PLANT RESEARCH INTERNATIONAL
WAGENINGEN UR

Setaria verticillata, Digitaria ischaemum and *Geranium molle*

Biology and control, a review of literature

A.C. Franke, C.J. van Dijk & M.M. Riemens

Nota 587

PLANT RESEARCH INTERNATIONAL
WAGENINGEN UR

Setaria verticillata, *Digitaria ischaemum* and *Geranium molle*

Biology and control, a review of literature

A.C. Franke, C.J. van Dijk & M.M. Riemens

Plant Research International B.V., Wageningen
November 2009

Note 587

Plant Research International B.V.

Address	:	Droevendaalsesteeg 1, Wageningen, The Netherlands
	:	P.O. Box 16, 6700 AA Wageningen, The Netherlands
Tel.	:	+31 317 48 60 01
Fax	:	+31 317 41 80 94
E-mail	:	info.pri@wur.nl
Internet	:	www.pri.wur.nl

Table of contents

1. Introduction

The review described in this report is a subactivity of the project 'Preventieve maatregelen ter beheersing van probleemonkruiden' (Preventive measures to control specific weed species), one of the projects of the BO- research program 'Plant gezondheid' (Plant health), theme 4 'Effectief en duurzaam middelen pakket' (Effective and sustainable control measures) subsidized by the Dutch ministry of LNV.

Farmers, both organic and conventional, contracters and the Dutch Plant Protection Service were asked to identify the most problematic weed species in the Netherlands at present and in the near future. In total 19 species were identified, 13 annuals:
Stellaria media, Polygonum persicaria, Polygonum aviculare, Polygonum convolvulus, Alopecuris myosuroides, Panicum verticillatum (Setaria verticillata), Panicum lineare, Amaranthus retroflexus, Æthusa cynapium, Poa annua, Chenopodium album, Solanum nigrum, Galinsoga parviflora and *Geranium molle,*

and 6 perennials:
Cyperus esculentus, Cirsium arvense, Persicaria amphibia, Mentha arvensis, Stachys palustris and Rorippa sylvestris.

This report describes the results of the literature survey on the biology and control of *Setaria verticillata, Digitaria ischaemum* and *Geranium molle*.

2. Biology of *Setaria verticillata*

Setaria verticillata (L.) (occasionally also referred to as *Panicum verticillata*) is a grassy, annual plant belonging to the gramineae plant family (also known as the Poaceae family) (van der Meijden, *et al.*, 1990). *S. verticillata* belongs to a group of closely related weedy *Setaria* species that may occasionally hybridize and probably have a common ancestor. Other members of this group showing weedy behaviour are *Setaria viridis* (green foxtail), *Setaria pumila* (yellow foxtail), *Setaria faberi* (giant foxtail) and *Setaria geniculata* (knotroot foxtail). *Setaria italica* (foxtail millet) is widely grown as a food crop in east Asia and sometimes cultivated as a sileage crop in Europe and north America. While each *Setaria* species has its own growth habits and ecological niche, a great deal of the biological traits and management options for *S. verticillata* are also applicable to the related species and vice versa.

2.1 Geographic Distribution

S. verticillata occurs in rural areas, road sides and on construction land in the Netherlands (van der Meijden, *et al.*, 1990). It flourishes at disturbed sites in agricultural fields, urban areas and coastal areas. *S. verticillata* is actually still rare in the Netherlands. The plant, however, causes serious control problems in other parts of the world and its occurrence has some major environmental and economic implications. The plant has travelled along with human activities all over the world and shows invasive behaviour. *S. verticillata* is also referred to as 'bristly foxtail' or 'rough bristle grass' in English and as 'kransnaaldaar' in Dutch.The Setaria genus probably originates from Africa from where it has spread to Eurasia (Dekker, 2003). After Setaria sp. was domesticated, it was spread over the world as a crop and a weed. *Setaria italica* (foxtail millet) is still widely grown as a food crop in east Asia and sometimes cultivated as a sileage crop in Europe and north America. *S. verticillata* is considered native to the tropical and temperate regions of the Old World. The plant is, however, rare in the Netherlands (van der Meijden, *et al.*, 1990).

S. verticillata is widespread in other agricultural, coastal and urban areas of the world ranging from temperate to tropical regions, including the Middle East Iran, Australia, New Zealand, northern, eastern and southern Africa, eastern and southern Europe, the United States and Canada (Al Kathiri, 1994;Ernst, 1991;Girma-Woldetsadik & Chinawong, 2005;Hanson & Smith, 1992;James & Rahman, 1993a;Keshavarzi & Seifali, 2007;Moyer, *et al.*, 1989;Steel, *et al.*, 1983;Uremis & Uygur, 2005;Wigg, *et al.*, 1973). It is considered a major invasive weed of the world (Dekker, 2003). In agricultural areas, the weed occurs in grasslands and arable fields.

2.2 Genetic Structure and Morphology

Setaria species are characterized by an unusually low intra-population genetic diversity and an unusually high genetic diversity between populations, compared to other common plant genera (Wang, *et al.*, 1995a;Wang, *et al.*, 1995b). This is likely to be related to the high level of self-pollination among *Setaria* species, combined with genetic drift and founder effects (Dekker, 2003). Outcrossing is rare, but if it occurs, wind is the vector transporting the pollen. *S. verticillata* cannot reproduce asexually. While the total genetic diversity of *S. verticillata* is limited, the plant shows a high degree of phenotypic plasticity, in reponse to environmental conditions (e.g. light, water, gases, nutrients, temperature and competitive pressure from other plants). This plasticity allows the plants to colonise many different niches. Interspecies hybridization occurs regularly within members of the Setaria genus that exhibit weedy behaviour (Dekker, 2003). Also polyploidization may occur among *Setaria* species. *S. verticillata* has been hypothesised to be the product of a chromosome doubling of *Setaria viridis* (green foxtail) in the past (Till Bottraud, *et al.*, 1992).

S. verticillata has fibrous roots (Steel, *et al.*, 1983). The branching architecture of *S. verticillata* consists of hierarchically organized, nested sets: tiller culm, panicle, fascicle, spikelet and floret (Dekker, 2003). This plant architecture is similar to most grass species. A complex pattern of branching, from plant to spikelet, provides diverse micro-evironments within which different levels of of dormancy are induced in individual seeds of the panicle and among panicles on a common plant (Dekker, 2003). As a result, seeds produced by a single plant have different germination behaviour. *S. verticillata* may be distinguished from other *Setaria* species by the spaced clusters of verticals of spikelets, especially at the base of the panicle. It has one prominent nerve on the first glume, its leaves are scabrous on both surfaces and it lacks villous hairs on the panicle axis (Steel, *et al.*, 1983).

2.2 Seed Longevity, Germination and Emergence

The longevity of *S. verticillata* seeds in the soil may be average for a small-seeded annual. After 3 years of burial in Turkey, 20% of the *S. verticillata* seeds were still able to germinate (Uremis & Uygur, 2002). After 7 years of burial in the same experiment, only 1.7% still had the ability to germinate (Uremis & Uygur, 2005). Depth of burial (15 or 30 cm deep) had no impact on seed viability in this study. However, in general, deeply buried seeds have an extended longevity and increased dormancy, relative to shallowly buried seeds. The maximum recorded longevity of *S. verticillata* seeds in the soil is 39 years (Toole & Brown, 1946).

All freshly harvested seeds of *S. verticillata* are dormant (Lee & Cavers, 1981). The state of dormancy differs between seeds from a single plant and from different plants. As a result, the germination and emergence of seeds in the field is spread over a longer period of time. This variability in germination requirements also implies that *S. verticillata* can rapidly adapt its germination behaviour to changing environmental conditions or new field management strategies. For example, herbicide applications early in the season can be escaped by delaying the seedling emergence.

