

Literature Review: Non-pesticide Control Options for Dandelions in Turfgrass

Darrell K. Tompkins

1. Introduction

Current Problem

Turfgrass refers to the use of grasses for functional, recreational and ornamental purposes (Beard, 1973). Since these grasses are mowed, particularly for recreational use, their ability to resist the encroachment of weeds is reduced. Consequently, controlling weeds, such as dandelions, in turf using herbicides has become a common practice in the management of turfgrasses.

About 44 tonnes of herbicides were applied for weed control on home lawns and gardens in Alberta in 1998 (McLean, 2000). Several additional tonnes of herbicides were applied to other urban and suburban settings such as school grounds, municipal parks and golf courses. In Calgary parks alone, about 3.5 tonnes of herbicides, accounting for 98% of pesticides used, were applied for weed control in 1998 (Alberta Environmental Protection, 1998). The intensive use of synthetic chemical herbicides in urban and suburban areas has resulted in concerns about environmental sustainability and other societal concerns including public health.

Some municipal governments in Canada and other countries have proposed a ban on pesticide use in residential and other public areas. In some areas, these bans have already been implemented. Therefore, the development of alternative tools for weed control in home lawns and gardens, school grounds, and municipal parks is needed. Dandelion control is a particular problem.

1.2 Cultural Options for Controlling Dandelions in Turf

Cultural options for controlling dandelions in turf would include: species selection, mowing height, and fertility management. In terms of fertility, the impact of nitrogen, phosphorous and potassium must all be considered in terms of how they impact the competition between turf and dandelions. The impact of other management options such as aeration and thatch reduction must also be considered.

1.3 Using Agricultural By-products for Control of Dandelions in Turf

Biologically based weed control methods using agricultural by-products provide an attractive and promising alternative solution to chemical herbicides. There are many plants that have allelopathic properties, including: corn gluten, soybean meal, mustard meal and quackgrass meal. However, this paper will focus, for the most part, on mustard meal.

Corn gluten can, inhibit weed seed germination but has no effect on established root systems (Liu, 1994). Based on this mode of action, a corn gluten based product has recently been granted a temporary registration by the Pesticide Management Regulatory Agency as a weed control product in lawns and turfgrass in Canada.

Corn gluten is a by-product of the wet milling of corn kernels for use in corn syrup and corn starch. The remaining material has shown some properties as a pre-emergent herbicide (Christians, 1993). Water soluble (hydrolyzed) root-inhibiting components of the corn gluten were isolated (Liu et al., 1994; Liu and Christians, 1994). These inhibitory compounds were identified as the dipeptides glutaminyl-glutamine, alaninyl-asparagine, alaninyl-glutamine, glycyl alanine, and alaninyl-alanine. Of the five identified dipeptides identified alaninyl-alanine and glycine-alanine were the most bioactive (Liu and Christians 1994).

Control of seed germination has been reported with a number of other agricultural by-products. These include mustard meal (Petersen et al., 2001), soybean meal (Liu et al., 1994) and quackgrass extracts (Weston and Putnam, 1986). To date there haven't been any studies that have looked at the effect of mustard meal or quackgrass residues on dandelions.

The Prairie Turfgrass Research Center (PTRC) has been involved in a project working with municipal Parks and Recreation Departments in a number of cities in Alberta, Saskatchewan and British Columbia. A study, concluded last year, found that products such as corn gluten and soybean meal have the potential to reduce dandelion seed germination, but don't affect mature plants. Actually, with some treatments, the level of control of dandelions was superior to that of using herbicides if the mature dandelions were controlled prior to the initiation of the project. However, at these rates, cost of the corn gluten may be an issue.

About 1.8 million tonnes of canola meal is produced across Canada each year (Statistic Canada, 2001). The present price for canola meal is about \$0.2/kg (Statistic Canada, 2001). Large quantities of other agricultural by-products are also produced and sell at relatively low prices. On the other hand, the average price of TurfMaize[®], the corn gluten based weed control product temporarily registered in Canada, is about \$3.00/kg. The recommended application rate in turfgrass is around 10 kg per 100 square meters. Therefore, the development of agricultural by-products as weed control agents has great potential to add value to some of the common Canadian agricultural by-products.

There is a large market potential for biologically based dandelion control products. In Alberta, the estimated area of home and garden turf is about 23,000 ha, Calgary parks 5,300 ha, Edmonton parks 3,700 ha, and golf courses 9,000 ha (Alberta Environmental Protection, 1998). Based on the application rate of TurfMaize[®], total corn gluten required could be 41,000 tonnes. If considering other provinces, the required agricultural by-products for dandelion control will be much greater. If mustard meal is effective at controlling dandelions, this would provide a huge boost to mustard production, a crop that is grown in Alberta.

