AN ABSTRACT OF THE THESIS OF

Matthew D. Schuster for the degree of Master of Science in Crop Science presented on December 3, 1999. Title: Annual Bluegrass (*Poa annua* L.) Emergence Under Different Residue Management Practices in Perennial Ryegrass; and Determination of Resistant and Susceptible Annual Bluegrass Germination Under Controlled Temperature and Moisture.

Abstract approved: Redacted for privacy
Carol A. Mallory-Smith

With the loss of field burning the amount of crop residue that remains in perennial ryegrass fields has increased. As the amount of crop residue remaining in the field increases so does annual bluegrass. This has resulted in the increased use of herbicides to control annual bluegrass. However, this increased use has also resulted in herbicide-resistant annual bluegrass. Field experiments were initiated in 1997 to investigate residue management options available to growers and their impacts on annual bluegrass emergence. Two sites, Glaser and Wirth, were established with three residue management treatments replicated four times. The treatments included full-straw, bale/flail, and vacuum sweep. Perennial ryegrass seed yield and annual bluegrass seed contamination were evaluated. The vacuum sweep treatment had lower annual bluegrass emergence than the full-straw or the bale/flail treatments during the 1997-98 growing season, for both sites. The fall of 1998 was much drier than the fall of 1997. Annual bluegrass emergence in all plots was lower in 1998 than in 1997 because of the dry conditions. Fall emergence in 1998 was higher in the vacuum sweep treatment than

in the other two treatments, which may have been the result of better soil-seed contact in the vacuum sweep treatment. Lower emergence in the spring at the Wirth site compared to the Glaser site may have been due to narrow crop row spacing and cultivar selection, which shaded the annual bluegrass. When growing seasons were combined, there were no treatment differences. However, more emergence was observed in the spring at the Glaser site compared to the Wirth site. Yield was highest for the vacuum sweep treatment at the Glaser site in the 1998-99 growing season. However, competition from volunteer perennial ryegrass in the full-straw and bale/flail treatments could have accounted for this increase. No other differences in yield and no difference in contamination among treatments were observed. However, contamination at the Glaser site was higher in the 1998-99 growing season than in the 1997-98 growing season.

Experiments were conducted in growth chambers to determine how differing environmental conditions affect seed germination of diuron-susceptible and diuron-resistant annual bluegrass. Cumulative germination for the susceptible-biotype decreased from 96% to 88% while the resistant-biotype remained above 95% as temperature decreased from 30/20 C to 10/2 C. The susceptible-biotype germinated sooner than the resistant-biotype regardless of temperature. The susceptible-biotype had a higher rate of germination than the resistant-biotype at 30/20 C, but not when the temperature decreased to 10/2 C. Germination response to differing matric potentials did not vary much within a biotype for a given soil type and temperature. Therefore, parameters estimated at -1.03 MPa were chosen to contrast susceptible- and resistant-biotypes, and soil types, for each temperature. Maximum cumulative germination was

greater than 96% for all treatments. When germination on a given soil type was contrasted, differences were only seen for the susceptible biotype vs. resistant biotype on Dayton soil; and the resistant biotype on Dayton soil vs. resistant biotype on Woodburn soil at both temperatures. The lag in onset of germination was shorter for the susceptible biotype on Dayton soil and resistant biotype on Woodburn soil than the resistant biotype on Dayton soil at 30/20 C. At 18/5 C, the lag in onset of germination was shorter for the susceptible biotype on Dayton soil and resistant biotype on Woodburn soil than the resistant biotype on Dayton soil ($P = 0.0001$ and 0.0001, respectively). But the rate of germination was faster for the resistant biotype on Dayton soil than both the susceptible biotype on Dayton soil and resistant biotype on Woodburn soil at 18/5 C ($P = 0.02$ and 0.0004, respectively). The rate of germination did not differ at 30/20 C. When just the soils were contrasted, at 18/5 C all annual bluegrass seeds on the Woodburn soil germinated sooner and the rate of germination was higher than on the Dayton soil. These results indicate that the hydraulic properties of the soils may influence germination. However, this was not observed at 30/20 C. The results suggest that the susceptible-biotype was more sensitive to temperature while the resistant-biotype was more sensitive to moisture. Changing crop management in ways that will reduce annual bluegrass emergence and establishment is needed. By altering management strategies, growers may obtain more efficient and effective use of herbicides, while reducing the selection of herbicide-resistant annual bluegrass.

Annual Bluegrass (Poa annua L.) Emergence Under Different Residue Management Practices in Perennial Ryegrass; and Determination of Resistant and Susceptible Annual Bluegrass Germination Under Controlled Temperature and Moisture

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Matthew D. Schuster, Author

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CONTRIBUTION OF AUTHORS

Dr. Carol Mallory-Smith assisted in the design, analysis, and writing of the following manuscripts. Her editing skills are greatly appreciated.

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INTRODUCTION

Annual bluegrass (*Poa annua* L.) is a serious weed that infests perennial ryegrass (*Lolium perenne* L.) fields in the Willamette Valley of Oregon. Although the species can reduce seed yield, it is much more serious as a weed seed contaminant that reduces the marketability of the perennial ryegrass seed. Field burning was once the main management strategy for elimination of crop residue remaining in the field after harvest. Burning also destroyed annual bluegrass and other weed seed contaminants. However, field burning has been phased out because of environmental and safety concerns. With the loss of field burning, increased amounts of residue and more viable annual bluegrass seeds remain in the field. Therefore, growers must consider several issues including the following. First, how will they manage the residue remaining in the field; and secondly, how will the management strategy they choose affect annual bluegrass populations.

Annual bluegrass is a common weed species found throughout the world. It is a native of Europe that is spread mainly by humans. Weeds of the West (Whitson, et al., 1996) describe the species as an "annual with spreading or erect flattened stems which are 2-12 inches long. Leaves are green and boat shaped with a curved tip. The inflorescence is more or less pyramidal and branches spreading." A long lived variety of annual bluegrass (var. *reptans*) has been identified as well (Warwick, 1979; Ellis et

al., 1971; Johnson and White, 1997a & b). This variety is more prostrate or semiprostrate and slower to flower and fruit.

Annual bluegrass is found outside Europe throughout the temperate regions of the world and has been found growing as high as 3,658 meters above sea level in the Himalayas (Arber, 1965) and in tropical America at high altitudes (Hitchcock, 1971). Ellis et al. (1971) compared seven populations of annual bluegrass; six from the southern hemisphere and one from Europe. Although distinctions were difficult to quantify, the more perennial types were found in areas with increased moisture and cooler temperatures, and annual types in areas of drought. Annual bluegrass can be found in disturbed areas such as waste areas, flower beds and gardens, roadsides, cultivated land, as well as grasslands and mountains (Warwick, 1979). Annual bluegrass is only absent in areas of high temperature and low rainfall, areas of highly competitive plant communities such as tall grasslands, and areas with high acid soils (Wieneck, 1988). Gibeault (1971) collected annual bluegrass plants from western Washington and Oregon and found both annual and perennial types of annual bluegrass. Annual forms were characterized by having fewer leaves and nodes, secondary tillers, and adventitious roots. Annuals reached reproductive maturity quicker and had a greater percentage of flowering tillers. Perennial types were found mainly in turf areas that received moderate to intensive supplemental irrigation, whereas, annuals were found in non-irrigated roughs.

The life cycle of annual bluegrass in the Pacific Northwest is usually as follows: annual bluegrass germinates in the fall and may remain quiescent or continue growing depending on conditions. Germination of seeds will resume again in the spring; plants

mature and produce seeds from the end of April until June then die once the environment becomes too hot and dry (Howe and Snaydon, 1986; Neidlinger, 1965). Standifer and Wilson (1988a & b) found similar results with annual bluegrass populations in environments characterized by high summer temperatures and frequent rains. Plant growth can continue later into summer if moisture conditions remain optimum. However, Martin and Wehner (1987) found a non-significant trend of seedling mortality when kept under moist conditions.

Natural seed dispersal is usually minimal and ranges up to about 0.5 meter from the parent plant. Long-distance dispersal is primarily achieved through machinery, humans, or livestock. Also, annual bluegrass is mainly self-pollinated and rarely cross-pollinates with other isolated stands (Darmency and Gasquez, 1983; Warwick, 1979).

Annual bluegrass is a major weed contaminant of turfgrass and agronomic grass seed production. Differences in leaf color, early seed dispersal, and death of annual biotypes causes esthetic damage in established turf and golf courses (Warwick, 1979). This undesirability has caused grass seed producers in the Willamette Valley to implement extensive control measures to manage annual bluegrass. With the loss of field burning, herbicide use increased along with increased residue in the field (Mueller-Warrant et al., 1994a & b). Together these factors have increased the costs of producing perennial ryegrass.

Control of annual bluegrass can be variable. Gaussoin and Branham (1989) found annual bluegrass populations increased 12% when grass clippings were returned to the soil surface. Herbicide control may be achieved for awhile, but is short-lived either due to build-up of resistance or inconsistent control (Gaul and Christians, 1988;

Mueller-Warrant et al., 1994a). Models developed by Maxwell et al. (1990) demonstrate that herbicide-resistant weeds can become established within 5 years of continuous herbicide use. The heavy reliance on herbicides, and lack of crop rotation in perennial ryegrass production, has led to the selection of herbicide-resistant annual bluegrass. Oregon State University has conducted herbicide resistant trials with annual bluegrass and confirmed the presence of herbicide-resistant biotypes in the Willamette Valley (Gamroth et al., 1997).

Several attempts have been made to use annual bluegrass as a beneficial grass in golf courses. In golf courses, plant growth regulators can give control by suppressing seedhead production (Petrovic et al., 1985; Danneberger et al., 1987) and enhancing root growth (Cooper et al., 1987). Unfortunately, one standard treatment was not found to always be effective; and the entire cultural management, including mowing techniques and height, seeding practices, and fertility has to be considered (Gaussoin and Branham, 1989; Petrovic et al., 1985).

Annual bluegrass is very responsive to environmental changes. Its shallow rooting system exhibits a high tolerance to puddling, and compacted and poorly aerated soils (Warwick, 1979). Annual bluegrass also has the ability to produce root hairs at low nitrogen availability, which may have an ecological advantage in fitness (Robinson and Rorison, 1987). Therefore, the Willamette Valley is an excellent habitat for annual bluegrass due to its mild climate and high rainfall. Kuo (1992a & b and 1993) reported that high lime and high phosphorus applications benefit the growth of annual bluegrass. However, it has been found that annual bluegrass exhibits a negative response to increasing sulfur, which results in decreased pH of the soil (Varco and Sartain, 1986).

The acidification of the soil increases the soluble and exchangeable aluminum that is phytotoxic to root growth and hinders uptake of calcium and phosphorus (Kuo et al., 1992a, 1992b, and 1993; Warwick, 1979). Therefore, it is recommended to avoid management strategies of high lime and phosphorus, which benefit the growth and establishment of annual bluegrass.

Standifer and Wilson (1988b) found that annual bluegrass does not require cold temperature to break dormancy and will germinate in subtropical climates. In northern climates annual bluegrass can act as a summer annual. This species also exhibits considerable heat tolerance and can withstand relatively high temperatures for short periods of time (Cordukes, 1977). However, annual bluegrass maintained under moist conditions exhibited a non-significant trend to be less heat tolerant than under dry conditions (Martin and Wehner, 1987). Standifer and Wilson (1988b) found conditional germination when annual bluegrass seeds were stored for two months at 30 and 35 C with 100% germination when moved to 10 or 15 C and poorer germination at 5 or 20 C. Viability decreased when stored at 35 C for more than two months. Percent germination of seeds stored at 10 to 30 C increased from 5 to 100% as germination temperature and storage time increased from 5 to 25 C and 1 to 12 months, respectively.

Differences in management affected temperature enforced dormancy in golf courses (Wu et al., 1987). At 25 C, less than 15% of seeds in the rough germinated, compared to 50% from the fairway. Germination increased when the seed was either incubated at 12 C or transferred from 25 to 12 C. Populations from the greens had a germination of about 80% at either 25 or 12 C. Standifer and Wilson (1988a & b) found varying responses to breaking dormancy of freshly harvested annual bluegrass

seeds by storing then in moist soil at 30 C, then testing for germination over a range of temperatures. Their results suggest that populations collected from Louisiana and Maryland have adapted to avoid high summer temperatures, but grow as a summer annual in Wisconsin where June-August temperatures are lower.

Annual bluegrass was found to respond to moisture and light, and can withstand widely fluctuating water conditions. In hydration-dehydration experiments, cycling generally resulted in delayed, but more uniform germination. However, annual bluegrass seeds were prevented from germination by 8-hr hydration phases coupled with 16 or 24-hr dehydration phase at -10 MPa (Allen et al., 1993). Good seed contact with soil resulted in higher water content and higher seed hydraulic conductivity; and the seeds themselves exhibited different hydraulic properties, which influenced water uptake (Ward and Shaykawich, 1972). Johnson and White (1997a) conducted vernalization experiments with two varieties of annual bluegrass; the annual variety (*P. annua* var. *annua*) and the more perennial variety (*P. annua* var. *reptans*). Vernalization requirements varied between var. *annua* and var. *reptans,* as well as among var. *reptans*. Only var. *annua* showed no response to vernalization treatments.

Flowering was affected by photoperiod and cold treatments (Johnson and White, 1997b). The annual type was not responsive to cold treatments and was day neutral. In the absence of cold treatments, one perennial biotype was induced to flower by long days, two by short days, and one was day neutral. Floral development after the cold treatment was generally favored by long days but was genotype dependent. Eggens (1979) found that under natural long days from June to November in the greenhouse and under 15-hr day length in the growth chamber, annual bluegrass generally produced

more tillers than Kentucky bluegrass (*Poa pratensis* L.). Under short day conditions this trend decreased. Brede and Duich (1986) found that the tillering rate generally increased with increasing temperature, daylength, and precipitation. Annual bluegrass had an increasing rate of tillering during early autumn, and perennial ryegrass had the highest rate during early summer.

Shading and plant interaction can affect plant growth. Light may have a greater effect on weed seed production since weeds are typically early colonizers and become established in open areas (Aldrich and Kremer, 1997). Chastain and Grabe (1989) found that shading by cereals reduced dry matter of tall fescue (*Festuca arundinacea* Schreb.) seedlings. Annual bluegrass will interact with other plant species. When populations of annual bluegrass and common groundsel (*Senecio vulgaris* L.) were grown together, common groundsel exhibited a higher rate of population growth when planted amidst clumped annual bluegrass than when planted amidst a random distribution (Bergelson, 1990 a and b). When Bergelson (1990a) investigated annual bluegrass alone, she concluded that the spatial distribution of annual bluegrass could influence the seed production per plant due to interspecific competition. The distribution of annual bluegrass in one generation will determine the distribution of mulch in the next, which has an impact on seedlings. In either case, dead annual bluegrass was dense enough to inhibit the establishment of seedlings. When Brede and Duich (1986) compared the growth of annual bluegrass against other grasses, they found that perennial ryegrass generally had the greatest growth below ground, while Kentucky bluegrass and annual bluegrass had the greatest growth above ground.

With the increase in herbicide use due to the loss of field burning, it is important to understand the interaction of increased residue remaining in the field and the impact on annual bluegrass emergence. Also, with the increased reliance on herbicide use in this monoculture system, the threat of herbicide-resistance is of concern. The objectives of this research were: 1) to evaluate the different residue management practices in perennial ryegrass impact annual bluegrass emergence; and 2) to investigate the germination of herbicide-resistant and susceptible annual bluegrass under controlled temperature and moisture conditions.

MANUSCRIPT I

ANNUAL BLUEGRASS (*POA ANNUA* L.) EMERGENCE UNDER DIFFERENT RESIDUE MANAGEMENT PRACTICES IN PERENNIAL RYEGRASS

Matthew D. Schuster and Carol Mallory-Smith

ABSTRACT

With the loss of field burning the amount of residue that remains in perennial ryegrass fields has increased. As the amount of crop residue remaining in the field increases so does annual bluegrass. Field experiments were initiated in 1997 to investigate the different residue management programs available to growers and their impacts on annual bluegrass emergence. Two sites, Glaser and Wirth, were established with three treatments replicated four times. The treatments included full-straw, bale/flail, and vacuum sweep. Soil moisture readings were taken each week and averaged by month. Annual bluegrass seedlings were counted on November 12 and April 13 for the 1997-98 growing season, and December 15 and April 15 for the 1998-99 growing season. Perennial ryegrass yield and annual bluegrass seed contamination was evaluated. The vacuum sweep treatment had lower annual bluegrass emergence than the full-straw or the bale/flail treatments during the 1997-98 growing season, at both sites. The fall of 1998 was much drier than the fall of 1997. Annual bluegrass emergence in all plots was lower in 1998 than in 1997 because of the low moisture conditions. Fall emergence in 1998 was higher in the vacuum sweep treatment than in the other two treatments, which may have been the result of better soil-seed contact in the vacuum sweep treatment. Lower emergence was observed in the spring at the Wirth site compared to the Glaser site that may have been due to narrow crop row spacing and cultivar selection, which increased shading of annual bluegrass. When growing seasons were combined, there were no treatment differences. Although, more emergence was observed in the spring at the Glaser site compared to the Wirth site. Yield was highest in the vacuum sweep treatment at the Glaser site for the 1998-99 growing season.

However, competition from volunteer perennial ryegrass in the full-straw and bale/flail treatments could have accounted for this increase. No other differences in yield and no difference in contamination among treatments were observed. However, contamination at the Glaser site was higher in the 1998-99 growing season than in the 1997-98 growing season. Changing crop management in ways that will reduce annual bluegrass emergence and establishment is needed. Altering management strategies may provide more efficient and effective use of herbicides and control of herbicide resistant annual bluegrass.

Nomenclature.

Annual bluegrass, *Poa annua* L., Perennial ryegrass, *Lolium perenne* L.

Key Words.

Moisture, residue, emergence

INTRODUCTION

Annual bluegrass (*Poa annua* L.) is a major weed species in perennial ryegrass (*Lolium perenne* L.) seed production in the Willamette Valley of Oregon. Its difference in leaf color, and early seed dispersal and death, cause aesthetic damage in established turf and golf courses (Warwick, 1979). This undesirability has caused grass seed producers in the Willamette Valley of Oregon to implement extensive control measures to manage annual bluegrass. Field burning was once used extensively. Not only did it remove the straw residue after harvest, it also destroyed the volunteer perennial ryegrass and weed seeds. However, legislation over the past decade has phased out this practice due to environmental and safety concerns. This change resulted in an increase in viable seeds remaining in the field. Growers must now deal with two issues: what to do with the perennial ryegrass residue after harvest? And how will the chosen management practice affect annual bluegrass populations?

In the Pacific Northwest annual bluegrass usually germinates in the fall and may remain quiescent or continue growing depending on conditions. Seeds will resume germination again in the spring; plants mature and produce seeds from the end of April till June then die once it becomes hot and dry (Howe and Snaydon, 1986; Neidlinger,

1965). Standifer and Wilson (1988b) found similar results with annual bluegrass populations in environments characterized by high summer temperatures and frequent rains. Plant growth can continue later into the summer if moisture conditions remain optimum. Although Martin and Whener (1987) found a non-significant trend of seedling mortality when kept under moist conditions.

Annual bluegrass is mainly self-pollinated and rarely cross-pollinates with other isolated stands. Natural seed dispersal is minimal and calculated to be about 0.5 meter from the parent plant. Long-distance dispersal is primarily achieved through machinery, humans, or livestock (Darmency and Gasquez, 1983; Warwick, 1979). Brede and Duich (1986) compared the growth of annual bluegass to perennial ryegrass and Kentucky bluegrass (*Poa pratensis* L.), and found that perennial ryegrass growth was generally greatest below-ground whereas Kentucky bluegrass and annual bluegrass was greatest above-ground.

Annual bluegrass responds to light, temperature, moisture, and soil conditions. Its shallow rooting system exhibits a high tolerance to puddling, and compacted and poorly aerated soils (Warwick, 1979). It has the ability to produce root hairs at low nitrogen availability, which may have an ecological advantage in fitness (Robinson and Rorison, 1987). Therefore, the Willamette Valley is an excellent habitat for annual bluegrass because of its mild climate and high rainfall. Annual bluegrass has a low tolerance to soils with a pH of less than 5.3. The acidification of the soil increases the soluble and exchangeable aluminum, which is phytotoxic to root growth and hinders uptake of calcium and phosphorus (Kuo et al., 1992a, 1992b, and 1993; Varco and Sartain, 1986). High lime and high phosphorus applications benefit the growth of

annual bluegrass (Kuo, 1992a and 1993). Therefore, it is recommended to avoid management strategies of high lime and phosphorus, which benefits the growth of annual bluegrass.

Annual bluegrass can withstand widely fluctuating water conditions. In hydration-dehydration experiments, cycling generally resulted in a delayed, but more uniform germination (Allen et al., 1993). However, annual bluegrass seeds were prevented from germination by 8-hr hydration phases coupled with 16 or 24-hr dehydration phase at -10 MPa. Good seed contact with soil resulted in higher water contact and higher seed hydraulic conductivity. Also, the seeds themselves exhibited different hydraulic properties which influences water uptake (Ward and Shaykawich, 1972). Standifer and Wilson (1988b) reported conditional germination when annual bluegrass seeds were stored for two months at 30 and 35 C with 100% germination when moved to 10 or 15 C and poorer germination at 5 or 20 C. Viability decreased when stored at 35 C for more than two months. Percent germination of seeds stored at 10 to 30 C increased 5 to 100% as germination temperature and storage time increased from 5 to 25 C and 1 to 12 months, respectively.

Johnson and White (1997a) conducted vernalization experiments with the annual and perennial varieties of annual bluegrass (*P. annua* var. *annua* and *P. annua* var. *reptans*, respectively). Vernalization requirements vary between var. *annua* and var. *reptans,* as well as among var. *reptans*. Only var. *annua* showed no response to vernalization treatments. Flowering was affected by photoperiod and cold treatments (Johnson and White, 1997b). The annual type was not responsive to cold treatments and was day-neutral. In the absence of cold treatments, one perennial was induced to

flower in long days, two in short days, and one was day neutral. Floral development after the cold treatment was generally favored by long days but was genotype dependent.