A stimulatory effect from light on the germination rate of *S. verticillata* has been reported by some (Salimi & Termeh, 2002), while others observed no effect from light on seed germination (Taylorson, 1982, 1986). *S. verticillata* seeds require a minimum germination temperature of 10 °C (Kaya & Nemli, 2004), exhibit an optimum germination at 25-35 °C (Kaya & Nemli, 2004;Uremis & Uygur, 1999) and have a maximum temperature at which germination still occurs of 40 °C (Uremis & Uygur, 1999). In addition, the influence of temperature on the dormancy state of the seeds and thus also on seed germination, varies with time and development (Dekker, 2003). Temperatures of 20 to 35 °C can promote rapid germination of non-dormant or almost completely after-ripened seeds, but dormant seeds after-ripen very slowly or not at all at these temperatures (Dekker, 2003). The seeds have a good ability to withstand extreme cold (e.g. -20 to -50 °C). *S verticillata* seeds also have a good ability to survive heat from burning and can withstand temperatures up to 100 °C for a short period (two minutes), as shown in field trials in Botswana (Ernst, 1991). Diurnal temperature fluctuations increase the germination of Setaria species when compared with germination under static temperatures (James, 1968). Furthermore, moisture conditions and gaseous components of the soil affect the seed germination rate (Dekker, 2003).

S. verticillata seeds emerge from relatively shallow depths, usually between 1 and 5 cm (Dekker, 2003). Emergence declines with depth to a maximum depth of around 7.5 to 14 cm (Buhler, 1995;Buhler & Mester, 1991). Emergence usually does not occur from the soil surface, except for when the soil is covered with debris in no-tillage systems. Most *S. verticillata* seedlings emerge in the first half of the growing season.

In a field study in New Zealand, the number of emerged seedlings of *S. verticillata* was found to be strongly correlated with the number of seeds in the soil with similar emergence rates reported for five different sites (Rahman, *et al.*, 2003). A simple linear regression model between the number of seeds in the soil and the number of emerged seedlings for different sites had an R^2 value of 98.7%. The fraction of seeds that emerged in a season was estimated to be 6.70% of the total number of *S. verticillata* seeds in the soil.

2.3 Plant Growth and Reproduction

The time from first emergence to last fruiting of *S. verticillata* is rather variable and may take between 118 and 167 days in Italy (Giudice & Roccuzzo, 1995). *S. verticillata* grows on a wide range of soil types from clay to river gravel, in soil of both low and high fertility, with pH values ranging from 6.1 to 8.0 (Steel, *et al.*, 1983). Vegetative growth of *S. verticillata* is relatively sensitive to shade, which reduces its competitiveness in a crop (Lee & Cavers, 1981).

Populations of *S. vertillata* are frequently found in places with full sun light. Plants growing in shade are significantly taller and have longer leaves than plants in full sunlight (Lee & Cavers, 1981). Plant size and reproductive capacity generally reduces with increasing competition from other plants. Plant mortality from density-dependent (e.g. effects of neighbours) and density-independent (e.g. effects of predation, parasitism, catastrophe) causes is an important source of weed population losses, but their causes are poorly understood (Douglas, *et al.*, 1985;Steel, *et al.*, 1983).

Seed rain in northern temperate regions occurs from July to December, depending on seasonal environmental conditions and field management. The seed number and seed yield produced by *S. verticillata* is highly plastic and strongly depend on available resources, competition from neighbours and the time of seedling emergence (Dekker, 2003). The larger the biomass of a plant, the more reproductive tillers it has and the more numerous its progeny (Dekker, 2003). In general, plant size and seed numbers are greater for plants emerging earlier rather than later in the growing season. Reports of seed productivity per plant vary from 1 to 12,000 (Born, 1971;Rominger, 1959;Steel, *et al.*, 1983) with an average seed production per head of 120 seeds (Steel, *et al.*, 1983). 1000-seed weight for two populations in Canada, Ontario, was 1.1 and 1.3 g (Steel, *et al.*, 1983). Seeds of *S. verticillata* are well adapted to dispersal by animals due to the retrorse barbs on the bristles of the inflorenscenes.

Seeds with different germination requirements are produced from a single plant. Early-fertilized seeds are more dormant than those developing later (Haar, 1998). Furthermore, seeds maturing early in the season in partial shade are considerably more dormant that those maturing on nearby plants in full daylight. Germination requirements are a function of genotype, plant architecture and environmental conditions during the life cycle (Dekker, 2003).

2.4 *S. verticillata* as a Host Reservoir for Pathogens

S. verticillata is known to be a host plant for yellow dwarf diseases in rice in India (Raychaudhuri, *et al.*, 1971). *S. verticillata* is also an alternative host of the viruses which cause wheat spot mosaic, barley stripe mosaic, wheat streak mosaic virus and the maize rough dwarf virus (Ellis, *et al.*, 2004;Nome, *et al.*, 1983;Steel, *et al.*, 1983). Furthermore, *S. verticillata* can be a host of *Anaphothrips swezeyi* and of the nematodes *Meloidogyne* sp. and *Pratylenchus pratensis* (de Man) (Steel, *et al.*, 1983). The importance of *S. verticillata* in the epidemiology of these microbial populations pathogenic to crops is unknown.

3. Management of *Setaria verticillata*

3.1 Cover crops

Cereal cover crops can reduce *S. verticillata* populations in maize, sugar beet and cotton. Field experiments were conducted to study the effect of three rye populations, six triticale cultivars and two barley cultivars, used as cover crops, on the emergence and growth of *S. verticillata* in Greece (Dhima, *et al.*, 2006b). Moreover, bioassay studies were conducted to assess allelopathic potential of the winter cereal extracts on the weed and maize. All winter cereal extracts reduced *S. verticillata* seed germination and growth, but none of them had any effect on maize. Four weeks after maize planting, *S. verticillata* emergence was reduced up to 67%, in winter cereal mulched plots compared with that in winter cereal mulch-free plots. On the contrary, maize emergence was not affected by any cover crop mulch. The results of this study suggested that some winter cereals could be used as cover crop for annual grass weed suppression in maize and consequently to minimize herbicide applications. Similar conclusions were drawn for the use of these winter cereal cultivars, followed by other crops (sugar beet and cotton). The winter cereals suppressed *S. verticillata* emergence, but had no impact on the sugar beet or cotton growth and yield (Dhima, *et al.*, 2006a;Vasilakoglou, *et al.*, 2006).

3.2 Mechanical control

Hoeing, or hoeing combined with inter-row cultivator can give good control of *S. verticillata* in maize in Turkey (Kasa & Karaca, 1977). Since *S. verticillata* is an annual, mowing close to the ground can prevent all seed production and rapidly exhaust the population (Sylwester, 1970). No other studies on the effectiveness of cultural control measures against *S. verticillata* have been found.

3.3 Biological control

While *S. verticillata* functions as a host for various plant pathogens (see above), these are all very pathogenic to most crops and therefore, cannot serve as a bio-control agent for the weed (Steel, *et al.*, 1983). No suitable agent for the bio-control of *S. verticillata* has been identified yet.

Cattle, sheep and geese eat *S. verticillata* readily and geese confined to small areas have been successfully employed in strawberries, raspberries, cotton, tabacco and maize, according to a study from the U.S. (Sylwester, 1970). However, animal manure can contain viable seeds of *S. verticillata* and requires a heat treatment to remove the viable seeds (Sylwester, 1970).

3.4 Chemical control

Control of *S. verticillata* in agricultural fields is primarily achieved through the application of herbicides. Usually, no distinction is made between Setaria species when control measures are recommended. In soybean, trifluralin and metribuzin achieve good control (Steel, *et al.*, 1983). In maize and sorghum, atrazine, simazine, triazine, meso-trione, acetochlor or rimsulfuron are often applied (Armel, *et al.*, 2003;Isaacs, *et al.*, 2002;Sylwester, 1970; Vasilakoglou & Eleftherohorinos, 2003). In potato, flumioxazin and metribuzin or rimsulfuron provide adequate control (Hutchinson, 2007). Other herbicides used against *S. verticillata* include: oryzalin (Nelson, *et al.*, 1983), imazamox (Kostov & Pacanoski, 2006) and sulfonylurea-based herbicides (James & Rahman, 1993b).

