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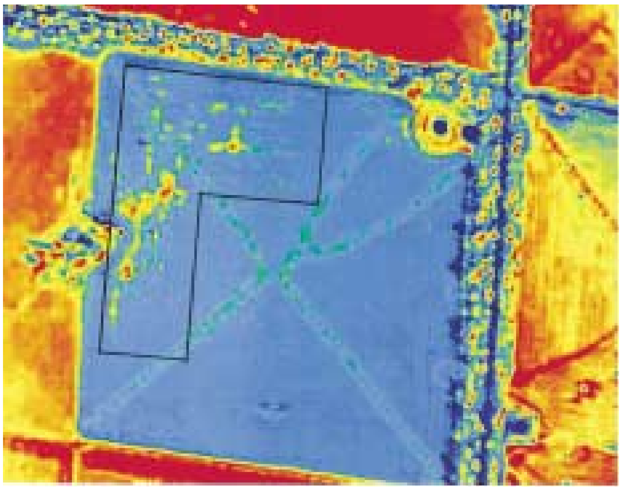

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# Post emergence spraying of clopyralid, picloram or pyridate in broccoli, Chinese cabbage, cabbage, or cauliflower kills weeds, with minimal crop damage

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*Abstract.* We investigated potential post-emergence herbicides for managing broadleaf weeds in broccoli, Chinese cabbage, cabbage, and cauliflower, as no products are currently registered for these uses in Australia. Subsequent to spraying clopyralid, picloram, or pyridate 5 weeks after direct-sowing broccoli or Chinese cabbage, or transplanting cabbage or cauliflower seedlings, we recorded crop phytotoxicity symptoms, measured marketable crop yields, and assessed weed control achieved. Neither maximum application rates of 90 g clopyralid/ha, nor 45 g clopyralid/ha mixed with 30 g picloram/ha, adversely affected vegetable yields. Spraying 60 g/ha clopyralid controlled burr medic (*Medicago polymorpha*), and suppressed common sowthistle (*Sonchus oleraceus*). Applying 90 g clopyralid/ha, or mixing 22.5 g clopyralid/ha with 15 g picloram/ha, controlled both burr medic and common sowthistle. At the rates tested, neither clopyralid nor picloram affected deadnettle (*Lamium amplexicaule*). Applying 450 g pyridate/ha caused chlorotic spotting of the sprayed vegetable leaves, but did not affect marketable yields of broccoli, cabbage or cauliflower. This rate controlled deadnettle, reduced sowthistle growth by only 30–50% compared with an unweeded control, and had no impact on burr medic. Spraying 900 g pyridate/ha increased the severity and persistence of chlorotic spotting, and resulted in lower broccoli and Chinese cabbage yields than obtained in the best treatments in the respective experiments. Cabbage and cauliflower yields were unaffected by spraying 900 g pyridate/ha. This rate improved sowthistle control to a commercially acceptable level. Our studies suggest that both clopyralid and pyridate could be successfully utilised in Australian vegetable brassica production, providing issues of the residual activity of clopyralid on following crops, and optimal application rates and timing for pyridate, were resolved.

## Introduction

Weed management comprises an average 8% of the pre-harvest variable costs of producing Chinese cabbages, broccoli, cabbages, and cauliflowers (Richardson pers. comm.). At present, brassica vegetable producers rely on combinations of cultivation, herbicide spraying, and hand weeding. Pre-emergence herbicides currently registered for use in transplanted brassica vegetables include pre-plant applications of trifluralin, pendimethalin or oxyfluorfen, or post-plant applications of metolachlor, S-metolachlor, propachlor or chlorthal-dimethyl (DPI INFOPEST 2001). Only trifluralin and chlorthal-dimethyl are registered for use in direct-sown brassica vegetables. Clethodim, fluazifop-p, quizalofop-p-ethyl, quizalofop-p-tefuryl and sethoxydim can be sprayed post-emergence for grass control. Paraquat and diquat can be spot sprayed, or applied with shielded sprayers to kill weeds inter-row. There are no herbicides registered in Australia for over-the-top, post-emergence spraying of broadleaf weeds in brassica vegetables.

