Abutilon theophrasti – its biology and management in New Zealand

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Summary *Abutilon theophrasti* Medikus is a declared 'Unwanted Organism' and has been subject to a control programme on 41 properties in Waikato, New Zealand since it's discovery in 2011. In 2015 *A. theophrasti* seed was introduced into New Zealand as a contaminant in fodder beet (*Beta vulgaris* L.) seed and later found to have grown on at least 250 farms throughout the country. In response, the Ministry for Primary Industries objective is 'containment with the long-term goal of eradication'. To assist with achieving this, a research programme commenced in 2016 to better understand critical aspects of the biology of *A. theophrasti* and to develop improved management programmes that also aid surveillance.

Field trials demonstrated excellent post-emergence control of *A, theophrasti* in maize with topramezone + atrazine + crop oil, in barley with MCPA + carfentrazone, and in pasture with flumetsulam + bentazone (small plants only) or 2,4-D. Results from the laboratory showed *A. theophrasti* seed emerging from depths up to 120 mm and germination commencing at 6°C. However, results from the field demonstrated germination typically occurred at higher temperatures, peaking in January in open ground and February in pasture.

Keywords Indian mallow, velvetleaf, control.

INTRODUCTION

Abutilon theophrasti Medikus, known variously as Indian mallow, velvetleaf or butter print, is a weed in many countries in North America, Europe, Asia and Africa (Warwick and Black 1988, Sattin *et al*. 1992). It was introduced to North America in the 18th century from China and has now become the main broadleaf weed in maize (*Zea mays* L.) and soyabean (also known as soybean (*Glycine max* (L.) Merr.)) crops there.

Abutilon theophrasti is a member of the mallow family (Malvaceae) and is easily distinguished by its tall, erect habit, its large, alternate, heart-shaped leaves which are soft and velvety to the touch and have a musky odour. It has small yellow to yellow-orange flowers which only open for a few hours during the hottest part of the day. It has distinctive black seed pods containing about 40 large, hard black seeds that show great persistence in the soil seed bank (Warwick and Black 1988, Cardina and Sparrow 1997). It is a summer-growing annual plant which has the ability to germinate throughout the warmer months. Growing to 3 m tall, its biological and ecological characteristics make it particularly competitive and persistent in cultivated fields. It has been reported to cause severe crop losses particularly in fields of maize, sorghum, soya bean and cotton (Spencer 1984). As *A. theophrasti* can germinate throughout the warm season, it is very difficult to eradicate and once established, it is almost impossible to avoid seed production (Warwick and Black 1988, Sattin *et al.* 1992).

The first reports of it in New Zealand are herbarium records from 1929 and 1948 where it was introduced for evaluation as a crop, the latter sourced from United States of America (Anon 2018). Since then it has been accidently imported with soyabean seed and as a contaminant of other grains. It is presently unknown if any of these persisted to the present day.

In 2011, a paddock size infestation of *A. theophrasti* was found in Waikato (James and Cooper 2012) and resulted in the Ministry for Primary Industries (MPI) declaring it an 'Unwanted Organism'. This initiated an incursion response and *A. theophrasti* has since been tracked to more than 40 other locations in the upper North Island. In 2015, *A. theophrasti* seed was introduced as a contaminant in six lines of fodder beet (*Beta vulgaris* L.) seed from Italy and was subsequently found in about 250 paddocks spread across New Zealand. Rapid response searches and effective tracing quickly delimited both the Waikato and the new fodder beet incursions. Tailored farm management plans were written for all affected properties and their implementation along with continuing surveillance appears to have contained the weed. The Ministry for Primary Industries current objective is 'containment with the long-term goal of eradication'. To assist with achieving this, a research programme commenced in 2016 to better understand critical aspects of its biology and to develop improved management programmes that also aid surveillance. Results from this programme are reported here.

MATERIALS AND METHODS

All the field trials reported here were carried out at the AgResearch trial site near Matamata in Waikato, where there was a natural soil seed bank of *A. theophrasti* from an uncontrolled incursion.