3.5 Herbicide-resistance

Atrazine-resistance of *S. verticillata* has been observed in Spain (De Prado & Franco, 2004) and triazine-resistance has been found in the U.S. (Holt & LeBaron, 2000). *Setaria viridis* has also developed resistance in the U.S. against trifluralin (Holt & LeBaron, 2000) and against and fenoxaprop-p-ethyl, fluazifop-p-butyl and sethoxydim (Heap, 2008). While the development of herbicide resistance has allowed certain Setaria species to invade previously uinfested parts of the U.S. (Dekker, 2003), no such evidence is available for *S. verticillata* (Heap, 2008).

4. Biology of *Digitaria ischaemum*

Digitaria ischaemum (Schreber) (in the past sometimes also referred to as *Panicum lineare*) is a grassy, annual plant belonging to the Poaceae plant family (also known as the Gramineae family). *Digitaria spp.* were grown for thousands of years as food and feed crops before they were considered weeds (Mitich, 1988). *D. ischaemum* is also known as 'smooth crabgrass' in English and as 'glad vingergras' in Dutch. Most studies on *D. ischaemum* focus on its control through herbicides, while studies on the biology and ecology of *D. ischaemum* are rather scarce.

4.1 Geographic Distribution

In the Netherlands, *D. ischaemum* occurs on sandy construction land and along road sides and railway tracks. The plant is fairly common in regions with sandier soils (van der Meijden, *et al.*, 1990) . *D. ischaemum* is not a weed with major economic or environmental implications in the Netherlands at present. However, the species is reported more often. *D. ischaemum* does cause serious problems in other parts of the world. *D. ischaemum* and *D. sanguinalis* have been introduced in the United States in the 19th and early 20th century as forage grasses (Mitich, 1988). The weed nowadays occurs in grasslands, where it is especially problematic in golf courses, lawns and gardens, forage crops, arable fields, fruit orchards and vineyards (Kim, *et al.*, 2002;Mitich, 1988).*D. ischaemum* is considered a weed in tropical, sub-tropical and temperate regions and occurs in most parts of Europe, the United States, Canada, Siberia, Iran, China, Japan and the Indian sub-continent (Abdallah, *et al.*, 2006;Abu-Dieyeh & Watson, 2007;Doyon & Bouchard, 1981;Kim, *et al.*, 2002;MacRae, *et al.*, 2007;Willis, *et al.*, 2007;Yin, *et al.*, 2006). The weed occurs in grasslands, where it is especially problematic in golf courses, lawns and gardens, forage crops, arable fields, fruit orchards and vineyards (Kim, *et al.*, 2002;Mitich, 1988).

4.2 Morphology

D. ischaemum typically has spreading stems up to 60 cm long that lie on the ground with the tips ascending. Blades are 5-14 cm long, 2-7 mm wide and without hairs. Sheaths are also without hairs and closed, with hairs in the collar region only. Ligules are 1-2 mm long, membranous with even margins. Leaves and sheaths may turn dark red or maroon with age. The inflorescence is a panicle in which the spike-like branches are arranged in digitate fashion. The spikelets are arranged in two rows on an angled or winged rachis. Each spikelet has two florets, only one of which is fertile. The first bracts at the base of the spikelets are either very minute or absent. The plant has a fibrous root system. *D. ischaemum* may be distinguished from the closely related species *Digitaria sanguinalis* (large crabgrass) by the absence of hairs on the leaves and sheath and only a few hairs found in the collar region of *D. ischaemum*. Moreover, *D. ischaemum* crabgrass does not root at the nodes, unlike *D. sanguinalis* (Mitich, 1988;Vega & Rugolo de Agrasar, 2001).

4.3 Seed Ecology, Seedling Emergence and Plant Growth

D. ischaemum seeds cannot withstand storage in water for three months or more, but remain almost 100% viable when seeds are dry-stored up to five years (Comes & Bruns, 1978). *D. ischaemum* may germinate when the average soil temperature is above 22.8 °C. Furthermore, *D. ischaemum* seeds are known to germinate well with alternating light/dark condition and temperatures varying at 20/30 °C (Comes & Bruns, 1978). *D. ischaemum* has a thousand seed weight of approximately 0.055 g (Riemens, unpublished).

D. ischaemum emerges poorly when the seeds reside in large or hard soil clods (Terpstra, 1986). Its germination and emergence patterns could be well predicted based on accumulated degree days (Fidanza & Dernoeden, 1996).

First emergence occurred after 42-78 degree days, while most seedlings emerged after 140-230 degree days (Fidanza & Dernoeden, 1996).

Research suggests that *D. ischaemum* is relatively competitive in arable fields and in turf grass in nutrient-poor environments and under dry conditions. The effect of various fertilization regimes on weed species composition and diversity was investigated in maize in China (Yin, *et al.*, 2006). *D. ischaemum* strongly dominated the weed composition when no fertilizer was applied, but reduced in numbers and even more in relative importance when N, P and / or K fertilizers were applied. Other research from China indicated that *D. ischaemum* has a relatively high level of drought resistance, which was about similar to that of turfgrass (*Poa pretensis*), but higher than that of other common weeds in turfgrass (i.e. *Violam prionatha*, *Geranium sibiricum*, *Potentilla anserine*, *Inula britanica* and *Potentilla supine*) (Wang, *et al.*, 2005).

5. Management of *Digitaria ischaemum*

5.1 Cultural weed control and Fertilisation

A field study was conducted to determine the effect of various pre-emergence herbicides (clomazone, ethalfluralin and halosulfuron) combinations with or without a winter rye cover crop on control of *D. ischaemum* in no-tillage cucumber and zucchini squash production (Walters, *et al.*, 2005;Walters, *et al.*, 2007). Winter rye provided a significant advantage for weed control compared with the no-cover-crop production system. Furthermore, the use of a winter rye cover crop increased the level of weed control achieved by herbicides in both sytems.

In turfgrass (tall fescue, *Festuca arundinacea*), mowing height and to a lesser extent nitrogen application rate, can have a strong impact on *D. ischaemum* populations (Dernoeden, *et al.*, 1993). In a field experiment in the United States, tall fescue mowed at 8.8 cm resisted *D. ischaemum* invasion, exhibited the best visual summer turf quality and contained the highest white clover populations (Dernoeden, *et al.*, 1993). Lower mowing height (3.2 or 5.5 cm) reduced summer turf quality. High nitrogen applications improved autumn and winter turf quality, but not summer quality. Non-herbicide-treated plots receiving high nitrogen applications had less *D. ischaemum* than plots receiving little N (30 vs. 55% *D. ischaemum*), but high nitrogen applications provided no additional *D. ischaemum* reduction in herbicide-treated plots. High mowing (at 8.8 cm) was found to be the best cultural management strategy for reducing *D. ischaemum* encroachment.

D. ischaemum in maize strongly dominated a weed community when no fertilizer was applied, but reduced in numbers and reduce even more in relative importance when N, P and / or K fertilizers were applied, as mentioned before (Yin, *et al.*, 2006). These results are in line with those from (Dernoeden, *et al.*, 1993), described above and results from (Buse, 2003). The results indicate that *D. ischaemum* is less able to compete with crops and other weeds when soil nutrient availability increases.

5.2 Biological control

Ustilago syntherismae causing loose smut has been proposed as a biological control agents of *Digitaria spp*, but turned out to be ineffective for the control of *D. ischaemum*, presumably because of a high tolerance of *D. ischaemum* against this pathogen (Johnson & Baudoin, 1997). Various insects feed on *Digitaria spp.* plants, including the caterpillars of *Hylephila phyleus* (Fiery Skipper) and the moth *Mocis texana* (Texas Mocis). The seeds of *Digitaria spp*. are an important source of food to many species of upland gamebirds and granivorous songbirds. However, a promising candidate to act as a biological control agent of *D. ischaemum* has not been identified yet.

