# ACTIVATED CARBON IMPROVES THE TOLERANCE OF LETTUCE TO MIXTURES OF NAPROPAMIDE WITH DIURON OR PROMETRYNE

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*Summary.* Propyzamide selectively controls weeds in lettuce, however, it is not effective against weeds of the same botanical family and chemicals that are effective also kill lettuce. To overcome this problem several means were tested of applying activated carbon to protect lettuce against various herbicides and herbicide mixtures in the glasshouse and field. Field treatments included mixtures of propyzamide (3 kg/ha) with napropamide (1, 2 and 3 kg/ha), linuron (0.5, 0.75 and 1 kg/ha), diuron (0.5, 0.75 and 1 kg/ha), propachlor (0.5, 1 and 2 kg/ha) or prometryne (0.25, 0.5 and 0.75 kg/ha). All mixtures provided excellent weed control and activated carbon applied above the lettuce seed at sowing protected the seedlings against mixtures containing napropamide, diuron and prometryne but to a lesser degree against those containing linuron and propachlor. A prototype machine has been developed to sow seed and apply activated carbon over the seed prior to herbicide application.

## INTRODUCTION

In common with other *Asteraceae*, lettuce is relatively tolerant of the herbicide propyzamide which is used to selectively control weeds in lettuce crops throughout Australia. The crops are predominantly grown near the coast, where potato weed (*Galinsoga parviflora* Cav., also a member of the *Asteraceae* family) thrives on cultivated land. In this environment, weed seed production (greater that 70,000 seeds per plant) and germination (greater than 20,000 seedlings/plant) continue all year round. Potato weed is resistant to propyzamide, and is the most economically important weed in the production of lettuce in Australia.

Activated carbon adsorbs herbicides (8), and with other adsorbents has been used to protect crops such as lettuce (1) from injury by herbicides and thus enhance selectivity. Toth *et al.* (6) used activated carbon to protect tomato against metribuzin and Taylor and Warholic (5) protected fluid drilled lettuce from various herbicides using activated carbon applied in gels with the seed. Germination of lettuce seed has been shown to be uninhibited by activated carbon (3).

The following experiments were conducted to investigate whether the tolerance of lettuce to pre-emergent herbicides could be improved by placing small quantities of activated carbon near the seed prior to application of the herbicides.

## METHODS

Glasshouse trials. The first experiment assessed the effects of 33 herbicide treatments (Table 1) on the growth of both potato weed and lettuce. The most promising 23 treatments (Table 2) were repeated in a second experiment. In both experiments white polystyrene cups were used as pots, each containing ~250 g of air-dry sandy loam. A mixed fertiliser solution was injected into each pot (6) then lettuce was sown into two thirds of the pots (10 seeds/pot) and potato weed into the remaining one third. Activated carbon suspension in water (2 mL containing 0.1 g of carbon) was applied on the soil surface immediately above the seed row in half of the pots containing lettuce. Herbicide treatments were applied and watered-in using a conventional spray

nozzle mounted in a specially designed spraying cabinet. Each treatment was replicated four times. Watering was maintained independently for each pot using jute wicks with one end implanted in the soil and the other immersed in water in a reservoir (7). Seedlings were counted at weekly intervals and plants were harvested, dried and weighed four weeks after emergence. The best treatments from the second glasshouse experiment were trialled in the field.

Field trial. In the field trial a randomised split plot design was used with 4 rows of lettuce per plot. There were eighteen main treatments and each treatment was split into 4 sub-treatments (1 row of lettuce). The trial was replicated 4 times. The main treatments included a nil control and a hand weeded control, all other treatments received 3 kg/ha propyzamide alone or in mixture with linuron (0.5, 0.75, 1.0 kg/ha), prometryne (0.25, 0.5, 0.75 kg/ha), diuron (0.5, 0.75, 1.0 kg/ha), propachlor (0.5, 1.0, 2.0 kg/ha) or napropamide (1.0, 2.0, 3.0 kg/ha). The sub-treatments used were seed with no protection, seed in xanthan gum, activated carbon placed on the soil surface above the seed, and seed in xanthan gum with activated carbon. The herbicide treatments were applied using a small compressed air plot spraying apparatus. Lettuce plants were counted 7 days after emergence. They were harvested and weighed green 60 days after planting.

## RESULTS AND DISCUSSION

Glasshouse trials. Data from the first experiment clearly illustrate the difficulty of selectively removing potato weed from lettuce since all the effective herbicides were also highly toxic to lettuce (Table 1). It would be a rather simpler task to remove lettuce from a crop of potato weed using butylate, profam or chlorthal! Selection of herbicides for subsequent experiments was therefore strongly influenced by the degree of protection afforded to the lettuce by activated carbon.