2. The Potential for Using Mustard Meal on Turf

2.1 Activity Against Weeds, Fungi and Insects

Mustard meal and other members of the Brassicaceae contain glucosinolates. Both the volatiles (Brown and Morra, 1995) and the water soluble products of glucosinolate

hydrolysis can inhibit seed germination (Brown and Morra, 1996; Mason-Sedun et al., 1986) inhibit seedling growth (Brown and Morra, 1997) and can kill a number of fungi (Sarwar et al., 1998) and insect species (Borek et al., 1998). However, mammalian systems metabolize and eliminate these products rapidly so they do not pose a problem to either humans or other mammals (Brown and Morra, 1997). Consequently, mustard meal is used as a feed supplement.

Weeds

The breakdown products of glucosinolates have been widely reported to inhibit seed germination or seedling emergence (Bialy et al., 1990; Boydston and Hang, 1995; Dale, 1986; Haramoto and Gallandt, 2005; Ju et al., 1983; Oleszek, 1987; Stiehl and Bible, 1989; Teasdale and Taylorson, 1986; Vaughn and Boydston, 1997; Vaughn et al., 2006). Most of these studies were conducted on agricultural crops and studied the effect either on weed seed or crop seed germination and emergence.

To date, the effect of these breakdown products on dandelions has not been reported, but none of these experiments have been done on turfgrass. However, there does seem to be activity against many different species and there may be greater activity against smaller seeded species so it might be expected that dandelions would be affected. It has also been reported that these breakdown products of glucosinolates can inhibit growth of young plants (Brown and Morra, 1997). There is not always a correlation between germination inhibition and growth inhibition. However, growth inhibition may be greater in soils with lower organic matter levels.

Fungi

The breakdown products of glucosinolates have also been reported to inhibit the growth of many different species of fungi including: *Gaeumannomyces graminis* or Take-all of cereals (Angus et al., 1994), grey snow mold (Hsiang and Yang, 2003), *Leptosphaeria maculans* or blackleg of canola (Mithen and Lewis, 1986), *Rhizoctonia solani*, *Fusarium graminearum*, *Bipolaris sorokiniana* and *Pythium irregulare* (Sarwar et al., 1998), *Aphanomyces euteiches* f. sp. *pisi* (Smolinska et al., 1997a), and *Fusarium oxysporum* (Smolinska et al., 2003).

A common characteristic of the fungi identified as being susceptible is that they are soil borne. Also, the fungi identified commonly cause pathogenic problems in agricultural crops. For example, *Fusarium graminearum* is the pathogen that causes *Fusarium* head blight in cereals and one of the pathogens that causes root rot in cereal crops. Therefore, there has been interest in the potential for using these products as biofumigants.

To date little progress has been made in making that a reality due to some of the problems with controlling soil borne pathogens. Since the soil is a much denser media than the air, uniform application can be a problem. For example, historically, the use of chemical soil drenches to control various pathogens has not been very reliable. However, breakdown products of glucosinolates are water soluble so they can move through the soil with water, but volatile products are also produced that can affect the pathogens. For example, volatiles produced from the degradation of canola seed meal passed through the

soil reduced the survival and inoculation potential of oospores of *Aphanomyces euteiches* f. sp. *pisi* (Smolinska et al., 1997a) and canola seed meal was reported to reduce oospore infection and inhibit mycelial growth (Smolinska et al., 1997b). Isothiocyanates produced by the degradation of glucosinolates was reported to have activity against *Fusarium oxysporum* although at the levels used in this study the effect on the pathogen was typically growth inhibition rather than death of the pathogen (Smolinska et al., 2003).

Insects

There have been a few reports of toxicity against insect species. Isothiocyanates produced by the breakdown of glucosinolates were used to control black vine weevil eggs (Borek et al., 1998) although different isothiocyanates had different levels of toxicity. In another study, rapeseed meal was amended to the soil to control *Limonius californicus* or wireworms, (Elberson et al., 1996). However, while it was possible to kill the wireworms, the concentration that was needed was too high to be practical.

2.2 Glucosinolates and Their Breakdown Products

There are many different types of glucosinolates. However, two broad classes of glucosinolates are the aromatic glucosinolates which contain a benzene ring in their chemical structure (referred to as benzyl) and the aliphatic glucosinolates which do not contain a benzene ring (referred to as allyl) (Norsworthy and Meeham, 2005). Within these two broad classes, there are many different glucosinolates (Brown and Morra, 1997).