Shading and plant interaction affect plant growth. Chastain and Grabe (1989) found that shading by cereals reduced dry matter of tall fescue seedlings. When populations of annual bluegrass and common groundsel (*Senecio vulgaris* L.) were grown together, common groundsel exhibited a high rate of population growth when planted in clumped annual bluegrass than when planted in a random distribution (Bergelson, 1990 a and b). When Bergelson (1990a) investigated annual bluegrass alone, she concluded that the spatial distribution of annual bluegrass influenced the amount of seed production per plant due to interspecific competition. Also, the distribution of annual bluegrass in one generation will determine the distribution of mulch in the next, which impacts seedlings. In either case, dead annual bluegrass was dense enough to inhibit the establishment of seedlings.

Brede and Duich (1986) found that the tillering rate generally increased with increasing temperature, daylength, and precipitation. Eggens (1979), found that under natural long days from June to November in the greenhouse and under 15-hr day length in the growth chamber, annual bluegrass generally produced more tillers than Kentucky bluegrass. Under short-day conditions this trend decreased. Annual bluegrass had an increasing rate of tillering during early autumn compared to perennial ryegrass which tillered more during early summer (Brede and Duich, 1986).

Control of annual bluegrass is quite variable. Kuo et al. (1992b) found that clipping yields of annual bluegrass was affected by aluminum toxicity more than pH or

the quantity of $NaHCO_3$-P; and Gaussoin and Branham (1989) found annual bluegrass populations increased 12% when grass clippings were returned to the soil surface.

Herbicide control is also variable and may be achieved for awhile, but is either short lived due to the build-up of resistance or inconsistent control (Gaul and Christians, 1988; Mueller-Warrant et al., 1994). With the loss of field burning an increase in annual bluegrass populations has been observed. Management of perennial ryegrass residue after grass-seed harvest may impact annual bluegrass emergence. Therefore, experiments were conducted to evaluate the three predominate residue management systems on annual bluegrass emergence.

MATERIALS AND METHODS

Field trials were established in 1997 at two sites, Wirth and Glaser, near Shedd, Oregon. The Wirth site belonged to Cala Farms (two miles northeast of Shedd on Wirth Rd.) with the variety 'Tetramax' planted at 10-inch row-spacings. The Glaser site belonged to Mid-Valley Farms (two miles north of Shedd on the corner of Bell Plain Rd. and Highway 99E) with the variety 'Affinity' planted at 12-inch row-spacings. Both were first year fields with an annual bluegrass problem.

The experimental design was a randomized complete block with three treatments and four replications. However, each site was treated as a separate experiment because of differences in variety and row spacing. Each plot measured 3.5 by 11 meters, and the residue treatments were full straw, bale/flail, and vacuum sweep. These treatments produce an approximate straw load of 6617 kg/ha, 1024 kg/ha, and

343 kg/ha, respectively (Chastain et al., 1994). A weather station, including a LI-1000 datalogger, six 1000-15 soil temperature sensors, and a 4000 series rain gauge (Li-COR, Inc., Lincoln, NE), was located in the middle of each site to record soil temperature and rainfall. A 6005L2 buriable waveguide soil moisture probe (Soilmoisture Equipment Corp., Goleta, CA) was located in each plot, and volumetric water content was measured with a model 6050X1 Trase System (Soil Moisture Equipment Corp., Golet, CA) using Time Domain Reflectometry (TDR).

Slug and rodent bait were applied as needed at each site. The Glaser plots were fertilized with 100 lbs-N, 40 lbs-N, and 120 lbs-N on March 27, 1998, October 8, 1998, and March 23, 1999, respectively. At the Wirth plots were fertilized with 150 lbs-N, 50 lbs-N, 40 lbs-N, and 120 lbs-N on March 27, 1998, April 13, 1998, October 8, 1998, and March 23, 1999, respectively. Fertilizer application rates were based on the rate the grower was applying to the rest of the field.

On July 30, 1997, the vacuum and bale/flail treatments were baled using a Heston baler (model 4570, AGCO Corporation, Duluth, GA) and then the entire area was flailed using a Rears 15-foot flail (Rears Manufacturing Co., Eugene, OR). Vacuum sweep treatments were applied August 11 (Vaccum sweep, Rears Manufacturing Co., Eugene, OR). In 1998, vacuum and bale/flail treatments were baled on August 11, flailed on August 16, and vacuum swept on September 4. Plots were treated with either paraquat or glufosinate at 1.93 lb ai/ha and 1.36 lb ai/ha, respectively. The herbicide was applied between the rows in fall and in spring to control volunteer perennial ryegrass. Volunteer perennial ryegrass usually emerges before annual bluegrass. Therefore, annual bluegrass mortality was minimal. Eight

destructive samples were taken in each plot using a quadrat measuring 45 cm^2. The seedlings were counted once in the fall and once in the spring as soon as the annual bluegrass reached the 2- to 3-leaf stage. In the 1997/98 growing season, annual bluegrass was counted on November 12 and April 13, respectively. In the 1998/99 growing season, annual bluegrass was counted on December 15 and April 15, respectively.

In the 1997/98 growing season, soil moisture readings began August 29 and continued through December 10, 1997, then again from March 16 through May 26, 1998. The fall of the 1998/99 growing season was much dryer than the previous fall, making it difficult to place the moisture probes in the ground until October. Therefore, readings were begun at the Wirth site on October 5 and October 12 at the Glaser site and continued through December 14, 1998, then resumed from March 1 through May 24, 1999. Weekly moisture readings were averaged for each month for which the moisture readings were taken.

In 1998, the Wirth plots were swathed on July 13 and the Glaser plots were swathed on July 20. Both sites were harvested on August 3. In 1999, both sites were swathed on July 13 and harvested on July 20. In both years a small plot combine was used to harvest the seed (Wintersteiger, Salt Lake City, UT). After harvest, the perennial ryegrass seed was cleaned (Seed Clipper, A.T. Ferrell & Co., Saginaw, MI) and weighed. A 50-ml sample of the perennial ryegrass seed was extracted from each treatment and annual bluegrass seed contamination was determined.

Soil moisture was analyzed using the repeated measure analysis of variance with SAS (SAS/STAT, 1990). This analysis provides both univariate and multivariate tests

for repeated measures of one response. This analysis not only compares the treatments for each month, but allows for month to month contrasts, but only in order of sequence. For example, September 1997 can be contrasted to either August 1997 or October 1997, but cannot be contrasted to any other month. The repeated measure analysis combines all data for the year to determine whether treatments were significantly different over time. Monthly moisture readings were contrasted year to year using least significant difference of the means by the general linear model procedure (SAS/STAT, 1990). For example, December 1997 was contrasted to December 1998. Analysis of annual bluegrass seedling counts, perennial ryegrass yields, and annual bluegrass seed contamination was conducted using least significant difference of the means.

Daily rainfall was measured in a tipping rain-bucket mounted on top of the weather station. The weather station measured soil temperature from two replications at each site. Since soil temperature could not recorded from each plot, no analysis was performed. However, rainfall and soil temperature, for both sites, were averaged and are presented in the appendix (Table A-7 and Figures A-1 to A-9).

RESULTS AND DISCUSSION

MOISTURE

Glaser Site:

All soil moisture readings are presented in the appendix (Table A-1 & A-2). The analysis of variance for each month (Appendix, Table A-3) showed that there were

only a difference among treatments for the month of August 1997 ($P = 0.03$). The repeated measure analysis of variance (Appendix, Table A-5) for the 1997-98 growing season showed a treatment difference for the month to month contrast of August and September ($P = 0.0007$). There were no other month to month treatment differences in the 1997-98 or the 1998-99 growing season. The repeated measure analysis (Appendix, Table A-5) also contrasts the month to month average of the treatments for each month. During the 1997-98 growing season, there was no difference for the August to September contrast ($P = 0.18$); however, all other contrasts were different at p-value of 0.005 or less. During the 1998-99 growing season, the month to month contrast for the treatment averages was significant for all contrasts at a p-value of 0.009 or less (Appendix, Table A-5).

Wirth Site:

The analysis of variance of the treatments for each month (Appendix, Table A-4) showed that there were no treatment differences for any month for either the 1997-98 or 1998-99 growing season. The repeated measure analysis (Appendix, Table A-6) showed no treatment differences for any month to month contrast for either the 1997-98 or the 1998-99 growing season. When the average of treatments was contrasted month to month for the 1997-98 growing season, the August-September contrast was non-significant ($P = 0.67$) while all others were different at a p-value of 0.0003 or less. During the 1998-99 growing season, all month to month contrasts of the treatment averages were different at a p-value of 0.0001.

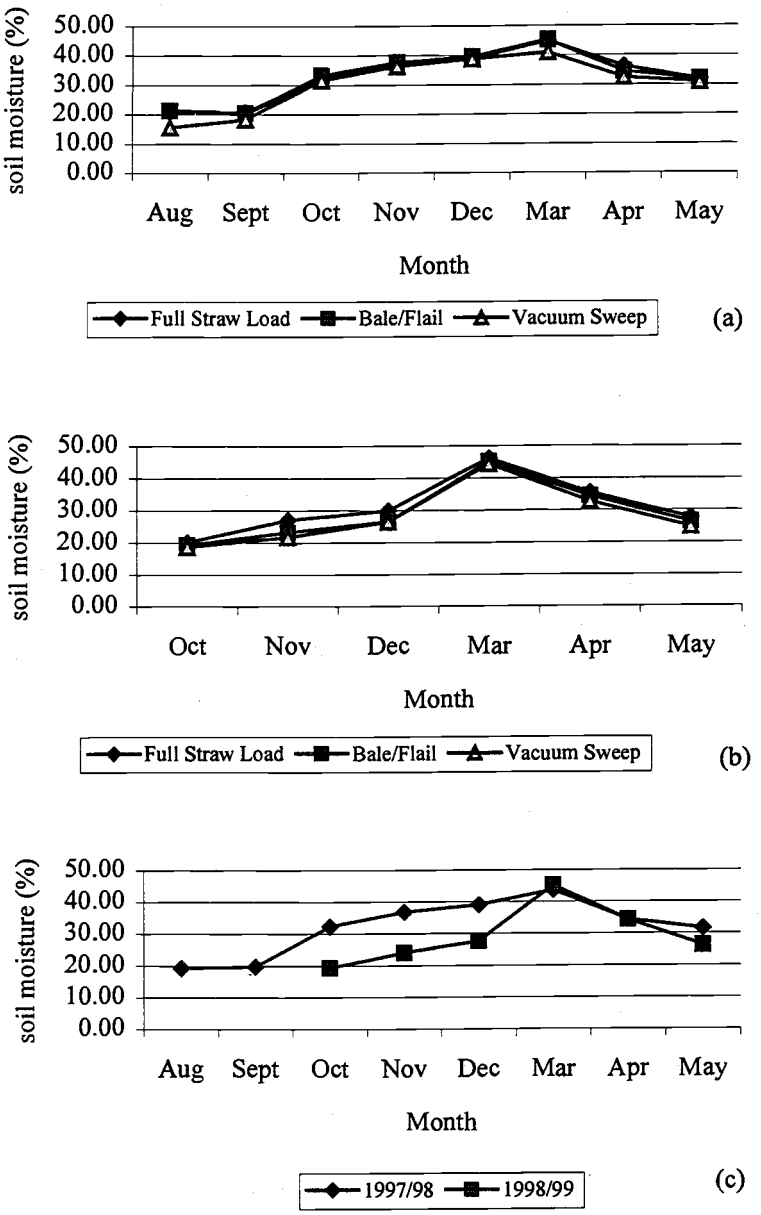
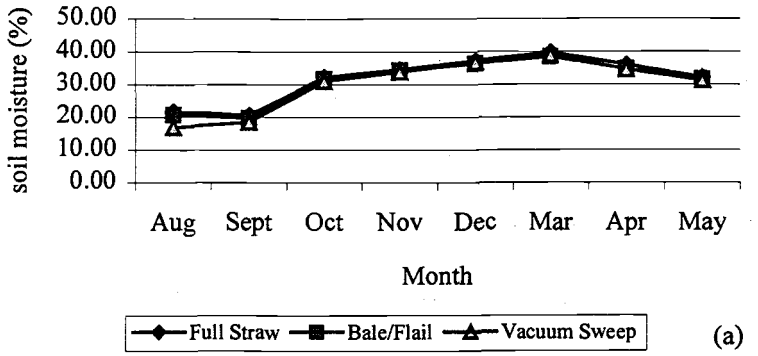
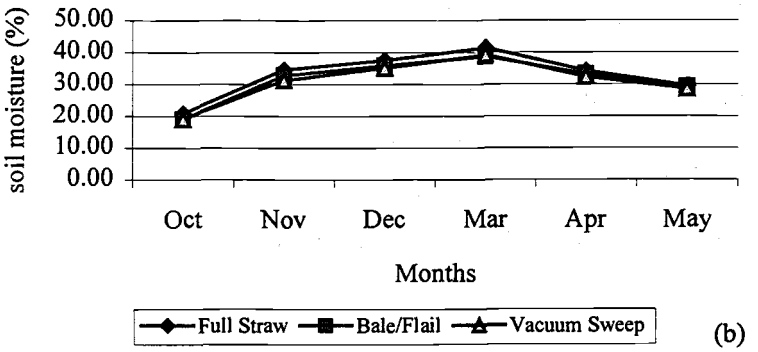


Figure I-1a-c. Percent soil moisture readings for the Glaser site. a) 1997-98 growing season, b) 1998-99 growing season, and c) average of treatments for each month for both 1997-98 and 1998-99 growing seasons.





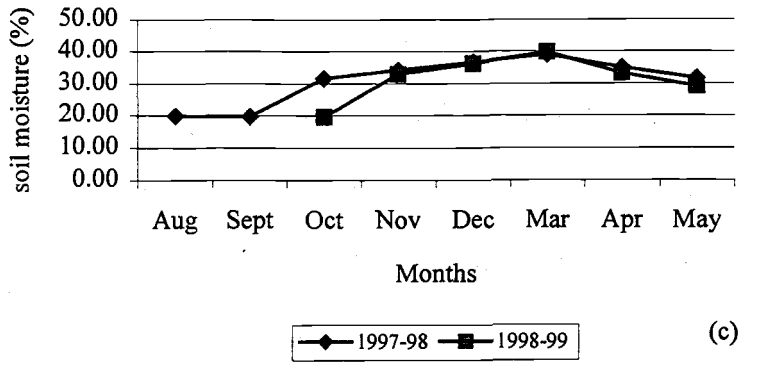


Figure I-2 a-c. Percent soil moisture readings for the Wirth site. a) 1997-98 growing season, b) 1998-99 growing season, and c) average of treatments for each month for both 1997-98 and 1998-99 growing seasons.

Year-to-Year Comparision:

The monthly moisture readings for the 1997-98 growing season were compared to the corresponding month during the 1998-99 growing season. At both the Glaser and Wirth sites, there was no treatment or treatment by year differences when the years were compared. But when the average of the treatments for each month was compared at the Glaser site (Figure 1c), the months of October, November, December, and May were different (all at $P = 0.0001$), but the March or April were not different ($P = 0.19$ and 0.91, respectively). At the Wirth site (Figure I-2c), the average of the treatments for each month differed for October, April, and May ($P = 0.0001$, 0.02, and 0.005, respectively), but not for November, December, or March ($P = 0.12$, 0.50, and 0.32, respectively).

The difference between years was more important than differences among treatments and months. The trend is the same for both years and both sites (Figures I-1a-c and I-2 a-c), it is dry from late summer to early fall, the moisture increases through the winter and early spring, then dries out going back into the summer. Although the treatments themselves had an impact on the emergence of annual bluegrass, soil moisture had an impact on the amount of emergence across treatments in the fall of 1998. The fall of 1998 was very dry and resulted in a lower annual bluegrass emergence compared to the previous year. As soil water potentials decrease, so does hydraulic conductivity, which can influence the rate of water uptake by seeds (Ward and Shaykewich, 1972). Gealy et al. (1994) found that mayweed chamomile (*Anthemis cotula* L.) growth was reduced up to 95% with soil water potential ranging from -0.25 MPa to -10 MPa. Allen et al. (1993) found that annual bluegrass was prevented from

germinating at -10 MPa for 16 or 24-hr coupled with 8-hr hydration phases. They concluded that annual bluegrass seeds progress toward germination with intermittent hydration.

EMERGENCE

1997-98

Glaser Site:

There was no interaction between season and treatment on annual bluegrass emergence at the Glaser site. However, when total annual bluegrass emergence was compared, the vacuum sweep treatment had fewer seedlings emerge than the full straw or the bale/flail treatments (Table I-1 and Figure I-5). When seasons were analyzed individually, treatment differences were found in fall (Table I-1 and Figure I-6). Emergence in the vacuum sweep treatment was lower than the full straw treatment but did not differ from the bale/flail treatment; and the bale/flail did not differ from the full straw treatment. These results are similar to Gaussoin and Branham (1989) who found that retaining clipping yields on fairways increased annual bluegrass establishment 12% over plots where clippings were removed.

Wirth Site:

No interaction was observed between season and treatment for annual bluegrass emergence at the Wirth site. However, total annual bluegrass emergence in the bale/flail treatment was higher than in the vacuum sweep, but not higher than the full straw treatment. The emergence of annual bluegrass in the full straw treatment did not differ from the vacuum sweep treatment (Table I-2 and Figure I-10). When seasons

Table I-1. Annual bluegrass emergence counts/45 cm^2 at the Glaser site for 1997-98 and 1998-99.

	1997-98			1998-99		
Treatments	Fall	Spring	Total	Fall	Spring	Total
Full Straw	2.76 a[1]	5.14 a	7.89 a	0.67 ab	3.08 a	3.74 a
Bale/Flail	1.98 ab	5.61 a	7.58 a	0.48 a	2.61 a	3.08 a
Vacuum	0.70 b	3.20 a	3.90 b	1.39 b	4.58 a	5.96 b

Table I-2. Annual bluegrass emergence counts/45 cm^2 at the Wirth site for 1997-98 and 1998-99.

	1997-98			1998-99		
Treatments	Fall	Spring	Total	Fall	Spring	Total
Full Straw	14.42 ab	10.61 a	25.02 ab	1.67 a	3.11 a	4.78 a
Bale/Flail	27.51 a	9.51 a	37.01 a	2.20 a	5.54 a	7.73 a
Vacuum	12.14 b	5.01 a	17.14 b	5.30 b	13.01 b	18.30 b

Table I-3. Fall, spring, and total emergence/45 cm^2 for the 1997-98 and 1998-99.

	Glaser			Wirth		
Years	Fall	Spring	Total	Fall	Spring	Total
1997-98	1.81	4.65	6.45	18.02	8.38	26.39
1998-99	0.85	3.42	4.26	3.05	7.22	10.27

Table I-4. Fall, spring, and total emergence/45 cm^2 for each treatment averaged at both sites for 1997-98 and 1998-99.

	Glaser			Wirth		
Treatments	Fall	Spring	Total	Fall	Spring	Total
Full Straw	1.72 a	4.11 a	5.81 a	8.04 a	6.86 a	14.89 a
Bale/Flail	1.23 a	4.11 a	5.34 a	14.86 a	7.53 a	22.37 a
Vacuum	1.05 a	3.89 a	4.92 a	8.72 a	9.01 a	17.37 a
Avg.	1.33	4.03		10.54	7.80	

[1]Means within a column with the same letter are not different at the 0.05 level.

were analyzed individually, treatment differences were observed in the fall. The emergence in the bale/flail treatment was higher than in the vacuum sweep treatment but not higher than in the full straw treatment. Emergence in the full straw treatment did not differ from the bale/flail treatment (Table I-2 and Figure I-11).

1998-99

Glaser Site:

As mentioned previously, the fall of 1998 was very dry compared to the previous fall, which had an effect on annual bluegrass emergence (Figure I-1c & I-2c and Appendix, Table A-1, A-2 and A-7). At the Glaser site, no interaction was observed between the seasons and treatments. When the seasons were analyzed individually, treatment differences were observed only in the fall (Table I-1). Emergence in the vacuum sweep treatment was higher than the bale/flail treatment but was not different from the full straw treatment. Emergence in the full straw and the bale/flail treatments did not differ (Table I-1).

Wirth Site:

There was a significant interaction between season and treatment at the Wirth site (Figure I-12). Emergence in both the bale/flail and vacuum sweep treatments were different between fall and spring ($P = 0.01$ and 0.0001, respectively), but not in the full straw treatment. Total annual bluegrass emergence was higher in the vacuum sweep than in either the full straw or bale/flail treatments (Table I-2). When seasons were analyzed individually, emergence in the vacuum sweep was again higher than in either the full straw or bale/flail treatments for both seasons (Table I-2 and Figure I-12). Ward

and Shaykewich (1972) found that the hydraulic conductivity of soil can influence the rate of water uptake by seeds. Since annual bluegrass seeds would be closer to the soil surface in the vacuum sweep treatment than the other treatments, this could explain why the vacuum sweep treatment exhibited a higher annual bluegrass emergence during the fall of 1998. Also, without adequate soil-root contact of the emerged seedling, there may not be adequate moisture to support the seedlings.

Total Emergence

Table I-3 contains the average emergence for each season and the total emergence for each year. At the Glaser site, annual bluegrass emergence was higher in the spring than in the fall in both the 1997-98 and 1998-99 growing seasons ($P = 0.0001$ and 0.0001, respectively; Figures I-6 and I-7). At the Wirth site, annual bluegrass emergence showed seasonal differences; during the 1997-98 growing season, fall emergence was higher than spring ($P = 0.007$; Figure I-11), however, spring emergence was higher than fall for the 1998-99 growing season ($P = 0.0001$; Figure I-12).

When the fall of 1997 and the fall of 1998 were compared (Figure I-5 and I-8), there was a significant interaction between season and treatment for both sites. There were differences in annual bluegrass emergence at the Glaser and Wirth sites for the full straw and bale/flail treatments, but not in the vacuum sweep treatment. There was an interaction between season and treatment for spring annual bluegrass emergence counts (Figures I-4 and I-9).

At the Glaser site, there was a significant season-treatment interaction for the bale/flail treatment, but not the full straw or the vacuum sweep treatments. At the Wirth site, there was a significant interaction for the full straw and the vacuum sweep

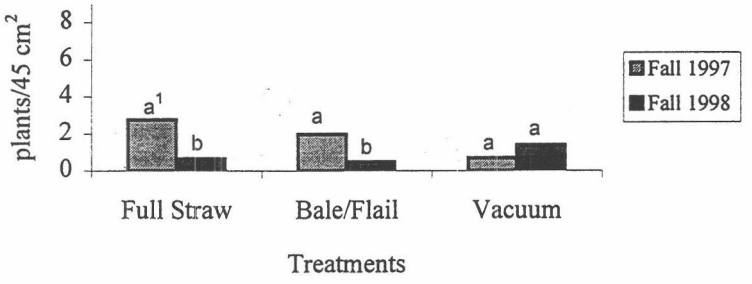


Figure I-3. Annual bluegrass emergence for the Fall 1997 and Fall 1998 at the Glaser site.