Activated carbon enhanced the tolerance of lettuce to all the herbicides, particularly linuron, prometryne and napropamide, as evidenced by both increased survival and weight of seedlings (Tables 1 and 2). However, this beneficial effect is not attributable solely to a reduction in phytotoxicity through adsorption. There are at least two confounding influences. First, activated carbon stimulated germination probably through adsorption of inhibitors (3). With the short duration of the experiments, this caused growth enhancements in the absence of herbicides (Table 2) and perhaps in their presence. Secondly, with linuron in the first experiment and prometryne in the second, increasing the herbicide dose increased dry weight in the presence of activated carbon. This is attributed to incomplete herbicide adsorption, resulting in growth stimulation from the residual low herbicide dose (2 and 4). We find such effects notoriously difficult to reproduce between experiments, but have observed them on several other occasions.

Field trials. There was a wide range of weed species in the experimental area. When no herbicide was applied grasses dominated and weed competition overwhelmed the crop (Table 3). When only propyzamide was applied the grasses and most of the broadleaves were controlled. Potato weed became dominant and the crop yield was reduced by more than 75% compared with the hand-weeded control (Tables 3 and 4).

All the herbicide mixtures provided excellent weed control. Therefore the effects of the treatments on yield are not due to weed competition (Tables 3 and 4). As in the glasshouse experiments the herbicide treatments that controlled the weeds were also toxic to lettuce (Table 3).

Table 1. Effect of treatments on establishment and growth of lettuce and potato weed in the first glasshouse experiment. Plants were harvested four weeks after emergence.

| Herbicide treatments | | Seedling establishment and growth (dry weight) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Lettuce | | | | Potato weed | |
| Combination | Rate (kg of ai/ha) | -AC[2] | | +AC[2] | | No. of plants | Dry wt. (g) |
| | | No. of plants | Dry wt. (g) | No. of plants | Dry wt. (g) | | |
| Propyzamide | 2.25 | 34 | 0.248 | 33 | 1.355 | 120 | 1.981 |
| | 4.50 | 26 | 0.357 | 23 | 1.147 | 70 | 1.693 |
| Propyzamide **plus** linuron | 2.25 + 0.125 | 28 | 0.202 | 27 | 0.794 | 106 | 2.973 |
| | 2.25 + 0.250 | 32 | 0.388 | 22 | 0.611 | 32 | 0.634 |
| | 2.25 + 0.375 | 28 | 0.260 | 30 | 1.791 | 24 | 0.243 |
| | 2.25 + 0.500 | 31 | 0.405 | 33 | 1.778 | 22 | 0.304 |
| Propyzamide **plus** prometryne | 2.25 + 0.125 | 12 | 0.099 | 34 | 1.866 | 7 | 0.009 |
| | 2.25 + 0.250 | 6 | 0.006 | 36 | 1.442 | 4 | 0.010 |
| | 2.25 + 0.375 | 9 | 0.016 | 34 | 1.247 | 3 | 0.005 |
| | 2.25 + 0.500 | 9 | 0.042 | 34 | 1.313 | - | - |
| Propyzamide **plus** propachlor | 2.25 + 0.65 | 29 | 0.324 | 29 | 1.334 | 15 | 0.027 |
| | 2.25 + 1.30 | 27 | 0.112 | 29 | 0.618 | 9 | 0.005 |
| | 2.25 + 1.95 | 23 | 0.066 | 28 | 1.186 | 6 | 0.008 |
| Propyzamide **plus** diuron | 2.25 + 0.25 | 31 | 0.277 | 27 | 1.211 | - | - |
| | 2.25 + 0.50 | 13 | 0.020 | 29 | 1.052 | 7 | 0.010 |
| Propyzamide **plus** napropamide | 2.25 + 0.50 | 29 | 0.253 | 37 | 1.479 | 96 | 0.951 |
| | 2.25 + 1.00 | 34 | 0.312 | 37 | 1.713 | 70 | 0.138 |
| | 2.25 + 1.50 | 32 | 0.242 | 32 | 1.362 | 68 | 0.108 |
| Propyzamide **plus** diphenamide | 2.25 + 0.80 | 29 | 0.469 | 31 | 0.626 | 54 | 0.812 |
| | 2.25 + 1.60 | 23 | 0.299 | 21 | 0.490 | 42 | 0.457 |
| | 2.25 + 2.40 | 29 | 0.282 | 35 | 1.016 | 39 | 0.468 |
| Bensulide | 5.00 | 28 | 0.203 | 33 | 0.500 | 86 | 3.011 |
| | 10.00 | 27 | 0.172 | 35 | 0.557 | 37 | 1.228 |
| Butylate | 1.00 | 33 | 0.073 | 36 | 0.541 | 81 | 3.040 |
| | 2.00 | 27 | 0.081 | 36 | 0.353 | 74 | 2.950 |
| | 3.00 | 25 | 0.064 | 36 | 0.561 | 99 | 3.579 |
| | 4.00 | 26 | 0.073 | 32 | 0.612 | 78 | 2.651 |
| Chlorthal-linuron (Shamrox[R]) | 3.125 | 27 | 0.110 | 34 | 0.758 | 4 | 0.092 |
| | 6.250 | 26 | 0.138 | 35 | 0.744 | - | - |
| Propham | 3.00 | 30 | 0.215 | 33 | 1.068 | 99 | 2.815 |
| | 6.00 | 29 | 0.087 | 29 | 0.642 | 79 | 2.554 |
| Chlorthal | 7.50 | 36 | 0.173 | 34 | 0.841 | 45 | 2.243 |
| Oryzalin | 0.50 | 27 | 0.071 | 35 | 0.890 | - | - |