Application of maize gluten meal can reduce *D. ischaemum* root and shoot development and plant survival (Bingaman & Christians, 1995). In a greenhouse experiment, application of 324, 649 and 973 g maize gluten meal m^{-2} reduced the survival of *D. ischaemum* by 51%, 85% and 97%, respectively and reduced shoot development by 44-89% and root development by 65-100% (Bingaman & Christians, 1995). Application of maize gluten meal thus has a good potential as a natural herbicide of *D. ischaemum*. Water-soluble enzymatically hydrolised maize gluten meal was found to be more effective as a herbicide than maize gluten itself, inhibiting the root growth of germinating seeds (Liu, *et al.*, 1994).

5.3 Chemical control

The control of *D. ischaemum* in turf grass with herbicides can be problematic because selective herbicides are required that control *D. ischaemum*, but do not injure the turf grass belonging to the same plant family. Nevertheless, *D. ischaemum* in turfgrass can be effectively controlled with a range of herbicides, although efficacy among products can vary from year to year and among regions. An evaluation of the effect of pendimethalin on

D. ischaemum in turfgrass concluded that granular application was more effective in controlling the weed than wettable powder (Gasper, *et al.*, 1994). Also rodiamine may give complete control of *D. ischaemum* in turfgrass with little reduction in turfgrass quality (Fermanian & Haley, 1994). Furthermore, bensulide and DCPA, granular or in liquid form, have been shown to be effective for the control of *D. ischaemum* without injuring the turf (*Poa pratensis*) (Bhowmik, 1987). Also quinclorac can provide consistent control of *D. ischaemum* in turfgrass (Dernoeden, *et al.*, 2003). A field study conducted in the United States evaluated commonly used pre- and postemergence herbicides for their *D. ischaemum* control performance in turf grass as rates were reduced (Dernoeden, 2001). Standard use rates of benefin, pendimethalin, prodiamine, dithiopyr and DCPA provided acceptable (< 5% *D. ischaemum* cover) control in the first year. In the second year, reduced rates of benefin + trifluralin and pendimethalin, prodiamine, dithiopyr and DCPA continued to provide commercially acceptable control. Fenoxaprop and quinclorac also provided effective (< 6% *D. ischaemum* cover) postemergence crabgrass control in a single application. *D. ischaemum* in turfgrass can also be controlled with sulfonylurea herbicides (trifloxysulfuron, rimsulfuron, sulfosufuron or foramsulfuron) (Willis, *et al.*, 2007). Application at 3 weeks after sowing was found to be more effective than application at 1 week after sowing turfgrass. However, in a pot experiment, rimsulfuron and nicosulfuron were found to be ineffective for the control of *D. ischaemum*, even at the highest recommended application rates (Mekki & Leroux, 1995), which is in line with results from a field study on weed control in maize and soybean using rimsufuron, nicosulfuron or a combination of the two (Mekki & Leroux, 1994). As a pre-emergence herbicide in zucchini squash production in the U.S., clomazone+imazamox and clomazone+ethalfuralin has been recommended for the control of *D. ischaemum* (Walters, *et al.*, 2004). In soybean in India, imazethapyr + pendimethalin was found to give satisfactory pre-emergence control of *D. ischaemum* (Raskar & Bhoi, 2002). In tomato in the United States, rimsulfuron has been recommended for *D. ischaemum* control (Mullen, *et al.*, 1999).

D. ischaemum has developed resistance against ACCase inhibitors and synthetic Auxins, namely resistance against quinclorac in California, the United States (Abdallah, *et al.*, 2006) and against fenoxaprop in New Jersey, the United States (Derr, 2002;YongIn, *et al.*, 1999). *Digitaria sanguinalis* has developed cross-resistance against several ACCase inhibitors (clethodim, fluazifop and sethoxydim) (Volenberg & Stoltenberg, 2002), resistance against Photosystem II inhibitors (atrazine) in several European copuntries (Monteiro & Rocha, 1992) and multiple resistance against ALS inhibitors and ACCase inhibitors (fluazifop, mhaloxyfop and imazethapyr) in Australia (Hidayat & Preston, 2001).

6. Biology of *Geranium molle*

6.1 Geographical distribution

Geranium molle, commonly known as dovefoot cranesbill (in Dutch: zachte ooievaarsbek). It is found throughout the temperate regions of the world and the mountains of the tropics, but mostly in the eastern part of the Mediterranean region. *G. molle* is also widespread in Canada and the USA after introduction from Europe. As well as its coastal habitats, this plant is widespread and frequent inland, on cultivated and waste places, open habitats, dunes dry grasland and roadsides (Aedo, 2000).

6.2 Morphology

Most *Geranium* species are summer annual weeds and survive over winter only as seeds. Although it can grow to over a foot (30cm) in height, it is usually much shorter. The stem is erect or decumbent, usually branched from the base. The whole plant is softly hairy, the flowers are about half an inch (c. 12mm) across and the petals are pink or pinkish-purple and notched.

6.3 Seed longevity and germination

Species of Geraniaceae produce seeds with a water-impermeable seed coat (physical dormancy). These seeds remain in a state of physical dormancy and can survive for a long period in the soil. After dispersal a small fraction of the seeds germinates and in common arable farming systems in Europe the other fraction is incorporated into the seedbank and germinates during summer in the subsequent years (Roberts & Boddrell, 1984). *G. molle* seeds emerge mainly in the period May-September, depending on the amount of rainfall. Flushes of seedlings appeared when rainfall followed cultivation (Roberts & Boddrell, 1985). Van Assche & Vandelook (2006) found that seeds of Geraniaceae became permeable and lost their physiological dormancy during dry storage within 3-12 months. However, fresh seeds buried immediately under natural conditions remained impermeable and viable for 1.5-2.5 years, with no seasonal change in germination capacity of exhumed seeds. They concluded that dormancy of impermeable, hard seeds under natural conditions may be broken by drying during the summer season, by specific temperature regimes or gradual softening of the seed coat. This ensures the spreading of germination over many seasons.

Earlier work of Lewis (1958) showed that *G. molle* seeds gave low germination rates after burial in mineral soil. Seeds were largely desintegrated and had less than 1% viability after two years. Stored in peat the viability of *Geranium* spp. seeds was very low and seeds desintegrated which was contributed to the acid environment in the peat.

6.4 Seedling emergence and growth

6.5 Seed production and dispersal

Geraniums produce circa five seeds per flower and disperce the seeds by forcibly ejecting them for several meters. Stamp and Lucas (1983) investigated whether explosive seed dispersers either maximize ballistic dispersal distance or maximize the use of secondary dispersal agents (water, wind or animals). The experimental results showed that explosive dispersers have sharply defined maximum distances for throwing their seeds. Geraniums spp. can throw their seeds 2-14 times further away then the other species tested (Phlox, Viola and Impatiens spp.). Regarding the shape, size and weight of the seeds Geraniums contrasted with the other species tested. The seeds were ovoid and more streamlined than the seeds of the other species. Seed weight was relatively conctant, seeds of *G. molle* were lighter than water. Based on the relatively constant seed size and weight the authors concluded that the ballastic mechanism of geraniums suggests a selection for maximizing the dispersal distance. Seeds are thrown for several metesr (1-4m). Although *G. molle* seeds have no special adaptations for secondary dispersal, the seed weight is relatively low. Therefore, seeds may be dispersed by (rain)water.

7. Management of *Geranium molle*

7.1 Non-chemical

Very little information is available on the non-chemical management of *G. molle* populations. Nothing has been reported on the efficacy of mechanical weed control techniques, or biological control agents.