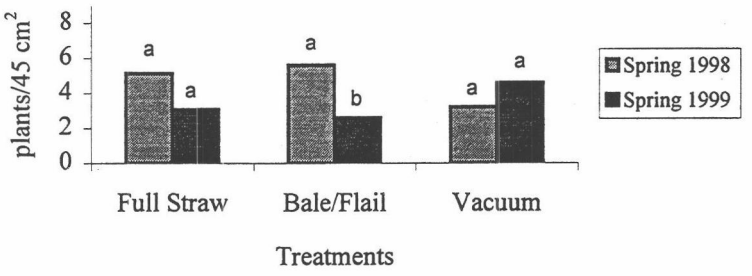


Figure I-4. Annual bluegrass emergence for the Spring 1998 and Spring 1999 at the Glaser site.

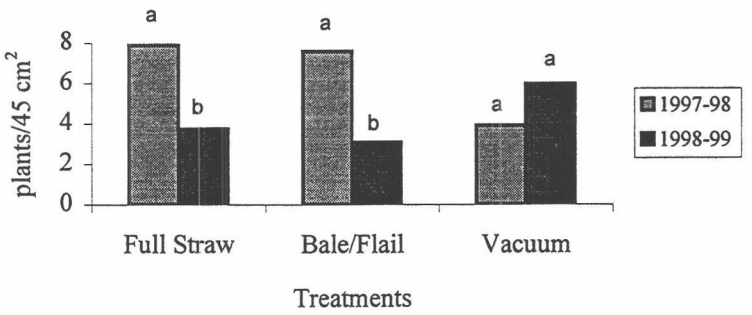


Figure I-5. Total annual bluegrass emergence at the Glaser site for the 1997-98 and 1998-99 growing season.

[1] Means for a treatment with the same letter are not different at the 0.05 level.

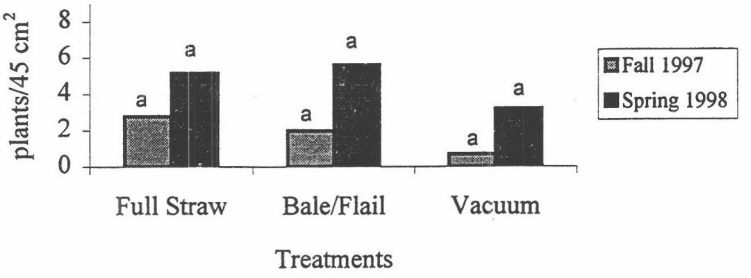


Figure I-6. Annual bluegrass emergence at the Glaser site for Fall 1997 and Spring 1998.

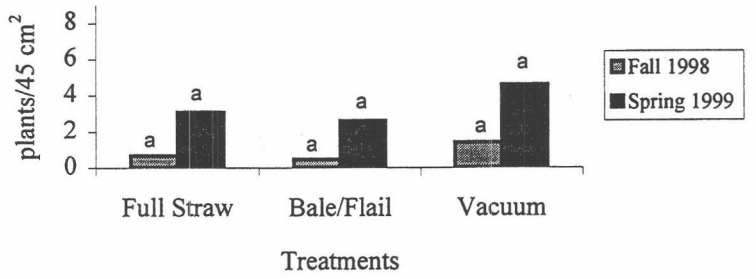


Figure I-7. Annual bluegrass emergence at the Glaser site for Fall 1998 and Spring 1999.

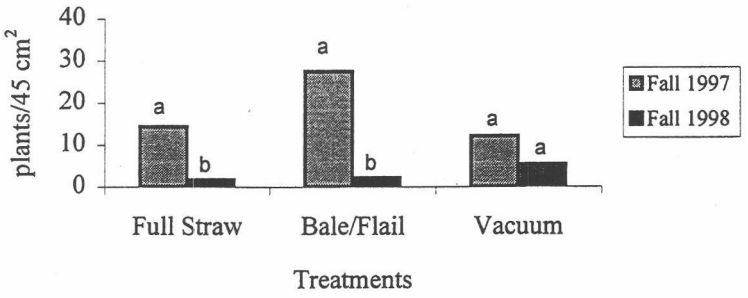


Figure I-8. Annual bluegrass emergence for the Fall 1997 and Fall 1998 at the Wirth site.

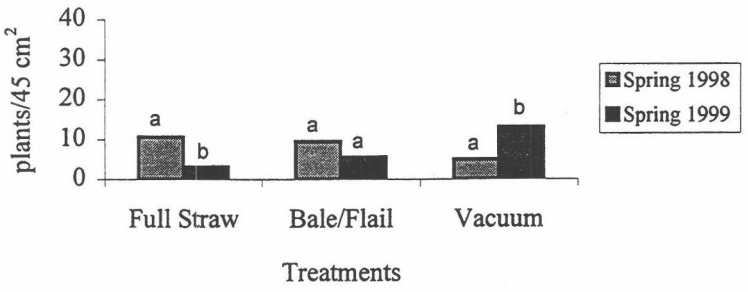


Figure I-9. Annual bluegrass emergence for the Spring 1998 and Spring 1999 at the Wirth site.

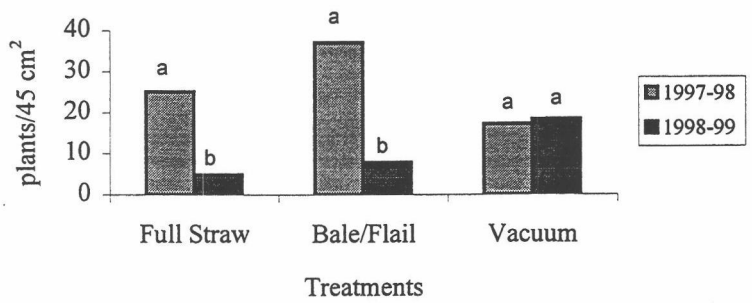


Figure I-10. Total annual bluegrass emergence for each treatment at the Wirth site for the 1997-98 and 1998-99 growing season.

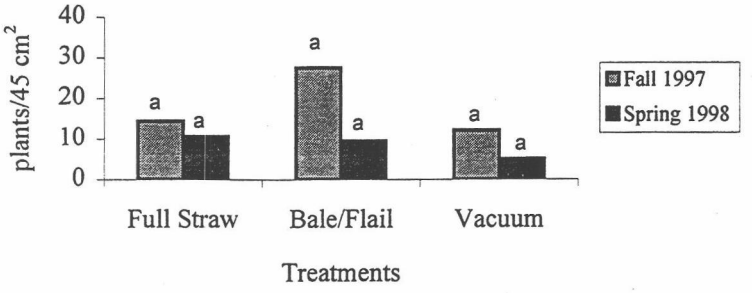


Figure I-11. Annual bluegrass emergence at the Wirth site for Fall 1997 and Spring 1998.

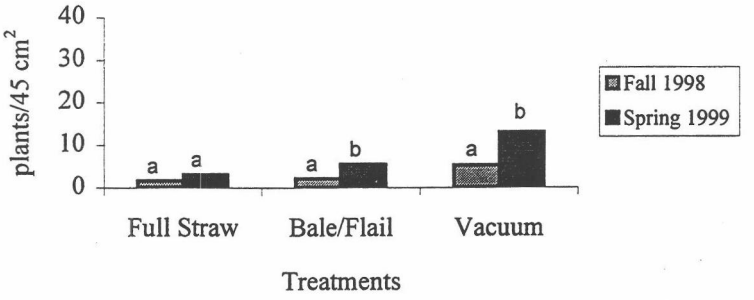


Figure I-12. Annual bluegrass emergence at the Wirth site for Fall 1998 and Spring 1999.

treatments, but not the bale/flail treatment. There were no treatment effects when growing seasons were combined, regardless of whether treatments were compared by season or for total annual bluegrass emergence (Table I-4).

In addition to treatment effects, environmental conditions and crop management may have had an impact on annual bluegrass emergence. Soil moisture (Figure I-1c and I-2c) and rainfall measurements (Appendix, Table A-7) show that the fall of 1998 was much drier than the fall of 1997, which probably impacted annual bluegrass germination. An average annual bluegrass emergence for treatments in both seasons, and total emergence are shown in Table I-3. At both sites during 1998-99 growing season, there was lower emergence in the fall than in the spring (Figures I-7 and I-12). When total emergence of both seasons were compared, both the Glaser and Wirth sites had lower germination during 1998-99 than during 1997-98 (Table I-3).

Management and crop variety selection appeared to have an effect on annual bluegrass emergence. The average emergence of both growing seasons for fall and spring are illustrated in Table I-4 and Figures I-6, I-7, I-11, and I-12. The Glaser site was planted at a wider row spacing and the variety did not grow as aggressively. Annual bluegrass emergence in the spring was greater than the fall (Figures I-6 and I-7). However, at the Wirth site, the crop was planted on narrower row spacing and the perennial ryegrass variety grew more aggressively resulting in a faster canopy cover in the spring as compared to the Glaser site. Although the difference was not significant when years were combined, there was lower emergence of annual bluegrass in the spring than in the fall ($P = 0.11$). If not for the dry fall in 1998, which resulted in low annual bluegrass emergence at both sites (Figure I-12), this difference may have been

similar to the previous growing season and resulted in a difference between the seasons. The total emergence pattern differed between the two sites as related to moisture and row spacing (Table I-3). In a fall with adequate soil moisture, annual bluegrass emergence was greater in treatments where the residue is not removed. Gaussoin and Branham (1989) found that removing clippings in fairways decreased annual bluegrass by 60%. However, this trend was found to be opposite when the fall was dry.

SEED YIELD DATA

Table I-5. Seed yield (kg/ha) for 1997-98 and 1998-99 growing seasons along with averages for treatments and years.

	Glaser			Wirth		
Treatment	1997-98	1998-99	Average	1997-98	1998-99	Average
Full Straw	1959.1 a	2123.6 a	2041.4 a	1487.5 a	1897.8 a	1692.7 a
Bale/Flail	2010.0 a	2402.7 a	2206.3 a	1656.6 a	1968.6 a	1812.6 a
Vacuum	1931.4 a	2758.2 b	2344.8 b	1486.4 a	1802.6 a	1644.5 a
Average	1966.8	2428.2		1543.5	1889.7	

Yields did not differ among treatments did not differ at the Glaser site in the 1997-98 growing season (Table I-5). However, yield for the vacuum sweep treatment was higher than the full-straw and bale/flail treatment for the 1998-99 growing season, and for the average over both growing seasons. At the Wirth site there was no difference in yield for any treatment in either growing season. Average yields for the 1998-99 growing season were higher than the 1997-98 growing season for both the Glaser and Wirth site ($P = 0.0001$ and 0.002, respectively). There was a significant interaction between growing season and treatment at the Glaser site for the bale/flail (P

= 0.02) and vacuum sweep treatments ($P = 0.0001$), but not the full straw treatment ($P = 0.30$). No interaction between the growing season and treatments was observed at the Wirth site (Table I-5).

Table I-6. Annual bluegrass seed contamination in a 50-ml harvest sample of perennial ryegrass.

	Glaser			Wirth		
Treatments	1997-98	1998-99	Average	1997-98	1998-99	Average
Full Straw	2.25 a	38.50 a	20.38 a	16.50 a	6.50 a	11.50 a
Bale/Flail	2.75 a	42.25 a	22.50 a	8.00 a	5.75 a	6.88 a
Vacuum	11.25 a	48.25 a	29.75 a	3.25 a	13.25 a	8.25 a
Average	5.42	43.00		9.25	8.50	

In addition to the yields, a 50-ml seed sample was taken after harvest to determine how many annual bluegrass seeds were in each sample. The number of annual bluegrass seeds for each treatment and growing season is presented in Table I-6.

For both the Glaser and Wirth sites, there were no differences among the treatments for either growing seasons or averages of the growing seasons. However, the annual bluegrass seed contamination was higher in 1998-99 than in 1997-98 at the Glaser site ($P = 0.002$). This increase in contamination did not occur at the Wirth site ($P = 0.84$).

The causes of these differences cannot be easily explained. The yields were expected to increase with age of the crop; however, the significantly higher yield in the vacuum sweep treatment at the Glaser site was not expected. What may have contributed to this increase was the presence of volunteer perennial ryegrass in the full straw and vacuum sweep treatments. During the 1998-99 growing season, spraying

between rows did not sufficiently control the volunteer perennial ryegrass. The vacuum sweep treatment successfully removes a majority of seeds off the ground compared to the other two treatments, resulting in decreased intraspecific competition in the treatment. Competition will interfere with crop growth and yields (Bergelson, 1990a & b; Brede and Duich, 1986; Chastain and Grabe, 1989; and Mueller-Warrant et al., 1994; Aldrich and Kramer, 1997), and may have contributed to the decrease in yield in the full straw and bale/flail treatments.

Differences in annual bluegrass emergence and contamination may have been affected by row spacing. With the exception of the dry fall in 1998, spring counts were higher compared to fall counts at the Glaser site (Table I-3). This trend was reflected in annual bluegrass contamination. The Glaser site had a significant increase in average annual bluegrass contamination for 1998-99 compared to 1997-98. At the Wirth site, there was no difference in contamination for either growing season. As stated before, the Wirth site is planted on narrower rows than the Glaser site. Narrower row-spacing has been shown to increase competition for light (Johnson and White, 1997b; Juhren et al., 1953; and Metcalfe, 1996), and this may have impacted annual bluegrass growth resulting in decreased contamination.

With the lack of cultural and mechanical controls, growers must rely heavily on herbicides to control weeds. Models developed by Maxwell et al. (1990) indicate that using the same control method, especially herbicides, will promote the establishment of resistant weed species. This has already occurred with annual bluegrass (Gamroth et al., unpublished; Fuks et al., 1992). It may be beneficial to alter management

techniques that will increase perennial ryegrass competition and reduce annual bluegrass populations, so that herbicides will not be so heavily relied upon.

Experiments conducted at Oregon State University (Mallory-Smith and Brewster, 1997-98a & b) found that spring planting of perennial ryegrass, and narrowing the row-spacing, reduced annual bluegrass populations in the fall by giving the crop a competitive edge. The results from the Wirth site in this study indicate that narrowing the crop row-spacing and planting a more aggressive crop variety reduced annual bluegrass emergence in the spring. Since herbicides result in such a high selection pressure for resistant-annual bluegrass, management through herbicides alone will probably not be obtained. However, by changing the cultural practices which make the crop more competitive while reducing annual bluegrass populations is worth exploring. While these changes may not provide complete control, they may alter the system enough to achieve more efficient and effective use of herbicides and reduce the threat of resistant-annual bluegrass.

REFERENCES

Aldrich, R.J., and Kremer, R.J. 1997. Principles in weed management, 2nd Ed. Iowa State University Press, Ames, Iowa.

Allen, P.S., White, D.B., and Markhart III, A.H. 1993. Germination of perennial ryegrass and annual bluegrass seeds subjected to hydration-dehydration cycles. Crop Sci. 33: 1020-1025.

Bergelson, J. 1990a. Life after death: site pre-emption by the remains of *Poa annua*. Ecology 71: 2157-2165.

Bergelson, J. 1990b. Spatial patterning in plants: opposing effects of herbivory and competition. J. of Ecology 78: 937-948.

Brede, A.D., and Duich, J.M. 1986. Plant interaction among *Poa annua, Poa pratensis,* and *Lolium perenne* turfgrasses. Agron. J. 78: 179-184.

Chastain, T.G., Young III, W.C., Garbacik, C.J., and Quabbeman, B.M. 1994. Residue management practices for grass seed crops grown in the Willamette Valley. p. 1-5 In W.C. Young III (ed.) 1994 Seed Production Research, Dept. Crop & Soil Sci/Ext./CrS 102.

Chastain, T.G., and Grabe, D.F. 1989. Spring establishment of turf-type tall fescue seed crops with cereal companion crops. Agron. J. 81: 488-493.

Darmency, H., and Gasquez, J. 1983. Esterase polymorphism and growth form differentiation in *Poa annua* L. New Phytol. 95: 289-297.

Eggens, J.L. 1979. The response of some Kentucky bluegrass cultivars to competitive stress from annual bluegrass. Can. J. Plant Sci. 59: 1123-1128.

Fuks, B., Van Eycken, F., and Lannoye, R. 1992. Tolerance of triazine-resistant and susceptible biotypes of three weeds to heat stress: a florescence study. Weed Research 32: 9-17.

Gammroth, D., and Mallory-Smith, C. 1997. Resistance of annual bluegrass (*Poa annua*L.) to diuron and ethofumesate. Master's Thesis, Oregon State University. Unpublished.

Gaul, M.C., and Christians, N.E. 1988. Selective control of annual bluegrass in cool-season turfs with fenarimol and chlorsulfuron. Agron. J. 80: 120-125.

Gaussoin, R.E., and Branham, R.E. 1989. Influences of cultural factors on species dominance in a mixed stand on annual bluegrass/creeping bentgrass. Crop Sci. 29: 480-484.

Gealy, D.R., Squier, S.A., and Ogg, A.G., Jr. 1994. Soil environment and temperature affect germination and seedling growth of mayweed chamomile (*Anthemis cotula*). Weed Tech. 8: 688-672.

Howe, C.D., and Snaydon, R.W. 1986. Factors affecting the performance of seedling and ramets of invading grasses in an established ryegrass sward. Jour. Of Applied Ecology 23: 139-146.

Johnson, P.G., and White, D.B. 1997a. Vernalization requirements among selected genotypes of annual bluegrass (*Poa annua* L.). Crop Sci. 37: 1538-1542.

Johnson, P.G., and White, D.B. 1997b. Flowering responses of selected annual bluegrass genotypes under different photoperiods and cold treatments. Crop Sci. 37: 1543-1547.

Juhren, M., Hiesey, Wm.M., and Went, F.W. 1953. Germination and early growth of grasses in controlled conditions. Ecology 34: 288-300.

Kuo, S. 1993. Effects of lime and phosphate on the growth of annual bluegrass and creeping bentgrass in two acid soils. Soil Sci. 156: 94-100.

Kuo, S., Brauen, S.E., and Jellum, E.J. 1992a. Phosphorus availability in some acid soils infulences bentgrass and annual bluegrass growth. Hort Sci. 27: 370.

Kuo, S., Brauen, S.E., and Jellum, E.J. 1992b. The effects of aluminum and phosphate on the growth of annual bluegrass and bentgrass in some acidic western Washington soils. Soil Sci. 153: 365-372.

Mallory-Smith, C., and Brewster, B. 1998a. Spring seeded perennial ryegrass, cultivar comparison. Weed Control Research in Agronomic Crops, 1997-98. Dept. of Crop and Soil Science, Oregon State University p. 19.

Mallory-Smith, C., and Brewster, B. 1998b. No plow seeding of perennial ryegrass, fall vs. spring. Weed Control Research in Agronomic Crops, 1997-98b. Dept. of Crop and Soil Science, Oregon State University p. 42.

Martin, D.L., and Wehner, D.J. 1987. Influence of prestress environment on annual bluegrass heat tolerance. Crop Sci. 27: 579-585.

Maxwell, B.D., Roush, M.L., and Radosevich, S.R. 1990. Predicting the evolution and dynamics of herbicide resistance in weed populations. Weed Tech. 4: 2-13.

Mecalfe, D.J. 1996. Germination of small-seeded tropical rain forest plants exposed to different spectral compositions. Can. J. Botany 74: 516-520.

Mueller-Warrant, G.W., Young III, W.C., and Mellbye, M.E. 1994. Influence of residue removal methods and herbicides on perennial ryegrass seed production: I. Weed Control. Agron. J. 86: 677-684.

Neidlinger, T.J. 1965. *Poa annua* L.: susceptibility to several herbicides and temperature requirements for germination. Master's Thesis, Oregon State University. Unpublished.

Robinson, D., and Rorison, I.H. 1987. Root hair and plant growth at low nitrogen availabilities. New Phytol. 107: 681-693.

SAS/STAT. 1990. SAS/STAT user's guide, version 6, 4th Ed. SAS Institute Inc., Cary, North Carolina. p. 908 & 951.

Standifer, L.C., and Wilson, P.W. 1988b. A high temperature requirement for after ripening of imbibed dormant *Poa annua* L. seeds. Weed Research 28: 365-371.

Varco, J.J., and Sartain, J.B. 1986. Effects of phosphorus, sulfur, calcium hydroxided, and pH on growth of annual bluegrass. Soil Sci. Soc. Am. J. 50: 128-132.

Ward, J., and Shaykewich, C.F. 1972. Water absorption by wheat seeds as influenced by hydraulic properties of soil. Can. J. Soil Sci. 52: 99-105.

Warwick, S.I. 1979. The biology of Canadian weeds: *Poa annua* L. Can. J. Plant Sci. 59: 1053-1066.

MANUSCRIPT II

DETERMINATION OF RESISTANT- AND SUSCEPTIBLE-ANNUAL BLUEGRASS (*POA ANNUA* L.) GERMINATION UNDER CONTROLLED TEMPERATURE AND MOISTURE CONDITIONS

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ABSTRACT

Perennial ryegrass production is a monoculture cropping system that relies heavily upon herbicides to control annual bluegrass. This strong selection pressure has resulted in herbicide-resistant biotypes of annual bluegrass. Germination experiments were conducted in growth chambers to determine how differing environmental conditions affect the germination of diuron-susceptible and -resistant annual bluegrass. Temperature experiments were conducted by placing 100 seeds in germination trays on filter paper soaked in distilled water. Experiments were conducted at 30/20 C, 18/5 C, and 10/2 C alternating at 16-, 12-, and 8-hr of light, respectively. Dayton and Woodburn soils were used as the germination media for the moisture experiments. Soil was dried, sieved, sterilized and rehydrated to -0.03, -0.53, -1.03, or -1.53 MPa. Soil was packed into petri dishes and 100 seeds placed on top, sealed with parafilm, and placed into growth chambers at either 30/20 or 18/5 C at 16- or 12-hr light, respectively. All treatments were replicated four times and the experiments were repeated. Cumulative germination for the susceptible-biotype decreased from 96% to 88% while the resistant-biotype remained above 95% as temperature decreased from 30/20 C to 10/2 C. The susceptible-biotype germinated sooner that the resistant-biotype across all temperatures. The susceptible-biotype had a higher rate of germination than the resistant-biotype at 30/20 C but not as the temperature decreased to 10/2 C. Germination response to differing matric potentials did not vary much within a biotype for a given soil type and temperature. Therefore, the parameters estimated at -1.03 MPa were chosen to contrast the susceptible and resistant-biotypes, and the soil types, for each temperature. Maximum cumulative germination was above 96% for all

treatments. When the germination of annual bluegrass biotypes on a given soil type was contrasted, differences were only seen for the susceptible biotype vs. resistant biotype on Dayton soil; and the resistant biotype on Dayton soil vs. resistant biotype on Woodburn soil at both temperatures. The lag in onset of germination was shorter for the susceptible biotype on Dayton soil and resistant biotype on Woodburn soil than the resistant biotype on Dayton soil at 30/20 C. At 18/5 C, the lag in onset of germination was shorter for the susceptible biotype on Dayton soil and resistant biotype on Woodburn soil than the resistant biotype on Dayton soil ($P = 0.0001$ and 0.0001, respectively). But the rate of germination was faster for the resistant biotype on Dayton soil than both the susceptible biotype on Dayton soil and resistant biotype on Woodburn soil at 18/5 C ($P = 0.02$ and 0.0004, respectively). The rate of germination did not differ at 30/20 C. When just the soils were contrasted, at 18/5 C all annual bluegrass seeds on the Woodburn soil germinated sooner and the rate of germination was higher than on the Dayton soil. These results indicate that the hydraulic properties of the soils may influence germination. However, this was not observed at 30/20 C. The results suggest that the susceptible-biotype is more sensitive to temperature while the resistant-biotype is more sensitive to moisture. With the build-up of resistant-annual bluegrass, cultural methods need to be altered to manage for resistance to obtain more efficient and effective use of herbicides.