Clopyralid, a pyridine herbicide (Australian Resistance Group I – disruptor of plant cell growth), is registered for use on brassica vegetables in England at a rate of 60–90 g/ha (Dow AgroSciences pers. comm.). The herbicide is applied once direct-sown brassicas have at least 2 true leaves, or transplanted crops have established and are growing strongly. Clopyralid is particularly active against Asteraceae, Fabaceae, Polygonaceae, and Solanaceae species (Weed Science Society of America 1989). Clopyralid formulations are registered in Australia for post-emergence use at 90 g clopyralid/ha in canola production (DPI INFOPEST 2001). Apart from killing emerged weeds, clopyralid also has substantial residual activity, inhibiting successful emergence of new weeds for many weeks following application.

In New Zealand, spraying 0.35 L/ha of a proprietary mix containing 225 g/L of clopyralid and 150 g/L of picloram is registered for weed management in fodder brassicas (Dow AgroSciences pers. comm.). Picloram provides a broader spectrum of weeds killed than clopyralid alone. Interestingly, Hall and Soni (1989) demonstrated that addition of clopyralid to a post-emergence picloram spray reduced the phytotoxic effects of picloram on *Brassica napus*.

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Pyridate is widely used at rates of 0.9–1.0 kg pyridate/ha in many parts of the world for weed management in brassica vegetables, particularly cabbages, although phytotoxicity is occasionally reported at such concentrations (Bullen *et al.* 1993; Bellinder *et al.* 1997). Pyridate is a phenyl-pyridazine herbicide (Australian Resistance Group C – inhibitor of photosynthesis at Photosystem II), with a different mode of action to clopyralid and picloram. Pyridate is more active than clopyralid against species such as fat hen (*Chenopodium album*), but is less effective against Fabaceae (Bullen *et al.* 1993; Parks *et al.* 1996).

Australian brassica vegetable industries seek post-emergence broadleaf herbicide options as part of integrated weed management systems. Post-emergence spraying could kill susceptible broadleaf weeds that were not controlled by pre-emergence herbicides (particularly in direct-sown brassicas where the pre-emergence herbicide options are limited). Post-emergence spraying (e.g. 90 g clopyralid/ha costing A$30) is cheaper than hand weeding (e.g. A$150/ha for chipping a moderately weedy field). Apart from in-crop benefits of reduced competition, minimising weed seed-set for long-term weed management may be an even more important outcome of such a spray program (Henderson and Bishop 2000; Jones 2000). The availability of new herbicide options would enhance herbicide rotation systems, to minimise the development of herbicide resistance and other long-term problems.

This paper describes the crop damage incurred and weed management achieved when we sprayed clopyralid, clopyralid/picloram mixtures, and pyridate for post-emergence weed control in broccoli, cabbage, cauliflower and Chinese cabbage crops.

## Materials and methods

The experiments were conducted during 1997 on a black earth soil containing 40–60% montmorillonite clays, at the Queensland Department of Primary Industries Gatton Research Station (27°33′S, 152°20′E). We grew broccoli (cv. Greenbelt), Chinese cabbage (cv. Hong Kong), cabbage (cv. Warrior), and cauliflower (cv. Plana) using irrigation, nutrition, and insect and disease management practices appropriate for each crop. Research station staff incorporated 400 kg/ha of a compound fertiliser (12% N, 5.2% P, 14% K, 4% S, 5% Ca and 1% Mg) into the soil 3 weeks before planting. They broadcast urea fertiliser at 60 kg N/ha 7 weeks after planting, and then incorporated that fertiliser with irrigation. Research station staff sprayed micronutrient solutions containing boron and molybdenum over the crop canopy on the same day they applied urea. They sprayed the crops with copper hydroxide to manage diseases, and with methomyl, chlorpyrifos, prothiofos, mevinphos, methamidophos, and dimethoate to manage insects. The experiments were irrigated about once a week with 20–30 mm of water, ensuring the vegetables did not suffer water stress.

Broccoli and Chinese cabbage were sown as seeds on 4 June 1997 and 4-week-old seedlings of cabbage and cauliflower were transplanted on the same day. Inter-row spacing for the Chinese cabbage was 0.50 m, and 0.75 m for the broccoli, cabbage, and cauliflower. Broccoli and Chinese cabbage were 0.33 m apart within rows, while intra-row spacing for cabbage and cauliflowers was 0.67 m.

