Persistence of *Fumaria densiflora* DC. seed in the field

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Summary Fumitory is a persistent weed of cropping systems in the southern winter cropping zone of Australia. Lack of information on its seed bank dynamics is hampering the development of effective management strategies. An experiment was carried out to investigate the seed persistence of one of the most widespread fumitory species, *Fumaria densiflora* DC., in undisturbed clay and sandy soils over depths ranging from 0 to 15 cm for a period of 28 months.

Seed persistence varied with soil type and burial depth. Germination and decay became significant sources of seed loss only from the second growing season onwards. Near the soil surface, greatest seed loss was due to germination, whereas at depth, seed decay was more important and was significantly higher in sandy than in clay soil. The viability of seeds which remained intact in the soil varied between 80 and 100% and was overall significantly higher in clay soil.

The seed bank on the surface of undisturbed soil is mostly only short-lived, whereas it can reach an estimated half-life of approximately 10 years at 15 cm depth in clay soil. Appropriate management of a fumitory seedbank requires knowledge of its likely depth distribution which can be deduced from the paddock history and past tillage regimes.

Keywords *Fumaria densiflora*, seed persistence, seed bank, seed decay, germination, seed viability, tetrazolium.

INTRODUCTION

During the past three decades, fumitory, a winter-annual of Mediterranean origin and a collective description for several species of the genus *Fumaria*, has increasingly become a problem in the southern cropping zone of Australia. This is due to an overall rise in area affected as well as the growing incidence of mass infestations. Due to restricted potential for herbicide use, these species are difficult to control in broad-leaved crops such as canola and grain legumes. Large seed banks, once established, appear difficult to eradicate, rendering some paddocks unsuitable for the growing of certain crops due to recurring infestations even after several rest years under pasture.

North-western European studies found that the seed half-life of *Fumaria officinalis* L., a rare species with restricted distribution in Australia, extended beyond 20 years and that its seed survival in undisturbed soil ranged from 25 to several hundred years (Chancellor 1986). However, comparable investigations are not available from the Mediterranean climatic zones in general or from Australia in particular, nor is it known whether they are applicable to other *Fumaria* species. Different levels of seed persistence over time have been reported between species of the same genus, of the same species in different soils and in contrasting climates. Among the environmental factors, different levels of soil moisture, humidity as well as temperature and gas exchange appear to govern seed persistence rates under diverging geographic and climatic conditions, while seed size, seed surface roughness, oil and phenolic compound content, level of dormancy, desiccation tolerance and degree of water permeability of the seed coats are most often responsible for species-specific variations.

In Australia, *F. densiflora* is one of the main contributors to the fumitory problem. It is probably the most wide-spread species due to its adaptability to a wide range of soil pH and occurrence in both heavy and light soils. Potential for massive seed production under favourable conditions also makes it one of the most insidious species (Norton 2003). Therefore, it was chosen in the following study which aimed to investigate the fate and survival of seeds buried at different depths in two contrasting, undisturbed soils under the natural climatic conditions prevailing in the southern cropping zone. Based on the results, predictions as to likely long-term seed persistence and practical consequences for weed management strategies are proposed.

MATERIALS AND METHODS

Field experiment The experiment was established in January 1998, well in advance of the beginning of the next growing season in April, in order to expose the seed as much as possible to natural conditions. Pots, filled with soil and *Fumaria* seed inserted at one of a number of depths, were buried in the field in order to combine accuracy of experimental treatments with the advantages of field environmental conditions.

F. densiflora seed was harvested from a mass infestation near Sebastopol, New South Wales (NSW), at the end of the previous growing season in October 1997. After drying and cleaning, lots of 100 seeds each were sealed in nylon mesh bags. Their viability was close to 100%.

Two contrasting soils, both originating from areas near Wagga Wagga, NSW, were used: Soil 1 was a light-medium clay (LMC) with pH 4.8; and Soil 2 was a sandy loam (SL) with pH 5.8.

