A survey of Apiaceae weeds in pyrethrum fields and an assessment of factors controlling the germination of *Torilis nodosa* and *Anthriscus caucalis*

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Summary Pyrethrum (*Tanacetum cinerariaefolium* L.) is a short-lived perennial horticultural crop grown in Northern Tasmania for the production of the natural insecticide, pyrethrin. Current weed management is heavily reliant on herbicide use and has unintentionally selected for a range of common plants e.g. *Trifolium repens* L. (white clover) and *Galium aparine* L. (cleavers) and also two newly emerged Apiaceae weeds *Anthriscus caucalis* M.Bieb. (burr chervil) and *Torilis nodosa* (L.) Gaertn. (knotted hedge parsley). Both *A. caucalis* and *T. nodosa* are a major concern to the industry as a result of lost productivity and cost of control. Although both species are commonly observed in pyrethrum no quantitative data is available on the severity and distribution of these species within pyrethrum growing districts. The first part of this paper reports the finding of a survey of all pyrethrum fields in which the occurrence and severity of Apiaceae weeds are integrated with the demographic distribution and agronomic history of pyrethrum fields.

In an attempt to manage these Apiaceae weeds, more detailed information is required on the factors influencing germination. Both species have been observed to behave predominantly as winter annuals germinating in the autumn and flowering in late spring to early summer, although some germination has also been observed to occur in early to mid spring. The second part of this paper reports the findings of laboratory and greenhouse experiments examining the effect of temperature, stratification, light, osmotic stress and planting depth on the germination and emergence of *T. nodosa* and *A. caucalis*.

Keywords Pyrethrum, weed survey, Apiaceae, *Anthriscus caucalis*, *Torilis nodosa*, germination.

INTRODUCTION

Weed mapping is a process of vital importance where the assessment of the level of a weed problem is sought and is a critical component in the development and monitoring of successful and economically sound weed management (Welsh 2000). At present no quantification or assessment of the level of infestation of *A. caucalis* or *T. nodosa* in pyrethrum crops has been undertaken. Such documentation will directly improve crop hygiene practices by reducing the level of transfer of seeds to non-infested fields by strategic harvesting procedures.

There is little published information regarding the factors involved in controlling seed germination of *T. nodosa* and *A. caucalis*, although other species of the family Apiaceae, previously Umbelliferae, have been examined in detail. Baskin *et al*. (2000) found germination of seeds of *A. sylvestris* increased with length of stratification period and was greater in light than in darkness and concluded that *A. sylvestris* displays morphophysiological dormancy, which is broken during winter allowing for spring germination. In contrast to the behaviour of *A. sylvestris*, *T. japonica* is a winter annual that disperses non-dormant seeds at maturity. Baskin and Baskin (1975) found that seeds of *T. japonica* which do not germinate in the autumn are induced into dormancy by low winter temperatures to prevent spring germination and during summer undergo an after ripening so that germination can occur in the following autumn.

An understanding of germination of *T. nodosa* and *A. caucalis* will provide valuable information for successful forecasting of germination trends and development of an effective integrated control program.

MATERIALS AND METHODS

Weed survey A total of 371 pyrethrum fields were surveyed across Northern Tasmania. Growing districts were divided into eight geographic areas (Figure 1); Burnie/Table Cape (1), Penguin/North Motton (2), Ulverstone/Kindred (3), Forth/Barrington (4), East Devonport/Wesley Vale (5), Latrobe/Sassafras (6), Deloraine/Cressy (7), North East (8). The number of sites surveyed within each district were, 52, 41, 75, 66, 51, 47, 26 and 13 respectively. Pyrethrum fields were assessed by visual examination. The presence or absence of the concerning weed species was recorded and where present the level of infestation was ranked accordingly:

- Low – Sparsely distributed and not forming dense patches. Total area effected <2 m^2
- Moderate – Weeds forming dense patches. Total area affected <30 m^2
- Severe – Weeds growing in numerous dense patches. Total area affected >30 m^2

- Very Severe – Immediate termination (removal) of crop due to an extremely high level of weed infestation.