A separate experiment was conducted for each of the 4 vegetable crops. In each experiment, 8 weed management treatments were replicated 4 times in a completely randomised design, with each plot 10 m long and 1.5 m wide. Six different post-emergence herbicide treatments were sprayed 5 weeks after sowing/transplanting, using a 1.5 m wide hand-held boom (with 5 flat-fan 100° hydraulic nozzles) applying 300 L/ha of solution at an operating pressure of 200 kPa. Wind speed at the time of spraying was <5 km/h, air temperature was 14°C and relative humidity was 85%. The 6 treatments that included herbicides were: (i) 60 g clopyralid/ha; (ii) 90 g clopyralid/ha; (iii) 22.5 g clopyralid/ha plus 15 g picloram/ha; (iv) 45 g clopyralid/ha plus 30 g picloram/ha; (v) 450 g pyridate/ha; or (vi) 900 g pyridate/ha. These rates were based on levels used in brassica vegetables overseas, and in consultation with manufacturing company technical representatives. The 6 herbicide treatments were compared with treatments (vii) hand weeded on 2 occasions (6 and 14 weeks after planting) or (viii) left unweeded.

The clopyralid formulation comprised 300 g clopyralid/L of aqueous concentrate and the pyridate formulation comprised 450 g pyridate/kg of wettable powder. The clopyralid/picloram mixture was an aqueous concentrate containing 225 g clopyralid/L and 150 g picloram/L.

### *Measurements*

*Crops.* The vegetable crops were visually assessed 10 days after spraying, and any symptoms of herbicide damage were noted. As they matured, the vegetables were harvested from the central 8 m length of each plot. All marketable broccoli heads were sequentially harvested 94, 97 and 99 days after planting (DAP) as the individual heads matured. The number of heads and their total weight were recorded at each harvest. All the marketable Chinese cabbages were cut 91 DAP, counted, and the weight of 18 randomly selected heads was noted. The marketable cabbage heads were cut 104 DAP, counted, and 6 randomly selected heads were weighed. The main cauliflower harvest took place 98 DAP, with a secondary harvest 6 days later. On each occasion, the numbers and weights of marketable heads in the sample area were noted.

*Weeds*. Weed densities were initially assessed 2 weeks before the herbicides were sprayed. At this assessment, the numbers of each weed species in 5 randomly placed 0.5 $m^2$ quadrats per plot were counted. Weed populations were assessed again 6 weeks after spraying, by counting the total numbers of each weed species in the central 8 $m^2$ of each plot. When the vegetables were near or at maturity (about 14 weeks after planting), all the weeds were harvested from the central 12 $m^2$ of each plot by cutting them off at ground level. The weeds were separated into species, counted, and immediately weighed (fresh).

### *Statistical analyses*

Each experiment was analysed separately at first and all crop yield variables were analysed using standard analysis of variance procedures. Owing to the nature of their distributions, log transformations of weed counts and biomass measurements were required as part of the analysis of variance process. Similar transformed means and error variances occurred for each weed species in the 4 crop experiments. On this basis, the weed population and biomass results were combined and mean values were determined for all experiments. Crop yield means and the transformed weed variate means were compared using the protected l.s.d. procedure operating at $P = 0.05$. The weed variate means were back-transformed for presentation.

## Results

### *Crop yields*

*Broccoli*. Treatments sprayed with 60 g clopyralid/ha or the low rate clopyralid/picloram mixture out-yielded both the hand-weeded and unweeded control treatments (Table 1). Broccoli yields from the higher rate of clopyralid or high rate

**Table 1. Marketable yields of four brassica vegetables following hand weeding, post-emergence herbicide applications, or no weed control practices**