Each soil was sieved, slightly moistened and mixed well before placement into straight-sided metal tins. These had an internal diameter of 175 mm, a height of 190 mm and a perforated bottom that held the soil in place, but permitted uninhibited drainage. In each pot, a seed bag was inserted at one of five depths, i.e. 0, 2, 5, 10 and 15 cm below the soil surface. The soil was compacted to achieve a bulk density comparable to that of naturally settled soil in the field. After covering the pots with fly mesh to prevent loss of surface-lying seed bags, they were buried in the field at Wagga Wagga, NSW. A series of complete sets of pots in identical lay-outs, arranged in completely randomised designs with four replications, was established in order to permit consecutive seed retrievals. Seeds were recovered 6 (June 1998), 16 (May 1999) and 28 months (May 2000) after seed burial.

In 1998 and 1999, germinated, decayed and intact seeds were counted, while in 2000, viability of the intact seeds was also determined using 2,3,5-triphenyl-tetrazolium-chloride (TTC). The number of germinated seeds was derived from the number of pericarp halves found, since on germination the two halves of the pericarp break apart at the keel. In contrast, decayed seeds leave behind intact but hollow pericarps.

TTC staining procedure Since a procedure for viability testing with TTC had not previously been established for *Fumaria* seed, methodology described for species with similar seed characteristics was modified and adapted (Moore 1993). This required the complete removal of the pericarp and nicking of the testa prior to soaking the seed for 18 to 24 hours in a 1% TTC solution. Assessment was carried out on one half of a longitudinally cut seed.

Statistical analysis Analysis of all data was carried out with GenStat 5th Edition, Release 4.2, using generalised linear modelling. Logit and natural logarithmic link functions were applied to binomial and Poisson data, respectively. Change of deviance was used to determine the significance of model terms, while means were compared using t-statistics. The graphics were produced using S-Plus 2000.

RESULTS

A decline of seeds remaining intact in the soil was noted in all treatments from the start of the experiment until its termination after 28 months. But the primary cause for and the extent of the decrease varied widely among them (Figure 1).

Almost six months after the establishment of the experiment and after seasonal seedling emergence had peaked, loss of intact seeds was exclusively from germination which ranged between 0 and 9%. There was no effect of soil type, but germination was significantly higher at 2 cm than at any other burial depth.

The second sampling was carried out ten months later and before the seedling emergence peak in 1999. In most cases, levels of intact seeds had not substantially changed since the previous sampling. However, now small proportions (up to 3%) of decayed seeds were found in most treatments. Furthermore, sporadic additional germination had occurred later in the previous year or possibly early after rains in March in the current year, but at 10 cm depth in SL the proportion of germinated seeds had doubled to 13%. Overall, there was a significant influence of soil type, burial depth and their interaction on the proportion of intact seeds left in the soil, with significantly fewer seeds remaining intact in sandy loam than clay and at 2 and 10 cm than at any other depth. In clay, between 97 and 99% of seeds were still intact in all treatments, except at 2 cm where there was a significantly lower proportion of only 91% left. In contrast in, sandy loam significantly more intact seeds were lost from the three greatest burial depths than from the soil surface, with the significantly fewest seeds remaining at 10 cm burial depth (86%).

A substantial change occurred in the levels of intact seeds during the 16–28 months period. At 28 months and before peak emergence of the season occurred, the proportion of germinated seeds was substantially increased in most treatments, and seed decay became an important factor. The proportion of decayed seeds varied between 2 and 37% and was significantly higher in sandy loam than in clay and lowest on the soil surface. In clay, most seeds decayed at 2 cm (16%) and in sandy loam at 10 cm (37%). In contrast to seed decay, germination was significantly higher in the heavier than the lighter soil. In both soils, its significantly highest levels were on the surface (96 and 63% in clay and sandy loam, respectively) and at a depth of 10 cm (25 and 31%, respectively). Overall, seed decay and germination led to significantly fewer seeds remaining intact in sandy loam (53%) than in clay (60%) and on the surface than at any of the other depths. In the heavy soil, virtually no seeds were left on the surface (2%), while the significantly highest