Examination of sites occurred in late autumn/early winter 2001 at which time emergence and assessment of the target weeds was possible.

Germination experiments A tetrazolium (TZ) test (ISTA 1985) was used to determine the viability of freshly collected seed lots of *T. nodosa* and *A. caucalis*. Initial germination percentage was also assessed. Unless stated otherwise, individual treatments for all laboratory experiments consisted of 50 seeds placed on two sheets of 75 mm diameter Postlip filter paper moistened with de-ionised water in 85 mm petri dishes. Petri dishes were incubated in a Contherm™ Incubator 145 MCP at a constant 20°C, with 15 Watt fluorescent tubes, producing a light intensity at seed level of approximately 14 µmol s^{-1} m^{-2}. Following each experiment, ungerminated seeds were examined and recorded as being hard ungerminated seeds or empty seeds. Determination of hard and empty seed was achieved by the application of slight pressure with forceps (Ball and Miller 1989). A seed was considered germinated when the radicle protruded 1 mm from the seed coat (ISTA 1999).

Stratification Moistened seeds of *A. caucalis* and *T. nodosa* were stored at 4°C for 0, 1, 2, 3, 4, 6, 8, 12 and 16 weeks and subjected to 12 hours of light each day. Following pre-chill treatment seeds were transferred to a constant 20°C with 12 h of light each day. A second batch of seeds were also stratified at 4°C for 0, 2, 4, 8 and 16 weeks but kept in complete darkness for the duration of the pre-chilling treatment and following transfer to 20°C by applying a double wrapping of reflective aluminium foil around each petri dish. Seeds incubated in light were counted weekly following placement at 20°C for four weeks and germinated seeds were recorded and removed. Seeds incubated in complete darkness were counted only once after 3 weeks of incubation at 20°C.

Temperature effects A theremogradient table with 10 thermocouples was used to determine the effect of temperature on germination. The theremogradient plate had thermocouples spaced 15 cm apart resulting in regions with constant temperature ranging from 4.0°C to 38.0°C. Treatment temperatures are shown in Tables 1 and 2. Seeds were observed daily for 28 days and germination counts were recorded every 7 days after incubation. Temperatures above 25°C caused localised drying, and consequently seeds were re-moistened twice daily through out the experiment.

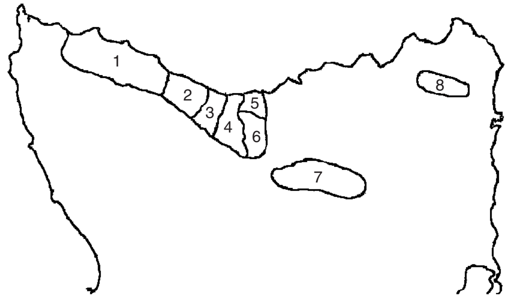

Figure 1. Geographic distribution of pyrethrum growing regions.

Individual treatments consisted of one hundred seeds.

Osmotic stress Solutions with osmotic potentials of 0.00, -0.25, -0.50, -0.75 and -1.00 MPa were achieved by mixing 0, 2.7, 2.9, 4.92, 5.6 g polyethylene glycol 8000 (PEG 8000) in 20 mL of distilled water, respectively (Michel 1983). The 0.00 Mpa (distilled water) solution was used as the control treatment.

Soil depth effects Krasnozem soil (Stace *et al.* 1968) was collected from the field and heat sterilised at 100°C for 24 hours to kill off as many weed seeds as possible. The soil was then crushed with a mortar and pestle and rewetted to help return the soil to its original structure. Krasnozem soil was chosen, as it is representative of the soil type on which the majority of pyrethrum crops are grown and where the concerning weeds occur.