Nomenclature.

Annual bluegrass, *Poa annua* L.

Key Words.

Germination, Moisture, Temperature, Resistant, Susceptible.

INTRODUCTION

Annual bluegrass (*Poa annua* L.) is a major weed species of turfgrass and agronomic grass seed production. Its difference in leaf color and early seed dispersal and death, causes aesthetic damage in established turf and golf courses (Warwick, 1979). These undesirable traits have caused grass seed producers in the Willamette Valley of Oregon to implement extensive control measures to manage annual bluegrass. Field burning, once the primary non-chemical weed control practice, is being phased out causing herbicide use to increase (Mueller-Warrant et al., 1994a & b). These factors have resulted in increased costs of production.

In the Pacific Northwest, annual bluegrass usually germinates in the fall and may remain quiescent or continue growing depending on conditions. Germination of seeds will resume in the spring, plants mature and produce seeds from the end of April until June, then die once the environment becomes hot and dry (Howe and Snaydon, 1986; Neidlinger, 1965). Standifer and Wilson (1988b) found similar results with annual bluegrass populations in environments characterized by high summer temperatures and frequent rains. Plant growth can continue later into the summer if moisture remains optimum. Although, Martin and Wehner (1987) found a non-

significant trend of seedling mortality when kept under moist conditions. Seed dispersal is usually minimal and calculated to be about 0.5 meter from the parent plant. Dispersal is primarily achieved by spread resulting from machinery, humans, or livestock. Annual bluegrass is mainly self-pollinated and rarely cross-pollinates with other isolated stands (Darmency and Gasquez, 1983; Warwick, 1979).

Standifer and Wilson (1988b) found that annual bluegrass does not require a cold temperature to break dormancy and initiate germination in subtropical climates. However, in northern climates, annual bluegrass can act as a winter annual. The species has the ability to germinate in almost any favorable climate and can withstand relatively high temperatures for short periods of time (Cordukes, 1977).

Annual bluegrass can withstand widely fluctuating water conditions. In hydration-dehydration experiments, it was found that cycling generally resulted in delayed, but more uniform germination. However, annual bluegrass seeds were prevented from germination by 8-hr hydration phases coupled with 16 or 24-hr dehydration phase at -10 MPa (Allen et al., 1993). Good seed contact with soil resulted in higher water contact and higher seed hydraulic conductivity. The seeds themselves exhibited different hydraulic properties, which influenced water uptake (Ward and Shaykewich, 1972). Experiments with mayweed chamomile (*Anthemis cotula* L.) showed increased germination with increasing temperature and soil water, and germination rate was affected less than germination percentage by reduced soil water levels (Gealy et al., 1994).

Standifer and Wilson (1988b) found conditional germination when annual bluegrass seeds were stored for two months at 30 and 35 C with 100% germination

when moved to 10 or 15 C and poorer germination at 5 or 20 C. Seed viability decreased when stored at 35 C for more than two months. Germination of seeds stored at 10 to 30 C increased 5 to 100% at 5 to 25 C, as storage time increased from 1 to 12 months and storage temperature increased 10 to 30 C.

Johnson and White (1997a) conducted vernalization experiments with annual and perennial varieties of annual bluegrass (*P. annua* var. *annua* and *P. annua* var. *retans*, respectively). Vernalization requirements varied between var. *annua* and var. *reptans,* as well as among var. *reptans*. Only var. *annua* showed no response to vernalization treatments. Flowering was affected by photoperiod and cold treatments (Johnson and White, 1997b). The annual type was not responsive to cold treatments and is day neutral. In the absence of cold treatments, flowering of one perennial was induced in long days, two in short days, and one was day neutral. Photoperiod did not affect 4 C cold treatment and floral development after the cold treatment was generally favored by long days, but was genotype dependent.

Management was found to affect temperature enforced dormancy in golf courses. At 25 C, less than 15% of seeds from the rough germinated, compared to 50% from the fairway. Germination increased when the seed was either incubated at 12 C or transferred from 25 to 12 C. Populations from the greens had about 80% germination at either 25 or 12 C (Wu et al., 1987). Standifer and Wilson (1988a) found varying responses to breaking dormancy of freshly harvested seeds by storing seeds in moist soil at 30 C, then testing for germination over a range of temperatures. Results suggest that seeds collected from Louisiana and Maryland adapted to avoid high summer temperatures, but grew as a summer annual in Wisconsin.

Shading, soil conditions, and management can affect plant growth. Light may have a greater effect on weed seed production since weeds are typically early colonizers and need open spaces to establish (Aldrich and Kremer, 1997). Chastain and Grabe (1989) found that shading by cereals reduced dry matter of tall fescue (*Festuca arundinacea* Schreb.) seedlings. Annual bluegrass establishment has a high requirement for phosphorus and negative response to sulfur which decreases pH to 5.6-4.3 (Varco and Sartain, 1966; Warwick, 1979). The acidification of the soil increases the soluble and exchangeable aluminum, which is phytotoxic to root growth and hinders the uptake of calcium and phosphorus (Kuo et al., 1992a, 1992b, and 1993; Varco and Sartain, 1986). Therefore, it is recommended to avoid management strategies of high lime and phosphorus, which benefits the growth of annual bluegrass.

Management practices, seed stock, or environmental factors may influence annual bluegrass growth. Gaussoin and Branham (1989) found annual bluegrass populations increased 12% when grass clippings were returned to the soil surface. In field experiments conducted by Schuster and Mallory-Smith (Chapter 2, this theses), differences in annual bluegrass emergence were observed between residue management treatments. At one site where perennial ryegrass was planted at a narrower row spacing, less annual bluegrass emerged in the spring than at another site which was planted at a wider row spacing. Also, less annual bluegrass emergence was observed during seasons of low moisture.

Little research has been conducted to evaluate the differences between germination of herbicide-resistant and -susceptible populations of annual bluegrass. Since these populations respond differently to herbicides, they may respond differently

to environmental conditions. Experiments conducted with chlorsulfuron-resistant and susceptible kochia (*Kochia scopara*) found differences in germination at varying temperatures (Thompson et al., 1994). No difference in seed viability or fecundity were found in sulfonylurea-resistant and susceptible prickly lettuce (*Lactuca serriola* L.) Alcocer-Ruthling et al., 1992). However, seeds from the resistant biotypes germinated as fast or faster than seed from the susceptible biotypes. Triazine-resistant annual bluegrass showed increased levels of reduced Q_A compared the susceptible biotype at a heat stress of 35 C (Fuks et al., 1992). Therefore, germination experiments were conducted to evaluate how moisture and temperature affect the germination of diuron-resistant and -susceptible annual bluegrass. The parameters of germination compared included the lag phase, the rate of increase, and the maximum cumulative germination.

MATERIALS AND METHODS

Two germination studies were conducted to determine the effects of differing temperatures and soil matric potentials on diuron-resistant (R) and susceptible (S) populations of annual bluegrass. The two biotypes were chosen from work previously conducted at Oregon State University (Gamroth, 1997). In each of the studies, each treatment was replicated four times and the studies were repeated. Experiments were conducted in a SG2-22SS SC controlled environmental chamber (Hoffman Manufacturing, Albany, Oregon). The same seed source was used for all experiments.

Seed were surface sterilized using 10% sodium hypochlorite and deionized distilled water. Temperature experiments were performed by soaking two 120# blue

blotter papers (Rochester Paper Co., Rochester, MI) and two regular weight seed germination papers (Anchor Paper Co., St. Paul, MN) in distilled water, and placing them in 11.8 x 11.8 x 2.8 cm germination trays. Moisture experiments used soil as the germination medium in 100 x 15 mm plastic petri dishes (Becton Pickson Labware, Rochester, NJ). One hundred seeds were placed in each tray. Germination was defined as emergence of the coleoptile to >2 mm in length and appeared to be normal. The germinated seeds were removed from the tray as they were counted. A tetrazolium test was conducted on annual bluegrass seeds that did not germinate to determine seed viability. Ungerminated seed was soaked overnight in water, pierced, and placed in 1% tetrazolium for 4-hr at 38 C. Tetrazolium was drained off and lactic acid added for 1-hr at 38 C. Seed was examined visually to determine viability as indicated by a red-stained embryo.

TEMPERATURE STUDIES

Three temperature regimes were evaluated for their effect on annual bluegrass: 30/20 C, 18/5 C, and 10/2 C alternating, at 16-hr, 12-hr, and 8-hr light, respectively. These temperatures and light correspond to the optimal conditions for annual bluegrass growth (Neidlinger, 1965), fall and spring temperatures, and winter temperatures in the mid-Willamette Valley of Oregon, respectively (Taylor, 1993). Seeds were checked every 12-hrs and removed once they germinated.

SOIL MATRIC POTENTIAL STUDIES

Moisture experiments were conducted using two soils (Dayton and Woodburn) as the germination media. The Woodburn soil is a silt loam containing 10-20% clay

and 3-5% organic matter. It was collected at Hyslop Research Farm (Oregon State University, Oregon) at location NW$^1/_4$, NE$^1/_4$, sec. 8, T. 11 S, R. 4 W (Soil Conservation Service, 1975). The Dayton soil is a silt loam containing 15-20% clay and 1-4% organic matter. It was collect from Cala Farms (Shedd, Oregon) at location NW$^1/_4$, NW$^1/_4$, sec. 5, T. 13 S, R. 3 W (Soil Conservation Service, 1987). The soils were oven dried, crushed and sifted with $^1/_{14}$ x ½ inch screen. Soil was sterilized using an autoclave (Consolidated Sterilizing, Boston, Massachusetts) and oven dried a second time. Approximately, 800 to 1000 g of soils was placed into polyethylene bags (Etherington and Evans, 1986) and rehydrated to matric potentials of -0.03, -0.53, -1.03, and -1.53 MPa. Soil was mixed daily for week until soil was equilibrilized. These matric potentials correspond with a range from field capacity to permanent wilting point for soils (Brady, 1990). Gealy et al. (1994) found germination of mayweed chamomile (*Anthemis cotula* L.) seeds began decreasing at a moisture content of -0.6 MPa. The amount of water needed to achieve the specific matric potentials was obtained using the pressure plate method curves for each soil type (Oregon State University Soils Lab, Figure A-10). After the equilibrium period, the soils were pressed into the petri dishes, the annual bluegrass seeds were placed on top of the soil (Etherington and Evans, 1986), and parafilm wrapped around the lid to minimize moisture loss. The germination trays were placed into a growth chamber in a completely randomized design at alternating 30/20 C or 18/5 C, with 16-hr or 12-hr light, respectively. Seeds were checked every 24-hrs and removed once they germinated.

ANALYSIS

Germination was modeled using a univariate nonlinear regression and the Gauss-Newton alogithm (Shafii et al., 1991; Thompson et al., 1994; SAT/STAT, 1990), and the results were reported as a single degree of freedom contrasts using dummy variable techniques (Bates and Watts, 1988). The logistic model used was in the form of:

$$y = M/(1+\exp(-K(t-L)))$$

where y = cumulative germination percentage at time t, M = the asymptote (theoretical maximum for y), L = time scale (lag related) constant, and K = rate of increase in y. The joint hypothesis of germination, which evaluates all the parameters, was evaluated for the shape of the germination curve.

Resistant and susceptible biotype models for the temperature experiment were developed from the data collected in Experiments 1 and 2. Moisture experiments conducted at 18/5 C used data collected from Experiments 1 and 2. However, germination counts were taken every 24-hr in the moisture experiments, it was difficult to fit the model in the moisture experiments conducted at 30/20 C since there was too much distance between data points. Although both experiments had high asymtotic error, a lower error was observed in Experiment 2. Therefore, Experiment 2 was used to estimate the parameters at the moisture experiments conducted at 30/20 C.

RESULTS AND DISCUSSION

The convergence criterion was met for all regression models using the Gauss-Newton algorithm indicating that a minimum sum of squares was determined for each model (Shafii et al., 1991). Parameter estimates for the temperature experiments (Table II-1) and moisture experiments at 18/5 C (Table II-3) were different from zero (P = 0.0001) with similar magnitude and sign showing all regression lines would be similar in shape. Parameter estimates for the moisture experiments at 30/20 C (Table II-3) were different from zero for the maximum cumulative germination (M) and lag phase (L), but not rate of increase (K).

TEMPERATURE EXPERIMENT

Maximum cumulative germination (M) ranged for 88.88% (S, 10/2 C) to 97.63% (R, 18/5 C) (Table II-1). As temperature decreased, 50% germination (L) ranged from 69.10-hr (S, 30/20 C) and increased as temperature decreased to 376.68-hr (R, 10/2 C). The rate of increase (K) ranged from 0.35 (S, 30/20 C) and decreased as temperature decreased to 0.06 (R, 10/2 C). The correlation coefficients for the parameter estimates associated with each model were not greater than 0.99, indicating that the model was not over-parameterized (Table II-2).

The contrasts comparing the joint hypothesis of parameters of the germination model, for all temperatures, were all different confirming that the R and S biotypes were different (Table II-2). Differences of maximum germination between R and S increased as temperature decreased. As the temperature decreased, the R biotype maintained maximum germination above 95%, while the S biotype decreased from 96.23% to 88.88% when temperature decreased from 30/20 to 10/2 C. Thompson et at (1994)

Table II-1. Maximum germination (M), lag phase (L), and rate of germination (K) along with asymptotic standard errors (in parenthesis) for susceptible and resistant biotypes of annual bluegrass at 30/20, 18/5, and 10/2 C. The correlation matrix of the parameters are given for each temperature/biotype treatment.

				------ Correlation Matrix ------		
Temp.(C)	Biotype	Parameters		M	L	K
30/20	Susceptible	M	96.23 (0.658)	1		
		L	69.10 (0.415)	0.11	1	
		K	0.35 (0.044)	-0.09	0.73	1
	Resistant	M	96.76 (0.851)	1		
		L	75.84 (0.486)	0.33	1	
		K	0.17 (0.012)	-0.30	-0.14	1
18/5	Susceptible	M	96.32 (0.320)	1		
		L	144.17 (0.288)	0.21	1	
		K	0.16 (0.007)	-0.19	-0.04	1
	Resistant	M	97.63 (0.320)	1		
		L	156.22 (0.295)	0.23	1	
		K	0.14 (0.005)	-0.21	-0.05	1
10/2	Susceptible	M	88.88 (0.426)	1		
		L	363.38 (0.650)	0.32	1	
		K	0.07 (0.003)	-0.30	-0.09	1
	Resistant	M	95.42 (0.417)	1		
		L	376.68 (0.589)	0.34	1	
		K	0.06 (0.002)	-0.31	-0.11	1

found similar results with chlorsulfuron-susceptible and -resistant kochia collected from Kansas. The difference for L between the annual bluegrass biotypes ranged approximately 6-hr to 13-hr (30/20 to 10/2 C, respectively). The S biotype consistently germinated sooner than the R biotype across all temperatures (Table II-2). The S biotype had a higher K than the R biotype at 30/20 C, but the difference was non-significant as the temperature decreased. These results differed from experiments with sulfonylurea- resistant and -susceptible prickly lettuce where the resistant biotypes

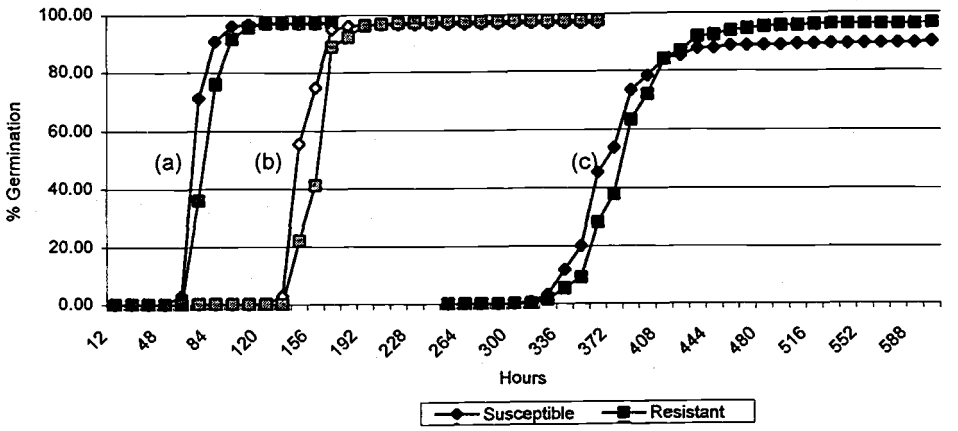

Figure II-1. Resistant and susceptible annual bluegrass germination at a) 30/20 C, b) 18/5 C and c) 10/2 C at 16-, 12-, and 8-hr light, respectively.

Table II-2. Contrasts for maximum cumulative germination (M), lag in onset of germination (L), rate of increase (K), and shape parameter (M&L&K) for susceptible (S) and resistant (R) biotypes at 30/20, 18/5, and 10/2 C.

Temp. (C)	Contrast	DF	F-stat	Pr > F
30/20	R vs. S			
	M	1	0.38	0.53
	L	1	175.72	0.0001
	K	1	22.15	0.0001
	M&L&K	3	122.44	0.0001
18/5	R vs. S			
	M	1	5.45	0.02
	L	1	545.22	0.0001
	K	1	3.60	0.06
	M&L&K	3	185.22	0.0001
10/2	R vs. S			
	M	1	126.78	0.0001
	L	1	243.33	0.0001
	K	1	1.91	0.17
	M&L&K	3	96.31	0.0001
All temp.	R vs. S			
	M	1	51.62	0.0001
	L	1	822.56	0.0001
	K	1	26.43	0.0001
	M&L&K	3	315.62	0.0001

germinated as fast or faster (Alcocer-Ruthling et al., 1992).

When the R and S annual bluegrass were contrasted across all temperatures there was a significant difference for all parameters. The R biotype had a higher germination than the S biotype. However, the S biotype germinated sooner and faster than the R biotype. The data suggests that the S biotype is much more sensitive to temperature than the R biotype in relation to M and K.

SOIL MOISTURE EXPERIMENT

Differences between moistures for a biotype at a given soil type and temperature varied only 0.7 to 11% for maximum germination and lag to onset of germination (Appendix, Table A-8). The rate of germination varied 10 and 66%, which is probably due to the large gap of time between measurements that resulted in a large asymtotic errors. However, the variability between the soil moisture levels was considered to be insignificant. Therefore, contrasts between the R and S biotype and the Dayton and Woodburn soils were conducted using only the -1.03 MPa. This moisture level is representative of the environmental conditions during the fall when the first herbicide application is applied.

The maximum germination was above 96% across all biotypes, soils, and temperature. The lag in onset of germination ranged from 68.31 (WS[1]) to 79.95 (DR) at 30/20 C, and 161.24 (DS) to 169.43 (DR) at 18/5 C. The rate of germination was similar to the temperature experiments where the S biotype was higher than the R biotype, ranging from 0.34 (WS) to 0.17 (DR), at the 30/20 C. At 18/5 C, K ranged for

[1] DS = Dayton soil, S-biotype; DR = Dayton soil, R-biotype; WS = Woodburn soil, S-biotype; WR = Woodburn soil, R-biotype.

Table II-3. Maximum germination (M), lag in onset of germination (L), rate of germination (K), and their asymptotic errors for susceptible and resistant biotypes germinated on Dayton or Woodburn soils at either 30/20 or 18/5 C. Correlation matrix of the parameters are given for each temperature, soil type, and biotype treatments at -1.03 MPa.