Different species may contain different types of glucosinolates. For example, *Sinapis alba* or yellow mustard contains hydroxybenzyl glucosinolate which is one of the benzyl glucosinolates (Borek and Morra, 2005). In contrast, *Brassica juncea* or oriental mustard contains sinigrin which belongs to the allyl class of glucosinolates (Vaughn et al., 2006).

Glucosinolates are produced by species that belong to the *Brassicaceae* or mustard family. However, there can be a lot of variation in the type and concentration of glucosinolate between species, cultivar or even plant part (Eberlein et al., 1998).

It is actually the breakdown products of the glucosinolates, the isothiocyanates (or ITC's) that have allelopathic, biofumigant or bioinsecticide qualities. When the cell vacuoles are ruptured the glucosinolates are hydrolyzed by the enzyme myrosinase to form a variety of potential allelochemicals (Borek et al., 1996)(Vaughn et al., 2006). Different glucosinolates produce different breakdown products which can have different activity against specific target organisms. Freezing and thawing helps to increase the concentration of ITC's (Morra and Kirkegaard, 2002).

Different breakdown products have different residence times in the soil. It is possible that differences in inhibition of seed germination may be related to residence times of the breakdown products as well as to amount and type of glucosinolates produced (Eberlein et al., 1998). Isothiocyanates remain in the soil for as little as a few days to a few weeks

and volatile losses are a major route of disappearance (Brown and Morra, 1997). Soil residence times are reduced as soil temperature increases and as soil moisture decreases. Losses are also more rapid in soils containing greater concentrations of organic carbon (Borek et al., 1995).

Glucosinolate containing plant material should be safe to use for bio control of plant pests as many of these products are used for human consumption or animal feed. Mammalian systems are able to metabolize and eliminate ITC's fairly rapidly. In addition, since the residence times of the ITC's in the soil are relatively short, negative environmental impacts are reduced. However, phytotoxicity may be a problem, particularly when used in soils with a low organic matter content (Brown and Morra, 1997).

Therefore, soil-borne pest suppression is likely to be improved by choosing a species and cultivar that has a high level of the appropriate glucosinolate. Adequate moisture will help to increase ITC release and soil retention (Morra and Kirkegaard, 2002).

2.3 Potential for Using Mustard Meal to Control Dandelions and Plant Diseases in Turf

The impact of glucosinolates (contained in mustard meal) on dandelion seed germination has not been reported. However, glucosinolates has been reported to impact seed germination of a wide range of species (Oleszek, 1987). One concern is whether the glucosinolates will have a phytotoxic effect on the turf itself. Ultimately, the potential for using glucosinolates without causing phytotoxic effects may depend on the rate of glucosinolates needed.

Preliminary work by Hsiang and Yang, 2003, suggest that there is potential for using mustard meal to control snow mold on turf. However, this must be tested further to determine efficacy under a wide range of environmental conditions and also to determine if there are phytotoxic effects either directly or by increasing the susceptibility of the turf to winter injury. Ideally, a fall application may serve to control both dandelion seed germination and snow mold.

Another soilborne disease that can be a major problem on turfgrass is fairy ring. It would be worthwhile to conduct a preliminary trial to determine if mustard meal might be able to control this disease. The fact that the breakdown products of the glucosinolates are water soluble suggests that there may be potential for movement through the soil. This would be essential to control a soilborne disease.

3. Dandelion Biology

3.1 General

Dandelions can tolerate a wide range of climatic conditions (Simon et al., 1996) and are widely distributed around the world in temperate and subtropical regions (Holm et al., 1997). Established plants are resistant to drought, but young plants are drought sensitive and are not likely to survive on rapidly drying soils. Therefore, establishment on coarse-textured soils can be a problem (von Hofsten, 1954).

Dandelions are apomictic. Most pollen grains are sterile and cannot form pollen tubes (Solbrig, 1971) so the seed develops without fertilization (Roberts, 1936). In fact, in North American populations there is no evidence of sexual reproduction (Vavrek et al., 1996). However, insects are attracted by the bright yellow flowers and may be needed to trigger seed set (Williams et al., 1996).

The dandelions overwinter either as seed or as basal rosettes under the snow cover (Cyr et al., 1990). Early spring growth, therefore, can be from seed germination, regrowth from roots or growth from the rosettes. Seeds produced in the spring during the peak flowering period generally emerge that same spring or don't emerge at all (Collins, 2000).