Forty-two plastic pots (12.5 cm in diameter) were labelled and placed in a glasshouse. Pots were filled to one of seven soil depths (0, 5, 10, 20, 30, 50 and 70 mm from the top of the plastic pots). Fifty and 100 seeds of *T. nodosa* and *A. caucalis* respectively were then distributed evenly across the surface of the soil. All pots were then filled and watered thoroughly. Pots were watered twice daily for five minutes to replace evapotranspiration losses. Emergence counts were conducted weekly, with the experiment terminated after seven weeks.

Statistical analysis All experiments were based on a randomised complete block design with four replications except for the temperature and soil depth studies, where three replications were used. Percentage germination values were subjected to analysis of variance with Fisher's Protected LSD test ($P<0.05$) for mean separation.

RESULTS

Weed survey The number of pyrethrum fields contaminated by Apiaceae weeds was 139 (37.5%). *Anthriscus caucalis* was the dominant species, observed in 94 fields alone and in 23 fields together with *T. nodosa*. *Torilis nodosa* was found alone in the remaining 22 fields.

The lowest percentage (13.4%) of contamination was found in newly planted crops while in comparison 100% contamination was found in crops planted in 1996 (Figure 2), although the severity of contamination was often low. Of the 94 fields contaminated by *A. caucalis* alone; 60.6% were low, 23.4% moderate and 16.0% severe, based on plant population estimates. 68.2% of *T. nodosa* fields were low, 22.7% moderate and 9.1% severe.

The highest level of contamination of *A. caucalis* was recorded in the Sassafras district with 55.3% of fields contaminated. The Penguin/North Motton district was most severely affected by *T. nodosa* with 22.0% of fields contaminated. The growing districts of Sassafras and Penguin/North Motton were the most severely contaminated, with Apiaceae weeds present in 57.4% and 53.7% of fields, respectively. Another Apiaceae weed *Daucus glochidiatus* (Native Carrot) was identified in the survey and was restricted to the Table Cape growing region.

Initial germination Seed lot viability as determined by the TZ test was found to be near 100% for *T. nodosa* and 51% for *A. caucalis.* 19% of *A. caucalis* seeds were found to be lacking a developed embryo. The germination percentage of freshly collected seeds of *T. nodosa* and *A. caucalis* was 96.5% and 22.0% respectively indicating that seeds of *T. nodosa* exhibited no dormancy behaviour while seeds of *A. caucalis* exhibited innate and or enforced dormancy.

Stratification There was no significant (P>0.05) difference in the germination percentage of *T. nodosa* and *A. caucalis* with the length of stratification. There was a significant (P<0.05) reduction in the germination percentage of *T. nodosa* when stratified in complete darkness. With out stratification the germination percentage of *T. nodosa* was 78.5% in complete darkness, which was significantly lower than the germination percentage with a 12 h photoperiod. Increases in the duration of stratification resulted in no significant (P<0.05) difference in the germination percentage of *T. nodosa* for those with a 12 h photoperiod. Seeds of *A. caucalis* showed low levels of germination for each treatment and breakage of any dormancy by cold stratification were unsuccessful. Highest germination was achieved with no stratification treatment and stratification in complete darkness decreased germination.