					---- Correlation Matrix ----		
Temp. (C)	Soil Type	Biotype	Parameters	Estimate	M	L	K
30/20	Dayton	Susceptible	M	98.20 (1.576)	1		
			L	69.57 (1.841)	-0.02	1	
			K	0.21 (0.149)	-0.15	0.90	1
		Resistant	M	98.15 (0.799)	1		
			L	79.95 (0.781)	0.40	1	
			K	0.17 (0.022)	-0.38	-0.76	1
	Woodburn	Susceptible	M	97.63 (1.420)	1		
			L	68.31 (17.526)	-0.02	1	
			K	0.34 (1.641)	-0.03	0.99	1
		Resistant	M	98.12 (2.602)	1		
			L	69.62 (2.832)	-0.01	1	
			K	0.21 (0.224)	-0.15	0.88	1
18/5	Dayton	Susceptible	M	96.74 (0.401	1		
			L	161.24 (0.401)	0.23	1	
			K	0.12 (0.005)	-0.18	0.22	1
		Resistant	M	98.06 (1.424)	1		
			L	169.43 (1.417)	0.33	1	
			K	0.09 (0.012)	-0.31	-0.13	1
	Woodburn	Susceptible	M	98.58 (0.697)	1		
			L	161.76 (0.687)	0.25	0	
			K	0.11 (0.007)	-0.21	0.14	1
		Resistant	M	98.36 (0.434)	1		
			L	163.61 (0.404)	0.15	0	
			K	0.14 (0.010)	-0.15	0.51	1

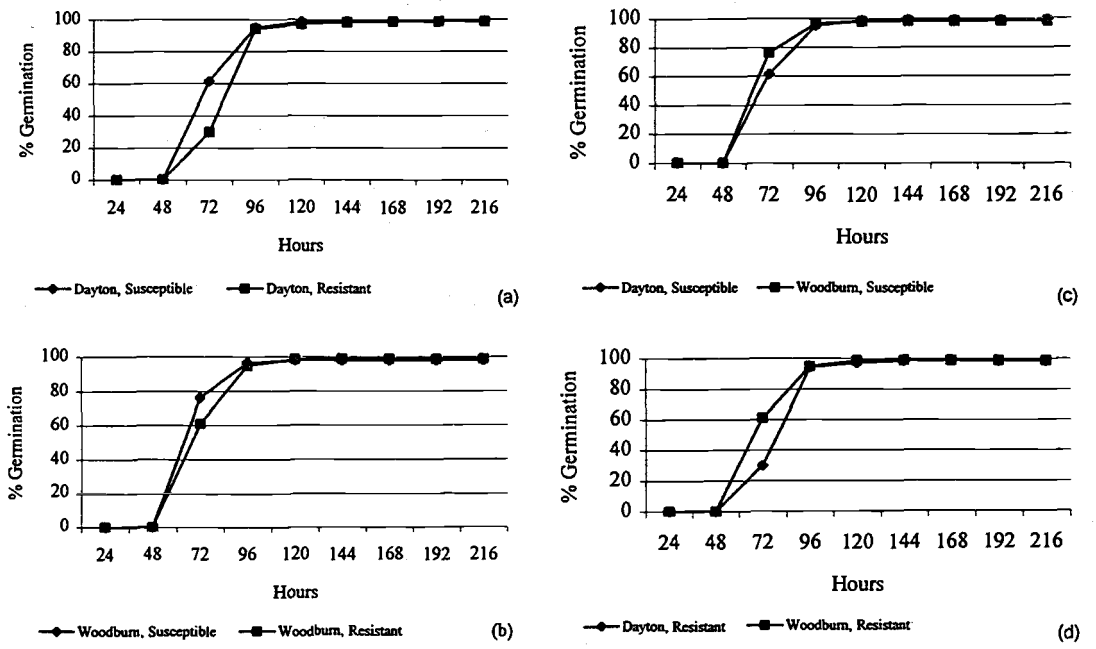

Figure II-2 a-d. Annual bluegrass germination curves for a) Dayton susceptible and resistant, b) Woodburn susceptible and resistant, c) Dayton susceptible and Woodburn susceptible, and d) Dayton resistant and Woodburn resistant at -1.03 MPa at 30/20 C.

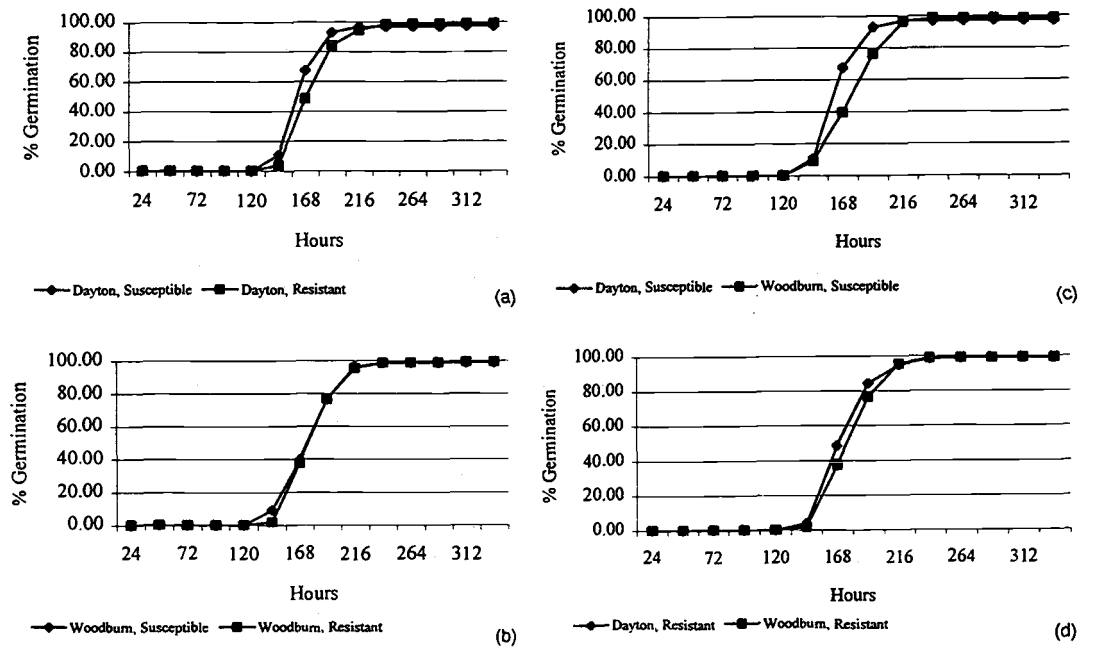

Figure II-3 a-d. Annual bluegrass germination curves for a) Dayton susceptible and resistant, b) Woodburn susceptible and resistant, c) Dayton susceptible and Woodburn susceptible, and d) Dayton resistant and Woodburn resistant at -1.03 MPa at 18/5 C.

Table II-4. Contrast for Dayton susceptible (DS), Dayton resistant (DR), Woodburn susceptible (WS), and Woodburn resistant (WR) for maximum germination (M), lag phase (L), rate of germination (K), and germination curve (M&L&K) at -1.03 MPa at 30/20 C.

Contrast	DF	F-stat	Pr > F
DS vs. DR			
M	1	0.0004	0.98
L	1	7.38	0.007
K	1	0.06	0.80
M&L&K	3	3.95	0.01
WS vs. WR			
M	1	0.045	0.83
L	1	0.004	0.95
K	1	0.005	0.94
M&L&K	3	1.92	0.13
DS vs. WS			
M	1	0.056	0.81
L	1	0.004	0.95
K	1	0.005	0.95
M&L&K	3	1.82	0.15
DR vs. WR			
M	1	0.0001	0.99
L	1	7.84	0.006
K	1	0.06	0.81
M&L&K	3	3.83	0.01
D vs. W			
M	1	0.03	0.86
L	1	0.16	0.67
K	1	0.008	0.93
M&L&K	3	5.31	0.002

Table II-5. Contrasts for Dayton susceptible (DS), Dayton resistant (DR), Woodburn susceptible (WS), and Woodburn resistant (WR) for maximum germination (M), lag phase (L), rate of germination (K), and germination curve (M&L&K) at -1.03 MPa at 18/5 C.

Contrast	DF	F-stat	Pr > F
DS vs. DR			
M	1	1.99	0.16
L	1	48.52	0.0001
K	1	5.15	0.02
M&L&K	3	19.52	0.0001
WS vs. WR			
M	1	0.03	0.85
L	1	2.89	0.09
K	1	3.62	0.06
M&L&K	3	1.61	0.18
DS vs. WS			
M	1	4.23	0.04
L	1	0.21	0.65
K	1	0.53	0.47
M&L&K	3	0.93	0.43
DR vs. WR			
M	1	0.06	0.8
L	1	26.34	0.0001
K	1	8.36	0.004
M&L&K	3	18.09	0.0001
D vs.R			
M	1	2.09	0.15
L	1	10.91	0.001
K	1	3.98	0.046
M&L&K	3	9.3	0.0001

0.14 (WR) to 0.09 (DR). The K parameter at 30/20 C was not considered different from zero for the S biotype germinated on Dayton or Woodburn soil and the R biotype germinated on the Woodburn soil.

The joint hypothesis for germination model (M&L&K) was only significant for the DS vs. DR and DR vs. WR (Table II-4). Suggesting that the WS vs. WR and the DS vs. WS germination process were not different. The lack of differences in the parameter estimates confirmed a similar germination process for WS v. WR and DS vs. WS. The Dayton soil was different from the Woodburn soil for the joint hypothesis of germination model.

Contrasts of parameter estimates were different for DS vs. DR and DR vs. WR for L. DS and WR were both faster than DR. M did not differ for any treatment and the asymptotic standard error for K was too high to give an accurate contrast. Increasing data collection from 24-hr to 4 or 6-hr periods may give more accurate contrasts by reducing the asymtotic standard error.

The contrasts for the 18/5 C moisture experiments are presented in Table II-5. The joint hypothesis of germination model was different for DS vs. DR and DR vs. WR, with the L and K parameters significantly different. The lag in onset of germination for DS was sooner than DR, but K was higher for DR than DS. WR had a faster L than DR, but DR had a higher K than WR. WS vs. WR and DS vs. WS did not differ in their joint hypothesis of germination model. The parameter contrasts support the hypothesis although DS had a lower germination than WS. D vs. W had a significant joint hypothesis of germination model with L being significantly faster for W than D. The

maximum germination did not differ between D and W, and the rate of germination was marginally higher for W than D.

Tetrazolium tests conducted on seed that did not germinate in temperature experiments indicate that viability was less than 1% at 30/20 C, ~1% at 18/5 C, and 2% for the R biotype and 7% for the S biotype at 10/2 C. In moisture experiments, dormancy ranged from 0% for DS, DR, and WR at 30/20 C to ~1.5% for WS at 18/5 C. The lack of dormancy in areas of warmer climate is in agreement with Standifer and Wilson (1988a & b). Although as temperature decreased, enforced dormancy of the S biotype appeared to increase.

Even though the error for the 30/20 C experiment was large, the analysis of the parameter estimates exhibited the same trend as the 18/5 C moisture experiments. The differences in the DR vs. WR contrast suggest that the R biotype is more sensitive to moisture than the S biotype. The Dayton soil has a higher moisture retention curve than the Woodburn soil (Appendix, Figure A-10). Therefore, R biotypes may have increased competitive ability in some soil types early in the growing season.

The cultural management and repeated herbicide use in perennial ryegrass favors resistant annual bluegrass establishment. Traditionally, perennial ryegrass is planted on wide rows in the fall allowing annual bluegrass to establish relatively competition free. Even when the crop becomes established, the wide row spacing allows annual bluegrass to become established if it germinates early. The results from the temperature experiments indicate that the S biotype will germinate faster allowing it to establish early. However, if a herbicide is applied to the crop that controls the S

biotype and injures the crop, that leaves a prime environment for the R biotype to germinate and establish during the winter.

The moisture experiments show that the R biotype can be sensitive to soil type. Mapplebeck et al. (1982) found consistently higher water content of germinated atrazine-susceptible wild turnip rape (*Brassica campestris* L.) compared to the resistant-biotype. In our studies, the R biotype was found to germinate later on the Dayton soil. If management is aimed at control early in the season when soil moisture is still low, only the S biotype will be present and controlled, giving a competitive edge to the R biotype in the winter. Further data are needed to pinpoint specific moisture levels and temperatures, to distinguish differences between the S and R biotypes of annual bluegrass. Not only should measurements be taken at shorter time intervals, but germination at lower than -1.53 MPa should be evaluated. The effects of shading need to be investigated. Previous work conducted by Schuster and Mallory-Smith (Chapter 2, this theses) showed less annual bluegrass establishment in the spring once the perennial ryegrass achieved full canopy cover.

From the results of these germination experiments, it is not surprising that that resistant-annual bluegrass has developed. Perennial ryegrass production is a monoculture cropping system with little crop rotation and mechanical controls. There is a heavy reliance on herbicides to control annual bluegrass. Resistance development models (Maxwell et al., 1990) show that resistant populations can build up in a field within five years of repeated herbicide use depending on the fitness of the weed species and management practices. Since susceptible-annual bluegrass germinated sooner and faster at higher temperatures. Herbicides that are applied early in the growing season

will only control the susceptible-annual bluegrass. This leaves a prime environment for the resistant-annual bluegrass to become established in the winter. The data shows that the resistant-annual bluegrass has a high germination percentage in the winter and will become easily established since there will be little crop competition.

Cultural practices need to be considered when developing an annual bluegrass management system. Narrowing the row spacing and planting the perennial ryegrass in the spring have proven to be effective in reducing annual bluegrass numbers (Mallory-Smith and Brewster, 1997 a & b), but by itself will not provide adequate control. However, these practices may be utilized to maximize other management practices to control R annual bluegrass.

REFERENCES

Alcocer-Ruthling, M., Thill, D.C., and Shafii, B. 1992. Seed biology of sulfonylurea-resistant and –susceptible biotypes of prickly lettuce (*Lactuca serriola*). Weed Tech. 6: 858-864.

Aldrich, R.J., and Kremer, R.J. 1997. Principles in weed management, 2nd Ed. Iowa State University Press, Ames, Iowa.

Allen, P.S., White, D.B., and Markhart III, A.H. 1993. Germination of perennial ryegrass and annual bluegrass seeds subjected to hydration-dehydration cycles. Crop Sci. 33: 1020-1025.

Bates, D.M., and Watts, D.G. 1988. Non-linear regression analysis and its application. John Wiley & Sons, New York.

Brady, N.C. 1990. The nature and properties of soils, 10th Ed. MacMillan Publishing Co. New York. p. 145.

Chastain, T.G., and Grabe, D.F. 1989. Spring establishment of turf-type tall fescue seed crops with cereal companion crops. Agron. J. 81: 488-493.

Cordukes, W.E. 1977. Growth habit and heat tolerance of a collection of *Poa annua* plants in Canada. Can. J. Plant Sci. 57: 1201-1203.

Darmency, H., and Gasquez, J. 1983. Esterase polymorphism and growth form differentiation in *Poa annua* L. New Phytol. 95: 289-297.

Etherington, J.R., and Evans, C.E. 1986. Technique for ecological studies of seed germination in relation to soil water potential. Plant and Soil 95: 285-288.

Fuks, B., Van Eycken, F., and Lannoye, R. 1992. Tolerance of triazine-resistant and susceptible biotypes of three weeds to heat stress: a florescence study. Weed Research 32: 9-17.

Gamroth, D., and Mallory-Smith, C. 1997. Resistance of annual bluegrass (*Poa annua* L.) to diuron and ethofumesate. Master's Thesis, Oregon State University, unpublished.

Gaussoin, R.E., and Branham, R.E. 1989. Influences of cultural factors on species dominance in a mixed stand on annual bluegrass/creeping bentgrass. Crop Sci. 29: 480-484.

Gealy, D.R., Squier, S.A., and Ogg, A.G., Jr. 1994. Soil environment and temperature affect germination and seedling growth of mayweed chamomile (*Anthemis cotula*). Weed Tech. 8: 688-672.

Howe, C.D., and Snaydon, R.W. 1986. Factors affecting the performance of seedling and ramets of invading grasses in an established ryegrass sward. J. of Applied Ecology 23: 139-146.

Johnson, P.G., and White, D.B. 1997a. Vernalization requirements among selected genotypes of annual bluegrass (*Poa annua* L.). Crop Sci. 37: 1538-1542.

Johnson, P.G., and White, D.B. 1997b. Flowering responses of selected annual bluegrass genotypes under different photoperiods and cold treatments. Crop Sci. 37: 1543-1547.

Kuo, S. 1993. Effects of lime and phosphate on the growth of annual bluegrass and creeping bentgrass in two acid soils. Soil Sci. 156: 94-100.

Kuo, S., Brauen, S.E., and Jellum, E.J. 1992a. Phosphorus availability in some acid soils infulences bentgrass and annual bluegrass growth. Hort Sci. 27: 370.

Kuo, S., Brauen, S.E., and Jellum, E.J. 1992b. The effects of aluminum and phosphate on the growth of annual bluegrass and bentgrass in some acidic western Washington soils. Soil Sci. 153: 365-372.

Mallory-Smith, C., and Brewster, B. 1998a Spring seeded perennial ryegrass, cultivar comparison. Weed Control in Agronomic Crops. Dept. of Crop and Soil Science, Oregon State University p. 19.

Mallory-Smith, C., and Brewster, B. 1998b. No plow seeding of perennial ryegrass, fall vs. spring. Weed Control in Agronomic Crops. Dept. of Crop and Soil Science, Oregon State University p. 42.

Mapplebeck, L.R., Souza Machado, V., and Grodzinski, B. 1982. Seed germination and seedling growth characteristics of atrazine-susceptible and resistant biotypes of *Brassica campestris*. Can. J. Plant Sci. 62: 733-739.

Martin, D.L., and Wehner, D.J. 1987. Influence of prestress environment on annual bluegrass heat tolerance. Crop Sci. 27: 579-585.

Maxwell, B.D., Roush, M.L., and Radosevich, S.R. 1990. Predicting the evolution and dynamics of herbicide resistance in weed populations. Weed Tech. 4: 2-13.

Mueller-Warrant, G.W., Young III, W.C., and Mellbye, M.E. 1994a. Influence of residue removal methods and herbicides on perennial ryegrass seed production: I. Weed Control. Agron. J. 86: 677-684.

Mueller-Warrant, G.W., Young III, W.C., and Mellbye, M.E. 1994b. Influence of residue removal method and heribicides on perennial ryegrass seed production: II. Crop Tolerance. Agron. J. 86: 684-690.

Neidlinger, T.J. 1965. *Poa annua* L.: susceptibility to several herbicides and temperature requirements for germination. Master's Thesis, Oregon State University. Unpublished.

SAS/STAT Institute Inc. 1990. SAS/STAT user's guide, version 6, 4th Ed. SAS Institute Inc., Cary, North Carolina p. 1153.

Shafii, B., William, J.P., Swensen, J.B., and Murray, G.A. 1991. Nonlinear estimation of growth curve models for germination data analysis. p. 19-36 in G.A. Milliken & J.R. Schwenke, eds. Proc. of 1991 Kansas State Univ. Conf. On Appl. Statitics in Agriculture. Kansas State Univ., Manhattan, Kansas 66506.

Soil Conservation Service. 1975. Soil survey of Benton County area, Oregon. United States Department of Agriculture, Washington D.C.

Soil Conservation Service. 1987. Soil survey of Linn County area, Oregon. United States Department of Agriculture, Washington D.C.

Standifer, L.C., and Wilson, P.W. 1988a. Dormancy studies in three populations of *Poa annua* L. seeds. Weed Research 28: 359-363.

Standifer, L.C., and Wilson, P.W. 1988b. A high temperature requirement for after ripening of imbibed dormant *Poa annua* L. seeds. Weed Research 28: 365-371.

Taylor, G.H. 1993. Climatological data for Oregon agricultural regions. p. 9-12. Oregon Agric. Expt. Station Special Report 912.

Thompson, C.R., Thill, D.C., and Shafii, B. 1994. Germination characteristics of sulfonylurea-resistant and –susceptible kochia (*Kochia scoparia*). Weed Sci. 42: 50-56.

Varco, J.J., and Sartain, J.B. 1986. Effects of phosphorus, sulfur, calcium hydroxided, and pH on growth of annual bluegrass. Soil Sci. Soc. Am. J. 50: 128-132.

Ward, J., and Shaykewich, C.F. 1972. Water absorption by wheat seeds as influenced by hydraulic properties of soil. Can. J. Soil Sci. 52: 99-105.

Warwick, S.I. 1979. The biology of Canadian weeds: *Poa annua* L. Can. J. Plant Sci. 59: 1053-1066.

Wu, L., Till-Bottraud, I., and Torres, A. 1987. Genetic differentiation in temperature-enforced seed dormancy among golf course populations of *Poa annua* L. New Phytologist 107: 623-631.

SUMMARY

Annual bluegrass is a serious weed in perennial ryegrass seed production, and with the loss of field burning as a management practice, weed control has required more attention. In the field experiments, during the 1997-98 growing season more annual bluegrass emergenced in full-straw and bale/flail treatments. However, emergence decreased across all treatments at both sites during the dry fall of 1998, and was lower in the full-straw and bale/flail treatments compared to the vacuum sweep treatment. In the spring, lower emergence was measured at the Wirth site where narrower row-spacing allowed quicker row closure which shaded annual bluegrass and inhibited its establishment.

A yield increase was observed for the vacuum sweep treatment over the other two treatments at the Glaser site for the 1998-99 growing season. However, increased volunteer perennial ryegrass at the Glaser site may have accounted for decreased yields of the full-straw and bale/flail treatments. No other yield differences were found. Annual bluegrass seed contamination after harvest increased dramatically at the Glaser site from the 1997-98 to 1998-99 growing seasons ($P = 0.002$), whereas at the Wirth site there was little change. Wider row-spacing and lack of perennial ryegrass competition early in the spring at the Glaser site may have accounted for this increase. Although no one treatment proved dominant over the others, each has its advantages and disadvantages. Vacuum sweep removes a majority of the residue and seeds from the ground resulting in less volunteer perennial ryegrass and less annual bluegrass when

moisture is adequate. However, this management practice is expensive and time consuming, and cannot be used practically on a wide acreage basis. The bale/flail and the full straw treatments are the management practices most widely used. Both are less expensive and the bale/flail treatment also allows some residue to be removed. Unfortunately, more residue means more volunteer perennial ryegrass and potentially a greater weed problems.

Herbicides have been found to be less effective as more residue is allowed to remain in the field (Muller-Warrant et al., 1994a & b). In the end, growers will choose whichever management practice they feel will best fit their production system. The findings from this research should give growers an idea of what could be expected in terms of management problems and potential weed problems during certain environmental conditions. The dry fall in 1998 showed that moisture had a major impact on the number of annual bluegrass seedlings found in the field. Brede and Duich (1986) found that annual bluegrass had an increased rate of tillering in early autunm while perennial ryegrass had an increased rate of tillering during early summer. It would be useful to know how these environmental factors impact germination and emergence, allowing for more effective management planning in terms of herbicide application and resistance management. Therefore, germination experiments were conducted to examine the environmental effects on the susceptible- and resistant-annual bluegrass seeds.

Germination temperature experiments showed that the susceptible biotype of annual bluegrass germinates faster and at a higher rate at increased temperatures. However, as temperature decreased to 10/2 C, the maximum germination of the

susceptible-biotype decreased to 88% while the resistant-biotype remained above 95%. The lag in onset of germination was shorter for the susceptible-biotype compared to the resistant-biotype across all temperatures. The rate of germination was faster for the susceptible-biotype but became non-significant as the temperature decreased.

Contrasts for the germination by moisture experiments were conducted at a soil moisture of -1.03 MPa. Although there was some variation between different moisture levels for a given annual bluegrass biotype and soil type, it was considered practically insignificant. The parameter estimates at a soil moisture of -1.03 MPa were chosen for the contrasts since it represents the moisture condition when herbicide application would begin in the Willamette Valley. At 30/20 and 18/5 C, contrast differences were seen between the susceptible biotype vs. the resistant biotype on Dayton soil and the resistant biotype on Dayton soil vs. the resistant biotype on Woodburn soil. Both the susceptible biotype on Dayton soil and resistant biotype on Woodburn soil germinated sooner than resistant biotype on Dayton soil at both 30/20 and 18/5 C. However, at 18/5 C the rate of germination was faster for resistant biotype on Dayton soil than the susceptible biotype on Dayton soil and the resistant biotype on Woodburn soil. When just the soil types were contrasted across all annual bluegrass biotypes, annual bluegrass seeds germinated sooner and the rate of germination was marginally faster on the Dayton soil than the Woodburn soil at 18/5 C. There were no differences between the soil types at 30/20 C.