Soil seed bank depletion At the trial site, an area of land 30 × 10 m was treated with glyphosate and then cultivated on 31 October 2016, 22 December 2016, 18 January 2017 and 1 March 2017 using a power harrow (3–4 passes). The following season the trial area was extended into the pasture by 10 m (now 40 × 10 m), treated with glyphosate and the total area cultivated on 17 November 2017, 9 December 2017, 9 January 2018 and 27 February 2018. About 4 weeks after each cultivation all *A. theophrasti* plants in the old (2016/2017) or both old and new (2017/2018) areas were separately counted and removed.

Control of *A. theophrasti* in pasture On 15 February 2017, a randomised, four replicate trial with 2 × 6 m plots and eight treatments (Table 1) was pegged out and sprayed. In two of the replicates *A. theophrasti* plants were 20–250 mm high with 3–7 leaves while the other two replicates had *A. theophrasti* plants only 20–130 mm high with 3–6 leaves. All treatments were applied in 200 L ha^{-1} water with a CO_2 powered backpack precision sprayer fitted with a 2 m boom and four TeeJet AI-11002 nozzles. At the time the ambient temperature was 22–23°C and there had been light rain (2–3 mm) the previous day. Plant counts per plot were made immediately prior to spraying and again on 7 March 2017 at which time all the *A. theophrasti* plants were removed as some had commenced flowering.

Table 1. Control of *A. theophrasti* in pasture.

Herbicide	Rate g ai ha^{-1}	Plants $plot^{-1}$	
		Pre-spray	Final
Untreated	–	23	42
Flumetsulam + bentazone	51 + 1440 g	40	11
Triclopyr + picloram + aminopyralid	150 + 50 + 4 g	41	80
Flumetsulam	52 g	32	3
2,4-D	2280 g	33	0
MCPA+MCPB	100 + 1500 g	20	20
Triclopyr + aminopyralid	400 + 60 g	41	52
Aminopyralid	60 g	45	71
LSD (P<0.05)		22.4	15.2

Control of *A. theophrasti* in maize and barley On 21 November 2017, a randomised, four replicate trial with 2 × 6 m (barley (*Hordeum vulgare* L.)) and 3 × 6 m (maize) plots and five treatments (Table 2) was pegged out, planted and pre-emergence treatments applied (sunny, 23°C). On 13 December 2017 early post-emergence treatments were applied (sunny, 24°C) to the plots previously treated with the pre-emergence treatments. On 8 January 2018 the late post-emergence treatments were applied (sunny, 25°C) to the plots that had not received any previous herbicide treatments. All treatments were applied as above with either a 2 m or 3 m boom (TeeJet AI-11003 nozzles) to match plot width. Counts of *A. theophrasti* were made on 13 December 2017, 8 January 2018 and 15 February 2018 using four random throws of a 0.1 m^2 quadrat. At this time all *A. theophrasti* plants were removed to prevent seeding.

Depth of emergence Burial depth from which *A. theophrasti* seed can emerge was investigated using. 60 (15 depths × four replicates) PVC tubes each 100 mm in diameter and from 20 to 200 mm long. These were filled with Horotiu silt loam soil on 30 August 2016 and 10 *A. theophrasti* seeds placed on top. Further tubes were added above the seed level to give a total height of 200 mm, and filled with the same soil. This resulted in columns where the seeds were on the surface (0 mm) and where they were buried at 10 mm increments to 100 mm deep and 20 mm increments to 180 mm deep. Thus when assembled, each column was the same height and contained the same amount of soil. There were four replicate columns for each depth. The columns were maintained with both top- and sub-irrigation to keep the soil moist. The tubes with buried seeds were maintained in a controlled glasshouse with a night time minimum of 15°C and daytime maximum of 25°C. They were checked for emergence daily for 42 days, although emergence ceased after 17 days. Once the emergence date had been recorded, the newly-emerged plants were severed 5 mm above the ground so that further emergence of other seeds was not inhibited.

Critical temperatures for emergence A LinTek GR10D thermogradient table was used to evaluate germination temperatures for *A, theophrasti*. The table was set to run a one-way gradient, using a temperature range of 5°C to 35°C. Eight replicates of 25 seed were placed on separate blotters at each 1°C increment across the table. Observations were made daily for 3 weeks and germinated seeds (2 mm radicle) counted and removed at this time.