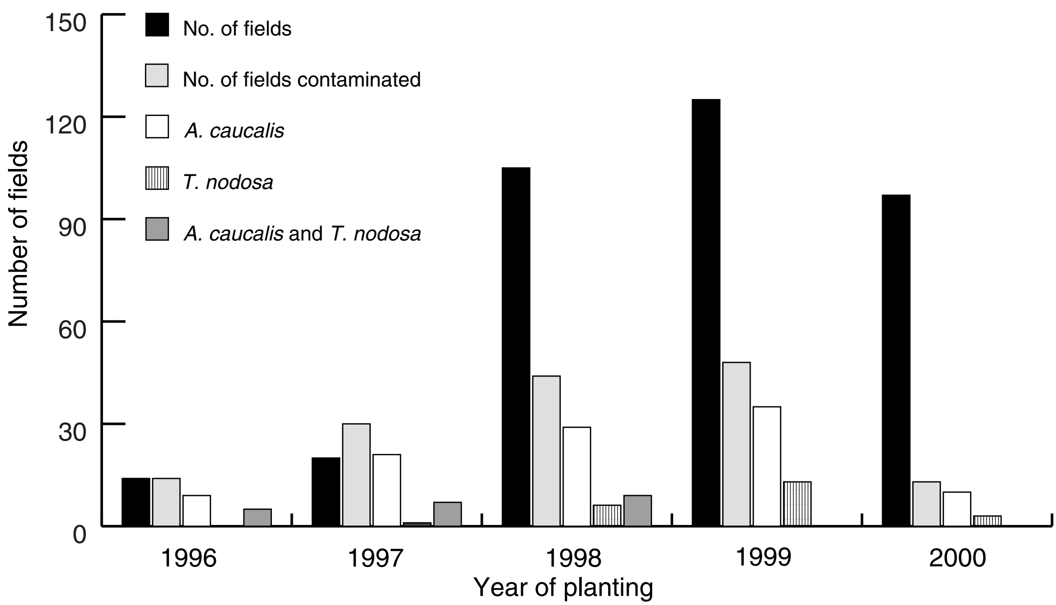

Figure 2. Presence of Apiaceae weeds, *A. caucalis* and *T. nodosa*, in pyrethrum fields against year of planting.

Temperature Temperature affected total germination and the rate of germination of both *T. nodosa* and *A. caucalis* (Tables 1 and 2).

Germination of *T. nodosa* occurred over a broad range of temperatures between 7.8°C and 30.8°C with maximum germination, 91.0% and 94.0% occurring at 18.2°C and 23.4°C respectively which was significantly (P<0.05) higher than all other treatments. *Anthriscus caucalis* seeds required a temperature above 4.2°C but below 25.5°C with maximum germination occurring between 7.8 and 15.4°C. It appears that the dormancy displayed by *A. caucalis* in the initial germination study was of an enforced nature, as germination of *A. caucalis* expressed as a percentage of viable seed was approximately 100% between 7.8 and 15.4°C.

Osmotic stress A highly significant (P<0.001) reduction in germination occurred at osmotic potentials of -0.75 and -1.00 Mpa for both *T. nodosa* and *A. caucalis* (Figure 3). There was no significant (P<0.05) difference in germination of *T. nodosa* and *A. caucalis* between 0 and -0.5 Mpa.

Planting depth Planting depth significantly affected seedling emergence. Optimum planting depth for both *T. nodosa* and *A. caucalis* occurred between 5 mm and 30 mm (Figure 4). Emergence was significantly reduced for both *A. caucalis* and *T. nodosa* at 50 mm with emergence totally inhibited at 70 mm. At 0 mm, germination of both species was significantly lower (P<0.05) than the optimum.

DISCUSSION

The high percentage of occurrence of *A. caucalis* and *T. nodosa* in pyrethrum fields and it's non occurrence in agricultural crops previously provides quantitative evidence to suggest that pyrethrum production favours the development of these Apiaceae weeds. This is most likely due to a combination of factors including; a non-tillage production system, which favours the incidence of small-seeded annuals (Ball and Miller 1990), reduced competition from more competitive weeds controlled by chemical application and the spread of seed through harvesting machinery. The increase in percentage of site contamination with increasing crop age, and the variation between growing regions is indicative that the spread of these weeds is a result of transportation of seeds from contaminated to non-contaminated fields. It is therefore recommended that a strategic harvesting procedure be developed; where first year clean crops are harvested prior to older sites or alternatively that a single harvester be devoted only for use in newly planted crops, free of these Apiaceae weeds. This survey not only quantified the occurrence and severity of Apiaceae weeds in pyrethrum but also provided a basis for continuation of such work in which the effectiveness of removal programs can be assessed and the emergence or control in following crops can be determined.