Values followed by the same letter are not significantly different at $P = 0.05$

| Treatment | Broccoli yield (t/ha) | Chinese cabbage yield (t/ha) | Cabbage yield (t/ha) | Cauliflower yield (t/ha) |
|---|---|---|---|---|
| 60 g clopyralid/ha | 9.71c | 111.1a | 57.5a | 29.8a |
| 90 g clopyralid/ha | 9.37bc | 129.2ab | 59.2a | 36.3ab |
| 22.5 g clopyralid/ha + 15 g picloram/ha | 9.81c | 135.8b | 60.8a | 37.5b |
| 45 g clopyralid/ha + 30 g picloram/ha | 8.85abc | 121.8ab | 58.0a | 40.0b |
| 450 g pyridate/ha | 8.63abc | 113.7a | 57.6a | 35.7ab |
| 900 g pyridate/ha | 7.50a | 112.1a | 56.3a | 36.1ab |
| Weeded | 7.78ab | 130.4ab | 61.7a | 38.2b |
| Unweeded | 7.97ab | 118.7ab | 60.1a | 32.5ab |

clopyralid/picloram mixture were not significantly less than the highest yields in the experiment. Where pyridate was applied at 900 g/ha, chlorotic spotting of sprayed leaves was observed. This treatment resulted in the lowest broccoli yields in the experiment. Any yield reductions were associated with both fewer and smaller marketable heads.

*Chinese cabbage*. Yields from Chinese cabbages sprayed with 60 g/ha clopyralid, or either rate of pyridate, were less than yields from areas treated with the mixture of 22.5 g/ha clopyralid with 15 g/ha picloram (Table 1). There were no significant differences in the number of marketable Chinese cabbage heads in each treatment. Any yield reductions were due to smaller individual heads.

*Cabbage*. There were no differences in cabbage yields associated with weed management treatments (Table 1).

*Cauliflower*. Cauliflower plants sprayed with only 60 g/ha clopyralid yielded less than plants sprayed with the clopyralid/picloram mixtures or the hand weeded control (Table 1). Crops sprayed with pyridate also yielded well. Lower yields were associated with smaller individual heads, rather than fewer marketable units.

### *Weed management*

Weeds present in the experimental area in sufficient numbers to effectively analyse included common sowthistle (*Sonchus oleraceus*), deadnettle (*Lamium amplexicaule*), and burr medic (*Medicago polymorpha*). Fat hen (*Chenopodium album*) was present at low densities, whilst lesser swinecress (*Coronopus didymus*), London rocket (*Sisymbrium irio*) and shepherd's purse (*Capsella bursa-pastoris*) were also sporadically recorded within the experimental area.

In the weed counts conducted 1 week before the post-emergence treatments were sprayed, sowthistle (mean 5.8 plants/$m^2$) and deadnettle (mean 2.8 plants/$m^2$) were found to be relatively common, whilst other weed species were sporadically distributed, with mean densities around 0.1 plants/$m^2$.

*Sowthistle*. Sowthistle was by far the most ubiquitous and dominant weed in the experimental area. Compared with the unweeded treatments, applying 60 g clopyralid/ha or 900 g pyridate/ha reduced the density of sowthistles present 6 weeks after spraying (Table 2). The higher clopyralid application rate of 90 g/ha, or the low rate clopyralid/picloram combination, killed more sowthistles than 450 g pyridate/ha. The highest rate of clopyralid/picloram virtually eliminated sowthistle.

By the time the brassica crops were harvested, the biomass developed by the sowthistle was consistent with the weed densities recorded several weeks earlier. There was

**Table 2. The effects of six weed management treatments on sowthistle (*Sonchus oleraceus*) and deadnettle (*Lamium amplexicaule*) densities six weeks after spraying, and biomass at crop harvest**

Values in parentheses (transformed treatment means) followed by the same letter are not significantly different at $P = 0.05$

| Treatment | Sowthistle | | Deadnettle | |
|---|---|---|---|---|
| | Density (plants/$m^2$) | Biomass (g/$m^2$) | Density (plants/$m^2$) | Biomass (g/$m^2$) |
| 60 g clopyralid/ha | 1.43 (3.11bc) | 170.6 (7.62de) | 1.73 (3.30c) | 17.5 (5.35b) |
| 90 g clopyralid/ha | 0.68 (2.41b) | 99.6 (7.09cd) | 1.60 (3.22c) | 23.5 (5.64b) |
| 22.5 g clopyralid/ha + 15 g picloram/ha | 0.71 (2.45b) | 44.1 (6.27c) | 0.89 (2.66bc) | 11.4 (4.93b) |
| 45 g clopyralid/ha + 30 g picloram/ha | 0.08 (0.81a) | 1.2 (2.72a) | 0.75 (2.51bc) | 16.0 (5.26b) |
| 450 g pyridate/ha | 2.36 (3.59cd) | 399.0 (8.47ef) | 0.13 (1.10a) | 0.3 (1.53a) |
| 900 g pyridate/ha | 1.06 (2.83bc) | 97.8 (7.07cd) | 0.14 (1.11a) | 0.2 (1.18a) |
| Weeded | 0.90 (2.67bc) | 11.7 (4.95b) | 0.48 (2.10ab) | 0.4 (1.71a) |
| Unweeded | 4.96 (4.32d) | 718.8 (9.06f) | 1.00 (2.77bc) | 10.3 (4.83b) |