From the results of these germination experiments, it is not surprising that that resistant-annual bluegrass has developed. Since perennial ryegrass production is a monoculture cropping system with little crop rotation and mechanical controls such as

tillage. There is a heavy reliance on herbicides to control annual bluegrass. Resistance development models (Maxwell et al., 1990) show that resistant populations can build up in a field within five years of repeated herbicide use depending on the fitness of the weed species and management practices. Since susceptible-annual bluegrass germinated sooner and faster at higher temperatures. Herbicides that are applied early in the growing season will only control the susceptible-annual bluegrass. This leaves a prime environment for the resistant-annual bluegrass to become established in the winter. The data shows that the resistant-annual bluegrass has a high germination percentage in the winter and will become easily established since there will be little crop competition.

New cultural methods need to be considered in order to manage resistant-annual bluegrass populations. Observation is the field experiments and other research conducted at Oregon State University (Mallory-Smith and Brewster, 1997-98a & b) indicate that narrowing the row-spacing of perennial ryegrass and planting in the spring can reduce annual bluegrass populations. Allen et al. (1993) found that annual bluegrass progressed toward germination at low moisture levels, allowing for rapid germination once soil moisture increases. Shading is also known to impact germination and growth of plants (Aldrich and Kremer, 1997; Chastain and Grabe, 1989) and was observed to impact annual bluegrass emergence at the Wirth site. Therefore, the impact of shading on annual bluegrass germination and emergence needs to be investigated further. Although these cultural practices will not control annual bluegrass by themselves, they may manipulate the emergence and establishment of annual bluegrass for more efficient and effective use of herbicides.

BIBLOGRAPHY

Alcocer-Ruthling, M., Thill, D.C., and Shafii, B. 1992. Seed biology of sulfonylurea-resistant and –susceptible biotypes of prickly lettuce (*Lactuca serriola*). Weed Tech. 6: 858-864.

Aldrich, R.J., and Kremer, R.J. 1997. Principles in weed management, 2nd Ed. Iowa State University Press, Ames, Iowa.

Allen, P.S., White, D.B., and Markhart III, A.H. 1993. Germination of perennial ryegrass and annual bluegrass seeds subjected to hydration-dehydration cycles. Crop Sci. 33: 1020-1025.

Arber, A 1965. The Gramineae. J. Cramer Weinheim, New York.

Bates, D.M., and Watts, D.G. 1988. Non-linear regression analysis and its application. John Wiley & Sons, New York.

Bergelson, J. 1990a. Life after death: site pre-emption by the remains of *Poa annua*. Ecology 71: 2157-2165.

Bergelson, J. 1990b. Spatial patterning in plants: opposing effects of herbivory and competition. J. of Ecology 78: 937-948.

Brady, N.C. 1990. The nature and properties of soils, 10th Ed. MacMillan Publishing Co. New York. p. 145.

Brede, A.D., and Duich, J.M. 1986. Plant interaction among *Poa annua, Poa pratensis,* and *Lolium perenne* turfgrasses. Agron. J. 78: 179-184.

Chastain, T.G., Young III, W.C., Garbacik, C.J., and Quebbeman, B.M. 1994. Residue management practices for grass seed crops grown in the Willamette Valley. p. 1-5 In W.C. Young III (ed.) 1994 Seed Production Research, Dept. Crop & Soil Sci/Ext./CrS 102.

Chastain, T.G., and Grabe, D.F. 1989. Spring establishment of turf-type tall fescue seed crops with cereal companion crops. Agron. J. 81: 488-493.

Cooper, R.S., Henderlong, P.R., Street, J.R., and Karnok, K.J. 1987. Root growth, Seedhead production, and quality of annual bluegrass as affected by mefluidide and a wetting agent. Agron. J. 79: 929-934.

Cordukes, W.E. 1977. Growth habit and heat tolerance of a collection of *Poa annua* plants in Canada. Can. J. Plant Sci. 57: 1201-1203.

Danneberger, T.K., Branham, B.E., and Vargas, Jr. J.M. 1987. Mefluidide application for annual bluegrass seedhead suppression based on degree-day accumulation. Agron. J. 79: 69-71.

Darmency, H., and Gasquez, J. 1983. Esterase polymorphism and growth form differentiation in *Poa annua* L. New Phytol. 95: 289-297.

Eggens, J.L. 1979. The response of some Kentucky bluegrass cultivars to competitive stress from annual bluegrass. Can. J. Plant Sci. 59: 1123-1128.

Ellis, W.M., Lee, B.T.O., and Calder, D.M. 1971. A biometric analysis of populations of *Poa annua* L. Evolution 25: 29-37.

Etherington, J.R., and Evans, C.E. 1986. Technique for ecological studies of seed germination in relation to soil water potential. Plant and Soil 95: 285-288.

Fuks, B., Van Eycken, F., and Lannoye, R. 1992. Tolerance of triazine-resistant and susceptible biotypes of three weeds to heat stress: a florescence study. Weed Research 32: 9-17.

Gamroth, D., and Mallory-Smith, C. 1997. Resistance of annual bluegrass (Poa annua L.) to diuron and ethofumesate. Master's Thesis, Oregon State University. Unpublished.

Gaul, M.C., and Christians, N.E. 1988. Selective control of annual bluegrass in cool-season turfs with fenarimol and chlorsulfuron. Agron. J. 80: 120-125.

Gaussoin, R.E., and Branham, R.E. 1989. Influences of cultural factors on species dominance in a mixed stand on annual bluegrass/creeping bentgrass. Crop Sci. 29: 480-484.

Gealy, D.R., Squier, S.A., and Ogg, A.G., Jr. 1994. Soil environment and temperature affect germination and seedling growth of mayweed chamomile (*Anthemis cotula*). Weed Tech. 8: 688-672.

Gibeault, V.A. 1971. Perenniality in Poa annua L. Ph.D Thesis, Oregon State University, Corvallis, Oregon, USA.

Hitchcock, A.S. 1971. Manual of the grasses of the United States, vol. 1 & 2. Dover Publ., New York. Page 106.

Howe, C.D., and Snaydon, R.W. 1986. Factors affecting the performance of seedling and ramets of invading grasses in an established ryegrass sward. J. of Applied Ecology 23: 139-146.

Johnson, P.G., and White, D.B. 1997a. Vernalization requirements among selected genotypes of annual bluegrass (*Poa annua* L.). Crop Sci. 37: 1538-1542.

Johnson, P.G., and White, D.B. 1997b. Flowering responses of selected annual bluegrass genotypes under different photoperiods and cold treatments. Crop Sci. 37: 1543-1547.

Juhren, M., Hiesey, Wm.M., and Went, F.W. 1953. Germination and early growth of grasses in controlled conditions. Ecology 34: 288-300.

Kuo, S. 1993. Effects of lime and phosphate on the growth of annual bluegrass and creeping bentgrass in two acid soils. Soil Sci. 156: 94-100.

Kuo, S., Brauen, S.E., and Jellum, E.J. 1992a. Phosphorus availability in some acid soils infulences bentgrass and annual bluegrass growth. Hort Sci. 27: 370.

Kuo, S., Brauen, S.E., and Jellum, E.J. 1992b. The effects of aluminum and phosphate on the growth of annual bluegrass and bentgrass in some acidic western Washington soils. Soil Sci. 153: 365-372.

Mallory-Smith, C., and Brewster, B. 1998a Spring seeded perennial ryegrass, cultivar comparison. Weed Control in Agronomic Crops. Dept. of Crop and Soil Science, Oregon State University p. 19.

Mallory-Smith, C., and Brewster, B. 1998b. No plow seeding of perennial ryegrass, fall vs. spring. Weed Control in Agronomic Crops. Dept. of Crop and Soil Science, Oregon State University p. 42.

Mapplebeck, L.R., Souza Machado, V., and Grodzinski, B. 1982. Seed germination and seedling growth characteristics of atrazine-susceptible and resistant biotypes of *Brassica campestris*. Can. J. Plant Sci. 62: 733-739.

Martin, D.L., and Wehner, D.J. 1987. Influence of prestress environment on annual bluegrass heat tolerance. Crop Sci. 27: 579-585.

Maxwell, B.D., Roush, M.L., and Radosevich, S.R. 1990. Predicting the evolution and dynamics of herbicide resistance in weed populations. Weed Tech. 4: 2-13.

Mecalfe, D.J. 1996. Germination of small-seeded tropical rain forest plants exposed to different spectral compositions. Can. J. Botany 74: 516-520.

Mueller-Warrant, G.W., Young III, W.C., and Mellbye, M.E. 1994a. Influence of residue removal methods and herbicides on perennial ryegrass seed production: I. Weed Control. Agron. J. 86: 677-684.

Mueller-Warrant, G.W., Young III, W.C., and Mellbye, M.E. 1994b. Influence of residue removal method and heribicides on perennial ryegrass seed production: II. Crop Tolerance. Agron. J. 86: 684-690.

Neidlinger, T.J. 1965. *Poa annua* L.: susceptibility to several herbicides and temperature requirements for germination. Master's Thesis, Oregon State University. Unpublished.

Petrovic, A.M., White, R.A., and Kligerman, M. 1985. Annual bluegrass growth and quality as influenced by treatments of growth retardants and wetting agents. Agron J. 77: 670-674.

Robinson, D., and Rorison, I.H. 1987. Root hair and plant growth at low nitrogen availabilities. New Phytol. 107: 681-693.

SAS/STAT Institute Inc. 1990. SAS/STAT user's guide, version 6, 4th Ed. SAS Institute Inc., Cary, North Carolina p. 908, 951, & 1153.

Shafii, B., William, J.P., Swensen, J.B., and Murray, G.A. 1991. Nonlinear estimation of growth curve models for germination data analysis. p. 19-36 in G.A. Milliken & J.R. Schwenke, eds. Proc. of 1991 Kansas State Univ. Conf. On Appl. Statitics in Agriculture. Kansas State Univ., Manhattan, Kansas 66506.

Soil Conservation Service. 1975. Soil survey of Benton County area, Oregon. United States Department of Agriculture, Washington D.C.

Soil Conservation Service. 1987. Soil survey of Linn County area, Oregon. United States Department of Agriculture, Washington D.C.

Standifer, L.C., and Wilson, P.W. 1988a. Dormancy studies in three populations of *Poa annua* L. seeds. Weed Research 28: 359-363.

Standifer, L.C., and Wilson, P.W. 1988b. A high temperature requirement for after ripening of imbibed dormant *Poa annua* L. seeds. Weed Research 28: 365-371.

Taylor, G.H. 1993. Climatological data for Oregon agricultural regions. p. 9-12. Oregon Agric. Expt. Station Special Report 912.

Thompson, C.R., Thill, D.C., and Shafii, B. 1994. Germination characteristics of sulfonylurea-resistant and –susceptible kochia (*Kochia scoparia*). Weed Sci. 42: 50-56.

Varco, J.J., and Sartain, J.B. 1986. Effects of phosphorus, sulfur, calcium hydroxided, and pH on growth of annual bluegrass. Soil Sci. Soc. Am. J. 50: 128-132.

Ward, J., and Shaykewich, C.F. 1972. Water absorption by wheat seeds as influenced by hydraulic properties of soil. Can. J. Soil Sci. 52: 99-105.

Warwick, S.I. 1979. The biology of Canadian weeds: *Poa annua* L. Can. J. Plant Sci. 59: 1053-1066.

Wieneck, D.L. 1988. *Poa annua* L. control with ethofumasate. Master's Thesis, Oregon State University. Unpublished.

Whitson, T.D., Burrill, L.C., Dewey, S.A., Cudney, D.W., Nelson, B.E., Lee, R.D., and Parker, R. 1996. Weeds of the West, 5th Edition. Western Society of Weed Science, California.

Wu, L., Till-Bottraud, I., and Torres, A. 1987. Genetic differentiation in temperature-enforced seed dormancy among golf course populations of *Poa annua* L. New Phytologist 107: 623-631.

APPENDIX

Table A-1. Moisture reading for both growing seasons at the Glaser site. Reading are presented for each plot and for treatment averages.

1997-98

Plot	Trt	Aug	Sept	Oct	Nov	Dec	Mar	Apr	May
101	F	22.70	21.84	33.88	37.70	39.70	45.57	36.53	32.23
102	B	23.80	23.44	34.85	38.98	41.10	45.10	35.00	30.65
103	V	15.20	17.90	31.15	35.90	37.90	40.40	33.28	30.78
201	F	22.80	21.82	31.95	36.10	38.20	40.30	34.48	30.05
202	V	17.50	19.16	31.20	35.58	38.00	41.53	32.63	28.05
203	B	21.80	20.00	32.30	38.25	39.45	46.53	29.60	31.75
301	V	16.30	18.68	32.63	36.63	39.10	35.40	27.55	31.00
302	B	22.40	20.66	33.95	37.45	39.20	44.23	39.03	35.15
303	F	17.20	17.54	30.53	35.20	38.30	47.10	36.38	31.58
401	B	17.30	17.82	31.43	35.63	38.05	44.57	34.18	29.48
402	V	13.30	17.26	31.13	37.23	39.80	46.50	36.13	33.28
403	F	20.40	19.34	31.80	36.40	39.25	46.23	37.30	33.03
Full Straw Chop		20.78	20.14	32.04	36.35	38.86	44.80	36.17	31.72
Bale/Flail		21.33	20.48	33.13	37.58	39.45	45.11	34.45	31.76
Vacuum Sweep		15.58	18.25	31.53	36.33	38.70	40.96	32.39	30.78
Average		19.23	19.62	32.23	36.75	39.00	43.62	34.34	31.42

1998-99

Plot	Trt	Oct	Nov	Dec	Mar	Apr	May
101	F	20.83	39.76	39.75	47.77	35.65	28.95
102	B	16.93	23.16	27.40	45.70	34.90	26.45
103	V	18.53	23.52	27.15	44.70	35.93	26.85
201	F	19.47	24.36	26.55	41.50	33.20	26.75
202	V	19.20	21.00	24.60	43.70	30.28	21.90
203	B	20.00	21.72	23.50	41.17	31.23	23.83
301	V	18.63	21.08	26.35	44.07	32.20	25.85
302	B	17.80	23.58	26.95	46.70	35.20	25.83
303	F	16.90	20.20	25.70	46.97	35.80	28.08
401	B	22.10	24.42	28.40	46.57	36.25	29.18
402	V	18.07	21.12	27.60	45.00	32.75	24.58
403	F	22.97	23.82	27.70	48.47	37.33	26.63
Full Straw Chop		20.04	27.04	29.93	46.18	35.49	27.60
Bale/Flail		19.21	23.22	26.56	45.03	34.39	26.32
Vacuum Sweep		18.61	21.68	26.43	44.37	32.79	24.79
Average		19.29	23.98	27.64	45.19	34.23	26.24

Table A-2. Moisture reading for both growing seasons at the Wirth site. Readings are presented for each plot and for treatment averages.

1997-98

Plot	Trt	Aug	Sept	Oct	Nov	Dec	Mar	Apr	May
101	F	24.70	22.32	37.18	37.25	38.10	43.55	37.78	35.55
102	B	21.50	20.66	32.08	34.65	37.00	38.90	35.08	30.83
103	V	16.20	18.12	30.53	32.93	35.60	39.20	34.60	31.45
201	V	15.20	17.26	28.98	31.48	35.03	38.03	33.25	30.38
202	F	22.40	21.96	31.70	35.75	40.07	40.67	36.90	33.63
203	B	20.80	19.44	32.40	35.43	37.27	37.63	34.15	31.05
301	B	19.20	19.78	31.55	34.78	37.33	40.13	35.50	32.68
302	F	20.50	18.96	30.55	32.83	35.67	37.43	35.48	28.08
303	V	17.90	19.56	32.45	36.08	38.23	40.00	36.10	31.90
401	F	19.30	18.92	29.60	32.03	34.80	37.03	33.20	30.75
402	V	18.10	19.00	31.68	34.83	37.60	37.93	34.03	30.95
403	B	21.50	18.90	30.45	31.78	33.27	36.40	33.63	31.08
Full Straw Chop		21.73	20.54	32.26	34.46	37.16	39.67	35.84	32.00
Bale/Flail		20.75	19.70	31.62	34.16	36.22	38.27	34.59	31.41
Vacuum Sweep		16.85	18.49	30.91	33.83	36.62	38.79	34.49	31.17
Average		19.78	19.57	31.59	34.15	36.66	38.91	34.97	31.53

1998-99

Plot	Trt	Oct	Nov	Dec	Mar	Apr	May
101	F	22.93	34.82	39.00	43.53	35.58	31.10
102	B	19.88	31.14	35.10	39.13	33.23	30.05
103	V	17.50	32.32	36.00	40.87	31.65	29.25
201	V	19.30	30.00	35.40	38.03	31.60	28.30
202	F	19.53	32.84	36.40	42.07	36.08	31.48
203	B	17.40	34.54	37.05	37.73	32.95	28.10
301	B	19.20	32.20	35.25	39.55	33.60	30.40
302	F	21.80	36.24	38.85	41.90	32.55	25.85
303	V	22.10	31.82	35.95	40.80	35.68	31.63
401	F	18.78	34.46	35.80	38.13	32.50	29.45
402	V	17.03	30.70	33.05	36.97	30.25	25.03
403	B	19.40	33.18	35.95	38.23	32.85	28.53
Full Straw Chop		20.76	34.59	37.51	41.41	34.18	29.47
Bale/Flail		18.97	32.77	35.84	38.66	33.16	29.27
Vacuum Sweep		18.98	31.21	35.10	39.17	32.29	28.55
Average		19.57	32.86	36.15	39.75	33.21	29.10

Table A-3. ANOVA tables of treatments for each month during both growing seasons at the Glaser site.

1997-1998

August

Source	d.f.	SS	MS	F-value	P-value
Model	2	80.54	40.27	6.71	0.01
Error	9	53.98	6.00		
Corr. Total	11	134.52			

R-squared	C.V.	Root MSE	Aug-Mean
0.60	12.74	2.45	19.23

September

Source	d.f.	SS	MS	F-value	P-value
Model	2	11.53	5.76	1.66	0.24
Error	9	31.33	3.48		
Corr. Total	11	42.85			

R-squared	C.V.	Root MSE	Sept-Mean
0.27	9.51	1.87	19.62

October

Source	d.f.	SS	MS	F-value	P-value
Model	2	5.38	2.69	1.66	0.24
Error	9	14.56	1.62		
Corr. Total	11	19.94			

R-squared	C.V.	Root MSE	Oct-Mean
0.27	3.95	1.27	32.23

November

Source	d.f.	SS	MS	F-value	P-value
Model	2	4.07	2.03	1.65	0.25
Error	9	11.09	1.23		
Corr. Total	11	15.15			

R-squared	C.V.	Root MSE	Nov-Mean
0.27	3.02	1.11	36.75

December

Source	d.f.	SS	MS	F-value	P-value
Model	2	1.25	0.62	0.63	0.55
Error	9	8.85	0.98		
Corr. Total	11	10.10			

R-squared	C.V.	Root MSE	Dec-Mean
0.12	2.54	0.99	39.00

March

Source	d.f.	SS	MS	F-value	P-value
Model	2	42.78	21.39	2.06	0.18
Error	9	93.50	10.39		
Corr. Total	11	136.28			

R-squared	C.V.	Root MSE	Mar-Mean
0.31	7.39	3.22	43.62

April

Source	d.f.	SS	MS	F-value	P-value
Model	2	28.58	14.29	1.47	0.28
Error	9	87.44	9.72		
Corr. Total	11	116.02			

R-squared	C.V.	Root MSE	Apr-Mean
0.25	9.08	3.12	34.34

May

Source	d.f.	SS	MS	F-value	P-value
Model	2	2.47	1.24	0.31	0.74
Error	9	36.46	4.05		
Corr. Total	11	38.93			

R-squared	C.V.	Root MSE	May-Mean
0.06	6.41	2.01	31.42

1998-1999

August

No Data

September

No Data

October

Source	d.f.	SS	MS	F-value
Model	2	4.16	2.08	0.52
Error	9	36.20	4.02	
Corr. Total	11	40.36		

R-squared	C.V.	Root MSE	Oct-Mean
0.10	10.40	2.01	19.29

November

Source	d.f.	SS	MS	F-value
Model	2	60.80	30.40	1.17
Error	9	234.48	26.05	
Corr. Total	11	295.28		

R-squared	C.V.	Root MSE	Nov-Mean
0.21	21.29	5.10	23.98

December

Source	d.f.	SS	MS	F-value
Model	2	31.43	15.72	0.95
Error	9	149.57	16.62	
Corr. Total	11	181.01		

R-squared	C.V.	Root MSE	Dec-Mean
0.17	14.75	4.08	27.64

March

Source	d.f.	SS	MS	F-value
Model	2	6.70	3.35	0.58
Error	9	51.85	5.76	
Corr. Total	11	58.55		

R-squared	C.V.	Root MSE	Mar-Mean
0.11	5.31	2.40	45.19

April

Source	d.f.	SS	MS	F-value
Model	2	14.80	7.40	1.68
Error	9	39.62	4.40	
Corr. Total	11	54.43		

R-squared	C.V.	Root MSE	Apr-Mean
0.27	6.13	2.10	34.23

May

Source	d.f.	SS	MS	F-value
Model	2	15.80	7.90	2.21
Error	9	32.12	3.57	
Corr. Total	11	47.92		

R-squared	C.V.	Root MSE	May-Mean
0.33	7.20	1.89	26.24

Table A-4. ANOVA tables of treatments for each month during both growing seasons at the Wirth site.