Table 2. *A. theophrasti* populations after pre- and post-emergence herbicides applied on 23.11.2017 and 8.1.2018 respectively.

Pre-emergence Crop/Herbicide	Rate (g ai ha^{-1})	Plant counts (# m^{-2}) 13.12.2017	Post-emergence Crop/Herbicide	Rate (g ai ha^{-1})	Plant counts (# m^{-2}) 8.1.2018
No crop, no herbicide	–	84	No crop, no herbicide	–	107
Maize, no herbicide	–	103	Maize, no herbicide	–	113
Maize + acetochlor + saflufenacil	2520 + 105 g	89	Maize, topramezone + atrazine	67 + 500 g	0
Barley, no herbicide	–	98	Barley, no herbicide	–	102
Barley + flufenacet + diflufenican	140 + 70 g	84	Barley, MCPA + carfentrazone	1170 + 17 g	0
LSD (P<0.05)		27.1			36.8

Table 3. Number of *Abutilon* seedlings at about 4 weeks after each cultivation.

Cultivation date	*A. theophrasti* seedlings	
	Original area Plants 300 m^{-2}	New area Plants 100 m^{-2}
31.10.16	119	–
22.12.16	497	–
18.1.17	149	–
1.3.17	15	–
17.11.17	354	2443
9.12.17	569	3522
9.1.18	29	296
27.2.18	117	526

RESULTS

Soil seed bank depletion The summer of 2016/2017 was 2–3°C cooler than average while that of 2017/2018 was 2–3°C warmer and wetter than average and too wet to cultivate the site until mid-November. The warmer summer of 2017/2018 is reflected in the emergence of *A. theophrasti* after cultivation with more seedlings emerging after the four cultivations in 2017/2018 compared to 2016/2017, even though no new seed was introduced to the site (Table 3).

Peak emergence occurred after the December cultivation in both years. In the new area cultivated for the first time after a year in pasture, large numbers of *A. theophrasti* still germinated in late February.

Control of *A. theophrasti* in pasture The results (Table 1) show two treatments, flumetsulam ± bentazone, controlling small plants but failing to control all the *A. theophrasti* in the two replicate plots containing larger plants (data not presented). In comparison, 2,4-D killed all the plants in all four replicate plots. Triclopyr, picloram, aminopyralid and MCPB+MCPA failed to achieve any control of *A. theophrasti*.

Control of *A. theophrasti* in maize and barley There was no rain within the two weeks of the application of the pre-emergence treatments, and consequently, they failed to control the *A. theophrasti* as it emerged (Table 2). In contrast both the early post-emergence treatments gave 100% control of the *A. theophrasti*. By the time the late post-emergence treatments were applied the *A. theophrasti* plants were 200–300 mm tall and although the treatments caused severe damage and defoliation, most of the *A. theophrasti* plants soon regrew (data not presented).

Depth of emergence All of the *A. theophrasti* seed placed at 20 mm depth emerged (Table 4). However, 80% or greater emerged from all depths up to 90 mm and 70% emerged from 100 mm depth. For the greater depths, only 8% emerged from 120 mm, and none emerged from 140, 160 or 180 mm depth. The cost of emergence from the greater depths was a delay in emergence time. Seeds buried between 10 and 30 mm emerged after 5 days while those planted at greater depths took longer to emerge (Table 4). For the seed on the surface and the seed at greater planting depths, emergence was more variable. The seed placed at 90 and 100 mm depth emerged over a 7-day period, 8–14 days after planting.

Critical temperatures for emergence On the thermogradient table, *A. theophrasti* had 17% germination at 5°C with germination commencing after 13 days (Table 5).

Table 4. Depth from which *Abutilon theophrasti* seedlings emerged (Number emerged is the sum of four replications (n = 40) seeds) at 42 days after planting.