They possess a deep tap root that can extend below the level of competing grass roots (Loomis, 1938) and make it difficult to remove plants by hand (Lovell and Rowan, 1991). The roots are capable of producing new shoots and roots within 1-2 weeks from very small segments (Mann and Cavers, 1979). While dandelions can regrow from the roots, new populations are spread by seed alone (Stewart-Wade et al., 2002). At the end of the growing season, the root shortens and draws the crown slightly into the soil to provide additional protection against adverse winter conditions (Longyear, 1918).

It has been reported that dandelions can live as long as 10 to 13 years (Roberts, 1936), but it is not known if they can survive this long in areas where there are harsh winter conditions.

3.2 Seed Germination and Seedbank Studies

Seedbank Studies

It is hard to predict weed populations from seedbank data (Cardina and Sparrow, 1996).

Only a small proportion of seed is lost to predators (Honek and Martinkova, 2005a) In the Czech Republic, seed dispersal occurred 10 days after flowering. Four weeks after the peak in seed dispersal 3.1% of seeds had germinated. Three weeks later only 11-13% of seed remained on the ground and most were damaged. Predation increased after seed dispersal. Therefore, predators destroyed 97% of seed, but effect on dandelion population biology is likely to be small as the number of seedling produced from the surviving seed was thought to approach the carrying capacity. The presence of viable seeds 6 weeks after seed dispersal indicates that some of the seeds may enter the soil seed bank This number may be greater in the absence of predators. It was concluded that seed predation did not significantly affect dandelion recruitment but probably decreased proportion of seeds entering the soil seedbank (Honek and Martinkova, 2005b).

Residual populations are important to replenish the seedbanks of dandelion, but dandelion are more frequent aboveground than in seed bank (Légère et al, 2005).

Dandelion populations spread by seed alone (Solbrig and Simpson, 1974) and abscission in dandelion controlled by horizontal wind speed (Greene, 2005).

Temporal heterogeneity impacts the within-population genetic structure. In other words, there are genotypes with contrasting seasonal performance through time (Vavrek et al., 1996).

In summary, dandelions don't have a persistent seed bank. Therefore, since it is a simple perennial, control of the seedling should limit dandelion spread (Hacault and Van Acker, 2006).

Seed Germination

Early emergence in the spring occurs from rootstock (50% emergence by 430 GDD T_{base} 0° C). Seedling emergence is later (E_{50} 980 GDD) and occurred after dandelions arising from rootstock had flowered and shed seed (Hacault and Van Acker, 2006).

Dandelion seeds from the seedbank emerge primarily in the spring. After 5 years < 1% dandelion seeds from seed bank are still viable. Dandelion seeds germinate shortly after dispersal and most of rest in spring (Roberts and Neilson, 1981).

Dandelion seeds are produced throughout the season with peaks in spring and fall (Vavrek et al., 1997). They lack primary dormancy (Stewart-Wade et al., 2002) and seed longevity in soil is short (Ogawa, 1978)

Seeds produced in the spring during the peak flowering period mostly emerged that same spring or did not emerge at all (Collins, 2000). Seeds produced at other times during the year produced seedlings throughout the year. And seedlings produced in the fall produced seeds in the spring in the following year (Stewart-Wade et al., 2002).

Seed germination occurs over a temperature range of 5 to 35° C (Stewart-Wade et al., 2002; Watson et al., 2001; and Ogawa, 1978), but germination rates are higher when there is light and higher temperatures (within the range of adaptation) (Letchamo and Gosselin, 1996).

Dandelion germination affected more by osmotic potential than by oxygen concentration or light (Boyd and Van Acker, 2004).

According to Letchmo and Gosselin, 1996, storage at room temperature for > 3 months reduced germination, however, the % germination was retained if stored at 4° C. Light and higher temperature promoted faster germination and shallow seeding also promoted germination.

3.3 Root Biology and Storage Compounds

Root Biology

Dandelions have a large competitive taproot that may be greater than 2m in length in mature plants (Mann and Cavers, 1979) (Watson et al., 2001). Older, undisturbed plants have greater competitive ability (Moyer et al., 1990) perhaps due to this long taproot (Stewart-Wade et al., 2002).

Root Storage Compounds

In roots, free amino acids and soluble proteins increase during fall and decline in spring. This may be important for spring regrowth. However, this may also be impacted by nitrogen deficiency (Bewley, 2002). Dandelions produce fructans as reserve polysaccharides (Cyr et al., 1990).