1997-1998

August

Source	d.f.	SS	MS	F-value	P-value
Model	2	4.82	2.41	0.29	0.75
Error	9	74.44	8.27		
Corr. Total	11	79.26			

R-squared	C.V.	Root MSE	Aug-Mean
0.06	14.54	2.88	19.78

September

Source	d.f.	SS	MS	F-value	P-value
Model	2	0.12	0.06	0.02	0.98
Error	9	23.41	2.60		
Corr. Total	11	23.53			

R-squared	C.V.	Root MSE	Sept-Mean
0.005	8.24	1.61	19.57

October

Source	d.f.	SS	MS	F-value	P-value
Model	2	2.77	1.39	0.28	0.76
Error	9	44.41	4.93		
Corr. Total	11	47.18			

R-squared	C.V.	Root MSE	Oct-Mean
0.06	7.03	2.22	31.60

November

Source	d.f.	SS	MS	F-value	P-value
Model	2	1.40	0.70	0.17	0.85
Error	9	37.71	4.19		
Corr. Total	11	39.11			

R-squared	C.V.	Root MSE	Nov-Mean
0.04	5.99	2.05	34.15

December

Source	d.f.	SS	MS	F-value	P-value
Model	2	5.83	2.92	0.82	0.47
Error	9	31.87	3.54		
Corr. Total	11	37.70			

R-squared	C.V.	Root MSE	Dec-Mean
0.15	5.13	1.88	36.66

March

Source	d.f.	SS	MS	F-value	P-value
Model	2	8.08	4.04	1.05	0.39
Error	9	34.70	3.86		
Corr. Total	11	42.79			

R-squared	C.V.	Root MSE	Mar-Mean
0.19	5.04	1.96	38.91

April

Source	d.f.	SS	MS	F-value	P-value
Model	2	1.49	0.75	0.31	0.74
Error	9	21.54	2.39		
Corr. Total	11	23.03			

R-squared	C.V.	Root MSE	Apr-Mean
0.06	4.42	1.55	34.98

May

Source	d.f.	SS	MS	F-value	P-value
Model	2	10.94	5.47	1.88	0.21
Error	9	26.19	2.91		
Corr. Total	11	37.13			

R-squared	C.V.	Root MSE	May-Mean
0.29	5.41	1.71	31.53

1998-1999

August

No Data

September

No Data

October

Source	d.f.	SS	MS	F-value	P-value
Model	2	13.77	6.88	2.45	0.14
Error	9	25.30	2.81		
Corr. Total	11	39.07			

R-squared	C.V.	Root MSE	Oct-Mean
0.35	8.57	1.68	19.57

November

Source	d.f.	SS	MS	F-value	P-value
Model	2	9.61	4.81	1.50	0.27
Error	9	28.75	3.91		
Corr. Total	11	38.36			

R-squared	C.V.	Root MSE	Nov-Mean
0.25	5.44	1.79	32.86

December

Source	d.f.	SS	MS	F-value	P-value
Model	2	5.74	2.87	1.13	0.37
Error	9	22.86	2.54		
Corr. Total	11	28.60			

R-squared	C.V.	Root MSE	Dec-Mean
0.20	4.40	1.59	36.15

March

Source	d.f.	SS	MS	F-value	P-value
Model	2	1.80	0.90	0.18	0.84
Error	9	44.98	5.00		
Corr. Total	11	46.78			

R-squared	C.V.	Root MSE	Mar-Mean
0.04	5.62	2.24	39.75

April

Source	d.f.	SS	MS	F-value	P-value
Model	2	3.10	1.55	0.44	0.66
Error	9	31.93	3.55		
Corr. Total	11	35.03			

R-squared	C.V.	Root MSE	Apr-Mean
0.09	5.67	1.88	33.21

May

Source	d.f.	SS	MS	F-value	P-value
Model	2	4.69	2.34	0.49	0.63
Error	9	43.21	4.80		
Corr. Total	11	47.90			

R-squared	C.V.	Root MSE	May-Mean
0.10	7.53	2.19	29.10

Table A-5. Repeated measures analysis of variance of contrast variables for Glaser site. Data presented is for treatment and month average differences for both growing seasons.

1997-1998

August to September

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	1.89	1.89	2.16	0.18
Treatment	2	31.23	15.61	17.83	0.0007
Error	9	7.88	0.88		

September to October

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	1908.65	1908.65	1721.08	0.0001
Treatment	2	3.78	1.89	1.70	0.24
Error	9	9.98	1.11		

October to November

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	245.26	245.26	350.07	0.0001
Treatment	2	0.53	0.26	0.38	0.70
Error	9	6.31	0.70		

November to December

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	60.75	60.75	286.34	0.0001
Treatment	2	0.90	0.45	2.12	0.18
Error	9	1.91	0.21		

December to March

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	255.86	255.86	26.52	0.0006
Treatment	2	33.57	16.79	1.74	0.23
Error	9	86.83	9.65		

March to April

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	1033.61	1033.61	105.71	0.0001
Treatment	2	11.34	5.67	0.58	0.58
Error	9	88.00	9.78		

April to May

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	102.43	102.43	13.44	0.005
Treatment	2	16.33	8.16	1.07	0.38
Error	9	68.57	7.62		

1998-1999

August to September

No Data

September to October

No Data

October to November

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	264.23	264.23	10.80	0.009
Treatment	2	33.51	16.75	0.68	0.53
Error	9	220.13	24.46		

November to December

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	160.67	160.67	55.22	0.0001
Treatment	2	7.48	3.74	1.29	0.32
Error	9	26.19	2.91		

December to March

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	3698.49	3698.49	279.04	0.0001
Treatment	2	10.75	5.38	0.41	0.68
Error	9	119.29	13.25		

March to April

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	1443.21	1443.21	608.04	0.0001
Treatment	2	2.24	1.12	0.47	0.64
Error	9	21.36	2.37		

April to May

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	765.44	765.44	367.22	0.0001
Treatment	2	0.07	0.03	0.02	0.98
Error	9	18.76	2.08		

Table A-6. Repeated measures analysis of variance of contrast variables for Wirth site. Data presented is for treatment and month average differences for both growing seasons.

1997-1998

August to September

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	0.49	0.49	0.19	0.67
Treatment	2	6.34	3.17	1.26	0.33
Error	9	22.69	2.52		

September to October

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	1734.49	1734.49	1041.64	0.0001
Treatment	2	3.22	1.61	0.97	0.42
Error	9	14.99	1.67		

October to November

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	78.39	78.39	81.03	0.0001
Treatment	2	3.51	1.76	1.82	0.22
Error	9	8.71	0.97		

November to December

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	75.75	75.75	101.36	0.0001
Treatment	2	2.30	1.15	1.54	0.27
Error	9	6.73	0.74		

December to March

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	60.44	60.44	32.07	0.0003
Treatment	2	7.32	3.66	1.94	0.20
Error	9	16.96	1.88		

March to April

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	185.65	185.65	211.18	0.0001
Treatment	2	2.65	1.33	1.51	0.27
Error	9	7.91	0.88		

April to May

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	142.62	142.62	76.27	0.0001
Treatment	2	4.39	2.19	1.17	0.35
Error	9	16.83	1.87		

1998-1999

August to September

No Data

September to October

No Data

October to November

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	2117.63	2117.63	638.48	0.0001
Treatment	2	20.35	10.18	3.07	0.10
Error	9	29.85	3.32		

November to December

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	130.28	130.28	146.41	0.0001
Treatment	2	4.70	2.35	2.64	0.13
Error	9	8.01	0.89		

December to March

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	155.09	155.09	108.81	0.0001
Treatment	2	9.40	4.70	3.30	0.08
Error	9	12.83	1.43		

March to April

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	512.47	512.47	190.22	0.0001
Treatment	2	1.21	0.61	0.22	0.80
Error	9	24.25	2.69		

April to May

Source	d.f.	Type III SS	MS	F-value	P-value
Mean	1	202.95	202.95	125.29	0.0001
Treatment	2	0.73	0.36	0.23	0.80
Error	9	14.58	1.62		

Table A-7. Total rainfall (mm) for 1997-98 and 1998-99 growing seasons for dates listed in each month.

	Month	Rain (mm)	Date
1997-98	Sept	34	(17th-30th)
	Oct	87	(1st-31st)
	Nov	107	(1st-30th)
	Dec	69	(1st-31st)
	Jan	176	(1st-31st)
	Feb	139	(1st-28th)
	Mar	145	(1st-31st)
	Apr	36	(1st-30th)
	May	125	(1st-31st)
	Total	918	
1998-99	Oct	38	(11th-31st)
	Nov	228	(1st-30th)
	Dec	173	(1st-31st)
	Jan	171	(1st-31st)
	Feb	171	(1st-15th/21st-29th)
	Mar	91	(1st-31st)
	Apr	16	(1st-17th/25th-30th)
	May	50	(1st-31st)
	Total	938	

Table A-8. Parameter estimates for susceptible and resistant annual bluegrass germinated on Dayton or Woodburn soil at -0.03, -0.53, -1.03, or -1.53 MPa at either 30/20 or 18/5 C. Tables are divided in a) experiment 1 and 2 combined, b) experiment 1, and c) experiment 2.

Table A.

Temp. (C	Soil Type	Biotype	MPa	Max Germ	50% Germ. (hrs	ate of Germ.
30/20	Dayton	Susceptibl	-0.03	95.56	68.15	0.31
			-0.53	97.69	68.81	0.30
			-1.03	67.41	68.82	0.25
			-1.53	96.91	68.75	0.26
		Resistant	-0.03	97.25	68.46	0.35
			-0.53	94.91	72.70	0.14
			-1.03	97.90	75.18	0.14
			-1.53	96.75	75.47	0.12
30/20	Woodburn	Susceptibl	-0.03	100.73	68.30	0.53
			-0.53	96.96	68.55	0.32
			-1.03	99.36	68.57	0.34
			-1.53	95.47	68.71	0.26
		Resistant	-0.03	96.84	68.66	0.27
			-0.53	95.70	69.27	0.29
			-1.03	98.10	68.43	0.26
			-1.53	97.13	68.38	0.29
18/5	Dayton	Susceptibl	-0.03	98.31	146.81	0.17
			-0.53	98.04	159.25	0.12
			-1.03	96.74	161.24	0.12
			-1.53	97.16	164.97	0.13
		Resistant	-0.03	98.73	155.80	0.14
			-0.53	98.60	165.47	0.11
			-1.03	98.06	169.43	0.09
			-1.53	98.05	167.96	0.11
18/5	Woodburn	Susceptibl	-0.03	96.48	152.57	0.15
			-0.53	98.55	159.90	0.13
			-1.03	98.58	161.76	0.11
			-1.53	98.19	164.72	0.16
		Resistant	-0.03	98.45	159.12	0.17
			-0.53	98.88	163.69	0.13
			-1.03	98.36	163.61	0.15
			-1.53	99.14	168.11	0.12

Table B.

Temp. (C	Soil Type	Biotype	MPa	Max Germ	50% Germ. (hrs	ate of Germ.
30/20	Dayton	Susceptibl	-0.03	93.43	69.65	0.20
			-0.53	96.93	68.91	0.28
			-1.03	96.67	68.27	0.31
			-1.53	97.96	68.64	0.33
		Resistant	-0.03	96.42	67.74	0.38
			-0.53	94.90	70.65	0.15
			-1.03	97.44	72.86	0.14
			-1.53	97.73	76.60	0.12
30/20	Woodburn	Susceptibl	-0.03	101.46	68.63	0.45
			-0.53	97.37	67.42	0.42
			-1.03	101.09	68.82	0.33
			-1.53	95.65	68.51	0.24
		Resistant	-0.03	94.14	69.06	0.21
			-0.53	94.84	68.74	0.30
			-1.03	98.13	67.56	0.34
			-1.53	96.38	69.78	0.61
18/5	Dayton	Susceptibl	-0.03	99.48	145.03	0.25
			-0.53	98.30	156.70	0.12
			-1.03	96.94	161.68	0.13
			-1.53	97.99	164.06	0.11
		Resistant	-0.03	98.77	153.75	0.15
			-0.53	98.43	163.49	0.15
			-1.03	98.02	176.82	0.08
			-1.53	97.45	164.48	0.15
18/5	Woodburn	Susceptibl	-0.03	96.54	152.61	0.14
			-0.53	98.12	160.24	0.14
			-1.03	99.84	165.42	0.12
			-1.53	97.64	165.29	0.15
		Resistant	-0.03	98.60	160.96	0.14
			-0.53	99.43	163.51	0.12
			-1.03	98.33	165.14	0.13
			-1.53	99.69	171.53	0.11

Table C.

Temp. (C	Soil Type	Biotype	MPa	Max Germ	50% Germ. (hrs	ate of Germ
30/20	Dayton	Susceptibl	-0.03	97.79	67.59	0.54
			-0.53	98.46	68.76	0.33
			-1.03	98.20	69.57	0.21
			-1.53	95.89	69.12	0.22
		Resistant	-0.03	98.08	69.33	0.36
			-0.53	94.79	74.76	0.14
			-1.03	98.15	79.95	0.17
			-1.53	95.73	74.28	0.12
30/20	Woodburn	Susceptibl	-0.03	100.00	68.18	0.71
			-0.53	96.56	69.92	0.26
			-1.03	97.63	68.31	0.34
			-1.53	95.30	69.04	0.30
		Resistant	-0.03	99.58	68.71	0.36
			-0.53	96.55	69.88	0.30
			-1.03	98.12	69.62	0.21
			-1.53	97.89	69.09	0.27
18/5	Dayton	Susceptibl	-0.03	97.20	148.84	0.15
			-0.53	97.77	161.84	0.11
			-1.03	96.53	160.79	0.11
			-1.53	96.32	165.88	0.15
		Resistant	-0.03	98.69	157.83	0.14
			-0.53	99.59	169.32	0.08
			-1.03	99.16	164.56	0.12
			-1.53	98.76	172.42	0.10
18/5	Woodburn	Susceptibl	-0.03	96.42	152.53	0.15
			-0.53	98.98	159.57	0.12
			-1.03	97.17	157.60	0.11
			-1.53	98.77	164.21	0.16
		Resistant	-0.03	98.37	157.15	0.20
			-0.53	98.33	163.93	0.14
			-1.03	98.48	162.34	0.17
			-1.53	98.70	164.99	0.13

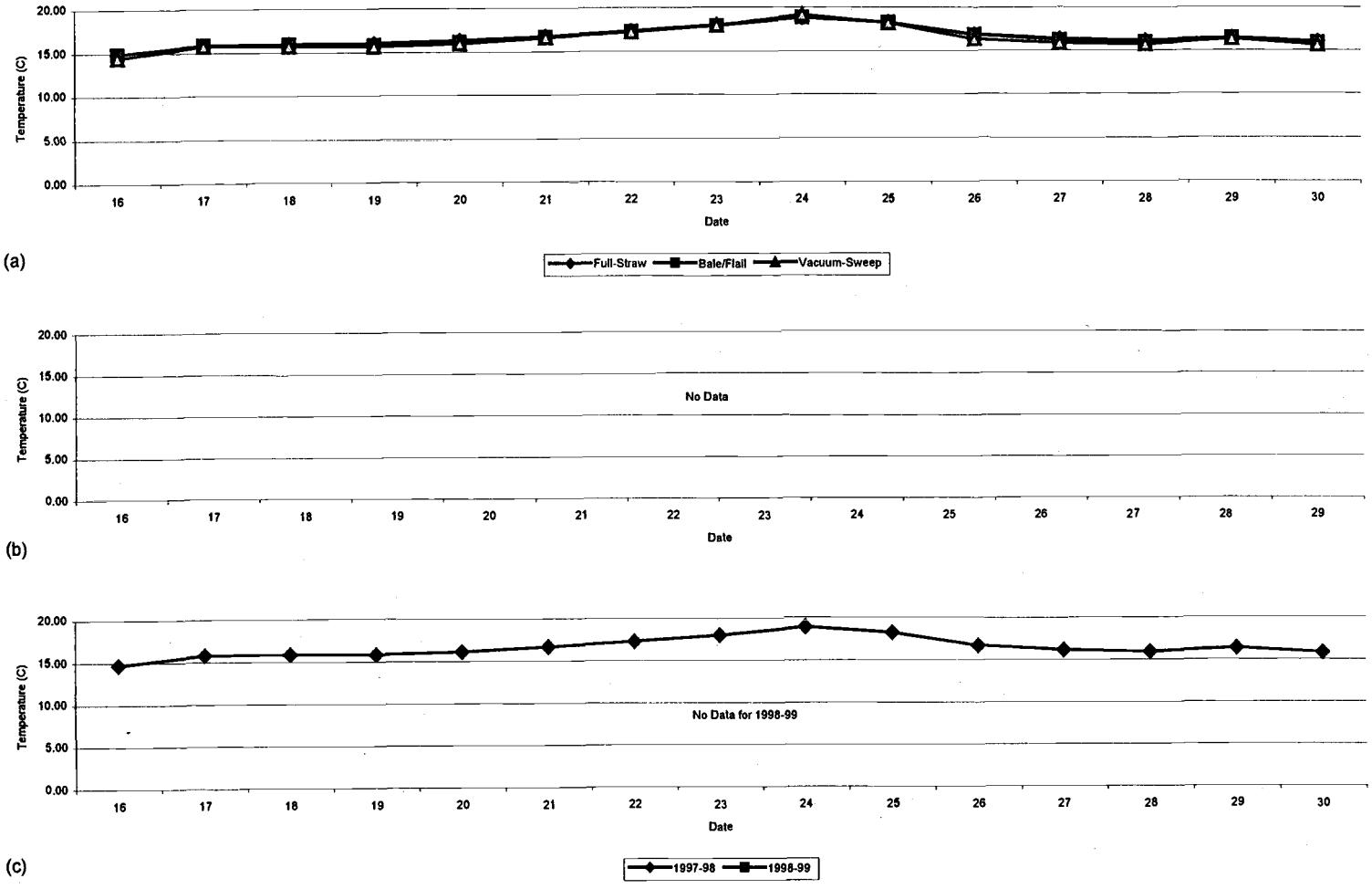

Figure A-1. Average daily soil temperature for September in a) 1997-98, b) 1998-99, and c) treatment means for 1997-98 and 1998-99.

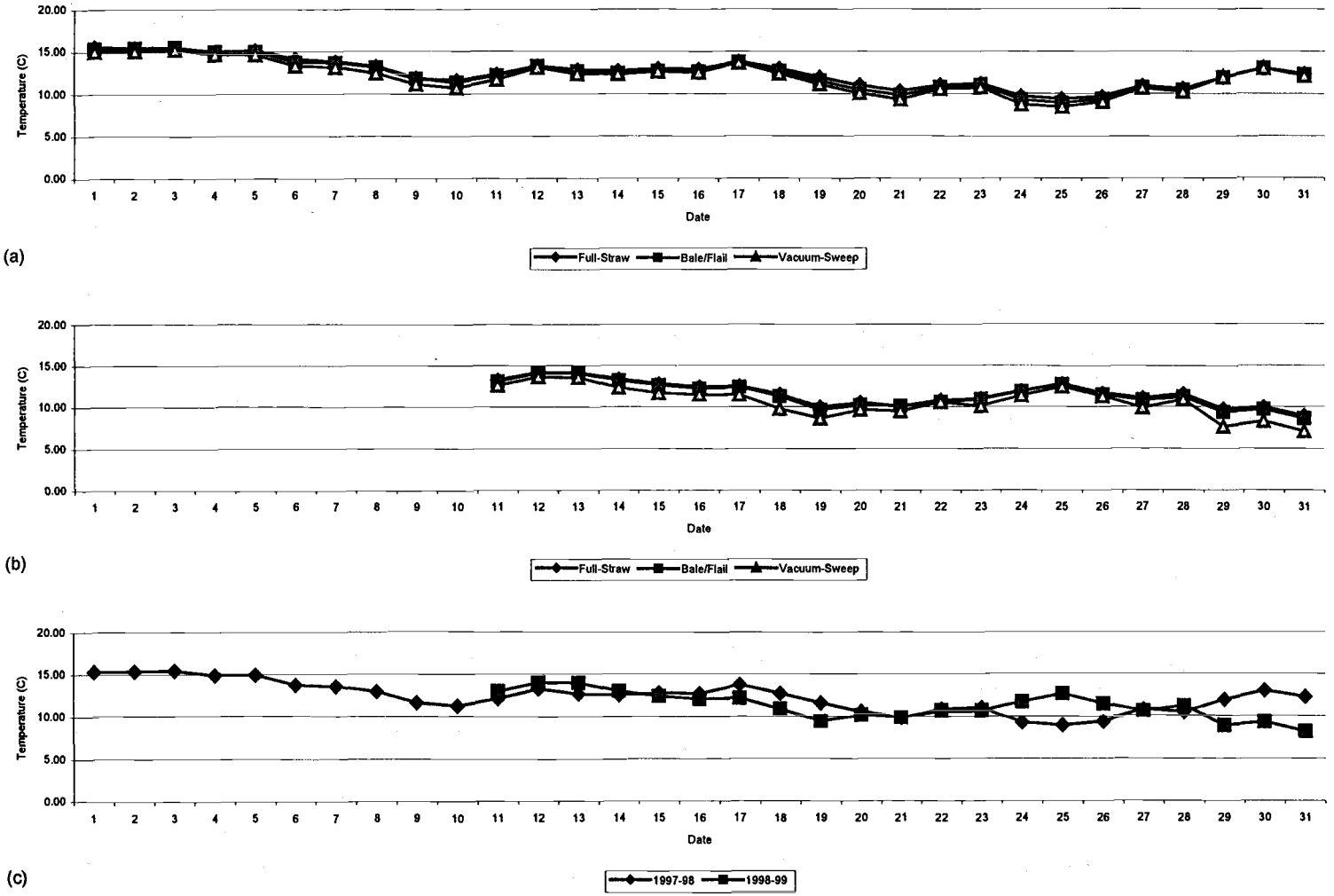

Figure A-2. Average daily soil temperature for October in a) 1997-98, b) 1998-99, and c) treatment means for 1997-98 and 1998-99.