The high initial germination percentage of *T. nodosa* is consistent with that found by Baskin and Baskin (1975) for *T. japonica*, however a high percentage of Apiaceae species have been shown to have low initial germination (Grime *et al*. 1981). Many species of Apiaceae produce a proportion of seeds which, although having well-formed endosperm and appearing normal, lack embryos and are incapable of

Table 1. Mean germination percentage of *T. nodosa* to differing temperatures.

Temp (°C)	7 DAI	14 DAI	21 DAI	28 DAI
4.2	0.0^d	0.0^d	0.0^d	0.0^d
7.8	0.0^d	0.7^d	35.3^b	83.3^b
9.7	0.0^d	73.0^b	84.3^a	84.7^b
15.4	13.0^c	84.3^a	87.3^a	87.3^b
18.2	36.0^a	88.0^a	89.3^a	91.0^a
23.4	39.0^a	86.3^a	88.0^a	94.0^a
25.5	27.7^b	80.7^a	83.0^a	86.0^b
30.8	1.0^d	9.3^c	19.0^c	43.0^c
35	0.0^d	0.0^d	0.0^d	0.0^d
36.8	0.0^d	0.0^d	0.0^d	0.0^d
LSD (P = 0.05)	5.0	7.8	9.4	6.3

*DAI (Days after initiation).

Table 2. Mean germination percentage of *A. caucalis* to differing temperatures.

Temp (°C)	7 DAI	14 DAI	21 DAI	28 DAI
4.2	0.0^c	0.0^d	0.0^d	0.0^d
7.8	0.0^c	0.0^d	23.3^c	48.3^a
9.7	0.0^c	48.0^a	54.0^a	54.7^a
15.4	7.7^b	49.0^a	50.0^a	50.0^a
18.2	15.0^a	36.7^b	36.7^b	36.7^b
23.4	6.0^b	23.0^c	23.7^c	24.0^c
25.5	0.0^c	0.0^d	0.0^d	0.0^d
30.8	0.0^c	0.0^d	0.0^d	0.0^d
35	0.0^c	0.0^d	0.0^d	0.0^d
36.8	0.0^c	0.0^d	0.0^d	0.0^d
LSD (P = 0.05)	1.9	5.7	8.4	6.8

*DAI (Days after initiation).

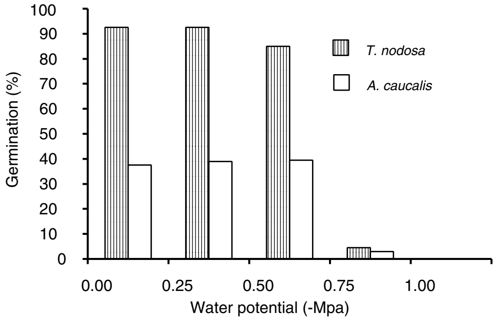

Figure 3. Effect of osmotic potential on the germination of *T. nodosa* and *A. caucalis.* (LSD (P=0.05): *T. nodosa* = 6.8, *A. caucalis* = 9.3).

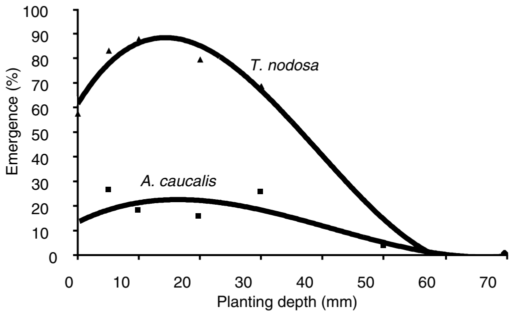

Figure 4. Effect of planting depth on the emergence of *T. nodosa* and *A. caucalis*. (LSD (P=0.05): *T. nodosa* = 26.6, *A. caucalis* = 14.0).

germination. This is consistent with that observed for *A. caucalis* and that reported by Flemion and Hendrickson (1949) for *A. sylvestris*.