minimal sowthistle growth in the hand weeded treatments, or those sprayed with the high rate clopyralid/picloram mixture, particularly compared with the 700 g/m$^2$ of fresh sowthistle biomass produced where weed management was not imposed. The next best treatment was the low rate clopyralid/picloram mixture. Either 90 g clopyralid/ha or 900 g pyridate/ha gave acceptable control of sowthistle. Spraying 60 g clopyralid/ha still allowed sowthistle to produce 25% of the biomass of the unweeded areas, whilst 450 g pyridate/ha was ineffective against this species.

*Deadnettle*. By 6 weeks after spraying, neither clopyralid nor clopyralid/picloram mixtures had reduced deadnettle populations compared to the unweeded controls (Table 2). Applying 450 g/ha of pyridate reduced deadnettle populations to less than 1 plant per 7 m$^2$, with no improvement in efficacy from doubling the concentration of pyridate. When the brassicas were harvested, areas sprayed with clopyralid and clopyralid/picloram mixtures had similar deadnettle biomass to the unweeded controls, whilst both pyridate treatments reduced deadnettle biomass by 98%.

*Burr medic.* The populations of this species were relatively low, and confounded by competition with the more common weeds, sowthistle, and deadnettle. Nevertheless, there were consistencies in the results that clarify the picture. By 6 weeks after spraying, application of clopyralid reduced burr medic densities by 85% compared to the unsprayed controls (Table 3), with no difference between the rates of application. Burr medic was completely eliminated in treatments sprayed with mixtures of clopyralid and picloram. In contrast, spraying pyridate had no effect on the density of burr medic present in the brassica crops.

Although low in absolute terms, the biomass of burr medic present when the brassicas were harvested was consistent with the earlier population assessments. All the clopyralid and clopyralid/picloram mixtures controlled burr medic, while pyridate had no effect.

*Other weeds.* Although fat hen densities were similar to those of burr medic, results were too inconsistent to draw any definitive conclusions. When weeds were counted 6 weeks after spraying, there were no differences in densities between treatments (Table 3). Similarly, when the brassica crops were harvested, any differences in fat hen biomass were inconclusive.

There were insufficient densities of the brassica weed species, lesser swinecress, London rocket or shepherd's purse, in the experiment to draw definite conclusions. There were no reductions in densities or final biomass of these species associated with any of the herbicide treatments (data not presented).

## Discussion

Although Chinese cabbages or cauliflowers sprayed with 60 g clopyralid/ha yielded less than the highest yields in their respective experiments, the high yields where those crops were sprayed with 90 g/ha of clopyralid suggest phytotoxicity from this chemical was not responsible for any observed yield reductions. It is more likely that the amount of sowthistle present in those treatments resulted in weed competition sufficient to slightly reduce Chinese cabbage or cauliflower yields.

In the experiments reported here, the rates of clopyralid and clopyralid/picloram mixtures used did not damage any of the brassica vegetables evaluated (broccoli, Chinese cabbage, cabbage or cauliflower). Spraying 90 g clopyralid/ha, or a mixture of 22.5 g clopyralid/ha with 15 g picloram/ha gave commercially acceptable control of sowthistle and burr medic. Neither herbicide affected deadnettle at the highest application rates tested.