Decreasing or freezing soil temperatures in the fall associated with increased fructose and decreased high DP fructans (Wilson et al., 2001). Carbohydrate concentrations in roots change in response to freezing temperatures as plants prepare to overwinter. Dicamba applied 10 days after the first frost provided better control than when applied 11 d before 1st frost with reduced concentrations of fructans (low degree-of-polymerization (DP) fructans). Fructans are produced as reserve polysaccharides. When soil froze in Dec., the % total sugars as sucrose and low DP fructans increased and mid-to high DP fructans decreased (Wilson and Michiels, 2003).

4.0 Non-chemical Management Options for Controlling Dandelions in Turfgrass

4.1 Species

In Ontario, Kentucky bluegrass was reported to be less competitive and perennial ryegrass more competitive with dandelions (Hall et al., 1992).

In mixtures of cool-season grasses evaluated under low maintenance in Alberta, weed encroachment is generally lower in mixtures than in individual species; but some individual species, including low growers among the fine fescues (*Festuca* spp.) resist weed encroachment (McKernan et al., 2001).

4.2 Mowing Height

Relative competitive ability of the turf may be influenced by mowing practices. Low mowing height increased crabgrass (Jagschitz and Ebdon, 1985) (Dunn et al. 1981) (Voight et al., 2001). Low mowing height also increased other weeds in perennial ryegrass and annual bluegrass (Adams, 1980). The persistence of Kentucky bluegrass and fine fescues were favoured in competition with several weed species, including dandelion, white cover and crabgrass, by mowing at 5.1 cm vs 1.9 cm. Generally, the persistence of bluegrasses and fescues were favored by high mowing, while bentgrass showed little response to mowing height (Davis, 1958).

4.3 Fertility

Higher rate of N fertilization reduces crabgrass (Dunn et al., 1981) (Johnson and Bowyer, 1982) and dandelion (Johnson and Bowyer, 1982) (Callahan and Overton, 1978) (Murray et al., 1983). However, fertilization when the turfgrass is not growing increases weeds (Dunn et al., 1981). It seems that dandelions are not sensitive to N levels (Watson, et al., 2001) but fertilizing turf may result in increased competition (Holm et al., 1997a) (Stewart-Wade et al., 2002).

Increasing P in soil may increase dandelion density as P affects root growth (Watson et al., 2001) (Turner, et al, 1979).

In one of the few studies that examined the effect of fertility without accompanying herbicide treatments, Tilman et al., 1999, reported that reduced K reduces the dandelion population.

4.4 Thatch Development

Treatments that favour thatch development may also result in smaller weed populations, perhaps by reducing canopy gaps (Busey, 2003). For example, the return of turfgrass clippings can reduce the population of a number of weed species. For example, there was less thatch with a mulching mower compared to a rotary mower where the clippings were not removed (Haley et al., 1985). Specifically, the return of clippings reduced dandelion populations in Kentucky bluegrass turf (Harivandi et al., 2001)

4.5 Other

Rapid establishment of the turf with a high seeding rate helped reduce weed populations (Busey, 2003).

Established dandelions are resistant to drought, but young plants are sensitive and have a limited chance of invading coarse-textured or rapidly drying soils (von Hofsten, 1954). This may indicate a potential for modifying irrigation practices.

Johnson and Burns, 1985, reported less dandelion cover at pH 5.0 than at 5.6 or 6.4. Unfortunately, this doesn't have great practical application.

A herbicide that was used to control grassy weeds caused a huge reduction in dandelion cover when used in conjunction with other treatments (Murray et al., 1983). This emphasizes the importance of an integrated approach to dandelion management.

There have been many herbicide studies. In fact, most management studies have been examinations of herbicide use in conjunction with mowing height or fertility. However, one particularly useful study reported that fall application of herbicide seems to provide the best control due to increased herbicide translocation into the roots (Dunn and Moyer, 1999)

4.6 Summary

Cultural management of weeds in turfgrass is a gradual process with reduction in weed populations sometimes taking place over years. In comparison, chemical management is often successful in a matter of weeks, but weed populations often reoccur in the same area requiring successive annual chemical treatment. Therefore, it is important to study integrated factors (i.e. mowing height and N fertilization) as they have typically been studied as single factor experiments or as single factors in combination with a herbicide regime (Busey, 2003).