Some information is available on the competitive ability of the species grown together with cereals from a simulation model. Storkey and Cussans (2007) developed a simulation model for weed growth and competition for a number of weed species in a winter wheat crop in the UK. They showed that winter wheat can experience some yield loss from competition with *G. molle*. No literature was found on the comparison of different crops or crop rotation for their competitive ability against *G. molle*.

7.2 Chemical control techniques

Field research of Hoek (2008) showed that *G. molle* can be controlled effectively by chemical control techniques in agricultural crops as mais, granes, sugarbeet and potato. Also for weed control on grassland for seed production chemical control techniques are available. Since the authorisation of Dosanex has expired the control of *G. molle* in carrots has become more difficult in the Netherlands. Furthermore, there are no herbicides available, at this moment, for effective weed control of *G. molle* in small area horticultural crops.

Chemical control of *G. molle* in arable crops

Mais

After emergence with the herbicide Mikado or Callisto and Milagro or Samson in combination with Laddok N, Gardoprim (terbuthylazin) or Basagran. A relatively new effective herbicide is Calaris (Hoek, 2008).

Cereals

For weed control during springtime the herbicides Ally, Artus, Primus, Vega and Basagran are effective. For weeds emerged in autumn both Stomp or Boxer can be applied (Hoek, 2008).

Sugarbeet

Herbicides Betanal Expert, Betanal Quattro, Frontier Optima, Dual Gold, Goltrix and Safari are available for controlling weeds in sugarbeet (Hoek, 2008). *Geranium molle* was identifed as an increasing weed problem in sugar beet in the UK during 2004. Farmers were advised to use metamitron (Goltrix) as a pre-emergence treatment and to include this herbicide in early post-emergence mixes. Post-emergence treatment should be applied when the weed is at the cotyledon stage, once true leaves start to develop it is difficult to control (May, 2005).

Potato

In potato the most common weeds including *G. molle* can be controlled with herbicides with linuron as active substant (Afalon, Brabant linuron), Sencor, Butisan S, Challenge and Boxer. However, Butisan S and Challenge are not allowed in *pootgoed?* After emergence *G. molle* can be controlled with Basagran and Titus. For weed control in *pootgoed* only herbicides with with linuron as active substant are available, but these herbicides are less effective against *G. molle* (Hoek, 2008).

Dow Agro Sciences has developed a new broad spectrum herbicide for cereal crops, with pyroxsulam (new) and florasulam as active substances. The mode of action of both components is the inhibition of acetolactate synthase and is effective against many grass weeds and a number of dicotyledonous weeds including geranium spp. Field testing was carried out in Germany.The herbicide was applied in the field after the emergence of the weeds until the 2-node-stage at 130-220 g/ha in a cereal crop. The rainfastness of the formulation was cica one hour (Becker, *et al.*, 2008).

Schulte et al (2008) reported the results of field tests with Colzor Trio herbicide for weed control in oil seed rape. Colzor Trio is a broad spectrum pre-emergence herbicide with three active ingredients, dimethachlor (187,5 g/l), napropamide (187,5 g/l) and clomazone (30 g/l). The combination with napropamide was introduced to give a good control of Geranium spp. Field tests with Colzor Trio (4 l/ha) were carried out in Germany and Austria in the season of 2000/01 until 2007/08. On average Colzor trio reduced the visual biomass production with 91-94% for the two geranium species when applied in autumn. Applied in spring biomass reduction was 85 and 95% respectively.

8. Summary/conclusions on management options

The amount of information on *Setaria verticillata, Digitaria ischaemum* and *Geranium molle* biology and control is very limited, especially for Dutch circumstances. However, some aspects from previous studies may be usefull for the control of *Setaria verticillata* and *Digitaria ischaemum* in the Netherlands as well.

The use of a winter cereal cover crop such as rye, triticale and barley may be incorporated in crop rotations and suppress the emergence and growth of *S. verticillata* after incorporation in the soil in spring and thereby help reduce the size of *S.verticillata* populations. The positive effects of a winter cover crop (rye) were also reported for the control of *D. ischaemum* populations.

Furthermore, the application of a mowing regime may be able to control *S. verticillata*, although frequency and height still need to be determined. Mowing at an optimum height of 8.8 cm can reduce *D. ischaemum* population size.
The competitive ability of *D. ischaemum* with crops decreases with increasing soil nutrient availability, indicating that a proper fertilization scheme can aid in reducing *D. ischaemum* populations.

To our knowledge, the efficacy of mechanical weed control techniques, the effect of crop rotations, cover crops, mowing or fertilizer regimes on *G. molle* has not been investigated. Chemical control of this species is possible in arable crops, however effective herbicides for application in small area horticultural crops are lacking.

Untill now, no promising biological control agents could be identified for either one of these species.

Literature Setaria

ABDALLAH I, FISCHER AJ, ELMORE CL, SALTVEIT ME & ZAKI M (2006)
Mechanism of resistance to quinclorac in smooth crabgrass (*Digitaria ischaemum*). *Pesticide Biochemistry and Physiology* **84**, 38-48.
ABU-DIEYEH M & WATSON AK (2007)
Population dynamics of broadleaf weeds in turfgrass as influenced by chemical and biological control methods. *Weed Science* **55**, 371-380.
BHOWMIK PC (1987)
Smooth crabgrass (*Digitaria ischaemum*) control in Kentucky Bluegrass (*Poa pratensis*) turf with herbicides applied preemergence. *Weed Technology* **1**, 145-148.
BINGAMAN BR & CHRISTIANS NE (1995)
Greenhouse screening of corn gluten meal as a natural control product for broadleaf and grass weeds. *Horticulture Science* **30**, 1256-1259.
BUSE P (2003)
Cultural management of weeds in turfgrass: a review. *Crop Protection* **43**, 1899-1911.
COMES RD & BRUNS (1978)
Longevity of certain weed and crop seeds in fresh water. *Weed Science* **26**, 336-344.
DERNOEDEN PH (2001)
Reduced herbicide rates for smooth crabgrass control in the Mid-Atlantic Region. *International Turfgrass Society Research Journal* **9**, 1005-1008.
DERNOEDEN PH, BIGELOW CA, KAMINSKI JE & KROUSE JM (2003)
Smooth crabgrass control in perennial ryegrass and creeping bentgrass tolerance to quinclorac. *Horticulture Science* **38**, 607-612.
DERNOEDEN PH, CARROLL MJ & KROUSE JM (1993)
Weed management and tall fescue quality as influenced by mowing, nitrogen and herbicides. *Crop Science* **33**, 1055-1061.
DERR JF (2002)
Detection of fenoxaprop-resistant smooth crabgrass (*Digitaria ischaemum*) in turf. *Weed Technology* **16**, 396-400.
DOYON D & BOUCHARD CJ (1981)
Survey of weeds in fields of maize in the country of St-Hyacinthe, Quebec. *Phytoprotection* **62**, 1-10.
FERMANIAN TW & HALEY JE (1994)
Fall application of prodiamine for spring crabgrass (Digitaria spp.) control. *Weed Technology* **8**, 612-616.
FIDANZA MA & DERNOEDEN (1996)
Degree-days for predicting smooth crabgrass emergence in cool-season turfgrasses. *Crop Science* **36**, 990-996.
GASPER JJ, STREET JR, HARRISON SK & POUND WE (1994)
Pendimethalin efficacy and dissipation in turfgrass as influenced by rainfall incorporation. *Weed Science* **42**, 586-592.
HIDAYAT I & PRESTON C (2001)
Cross-resistance to imazethapyr in a fluazifop-P-butyl-resistant population of *Digitaria sanguinalis*. *Pesticide Biochemistry and Physiology* **71**, 190-195.
JOHNSON DA & BAUDOIN ABAM (1997)
Mode of infection and factors affecting disease incidence of loose smut of crabgrass. *Biological Control* **10**, 92-97.
KIM T-J, NEAL JC, DITOMASO JM & ROSSI FS (2002)
A survey of weed scientsts' perceptions on the significance of crabgrass (*Digitaria* spp.) in the United States. *Weed Technology* **16**, 239-242.