Both clopyralid and picloram would be useful weed management tools for brassica vegetable producers. A concern with these herbicides is persistence of soil residues once the brassica crops are harvested. Persistent soil residues would have substantial implications for crop rotation management, an important consideration in intensive vegetable cropping regions. Both herbicides are degraded by microbial activity, which is favoured by high soil temperatures and moist soils. Periods between clopyralid and/or picloram use and planting sensitive crops (such as

**Table 3. The effects of six weed management treatments on burr medic (*Medicago polymorpha*) and fat hen (*Chenopodium album*) densities six weeks after spraying, and biomass at crop harvest**

Values in parentheses (transformed treatment means) followed by the same letter are not significantly different at $P = 0.05$

| Treatment | Burr medic | | Fat hen | |
|---|---|---|---|---|
| | Density (plants/m$^2$) | Biomass (g/m$^2$) | Density (plants/m$^2$) | Biomass (g/m$^2$) |
| 60 g clopyralid/ha | 0.01 (0.09a) | 0.04 (0.40ab) | 0.04 (0.46a) | 0.18 (1.14ab) |
| 90 g clopyralid/ha | 0.01 (0.13a) | 0.02 (0.19ab) | 0.06 (0.66a) | 0.19 (1.20ab) |
| 22.5 g clopyralid/ha + 15 g picloram/ha | 0.00 (0.00a) | 0.04 (0.42ab) | 0.03 (0.34a) | 0.04 (0.40a) |
| 45 g clopyralid/ha + 30 g picloram/ha | 0.00 (0.00a) | 0.00 (0.00a) | 0.03 (0.32a) | 0.10 (0.80ab) |
| 450 g pyridate/ha | 0.03 (0.35ab) | 0.23 (1.33bc) | 0.01 (0.17a) | 0.12 (0.87ab) |
| 900 g pyridate/ha | 0.07 (0.75bc) | 1.89 (3.16d) | 0.04 (0.43a) | 0.11 (0.82ab) |
| Weeded | 0.11 (0.95c) | 0.09 (0.76ab) | 0.02 (0.29a) | 0.04 (0.38a) |
| Unweeded | 0.07 (0.68bc) | 0.50 (1.95c) | 0.04 (0.50a) | 0.45 (1.86b) |

lettuce or beans) would be longer in southern vegetable producing areas of Australia than in Queensland.

Although 450 g pyridate/ha caused initial chlorotic flecking of sprayed crop leaves, yield reductions in broccoli, cabbage or cauliflower were not statistically detectable. Where this rate was doubled to 900 g pyridate/ha, the chlorotic flecking was more pronounced and persistent. Herbst and Derr (1990), Bullen *et al*. (1993), and Al-Khatib *et al*. (1995) all noted that post-emergence application of pyridate caused chlorotic spotting in brassica vegetables. However, overseas studies suggest damage at up to 1.0 kg/ha of pyridate to cabbage was transient, and did not affect final yields (Bullen *et al.* 1993; Bellinder *et al*. 1997). In our investigations, broccoli and Chinese cabbage sprayed with 900 g pyridate/ha yielded less than the best treatments in our experiments. This agrees with the findings of Herbst and Derr (1990) that 0.9–1.0 kg pyridate/ha is at the marginal limits of crop safety in direct-sown broccoli.

Our results show broccoli and Chinese cabbage to be more sensitive to pyridate than cabbage or cauliflower, which may be related to the timing of spraying in relation to crop development stage. Bellinder *et al*. (1997) discussed the need to investigate the interactions between time of pyridate application and leaf cuticle development in cabbage plants, as a means of reducing the risk of crop phytotoxicity.

The experiments described in this paper suggest that an application rate of about 600–700 g pyridate/ha should give acceptable weed control, whilst reducing crop damage risks. Although spraying 450 g pyridate/ha killed deadnettle, the higher rate was required to give commercially acceptable control of sowthistle. Pyridate did not control burr medic or weeds from the Brassicaceae family.

If both clopyralid and pyridate were available for post-emergence use in brassica vegetables, producers could select the most appropriate herbicides for the key weeds present. Where weeds from the Asteraceae or Fabaceae families dominate spectrums, clopyralid would be the herbicide of choice. Our experiments, and other investigations (Bullen *et al*. 1993) indicate pyridate is preferred where deadnettle or fat hen is more problematic.

Our studies suggest clopyralid and pyridate could be successfully used in Australian vegetable brassica production. More investigation is needed into the rotational implications of using clopyralid, and the best application timing and rate for efficacious and safe use of pyridate.

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