5.0 References

5.1 Dandelion Biology

- Bewley, J.D. 2002. Root storage proteins, with particular reference to taproots. *Can. J. Bot.* 80:321-329.
- Boyd, N.S. and R.C. Van Acker. 2003. The effects of depth and fluctuating soil moisture on the emergence of eight annual and six perennial plant species. *Weed Sci.* 51:725-730.
- Boyd, N. and R. Van Acker. 2004. Seed germination of common weed species as affected by oxygen concentration, light, and osmotic potential. *Weed Sci.* 52:589-596.
- Busey, P. 2003. Cultural management of weeds in turfgrass: a review. *Crop Sci.* 43:1899-1911.
- Cardina, J. and D.E. Sparrow. 1996. A comparison of methods to predict weed seedling populations from the soil seedbank. *Weed Sci.* 44:46-51.
- Cyr, D.R., J.D. Bewley and E.B. dumbroff. 1990. seasonal dynamics of carbohydrate and nitrogenous components in the roots of perennial weeds. *Plant Cell Environ.* 13:359-365
- Davis, R.R. 1958. The effect of other species and mowing height on persistence of lawn grasses. *Agron. J.* 50:671-673.
- Dunn, R. and J. Moyer. 1999. Dandelion control in direct seeding systems. Available: <http://www.agric.gov.ab.ca/agdex/500/5-9-26.html>
- Greene, D.F. 2005. The role of abscission in long-distance seed dispersal by the wind. *Ecology* 86:3105-3110.
- Hacault, K. 200?. Dandelion (*Taraxacum officinale*) biology and ecology. U. Manitoba.
- Hacault, K.M. and R.C. Van Acker. 2006. Emergence timing and control of dandelion (*Taraxacum officinale*) in spring wheat. *Weed Sci.* 54:172-181.
- Haley, J.E., D.J. Wehner and T.W. Fermanian. 1985. Comparison of conventional and mulching mowers for Kentucky bluegrass maintenance. *HortScience* 20:105-107.
- Honek, A. and Z. Martinkova. 2005. Pre-dispersal predation of *Taraxacum officinale* (dandelion) seed. *J. Ecol.* 93:335-344.
- Honek, A. and Z. Martinkova. 2005. Post-dispersal predation of *Taraxacum officinale* (dandelion) seed. *J. Ecol.* 93:345-352.
- Johnson, B.J. and T.H. Bowyer. 1982. Management of herbicide and fertility levels on weeds and Kentucky bluegrass turf. *Agron. J.* 74:845-850.
- Johnson, B.J. and R.E. Burns. 1985. Effect of soil pH, fertility and herbicides on weed control and quality of bermudagrass (*Cynodon dactylon*) turf. *Weed Sci.* 33:366-370.

Légère, A., F.C. Stevenson, D.L. Benoit and N. Sampson. 2005. Seedbank-plant relationships for 19 weed taxa in spring barley-red clover cropping systems. *Weed Sci.* 53:640-650.

Letchamo, W. and A. Gosselin. 1996. Light, temperature and duration of storage govern the germination and emergence of *Taraxacum officinale* seed. *J. Hort. Sci.* 71:373-377.

McKernan, D.K., J.B. Ross and D.K. Tompkins. 2001. Evaluation of grasses grown under low maintenance conditions. *Int. Turfgrass Soc. Res. J.* 9:25-32.

Moffat, A.S. 1999. New, Nonchemical pest control proposed. *Science* 284:1249-1250.

Murray, J.J., D.L. Klingman, R.G. Nash and E.A. Woolson. 1983. Eight years of herbicide and nitrogen fertilizer treatments on Kentucky bluegrass (*Poa pratensis*) turf. *Weed Sci.* 31:825-831.

Roberts, H.A. and J.E. Neilson. 1981. Seed survival and periodicity of seedling emergence in twelve weedy species of compositae. *Annals of App. Bio.* 97:325-334.

Solbrig, O.T. and B.B. Simpson. 1974. Components of regulation of a population of dandelions in Michigan. *J. Ecol.* 62:473-486

Stewart-Wade, S.M., S. Neumann, L.L. Collins and G.J. Boland. 2002. The biology of Canadian weeds. 117. *Taraxacum officinale* G.H. Weber ex Wiggers. *Can. J. Plant Sci.* 82:825-853.

Turner, T.R., D.V. Waddington and T.L. Watschke. 1979. The effect of soil fertility levels on dandelion and crabgrass encroachment of Merion Kentucky bluegrass. *Proc. Northeast. Weed Sci. Soc.* 33:280-286.

Vavrek, M.C., J.B. McGraw and H.S. Yang. 1996. within-population variation in demography of *Taraxacum officinale*: Maintenance of genetic diversity. *Ecology* 77:2098-2107.