Depth (mm)	Number emerged[1]	Time to emergence (d)	
		First	Last
0	37 ± 1.0	5	9
10	37 ± 1.0	5	5
20	40 ± 0	5	5
30	35 ± 0.5	5	6
40	37 ± 0.5	6	6
50	35 ± 0.5	6	8
60	38 ± 0.6	6	8
70	37 ± 1.0	6	12
80	32 ± 0.8	8	8
90	33 ± 1.0	8	14
100	28 ± 2.4	8	14
120	3 ± 1.5	12	12
140	0	–	–
160	0	–	–
180	0	–	–

[1] Cumulative total ± standard deviation.

Table 5. Germination of *Abutilon theophrasti* at different temperatures (Number emerged is the sum of eight replications (n = 200) seeds) at 21 days after planting.

Temp. (°C)	Number emerged[1]	Time to first emergence (d)
5	34 ± 3.3	13
6	63 ± 5.7	7
7	88 ± 7.9	6
8	116 ± 7.3	5
9	117 ± 6.8	4
10	132 ± 6.7	4
11	104 ± 8.0	4
12	109 ± 7.3	4
13	124 ± 6.9	4
14	112 ± 5.9	4
15	135 ± 4.8	4
16	148 ± 4.9	4
17	156 ± 3.5	4
18	168 ± 3.9	4
19	154 ± 5.2	4
20	183 ± 2.5	4
21–35	176–191	4

[1] Cumulative total ± standard deviation.

Total germination steadily increased up to about 20°C. Between 20 and 35°C the total germination remained constant and occurred at high numbers (176–191/200 seed). Time to germination was slower at 5°C, as the temperature increased, the time taken to germination decreased until 9°C. From 9°C until 35°C the time to germination at all temperatures was 4 days.

DISCUSSION

Although some mature *A. theophrasti* plants were found in the South Island after the fodder beet incursion of 2015/2016, no subsequent plants were found in 2016/2017 but 35 plants have been found at two sites in Canterbury in 2017/2018 (S. Beaumont, pers. comm.). This low number of subsequent finds could be due to the infested fields being returned to pasture and the cooler soil temperatures under pasture not being conducive to germination of *A. theophrasti*. In the North Island small numbers of *A. theophrasti* have been found in fields after the fodder beet incursion even though those fields were returned to pasture. This is supported by the observations of delayed emergence of this weed in pasture at the Waikato, North Island trial site. This field evidence also runs contrary to the results from the thermogradient table where *A. theophrasti* germinated at the low temperature of 6°C suggesting that other critical factors are involved. In controlled environment studies evaluating germination of *A. theophrasti* in soil, Mester and Buhler (1991) found that no seed germinated at 5°C, 30% at 10°C but peak germination was at 20°C. Horowitz and Taylorson (1984) also found 24–30°C to be optimal for germination of *A. theophrasti* and further that germination commenced to decline above 35°C, the limit of our experiment. This also fits with Sadeghloo *et al.* (2013) who found the three cardinal temperatures; base, optimum and ceiling, for *A. theophrasti* to be 5, 35 and 48°C respectively.

This project has demonstrated good control of *A. theophrasti* in pasture, maize and barley although maize is not a favoured crop as searching for escapes is difficult. Barley (for silage) may be a better alternative as any escaped *A. theophrasti* plants would be easier to find. Pasture is also an alternative for managing this weed but as results have demonstrated this crop reduces or prevents germination and the seed is likely to remain viable in the soil seed bank for a long time (Lueschen and Andersen 1980). Constantly reworking the soil should ultimately reduce the soil seed bank if fresh inputs of seed are denied but over the two-year period of this study there was little evidence of this.

Although we have demonstrated improved tools and identified important ecological data for *A. theophrasti* it will still remain a constant and long-term battle to eliminate this pernicious weed from New Zealand. To further assist farmers and authorities in this effort, over the next 3 years the research programme will:

- study the growth and development of *A. theophrasti* in different regions to determine Growing Degree Days to reach maturity and identify habitat limitation;
- investigate the genetics of various populations to determine whether there have been several incursions or simply recurring incidents;
- determine the interaction of *A. theophrasti* with other forage crops and develop management regimes to give farmers more options and allow for easier locating of isolated *A. theophrasti* escapes;
- extend the soil seed bank studies to other soil types and investigate means to more rapidly deplete the seed reservoir; and
- establish the criteria which would need to be met in order to declare a site free of *A. theophrasti*.

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