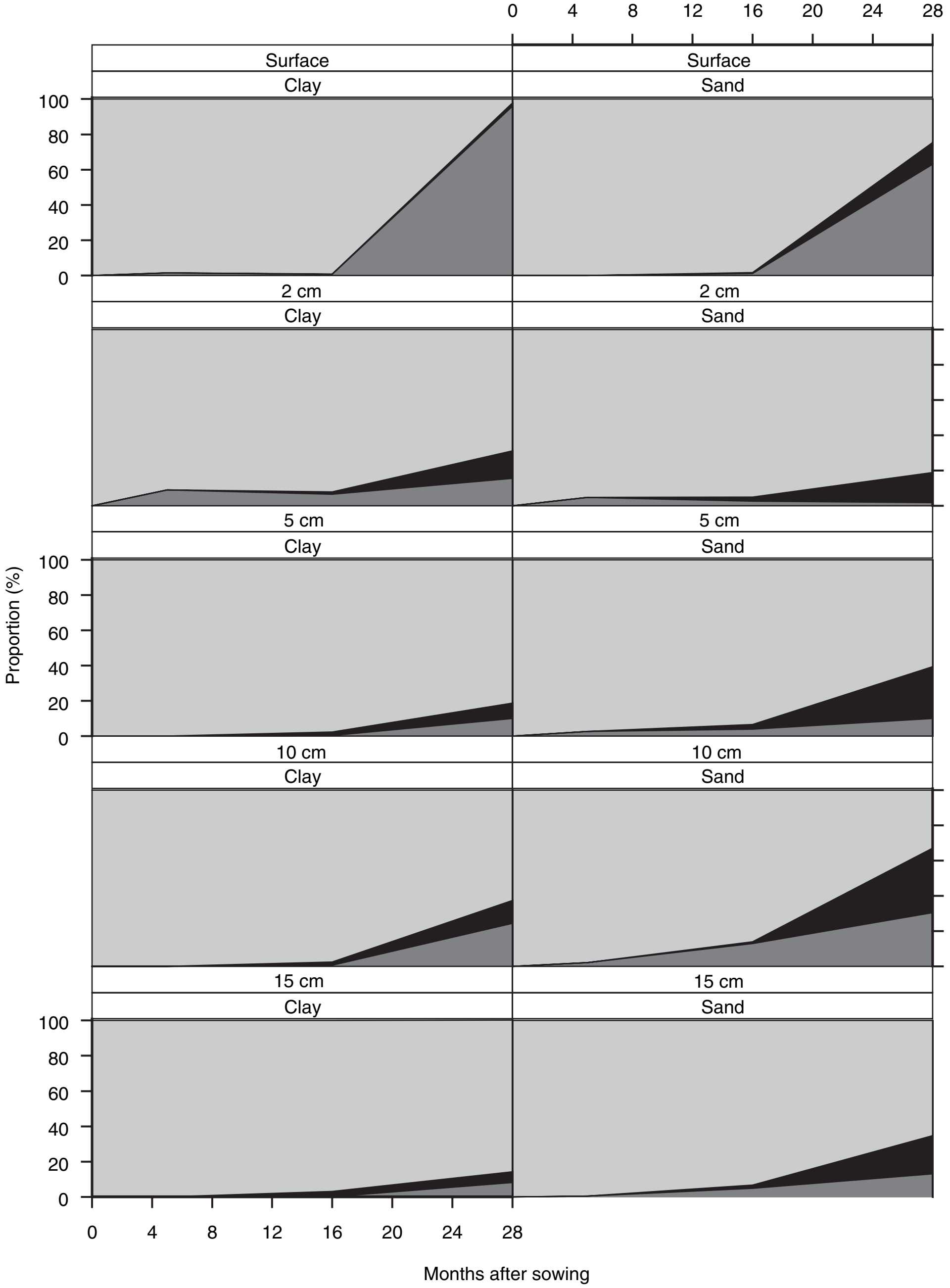

Figure 1. Development of the proportion of intact (light grey), germinated (dark grey) and decayed seeds (black) of *Fumaria densiflora* over a course of 28 months and as influenced by soil type and seed burial depth.

levels occurred (>81%) at 5 and 15 cm. In sandy soil, seed loss from the surface (75%) was significantly less than in clay, but at 10 cm depth, it was almost as high as on the surface. Most seeds (82%) were still intact at 2 cm.

