	9.1	8.0
Amiben	4	0.1	8.1	9.2	5.8
Amiben	2	1.5	9.3	9.8	6.8
Chlorpropham	4	0.6	8.9	9.4	6.3
Chlorpropham	2	0	7.6	10.0	5.9
Post					
Carrot oil	60 gal.	2.6	8.3	7.9	6.2
Dicryl	4	1.7	9.2	9.5	6.7
Karsil	4	1.8	6.9	8.4	5.7
Propazine	1	0.6	8.8	9.8	6.4
Control	—	0.4	8.9	9.8	6.5

(Subsequent rainfall: 10.27 in. fell during the 16 weeks following the pre-emergent treatment)

PRE-EMERGENCE TREATMENTS

On this very light sandy soil propazine at 2 lb a.i. per acre slightly suppressed germination and reduced the initial vigour of the carrot seedlings. However the weed control for propazine at both 1 and 2 lb a.i. per acre was almost complete 16 weeks after treatment and the quality and general yield of the carrots at harvesting according to the grower was excellent. Under these light soil and high moisture conditions trietazine at 2 lb a.i. per acre was distinctly toxic toward the carrots. Both the crop survival and vigour were severely reduced, though the weed control was very good. The weed control obtained from trietazine at 1 lb a.i. per acre was distinctly inferior by comparison, but the crop vigour and survival were much improved. Though both amiben and chlorpropham appeared to be quite selective toward the carrots, they gave only acceptable initial weed control and very marginal residual control. Amiben at 4 lb a.i. per acre may have slightly reduced the final vigour of the carrots. Both of the new anilide compounds dicryl and karsil as pre-emergent applications had very little effect on the weeds. Only a slight suppression of the weeds was evident four weeks after treatment, especially with dicryl, but no reduction in weed cover was obtained.

POST-EMERGENCE TREATMENTS

Carrot oil was the most effective post-emergence herbicide tested, but was slightly more damaging to the carrots than the anilide compounds dicryl and karsil. The carrot oil showed a higher acute toxicity to the weeds with its more rapid contact injury of the plant tissue. Dicryl and karsil were slower in action with the development of a general necrosis of the young weeds. None of these materials had any significant residual weed control activity and later germinating weeds offered competition to the crop. Propazine at 1 lb a.i. per acre applied post-emergence was almost ineffective for weed control, there being merely a suppression and marginal chlorosis of the leaves of the weeds.

Summarising this trial, the most selective treatment was propazine at 1 lb a.i. per acre which gave almost complete weed control for the duration of the crop with normal crop survival. The minor initial reduction in crop vigour was not reflected in the final yield. No cultivation was carried out

after the treatments except for surface hoeing in plots showing unacceptable weed control. Following harvest the soil was roto-tilled to a depth of 6 in. Lettuce were then planted into the whole trial block six months after the original herbicide application. No residual toxic effects have been shown from any of the treatments, including the propazine at 2 lb a.i. per acre.

A further small- and large-scale plot trial was laid down in October 1960 at Rangatau, Ohakune. The soil type was a silt loam of volcanic ash origin. The two carrot varieties sown were a Manchester Table type (Nantes Stump Rooted) and the variety Touchon. The pre-emergence applications were applied one week after seeding the carrots on the soil surface without covering the seed. Post-emergence applications were made six weeks after the pre-emergence treatment when the carrots were in the four true leaf stage and the weeds were 1 in. to 2 in. high. The weeds present were principally fathen, spurrey, *Poa annua*, sheep sorrel (both as seedling and regrowth plants), and yarrow as regrowth plants.

TABLE 3—RESULTS FROM THE FINAL RATING MADE 19 AND 12 WEEKS AFTER THE PRE- AND POST-EMERGENCE TREATMENTS

Chemical	lb a.i. per acre	Weed control	Weed count (per sq. ft)	Crop vigour	Selectivity index
Pre					
Propazine	2	8.6	3.8	9.8	9.2
Propazine	1	7.5	14.6	9.0	8.2
Trietazine	1	6.2	19.5	8.7	7.4
Ipazine	4	8.4	4.2	9.6	9.0
Ipazine	2	8.2	5.2	9.5	8.8
Amiben	4	7.7	8.4	9.3	8.5
Amiben	2	7.5	11.0	8.9	8.2
Chlorpropham	4	7.5	19.3	9.6	8.5
Post					
Karsil	6	6.5	—	8.4	7.4
Karsil	4	4.3	—	8.4	6.4
Carrot oil	100 gal.	3.0	—	8.1	5.5
Control	—	0	61	10	5.0

(Subsequent rainfall: 19.09 in. fell during the 19 weeks following the pre-emergence treatments)

At this final rating all treatments indicated no serious residual toxic effects on the carrots whether applications were made pre- or post- emergence. Pre-emergence applications of the triazine compounds gave the most effective residual control of the annual weeds. Weed control from propazine was outstanding. Ipazine was only slightly inferior to propazine in its herbicidal activity. Both ipazine and propazine under the prevailing soil and moisture conditions appeared to be most selective toward the carrots. The post-emergence applications of karsil appeared to be at least as effective in weed control as the carrot oil at 100 gallons to the acre. All post-emergence treatments were selective toward the carrots and the slight reduction in crop vigour was probably due to the increased competition of the uncontrolled weeds. At the time of treatment the weeds may have been slightly advanced for the most effective control by karsil and carrot oil.

Large-scale treatments applied with the "Landrover" unit to $\frac{1}{4}$ acre blocks were as follows:

Propazine, pre-emergence: 1.7, 0.95, 1.04 lb.