LIU DLY, CHRISTIANS NE & GARBUTT JT (1994)
Herbicidal activity of hydrolyzed corn gluten meal on three grass species under controlled environments. *Journal of plant growth regulation* **13**, 221-226.
MACRAE AW, MITCHEM WE, MONKS DW, PARKER ML & GALLOWAY RK (2007)
Tree growth, fruit size and yield response of mature peach to weed-free intervals. *Weed Technology* **21**, 102-105.
MEKKI M & LEROUX GD (1994)
Activity of nicosulfuron, rimsulfuron and their mixture on field corn (*Zea mays*), soybean (*Glycine max*) and seven weed species. *Weed Technology* **8**, 436-440.
MEKKI M & LEROUX GD (1995)
Foliar absorption and translocation of nicosulfuron and rimsulfuron in five annual weed species. *Weed research* **35**, 377-383.
MITICH LW (1988)
Intriguing world of weeds - Crabgrass. *Weed Technology* **2**, 114-115.
MONTEIRO I & ROCHA F (1992)
Study of a survey of weed biotypes resistant to atrazine. In: Proceedings 1992 1992 Congress of the Spanish Weed Science Society, Spain, 315-319.
MULLEN RJ, CAPRILE J, VIOSS TC, WHITELEY RW & RIVARA CJ (1999)
Recent research developments in tomato weed management. *Acta Horticulturae* **487**, 165-170.
RASKAR BS & BHOI PG (2002)
Bioefficacy and phytotoxicity of new herbicide formulations against weeds in soybean (*Glycine max*). *Indian Journal of Agricultural Sciences* **72**, 673-675.
TERPSTRA R (1986)
Behavior of weed seed in soil clods. *Weed Science* **34**, 889-895.
VAN DER MEIJDEN R, WEEDA EJ, HOLVERDA WJ & HOVENKAMP PH (1990)
Heukels' flora van Nederland. Wolters-Noordhoff, Groningen.
VEGA AS & RUGOLO DE AGRASAR Z (2001)
Morphological interpretation of the spikelet in Digitaria atra (Poaceae: Panicoideae: Paniceae) and amended generic description. *American Journal of Botany* **88**, 1670-1674.
VOLENBERG D & STOLTENBERG D (2002)
Altered acetyl-coenzyme A carboxylase confers resistance to clethodim, fluazifop and sethoxydim in *Setaria faberi* and *Digitaria sanguinalis*. *Weed research* **42**, 342-350.
WALTERS SA, NOLTE SA & YOUNG BG (2005)
Influence of winter rye and preemergence herbicides on weed control in no-tillage zucchini squash production. *Horticulture Technology* **15**, 238-243.
WALTERS SA, YOUNG BG & KINDHART JD (2004)
Weed control in no-tillage zucchini squash production. *Acta Horticulturae* **638**, 201-207.
WALTERS SA, YOUNG BG & NOLTE SA (2007)
Cover crop and pre-emergence herbicide combinations in no-tillage fresh market cucumber production. *Journal of Sustainable Agriculture* **30**, 5-19.
WANG Y, ZHAO L & SHAO Y (2005)
Comparative analysis of the drought-resistances for turfgrass and main weeds in the temperate semi-arid region. *Chinese Journal of Ecology* **24**, 1-5.
WILLIS JB, RICKER DB & ASKEW SD (2007)
Sulfonylurea herbicides applied during early establishment of seeded bermudagrass. *Weed Technology* **21**, 1035-1038.
YIN L, CAI Z & ZHONG W (2006)
Changes in weed community diversity of maize crops due to long-term fertilization. *Crop Protection* **25**, 910-914.
YONGIN K, JINGRUI W, DERR F & HATZIOS K (1999)
Mechanisms of fenoxaprop resistance in an accession of smooth crabgrass (*Digitaria ischaemum*). *Pesticide Biochemistry and Physiology* **64**, 112-123.

Literature Digitaria

ABDALLAH I, FISCHER AJ, ELMORE CL, SALTVEIT ME & ZAKI M (2006)
Mechanism of resistance to quinclorac in smooth crabgrass (*Digitaria ischaemum*). *Pesticide Biochemistry and Physiology* **84**, 38-48.

ABU-DIEYEH M & WATSON AK (2007)
Population dynamics of broadleaf weeds in turfgrass as influenced by chemical and biological control methods. *Weed Science* **55**, 371-380.

AL KATHIRI CR (1994)
Weeds: a factor limiting crop production in Yemen. *Indian journal of plant protection* **22**, 5-8.

ARMEL GR, WILSON HP, RICHARDSON RJ & HINES TE (2003)
Mesotrione, acetochlor and atrazine for weed management in corn (*Zea mays*). *Weed Technology* **17**, 284-290.

BHOWMIK PC (1987)
Smooth crabgrass (*Digitaria ischaemum*) control in Kentucky Bluegrass (*Poa pratensis*) turf with herbicides applied preemergence. *Weed Technology* **1**, 145-148.

BINGAMAN BR & CHRISTIANS NE (1995)
Greenhouse screening of corn gluten meal as a natural control product for broadleaf and grass weeds. *Horticulture Science* **30**, 1256-1259.

BORN V (1971)
Freen foxtail: seed dormancy, germination and growth. *Canadian journal of plant science* **51**, 53-59.

BUHLER DD (1995)
Influence of tillage systems on weed population dynamics and management in corn and soybean in the central USA. *Crop Science* **35**, 1247-1258.

BUHLER DD & MESTER TC (1991)
Effect of tillage systems on the emergence depth of giant (Setaria faberi) and green foxtail (Setaria viridis). *Weed Science* **39**, 200-203.

BUSE P (2003)
Cultural management of weeds in turfgrass: a review. *Crop Protection* **43**, 1899-1911.

COMES RD & BRUNS (1978)
Longevity of certain weed and crop seeds in fresh water. *Weed Science* **26**, 336-344.

DE PRADO RA & FRANCO AR (2004)
Cross-resistance and herbicide metabolism in grass weeds in Europe: biochemical and physiological characteristics. *Weed Science* **52**, 441-447.

DEKKER J (2003)
The foxtail (Setaria) species group. *Weed Science* **51**, 641-656.

DERNOEDEN PH (2001)
Reduced herbicide rates for smooth crabgrass control in the Mid-Atlantic Region. *International Turfgrass Society Research Journal* **9**, 1005-1008.

DERNOEDEN PH, BIGELOW CA, KAMINSKI JE & KROUSE JM (2003)
Smooth crabgrass control in perennial ryegrass and creeping bentgrass tolerance to quinclorac. *Horticulture Science* **38**, 607-612.

DERNOEDEN PH, CARROLL MJ & KROUSE JM (1993)
Weed management and tall fescue quality as influenced by mowing, nitrogen and herbicides. *Crop Science* **33**, 1055-1061.

DERR JF (2002)
Detection of fenoxaprop-resistant smooth crabgrass (*Digitaria ischaemum*) in turf. *Weed Technology* **16**, 396-400.

DHIMA KV, VASILAKOGLOU I, ELEFTHEROHORINOS I & LITHOURGIDIS A (2006a)
Allelopathic potential of winter cereal cover crop mulches on grass weed suppression and sugarbeet development. *Crop Science* **46**, 1682-1691.