Germination of seeds of *T. nodosa* are unaffected by stratification at 4°C and inducement of dormancy over winter period is unlikely. This is in contrast to the related species *T. japonica* were field populations of *T. japonica* have been found to be induced into dormancy by low temperatures (Baskin and Baskin 1975). In contrast, other studies with *T. japonica* have found that the seeds are dormant at the time of dispersal and that chilling is required to break dormancy (Roberts 1978; Thompson and Baster 1992). Seed germination characteristics are strongly influenced by maternal conditions (Wulff, 1995) and from the current study, dispersed seeds of *T. nodosa* display no dormancy and are not induced into dormancy by cold stratification. Germination is restricted however by stratification at 4°C when in combination with complete darkness.

Seeds of *A. caucalis* showed low levels of germination for each stratification treatment and breakage of dormancy by cold stratification was unsuccessful. Highest germination was achieved with no stratification treatment and stratification in complete darkness decreased germination. Reduction in germination in response to stratification of *A. caucalis* is consistent with that for *Conium maculatum*, (Baskin and Baskin 1990).

The optimum germination temperature of *A. caucalis* occurred between 7.8°C and 15.4°C, indicating that the dormancy displayed in the initial germination study was of an enforced nature. Although 51% of the seed lot was shown to be viable as determined by the TZ test the level of viability may increase for a more mature seed lot and that some innate dormancy may also present. Further investigations are therefore required into the type and level dormancy displayed by *A. caucalis* with differing seed lots.

It has been observed for both species that seed dispersal occurs through the summer period, when prevailing soil surface temperatures at that time will most likely be restrictive to germination. As soil temperature begins to decrease with the onset of autumn, the upper temperature limit of germination will be higher than the prevailing temperatures at that time allowing germination of the species to proceed. During winter, soil temperature may fall below the minimum required temperature for germination and germination of *T. nodosa* and *A. caucalis* will be prevented. The optimum temperature range for germination of *A. caucalis* is narrower and the maximum temperature at which germination can occur is lower than that of *T. nodosa*. The results indicate that both species would most likely behave predominantly as facultative winter annuals with *A. caucalis* more likely to behave as a strict winter annual due to its lower optimum germination range.

The results of the osmotic study indicate that both *T. nodosa* and *A. caucalis* seeds are sensitive to low water potential. Following planting of pyrethrum there is zero tillage activity and it has been observed that during the summer period the upper 5 cm of a Krasnozem soils becomes very dry with water potential levels below permanent wilting point quite common. Dispersed seeds of *T. nodosa* and *A. caucalis* will fail to germinate at this time due to osmotic stress.

It is suggested that emergence of both *T. nodosa* and *A. caucalis* is restricted at depths greater than 30 mm due to the small size of the seed. At 0 mm, low levels of moisture availability may have restricted germination, which is consistent with the results found for the osmotic study. The results suggest that a non-tillage production system such as that for a short-lived perennial crop like pyrethrum would favour the germination of both *T. nodosa* and *A. caucalis*. Although germination was reduced near the surface, burial of the seeds just below the surface would occur as result of the movement of machinery, grazing animals and abiotic factors during the growing season. In attempting to reduce the impact of seedling emergence in following crops, preparation of the crop by conventional tillage may potentially bury a large proportion of the seed to depths incapable of emergence.

It is concluded that the non-tillage production system associated with pyrethrum favours the germination and establishment of both *A. caucalis* and *T. nodosa*. It is also appears that there is significant variation in the seed lot of *A. caucalis* and this is most likely a result of variation in the maturity of the seed lot. Conclusion regarding the level of viability and the dormancy displayed will require further investigation, however the significant differences displayed between treatments for *A. caucalis* and *T. nodosa* will provide valuable information in the development of an integrated weed management approach to the control of *T. nodosa* and *A. caucalis*.

ACKNOWLEDGMENTS

Thank you to field staff of Botanical Resources Australia for their cooperation and assistance with the field survey.

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