Wilson, R.G., S.D. Kachman and A.R. Martin. 2001. Seasonal changes in glucose, fructose, sucrose and fructans in the roots of dandelion. *Weed Sci.* 49:150-155.

Wilson, R.G. and A. Michiels. 2003. fall herbicide treatments affect carbohydrate content in roots of Canada thistle (*Cirsium arvense*) and dandelion (*Taraxacum officinale*). *Weed Sci.* 51:299-304.

5.2 Glucosinolates

Angus, J.F., P.A. Gardner, J.A. Kirkegaard and J.M. Desmarchelier. 1994. biofumigation: isothiocyanates released from *Brassica* roots inhibit growth of the take-all fungus. *Plant Soil* 162:107-112.

- Bialy, Z., W.Oleszek, J. Lewis and G.R. JFenwick. 1990. Allelopathic potential of glucosinolates (mustard oil glycosides) and their degradation products against wheat. *Plant Soil* 129:277-281.
- Borek, V., L.R. Elberson, J.P. McCaffrey and M.J. Morra. 1998. Toxicity of isothiocyanates produced by glucosinolates in Brassicaceae species to black vine weevil eggs. *J. Agric. Food Chem.* 46:5318-5323.
- Borek, V. and M.J. Morra. 2005. Ionic thiocyanate (SCN⁻) production from 4-hydroxybenzyl glucosinolate contained in *Sinapis alba* seed meal. *J. Agric. Food Chem.* 53:8650-8654.
- Borek, V., M.J.Morra, P.D.Brown and J.P.McCaffrey. 1995. Glucosinolate-derived allelochemicals allyl isothiocyanate and allyl nitrile in soil. *J. Agric. Food Chem.* 43:1935-1940.
- Borek, V., M.J.Morra, and J.P.McCaffrey. 1996. Myrosinase activity in soil extracts. *Soil Sci. Soc. America J.* 60:1792-1797.
- Boydston, R.A. and A. Hang. 1995. Rapeseed (*Brassica napus*) green manure crop suppresses weeds in potato (*Solanum tuberosum*). *Weed Technol.* 9:669-675.
- Brown, P.D. and M.J.Morra. 1995. Glucosinolate-containing plant tissues as bioherbicides. *J. Agricultural and Food Chem.* 43: 3070-3074.
- Brown, P.D. and M.J.Morra. 1996. Hydrolysis products of glucosinolates in *Brassica napus* tissues as inhibitors of seed germination. *Plant Soil* 181:307-316.
- Brown, P.D. and M.J. Morra. 1997. Control of soil-borne plant pests using glucosinolate-containing plants. *Advances in Agronomy* 61:167-231.
- Dale, J.E. 1986. Decline in phytotoxicity of benzyl isothiocyanate formulated as granules. *Weed Sci.* 34:325-327.
- Eberlein, C.V., M.J. Morra, M.J.Guttieri, P.D.Brown and J.Brown. 1998. Glucosinolate production by five field-grown *Brassica napus* cultivars used as green manures. *Weed Technology* 12:712-718.
- Elberson, L.R., V. Borek, J.P. McCaffrey and M.J. Morra. 1996. Toxicity of rapeseed meal-amended soil to wireworms, *Limonijs californicus* (Coleoptera:Elateridae). *J. Agr. Entomology* 13:323-330.
- Hallett, S.G. 2005. Symposium Where are the bioherbicides? *Weed Sci.* 53:404-415