[1] Data are totals for the four replicates.
[2] +AC = activated carbon added and -AC = no activated carbon added.

Table 2. Effect of treatments on establishment and growth of lettuce and potato weed in the second glasshouse experiment. Plants were harvested four weeks after emergence.

| Herbicide treatments | | Seedling establishment and growth (dry weight) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Lettuce | | | | Potato weed | |
| Combination | Rate (kg of ai/ha) | -AC[2] | | +AC[2] | | No. of plants | Dry wt. (g) |
| | | No. of plants | Dry wt. (g) | No. of plants | Dry wt. (g) | | |
| Propyzamide | 0 | 36 | 0.287 | 32 | 0.425 | 62 | 2.795 |
| | 2.25 | 33 | 0.307 | 33 | 0.311 | 33 | 0.997 |
| Propyzamide **plus** linuron | 2.25 + 0.250 | 33 | 0.286 | 38 | 0.687 | 19 | 0.240 |
| | 2.25 + 0.375 | 11 | 0.098 | 36 | 0.432 | 4 | 0.027 |
| | 2.25 + 0.500 | 11 | 0.051 | 37 | 0.443 | 1 | 0.002 |
| Propyzamide **plus** prometryne | 2.25 + 0.125 | 34 | 0.308 | 32 | 0.223 | 22 | 0.288 |
| | 2.25 + 0.250 | - | - | 32 | 0.399 | 10 | 0.017 |
| | 2.25 + 0.375 | - | - | 33 | 0.440 | 6 | 0.026 |
| | 2.25 + 0.500 | 1 | 0.002 | 34 | 0.624 | - | - |
| Propyzamide **plus** propachlor | 2.25 + 0.65 | 10 | 0.054 | 24 | 0.222 | 24 | 0.063 |
| | 2.25 + 1.30 | - | - | 31 | 0.226 | 12 | 0.039 |
| | 2.25 + 1.95 | - | - | 28 | 0.226 | 7 | 0.009 |
| Propyzamide **plus** diuron | 2.25 + 0.20 | 27 | 0.148 | 31 | 0.243 | 20 | 0.178 |
| | 2.25 + 0.40 | 33 | 0.188 | 29 | 0.205 | 17 | 0.015 |
| | 2.25 + 0.60 | 23 | 0.114 | 34 | 0.214 | 1 | 0.002 |
| | 2.25 + 0.80 | 3 | 0.008 | 33 | 0.219 | 1 | 0.003 |
| Propyzamide **plus** napropamide | 2.25 + 1.00 | 30 | 0.153 | 34 | 0.223 | 32 | 0.412 |
| | 2.25 + 1.50 | 33 | 0.125 | 36 | 0.378 | 44 | 0.076 |
| Propyzamide **plus** diphenamide | 2.25 + 1.60 | 35 | 0.166 | 31 | 0.468 | 44 | 0.280 |
| | 2.25 + 2.40 | 34 | 0.163 | 35 | 0.254 | 33 | 0.068 |
| Propyzamide **plus** oryzalin | 2.25 + 0.25 | 33 | 0.151 | 36 | 1.053 | 12 | 0.018 |
| | 2.25 + 0.50 | 32 | 0.116 | 32 | 0.726 | 2 | 0.003 |

[1] Data are totals for the four replicates.
[2] +AC = activated carbon added and -AC = no activated carbon added.