DHIMA KV, VASILAKOGLOU IB, ELEFTHEROHORINOS IG & LITHOURGIDIS AS (2006b)
Allelopathic potential of winter cereals and their cover crop mulch effect on grass weed suppression and corn development. *Crop Science* **46**, 345-352.
DOUGLAS BJ, THOMAS AG, MORRISON IN & MAW MG (1985)
The biology of Canadian weeds. 70. Setaria viridis (L.) Beauv. *Canadian journal of plant science* **65**, 669-690.
DOYON D & BOUCHARD CJ (1981)
Survey of weeds in fields of maize in the country of St-Hyacinthe, Quebec. *Phytoprotection* **62**, 1-10.
ELLIS MH, REBETZKE GJ, KELMAN WM, MOORE CS & HYLES JE (2004)
Detection of Wheat streak mosaic virus in four pasture grass species in Australia. *Plant Pathology* **53**, 239.
ERNST WHO (1991)
Fire, dry heat and germination of savanna grasses in Botswana. In: *Modern Ecology: Basic and Applied Aspects* (eds G Esser & D Overdieck), 77-96. Amsterdam, Netherlands: Elsevier, Amsterdam.
FERMANIAN TW & HALEY JE (1994)
Fall application of prodiamine for spring crabgrass (Digitaria spp.) control. *Weed Technology* **8**, 612-616.
FIDANZA MA & DERNOEDEN (1996)
Degree-days for predicting smooth crabgrass emergence in cool-season turfgrasses. *Crop Science* **36**, 990-996.
GASPER JJ, STREET JR, HARRISON SK & POUND WE (1994)
Pendimethalin efficacy and dissipation in turfgrass as influenced by rainfall incorporation. *Weed Science* **42**, 586-592.
GIRMA-WOLDETSADIK & CHINAWONG S (2005)
Growth, yield attributes and weed characteristics as influenced by integrated nitrogen fertilization and weed-control of maize (*Zea mays* L.) in central Rift Valley of Ethiopia. *Kasetsart Journal, Natural Sciences* **39**, 338-349.
GIUDICE VL & ROCCUZZO G (1995)
Preliminary observations on the life cycle of some weeds of citrus orchards. *Difesa delle Piante* **18**, 227-233.
HAAR JM (1998)
Characterisation of foxtail (Setaria spp.) seed production and giant foxtail (*Setaria faberii*) seed dormancy at abscission. Ph.D. dissertation, Iowa State University, Ames
HANSON PM & SMITH LM (1992)
Economics of chemical and manual weed control in hybrid maize in the Kenya highlands. *Tropical Pest Management* **38**, 210-213.
HEAP I (2008)
The International Survey of Herbicide Resistant Weeds (Internet). www.weedscience.org.
HIDAYAT I & PRESTON C (2001)
Cross-resistance to imazethapyr in a fluazifop-P-butyl-resistant population of *Digitaria sanguinalis*. *Pesticide Biochemistry and Physiology* **71**, 190-195.
HOLT JS & LEBARON HM (2000)
Significance and distribution of herbicide resistance. *Weed Technology* **4**, 141-149.
HUTCHINSON PJS (2007)
A comparison of flumioxazin and rimsulfuron tank mixtures for weed control in potato. *Weed Technology* **21**, 1023-1028.
ISAACS MA, WILSON HP & TOLER JE (2002)
Rimsulforon plus thifensulfuron-methyl combination with selected postemergence broadleaf herbicides in corn (*Zea mays*). *Weed Technology* **16**, 664-668.
JAMES AL (1968)
Some influences of soil atmosphere on germination of annual weeds, Iowa State University, Ames
JAMES TK & RAHMAN A (1993a)
Adjuvants improve control of warm zone grasses with sulfonylurea herbicides in maize. In: Proceedings 1993a Proceedings of the 10th Australian Weeds Conference and 14th Asian-Pacific Weed Science Society Conference, Brisbane, Australia, 68-72.
JAMES TK & RAHMAN A (1993b)
Adjuvants improve control of warm zone grasses with sulfonylurea herbicides in maize. In: Proceedings 1993b

10th Australian Weeds Conference and 14th Asian Pacific Weed Science Society Conference, Brisbane, Australia, 68-72.

JOHNSON DA & BAUDOIN ABAM (1997)
Mode of infection and factors affecting disease incidence of loose smut of crabgrass. *Biological Control* **10**, 92-97.

KASA M & KARACA I (1977)
Investigations on the determination and control of important weeds in corn fields in the Black Sea area of Turkey. *The Journal of Turkish phytopathology* **6**, 9-14.

KAYA I & NEMLI Y (2004)
Determination of minimum and maximum germination temperature of certain weed species in cotton fields in Nazilli and Menemen. *Turkiye Herboloji Dergisi* **7**, 13-19.

KESHAVARZI M & SEIFALI M (2007)
Systematic study of weedy species of Setaria (L.) P. Beauv. (Poaceae) in Iran. *Pakistan Journal of Biological Sciences* **10**, 3362-3367.

KIM T-J, NEAL JC, DITOMASO JM & ROSSI FS (2002)
A survey of weed scientsts' perceptions on the significance of crabgrass (*Digitaria* spp.) in the United States. *Weed Technology* **16**, 239-242.

KOSTOV T & PACANOSKI Z (2006)
Pakistan Journal of Weed Science Research **12**, 299-306.

LEE SM & CAVERS PB (1981)
The effects of shade on growth, development and resource allocation patterns of three species of foxtail (Setaria). *Canadian journal of botany* **59**, 1776-1786.

LIU DLY, CHRISTIANS NE & GARBUTT JT (1994)
Herbicidal activity of hydrolyzed corn gluten meal on three grass species under controlled environments. *Journal of plant growth regulation* **13**, 221-226.

MACRAE AW, MITCHEM WE, MONKS DW, PARKER ML & GALLOWAY RK (2007)
Tree growth, fruit size and yield response of mature peach to weed-free intervals. *Weed Technology* **21**, 102-105.

MEKKI M & LEROUX GD (1994)
Activity of nicosulfuron, rimsulfuron and their mixture on field corn (*Zea mays*), soybean (*Glycine max*) and seven weed species. *Weed Technology* **8**, 436-440.

MEKKI M & LEROUX GD (1995)
Foliar absorption and translocation of nicosulfuron and rimsulfuron in five annual weed species. *Weed research* **35**, 377-383.

MITICH LW (1988)
Intriguing world of weeds - Crabgrass. *Weed Technology* **2**, 114-115.

MONTEIRO I & ROCHA F (1992)
Study of a survey of weed biotypes resistant to atrazine. In: Proceedings 1992 1992 Congress of the Spanish Weed Science Society, Spain, 315-319.

MOYER JR, OWENYA ZJ & KIBUWA SP (1989)
Weed populations and agronomic practices at wheat farms on the Hanang plains in Tanzania. *Tropical Pest Management* **35**, 26-29.

MULLEN RJ, CAPRILE J, VIOSS TC, WHITELEY RW & RIVARA CJ (1999)
Recent research developments in tomato weed management. *Acta Horticulturae* **487**, 165-170.

NELSON JE, MEGGITT WF, PENNER D & LADLIE JS (1983)
The influence of environmental factors on oryzalin activity. *Weed Science* **31**, 752-758.

NOME SF, LENARDON S, MUNOZ J & ZUMELZU G (1983)
Digitaria sanguinalis (.) Scop and Setaria verticillata (L.) P. Beauvois, natural reservoirs of maize rough dwarf virus. *Revista de Investigaciones Agropecuarias* **18**, 321-328.

RAHMAN A, JAMES TK, MELLSOP JM & GRBAVAC N (2003)
Relationship between soil seedbank and field populations of grass weeds in maize. *New Zeland Plant Protection* **56**, 215-219.