- Hsiang, T. and Y. Yang. 2003. Control of snow molds by Brassica glucosinolates. Guelph turfgrass Institute 2003 Annual Res. Report p. 77-79
- Haramoto, E.R. and E.R. Gallandt. 2005. Brassica cover cropping: I. Effects on weed and crop establishment. *Weed Sci.* 53:695-701
- Jaakkola, S. 2005. White mustard mulch is ineffective in weed control. Fourth World Congress on Allelopathy
- Ju, H.K., B.B. Bible, and C. Chong. 1983. Influence of ionic thiocyanate on growth of cabbage, bean and tobacco. *J. Chem Ecol.* 9:1255-1262.
- Mason_Sedun, W., R.S. Jessop and J.V. Lovett. 1986. Differential phytotoxicity among species and cultivars of the genus Brassica to wheat. *Plant Soil* 93:3-16.
- Mithen, R.F. and B.G. Lewis. 1986. *In vitro* activity of glucosinolates and their products against *Leptosphaeria maculans*. *Tran. Br. Mycol. Soc.* 87:433-440.
- Morra, M.J. and J.A. Kirkegaard. 2002. Isothiocyanate release from soil-incorporated Brassica tissues. *Soil Biology and Biochem.* 34:1683-1690.
- Norsworthy, J.K. and J.T. Meehan IV. 2005. Herbicidal activity of eight isothiocyanates on Texas panicum (*Panicum texanum*), large crabgrass (*Digitaria sanguinalis*), and sicklepod (*Senna obtusifolia*). *Weed Sci.* 53:515-520.
- Oleszek, W. 1987. Allelopathic effects of volatiles from some Cruciferae species on lettuce, barnyard grass, and wheat growth. *Plant Soil* 102:271-273.
- Peterson, J., R. Belz, F. Walker and K. Hurlle. 2001. Weed suppression by release of isothiocyanates from turnip-rape mulch. *Agron. J.* 93:37-43
- Sarwar, M., J.A. Kirkegaard, P.T.W. Wong and J.M. Desmarchelier. 1998. Biofumigation potential of brassicas. III. *In vitro* toxicity of isothiocyanates to soil-borne fungal pathogens. *Plant Soil* 201:103-112.
- Smolinska, U., G.R. Knudsen, M.J. Morra and V. Borek. 1997. Inhibition of *Aphanomyces euteiches* f. sp. *pisi* by volatiles produced by hydrolysis of *Brassica napus* seed meal. *Plant Dis.* 81:288-292.
- Smolinska, U., M.J. Morra, G.R. Knudsen and P.D. Brown. 1997. Toxicity of glucosinolate degradation products from *Brassica napus* seed meal toward *Aphanomyces euteiches* f. sp. *pisi*. *Phytopathology* 87:77-82.
- Smolinska, U., M.J. Morra and G.R. Knudsen. 2003. Isothiocyanates produced by brassicaceae species as inhibitors of *Fusarium oxysporum*. *Plant Dis.* 87:407-412.

Stiehl, B. and B.B.Bible. 1989. Reaction of crop species to thicyanate ion toxicity. *HostScience* 24:99-101.

Teasdale, J.R., and R.B.Taylorson. 1986. Weed seed response to methyl isothiocyanate and metham. *Weed Sci.* 34:520-524.

Vaughn, S.F. and R.A.Boydston. 1997. Volatile allelochemicals released by crucifer green manures. *J. Chem. Ecol.* 23:2107-2116.

Vaughn, S.F., D.E. Palmquist and S.M. Duval. 2006. Herbicidal activity of glucosinolate-containing seedmeals. *Weed Science* 54:743-748

Wolf, R.B., G.F.Spencer, and W.F. Kwolek. 1984. Inhibition of velvetleaf (*Abutilon theophrasti*) germination and growth of benzyl isothiocyanate, a natural toxicant. *Weed Sci.* 32:612-615.

Wu, Y.F. and E. Basler. 1969. Effects of ammonium thiocyanate on carbohydrate metabolism in the cotton plant. *Weed Sci.* 17:362-365.

5.3 Quackgrass

Gabor, W.E. and C. Veatch. 1981. Isolation of a phytotoxin from quackgrass (*Agropyron repens*) rhizomes. *Weed Sci.* 29: 155-159.

Toai, T.V. and D.L. Linscott. 1979. Phytotoxic effect of decaying quackgrass (*Agropyron repens*) residues. *Weed Sci.* 27:595-598.

Weston, L.A. and A.R. Putnam. 1986. Inhibition of legume seedling growth by residues and extracts of quackgrass (*Agropyron repens*). *Weed Sci.* 34:366-372.

5.4 Other Plants With Allelopathic Properties

Brainard, D.C. and R.R. Bellinder. 2004. Weed suppression in a broccoli-winter rye intercropping system. *Weed Sci.* 52:281-290.

Christians, N.E. 1993 The use of corn gluten meal as a natural preemergent weed control in turf. In R.C. Carrow et al. (ed) *Int. Turfgrass Soc Res. J.* 7:284-290.

Gannon, T.W., F.H. Yelverton and J.S. McElroy. 2006. Allelopathic potential of centipedegrass (*Eremochloa ophiuroides*). *Weed Sci.* 54:521-525.

Liu, D.L. and N.E. Christians. 1994 Isolation and identification of root-inhibiting compounds from corn gluten hydrolysate. *J. Plant Growth Regul.* 13:227-230.

Liu, D.L., N.E. Christians, and J.T. Garbutt. 1994 Herbicidal activity of hydrolyzed corn gluten meal on three grass species under controlled environments. *J. Plant Growth Regul.* 13:221-226.