Sowing treatments that did not include activated carbon did not reduce the phytotoxicity of the herbicides to lettuce (Table 3). Under these conditions, mixtures containing linuron or diuron were very toxic. Application of activated carbon on the soil surface above the seed gave superior protection compared with its application in xanthan gum (Table 3).

Placement of activated carbon on the soil surface increased lettuce yield in the absence of herbicides as it had done in the glasshouse (Table 3). When herbicides were applied over the activated carbon the optimum rates were linuron (0.5 kg/ha), prometryne (0.25-0.50 kg/ha), diuron (0.75 kg/ha), propachlor (1.0 kg/ha) and napropamide (3.0 kg/ha). However, by comparison with the hand-weeded control, yields were depressed even at the lowest rates of linuron, prometryne and propachlor (Tables 3 and 4). These results have been confirmed in other field experiments at Richmond and Gosford, NSW. In choosing between the optimal rates of diuron and napropamide, horticulturists should consider both the cost of the herbicides and their residual effects on following crops.

Table 3. Weight (g) of lettuce plants 60 days after emergence in the field trial[3].

| Herbicide treatments | | Fresh weight of lettuce (kg) | | | |
|---|---|---|---|---|---|
| | | Sowing treatments | | | |
| Combination | Rate (kg/ha) | Seed only | Seed+X[1] | Seed+AC[2] | Seed+X+AC[2] |
| Nil control | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Hand weeded | 0 | 30.4 | 22.2 | 33.2 | 28.6 |
| Propyzamide | 3 | 5.4 | 7.1 | 7.9 | 6.7 |
| Propyzamide | 3 + 0.50 | 0.0 | 0.0 | 25.4 | 6.4 |
| **plus** linuron | 3 + 0.75 | 0.0 | 0.0 | 9.7 | 2.3 |
| | 3 + 1.0 | 0.0 | 0.0 | 11.3 | 0.3 |
| Propyzamide | 3 + 0.25 | 12.3 | 10.6 | 27.5 | 19.4 |
| **plus** prometryne | 3 + 0.50 | 4.4 | 3.0 | 28.0 | 17.2 |
| | 3 + 0.75 | 1.4 | 2.4 | 20.7 | 14.8 |
| Propyzamide | 3 + 0.50 | 0.5 | 0.1 | 29.9 | 13.0 |
| **plus** diuron | 3 + 0.75 | 0.0 | 0.0 | 34.7 | 3.0 |
| | 3 + 1.00 | 0.2 | 0.0 | 23.0 | 3.7 |
| Propyzamide | 3 + 0.5 | 16.1 | 12.7 | 21.9 | 19.5 |
| **plus** propachlor | 3 + 1.0 | 11.3 | 5.8 | 26.1 | 18.4 |
| | 3 + 2.0 | 1.7 | 6.3 | 24.4 | 13.1 |
| Propyzamide | 3 + 1.0 | 4.9 | 8.0 | 30.9 | 11.6 |
| **plus** | 3 + 2.0 | 0.7 | 2.1 | 31.3 | 8.6 |
| napropamide | 3 + 3.0 | 0.2 | 0.3 | 35.2 | 2.3 |

[1] X = xanthan gum.
[2] AC = activated carbon added.
[3] Data are total for the four replicates.

Table 4. Lettuce yield in the field experiment relative to the hand weeded control when activated carbon applied on the soil surface is used to protect the seed.

| Treatment | Lettuce yield as a per cent of hand weeded control calculated for different herbicide application rates[1] | | Comments |
|---|---|---|---|
| | Optimum rate[2] | Average for three rates[2] | |
| Nil treatment | 0.0 | 0.0 | Weeds completely overgrew the plots |
| Propyzamide | 23.8 | 23.8 | Potato weed reduced yield on these plots |
| Propyzamide plus linuron | 76.5 | 46.5 | No weeds |
| Propyzamide plus prometryne | 84.5 | 76.5 | No weeds |
| Propyzamide plus diuron | 104.5 | 88.0 | No weeds |
| Propyzamide plus napropamide | 105.9 | 97.7 | No weeds |

[1] Data calculated from Table 3.
[2] Rates given in Table 3.

As a result of these experiments a prototype machine has been developed to sow seed and apply a small patch of activated carbon on the surface of the soil above the seed prior to herbicide application.

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