At the end of the experiment, viability of the remaining intact seeds was tested using TTC. The results are not presented graphically, as only very few differences were detected among treatments. After discounting the surface results, where there were too few seeds to draw conclusions, the proportion of unviable seeds was similar in all treatments (3 to 7%), except at 10 cm in sandy loam where it was significantly higher (19%). There was no difference in the level of slightly deteriorated seeds (2 to 6%) among the treatments.

DISCUSSION AND CONCLUSIONS

Most results of this study agree with findings made previously in investigations of other weeds. The general trends of rising seed bank decline with increasing passage of time and generally highest loss of viable seed from the soil surface were, among others, reported by Lutman *et al*. (2002). The same authors also found greater seed loss of *F. officinalis* in sand than clay in Britain, and greatest seed decay between 24 and 36 months after seed burial was observed by Nisensohn and Faccini (1993) in *Amaranthus quitensis* Kunth. Different moisture availability patterns and better aeration promoting soil microbial growth in sand, while at the same time leading to initiated, but not completed germination and subsequent seed death, could be responsible for the first result. Persistent dormancy as well as insufficient degradation and weathering of the hard seed coats for soil micro-organisms to successfully attack the seed before the second growing season, could explain the second finding. Peak germination in only the second year after seed shed, though uncommon in most weeds, appears to be frequently occurring in *F. densiflora* (Roberts and Boddrell 1983, Norton 2003).

A peculiar feature of the seed persistence of *F. densiflora* in undisturbed soil was the existence of a second peak of seed loss at a depth of 10 cm in both soils, but particularly so in sandy loam. Its reasons are not clear, but related emergence experiments showed that this fumitory species produced a second seedling cohort from this depth later in the season (Norton 2003). In addition, it appears all environmental and seed-related factors combined to create optimum conditions for seed attacking micro-organisms at this depth in the light soil.

Since the above experiment was terminated after less than 2.5 years, and since major seed deterioration processes only began to take effect in the last experimental year, estimations of the seed longevity of *F. densiflora* can only be speculative in the 2 to 10 cm range of burial depths where most microbial activity occurred. However, it can be stated with reasonable confidence, that the seedbank on or very close to the soil surface will likely not survive much longer than three growing seasons in heavy soil and a few years longer in light soil. But on the basis of only slow and constant seed loss, it is likely that seed buried at a depth of 15 cm or more in heavy, undisturbed soil will persist for a long time. Under the assumption of an annual decline rate of 7% from the results presented, and when applying the negative exponential seed survival curve proposed by Murdoch and Ellis (1992), a seed half-life of about 10 years and some seeds surviving as long as 50 years can be calculated under these conditions. This is lower than the values obtained for *F. officinalis* (Chancellor 1986), but justifies the classification of *F. densiflora* as a persistent weed.

These results suggest that the likely depth distribution of the seedbank as produced by past tillage regimes will have an influence on the management options of the weed. While a pasture-, ley- or no-till cropping period of at least three years, accompanied by adequate weed control, could largely eliminate a shallow seed bank, even long pasture phases as part of a cropping rotation will be unsuitable for the removal of deeply deposited seeds. Any subsequent deep tillage will move seeds close to the soil surface and lead to new infestations.

ACKNOWLEDGMENTS

The work was funded by the Grains Research and Development Corporation. Norbert Leist, International Seed Testing Association, gave useful comments on the interpretation of the TTC results.

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