Carrot oil, post-emergence: Six weeks after planting with the carrots at the 4 true leaf stage, 66 gallons per acre.

The carrots received a distinct check from the application of the carrot oil. An assessment of yield was made in the large-scale treatment block 14 weeks after sowing, when the first carrots were to be harvested for

marketing. The yields of carrot roots obtained including the tops were as follows:

Propazine	1.7 lb a.i. per acre	37.3 tons per acre
Carrot oil	66 gallons per acre	24.3 tons per acre

Samples of these carrots were cooked and no tainting could be detected as result of any treatment.

Further large-scale treatments with propazine alone were made at Tuakau, Pukekohe, where the soil type is a clay loam and the carrot variety tested was Chantenay Long. Applications were made to $\frac{1}{4}$ acre areas with the "Landrover" unit and an 18 ft articulated boom. The rates of application were 1.8, 1.7, 1.4, 0.85 lb a.i. per acre of propazine. From present evaluations the higher rates of application for propazine are clearly superior in their weed control to the 0.85 lb a.i. per acre treatment. It appears that more than 1 lb a.i. per acre of propazine is required for complete residual weed control in soils with a higher adsorptive capacity such as clays, clay loams, and organic soil types. Yield data are not available from the Tuakau trial, as this crop is not yet ready for harvesting.

CONCLUSIONS

As a result of the series of trials carried out in New Zealand in the last 18 months it has been concluded that propazine at 1 to 2 lb a.i. per acre applied pre-emergence to crop and weeds offers real promise as a new selective herbicide for carrots. Provided soil moisture conditions are adequate at the time of planting and in the first month following treatment with propazine, excellent residual weed control of a wide range of annual broad-leaf weeds and grasses can be obtained. If the top 1 in. of soil remains dry for the initial growing period, limited weed control may be obtained. Propazine is of very low solubility (8.6 p.p.m.) and, like the related triazine simazine, acts almost solely through the roots of plants. It must, therefore, have adequate soil moisture to be carried into the soil solution and thereby enter the roots of the plants. Like simazine, and other active chloro substituted triazines, propazine appears to act by interfering with an enzyme system involved in oxygen liberation in a particular stage of photosynthesis. Therefore the completely lethal action of the propazine is not fully exerted until the young weed seedling has actually germinated and begun chlorophyll synthesis and photo-synthetic activity. Consequently, the weeds may be observed to germinate and grow to the cotyledon stage, and then become chlorotic and die. Weeds reestablishing from rhizomes or those germinating from deeper layers in the soil may not be killed, but their growth is usually retarded by propazine. This process has been observed to occur in such perennial plants as couch, Californian thistle (*Cirsium arvense*), sheep sorrel, yarrow, and broad-leaf dock. It would appear that the selectivity shown by propazine toward carrots is based on the fact that this crop, and probably other members of the *Umbelliferae*, are able to metabolise the propazine in their roots before it actually reaches the leaves. Overseas analytical data have indicated that no detectable residues of propazine (less than 0.2 p.p.m.) have been found in carrots treated with 3.4 lb a.i. per acre of propazine. This is a dosage in excess of the rate normally required for adequate season-long weed control in carrots.

Propazine appears to have a residual action in the soil at least comparable to that of simazine, which is recognised as a long-term soil sterilant. However, in the present series of tests residual action of propazine has been found only where applied at 2 lb a.i. per acre on a very light sandy soil four months following application. In this case, the residual action was clearly seen in a subsequent crop of oats grown as a cover crop. According to Sheets (1959) oats are one of the plants most sensitive to residues of triazines in the soil and are used as an indicator crop for their detection. In bio-assay determinations residues down to 0.03 p.p.m. of certain triazines are detectable in light sandy soils, using the germinating oat as the indicator species. In a similar sandy soil at Wanganui, lettuce

which were planted into the treated area (propazine 2 lb a.i. per acre) showed no toxic effects from any residual amounts of the chemical. Lettuces are recognised as being one of the most sensitive vegetable crop plants for the detection of triazine residues. Other crops such as cabbages, cauliflowers, and beans have shown no residual toxic effects from propazine treatments at 2 lb a.i. per acre, from four to six months after the application in silty clay loam soils. However, as a precaution to eliminate any possible residues of propazine remaining in the soil, ploughing to a depth of 9 in. and the complete inversion of the soil is recommended as the cultivation practice following harvesting of the propazine treated crop. Though no long-term field studies have been made of propazine residues, it is believed that an application rate of 2 lb a.i. per acre of propazine is unlikely to lead to accumulation of toxic levels of the chemical in the soil under most New Zealand conditions.

A light surface cultivation two months after planting has not affected the final weed control obtained with propazine. Provided that no disturbance of the soil is carried out in the critical period one month after application, a clean weed-free bed will be maintained until the carrots have grown to such a stage as to out-compete any late germinating weeds. A light cultivation for the purposes of soil aeration and for covering the tops of the crown to avoid greening may be carried out without detriment to the final weed control and crop yield.

In summary, it can be concluded that propazine applied at the rate of 1 lb a.i. per acre on sandy and silty soils and at 2 lb a.i. per acre in clay, clay loam, and organic soil types will give residual weed control in carrots with an adequate safety margin to the crop. Potentially, an increased yield may be obtained as a result of the elimination of weed competition in the very early stages of crop growth. The use of pre-emergence applications of propazine for weed control in carrots grown for stock feeding could now offer the prospect of an expansion in production of this crop for winter feeding of dairy cattle and pigs in suitable areas. To some extent this may offer a possible alternative to the problem of the production of brassica supplementary feed crops because of our present inability to control weeds effectively which so seriously compete with the production of these crops.

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