RASKAR BS & BHOI PG (2002)
Bioefficacy and phytotoxicity of new herbicide formulations against weeds in soybean (*Glycine max*). *Indian Journal of Agricultural Sciences* **72**, 673-675.
RAYCHAUDHURI SP, MISHRA MD & BASU AN (1971)
Investigations on tungro and yellow dwarf diseases of rice. *Oryza* **8**, 361-363.
ROMINGER JM (1959)
Taxonomy of Setaria (Gramineae) in North America.
SALIMI H & TERMEH F (2002)
A study on seed dormancy and germination in ten species of grass weeds. *Rostaniha* **3**, 9-12.
STEEL MG, CAVERS PB & LEE SM (1983)
The biology of Canadian weeds. 59. Setaria glauca (L.) Beauv. and S. verticillata (L.) Beauv. *Canadian journal of plant science* **63**, 711-725.
SYLWESTER EP (1970)
The ten worst weeds of field crops. 6. Foxtails. *Crop Soils* **22**, 11-13.
TAYLORSON RB (1982)
Anesthetic effects on secondary dormancy and phytochrome responses in Setaria faberi seeds. *Plant Physiology* **70**, 882-886.
TAYLORSON RB (1986)
Water stress-induced germination of giant foxtail (Setaria faberi) seeds. *Weed Science* **34**, 871-875.
TERPSTRA R (1986)
Behavior of weed seed in soil clods. *Weed Science* **34**, 889-895.
TILL BOTTRAUD I, LAVIGNE C, REBOUD X, *et al.* (1992)
Gene flow between wild and cultivated Setaria: consequences for the release of transgenic crops IXe Colloque international sur la biologie des mauvaises herbes, 16 18 September 1992, Dijon, France.
TOOLE EH & BROWN E (1946)
Final results of the Duvel buried seed experiment. *Journal of Agricultural Research* **72**, 201-210.
UREMIS I & UYGUR FN (1999)
Minimum, optimum and maximum germination temperaturs of some important weed species in the Cukurova Region of Turkey. *Turkiye Herboloji Dergisi* **2**, 1-12.
UREMIS I & UYGUR FN (2002)
Variation of viability rates of some weed seeds in different depths of the soil by times. *Turkiye Herboloji Dergisi* **5**, 23-34.
UREMIS I & UYGUR FN (2005)
Seed viability of some weed species after 7 years of burial in the Cukurova Region of Turkey. *Asian Journal of Plant Sciences* **4**, 1-5.
VAN DER MEIJDEN R, WEEDA EJ, HOLVERDA WJ & HOVENKAMP PH (1990)
Heukels' flora van Nederland. Wolters-Noordhoff, Groningen.
VASILAKOGLOU I, DHIMA K, ELEFTHEROHORINOS I & LITHOURGIDIS A (2006)
Winter cereal cover crop mulches and inter-row cultivation effects on cotton development and grass weed suppression. *Agronomy Journal* **98**, 1290-1297.
VASILAKOGLOU IB & ELEFTHEROHORINOS IG (2003)
Persistence, efficacy and selectivity of amide herbicides in corn. *Weed Technology* **17**, 381-388.
VEGA AS & RUGOLO DE AGRASAR Z (2001)
Morphological interpretation of the spikelet in Digitaria atra (Poaceae: Panicoideae: Paniceae) and amended generic description. *American Journal of Botany* **88**, 1670-1674.
VOLENBERG D & STOLTENBERG D (2002)
Altered acetyl-coenzyme A carboxylase confers resistance to clethodim, fluazifop and sethoxydim in *Setaria faberi* and *Digitaria sanguinalis*. *Weed research* **42**, 342-350.
WALTERS SA, NOLTE SA & YOUNG BG (2005)
Influence of winter rye and preemergence herbicides on weed control in no-tillage zucchini squash production. *Horticulture Technology* **15**, 238-243.
WALTERS SA, YOUNG BG & KINDHART JD (2004)
Weed control in no-tillage zucchini squash production. *Acta Horticulturae* **638**, 201-207.

WALTERS SA, YOUNG BG & NOLTE SA (2007)
Cover crop and pre-emergence herbicide combinations in no-tillage fresh market cucumber production. *Journal of Sustainable Agriculture* **30**, 5-19.

WANG R, WENDEL JF & DEKKER J (1995a)
Weedy adaptation in Setaria spp. II. Genetic diversity and population genetic structure in S. glauca, S. geniculata and S. faberii (Poaceae). *American Journal of Botany* **82**, 1031-1039.

WANG RL, WENDEL J & DEKKER J (1995b)
Weedy adaptation in Setaria spp. I. Isozyme analysis of genetic diversity and population genetic structure in Setaria viridis. *American Journal of Botany* **82**, 308-317.

WANG Y, ZHAO L & SHAO Y (2005)
Comparative analysis of the drought-resistances for turfgrass and main weeds in the temperate semi-arid region. *Chinese Journal of Ecology* **24**, 1-5.

WIGG PM, OWEN MA & MUKURASI NJ (1973)
Influence of farmyard manure and nitrogen fertilizers on sown pastures, seed yield and quality of Cenchrus ciliaris L. at Kongwa. *East African agricultural and forestry journal* **38**, 367-374.

WILLIS JB, RICKER DB & ASKEW SD (2007)
Sulfonylurea herbicides applied during early establishment of seeded bermudagrass. *Weed Technology* **21**, 1035-1038.

YIN L, CAI Z & ZHONG W (2006)
Changes in weed community diversity of maize crops due to long-term fertilization. *Crop Protection* **25**, 910-914.

YONGIN K, JINGRUI W, DERR F & HATZIOS K (1999)
Mechanisms of fenoxaprop resistance in an accession of smooth crabgrass (*Digitaria ischaemum*). *Pesticide Biochemistry and Physiology* **64**, 112-123.

Literature Geranium

AEDO, C. (2000).
The genus geranium L. (Geraniaceae) in Northe America. I. Annul species. Anales Jard. Bot. Madrid 58(1): 39-82.

BECKERS, J., J. SCHRODER, D. LARELLE, I. ERDEI, U. HOMA and R. GAST (2008).
DOW 00742 H (GF-1361) A novel cereal herbicide containing a new active ingredient (pyroxsulam) and florasulam with a broad activity on grass and dicotyledonous weeds.
J. Plant Disease and Protection Special Issue XXI, 623-628.

FRECKLETON, R.P and A.R. WATKINSON (1998).
Predicting the determinants of weed abundance: a model for the population dynamics of Chenopodium album in sugar beet. J. Appl. Ecol. 35: 904-920.

HOEK, H. (2008).
Lastig onkruid in de kiem smoren. Boerderij 93, no. 31.

LEWIS, J. (1958).
Longevity of crop and weed seeds 1. First interim report. Proc. Int. Seed – Test Ass. 23(2): 340-354.

MAY, M. (2005).
Weed control experiences in 2004 and prospects for 2005. Beet review, 73(1): 8.

ROBERTS, H.A. and J.E. BODDRELL (1984).
Seed survival ans seasonal emergence in plant species from different habitats. Journal of Applied Ecology 21: 639-656.

ROBERTS, H.A. and J.E. BODDRELL (1985).
Seed survival ans seasonal emergence in some species of Geranium, Ranunculus and Rumex. Annals of Applied Biology 107:231-238.

SCHULTE, M., U. RICHTER and G. HALL (2008).
Colzor Trio – Three herbicidal active ingrdients for use in oil seed rape viewed in a new light.
J. Plant Disease and Protection Special Issue XXI, 635-642.

STAMP, N.E. and J.R. LUCAS (1983).
Ecological correlates of explosive seed dispersal. Oecologia 59: 272-278.

STORKEY, J. and J.W. CUSSANS (2007).
Reconciling the conservation of in-field biodiversity with crop production using a simulation model of weed growth and competition. Agriculture, Ecosystems and Environment 122: 173-182.

VAN ASSCHE, J.A. and F.E.A. VANDELOOK (2006).
Germination ecology of eleven species of Geraniaceae and Malvaceae, with special reference to the effects of drying seeds. Seed Science Research 16: 283-290.

WHITE, G.P., W.G. RICHARDSON and J.H. ORSON (1984).
Potential control of Geranium molle in oil seed rape, pre-emergence. Annals of Applied Biology 104: 72-73.