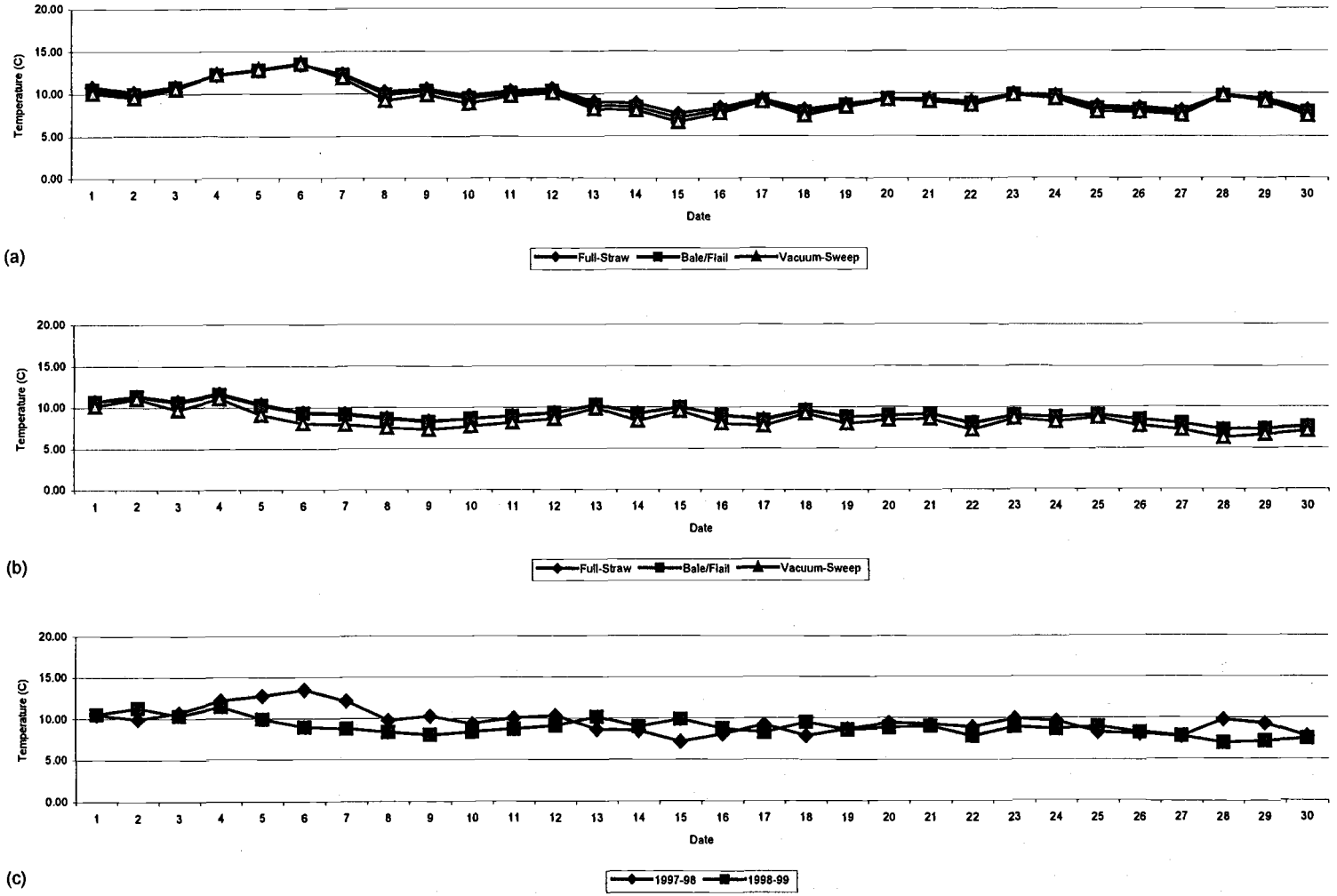

Figure A-3. Average daily soil temperature for November in a) 1997-98, b) 1998-99, and c) treatment means for 1997-98 and 1998-99.

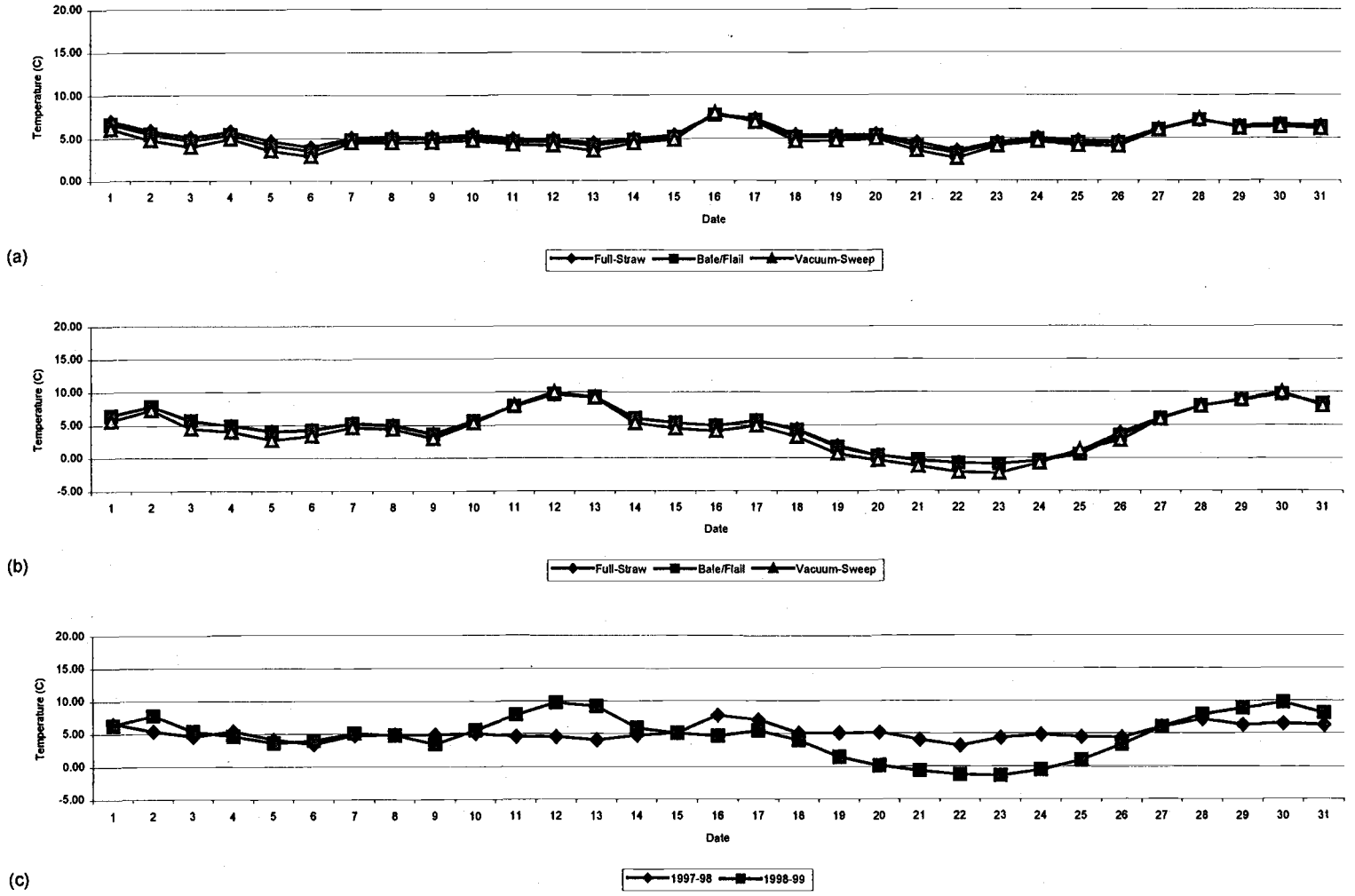

Figure A-4. Average daily soil temperature for December in a) 1997-98, b) 1998-99, and c) treatment means for 1997-98 and 1998-99.

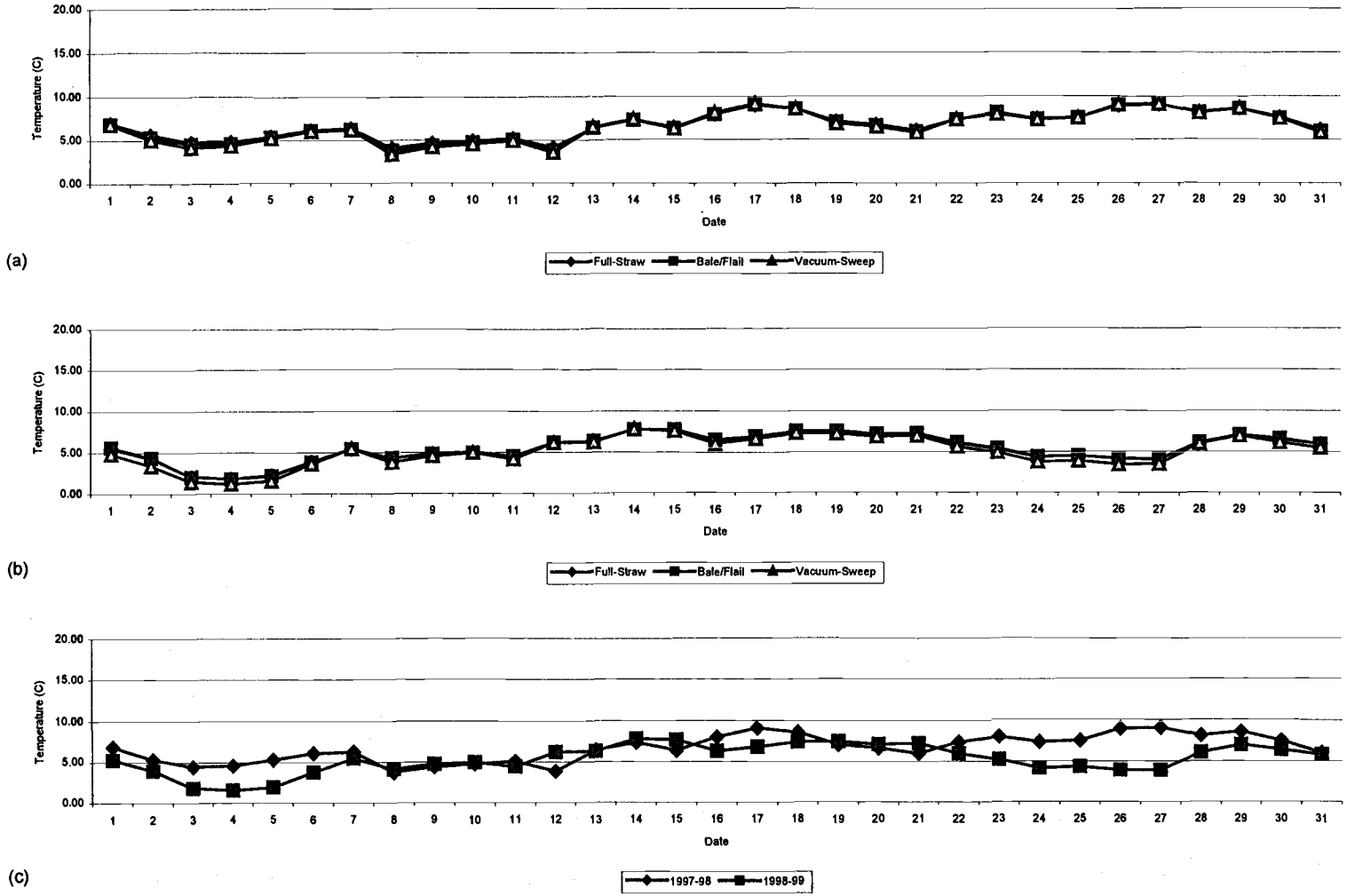

Figure A-5. Average daily soil temperature for January in a) 1997-98, b) 1998-99, and c) treatment means for 1997-98 and 1998-99.

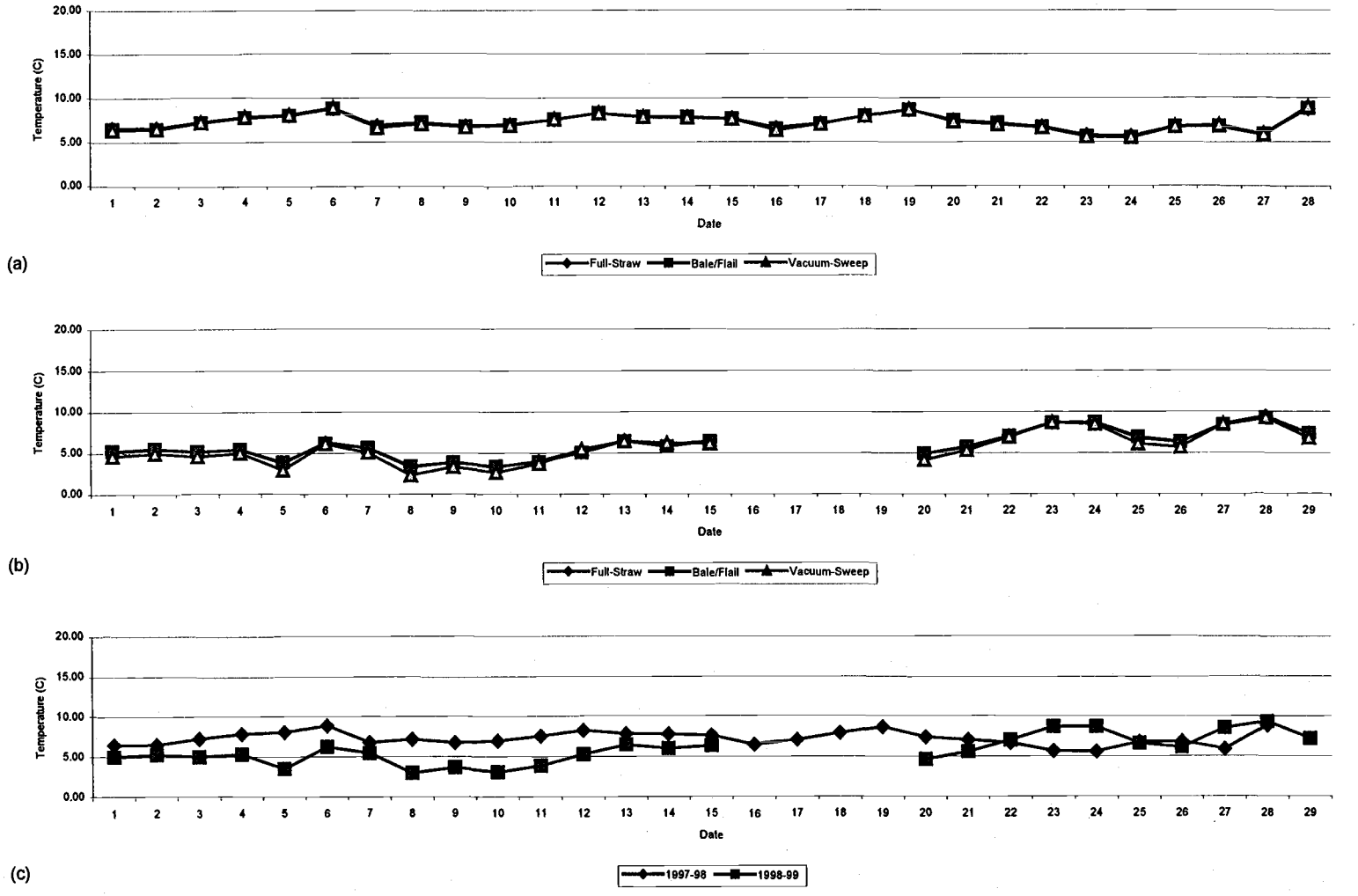

Figure A-6. Average daily soil temperature for February in a) 1997-98, b) 1998-99, and c) treatment means for 1997-98 and 1998-99.

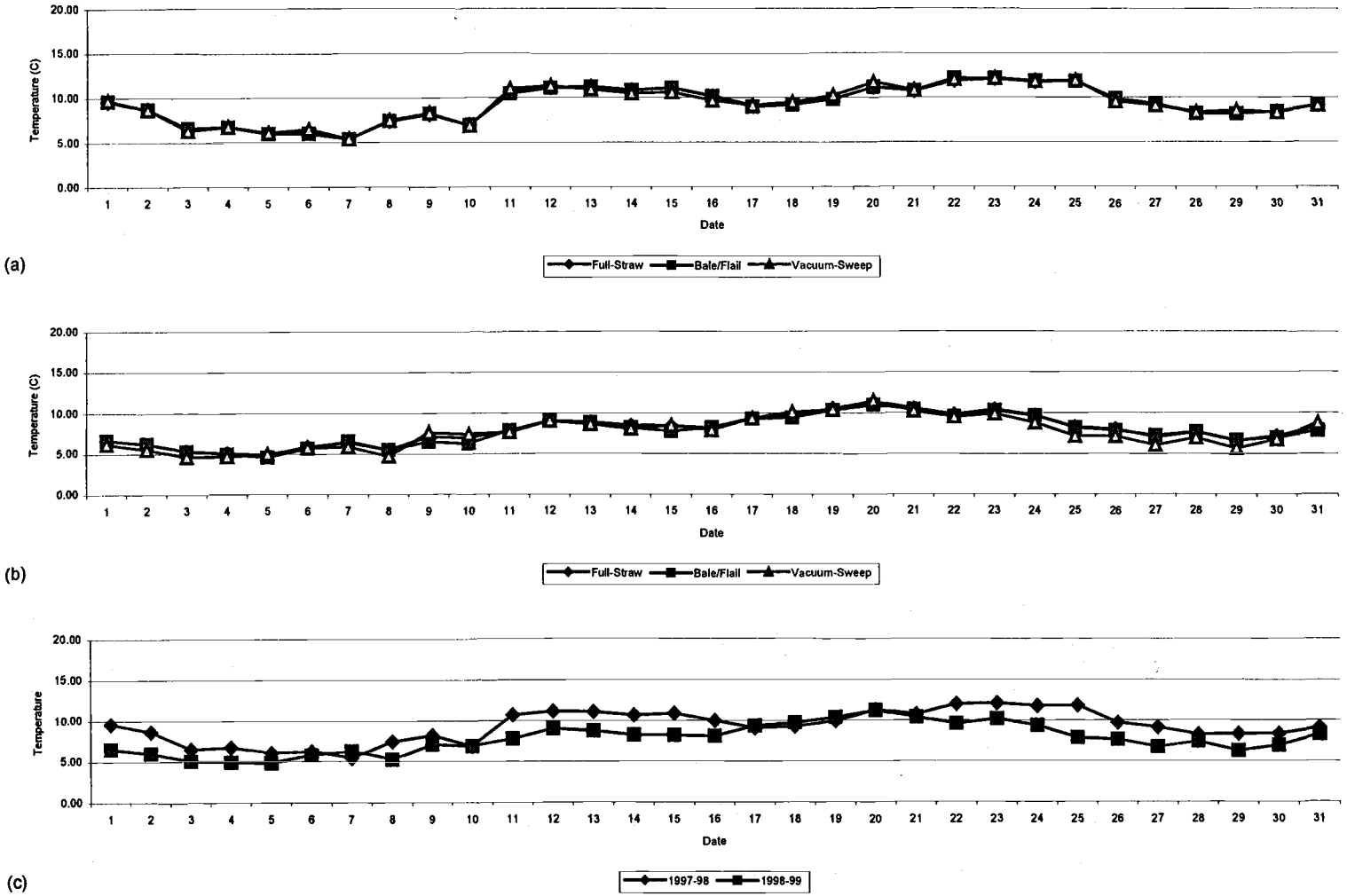

Figure A-7. Average daily soil temperature for March in a) 1997-98, b) 1998-99, and c) treatment means for 1997-98 and 1998-99.

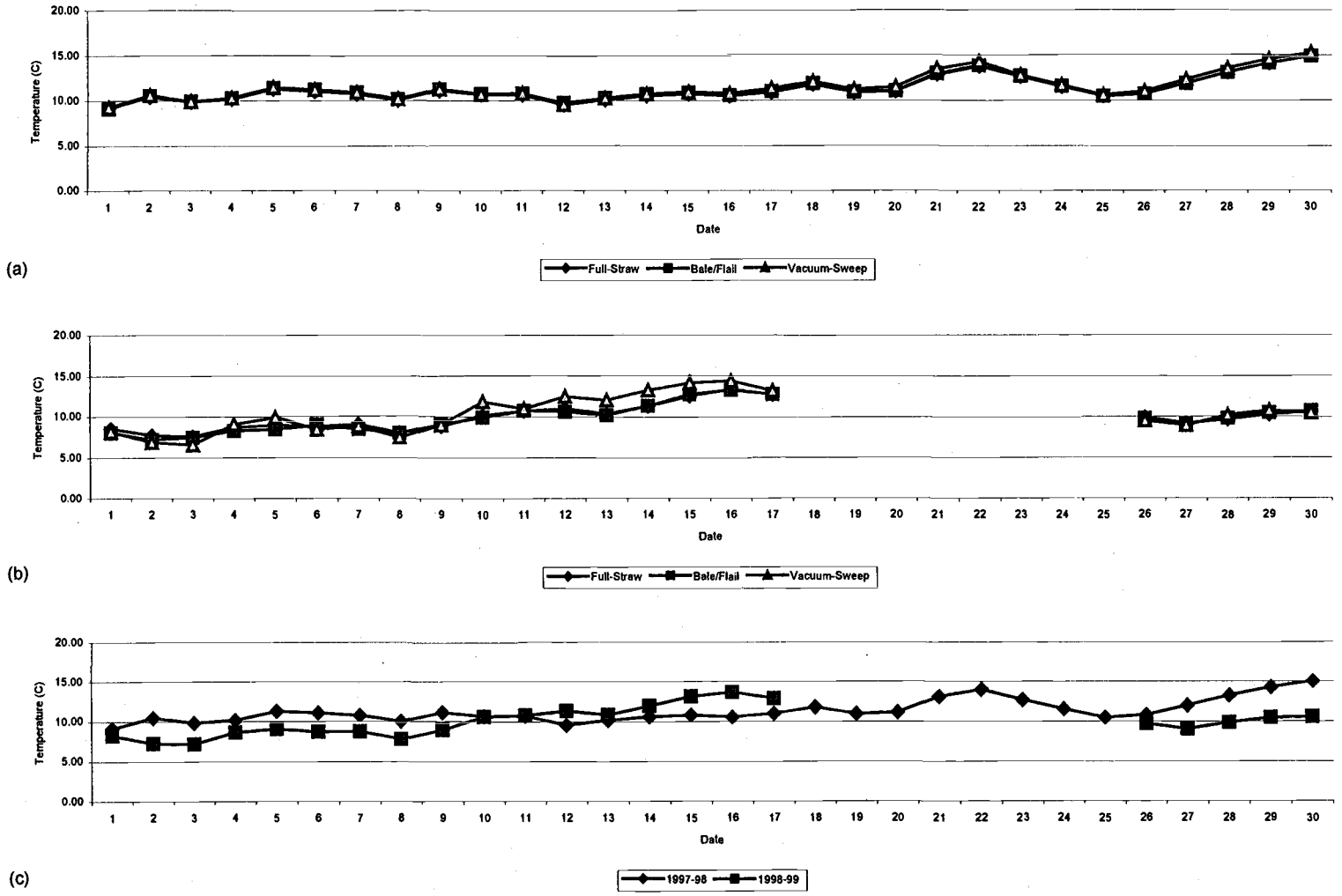

Figure A-8. Average daily soil temperature for April in a) 1997-98, b) 1998-99, and c) treatment means for 1997-98 and 1998-99.

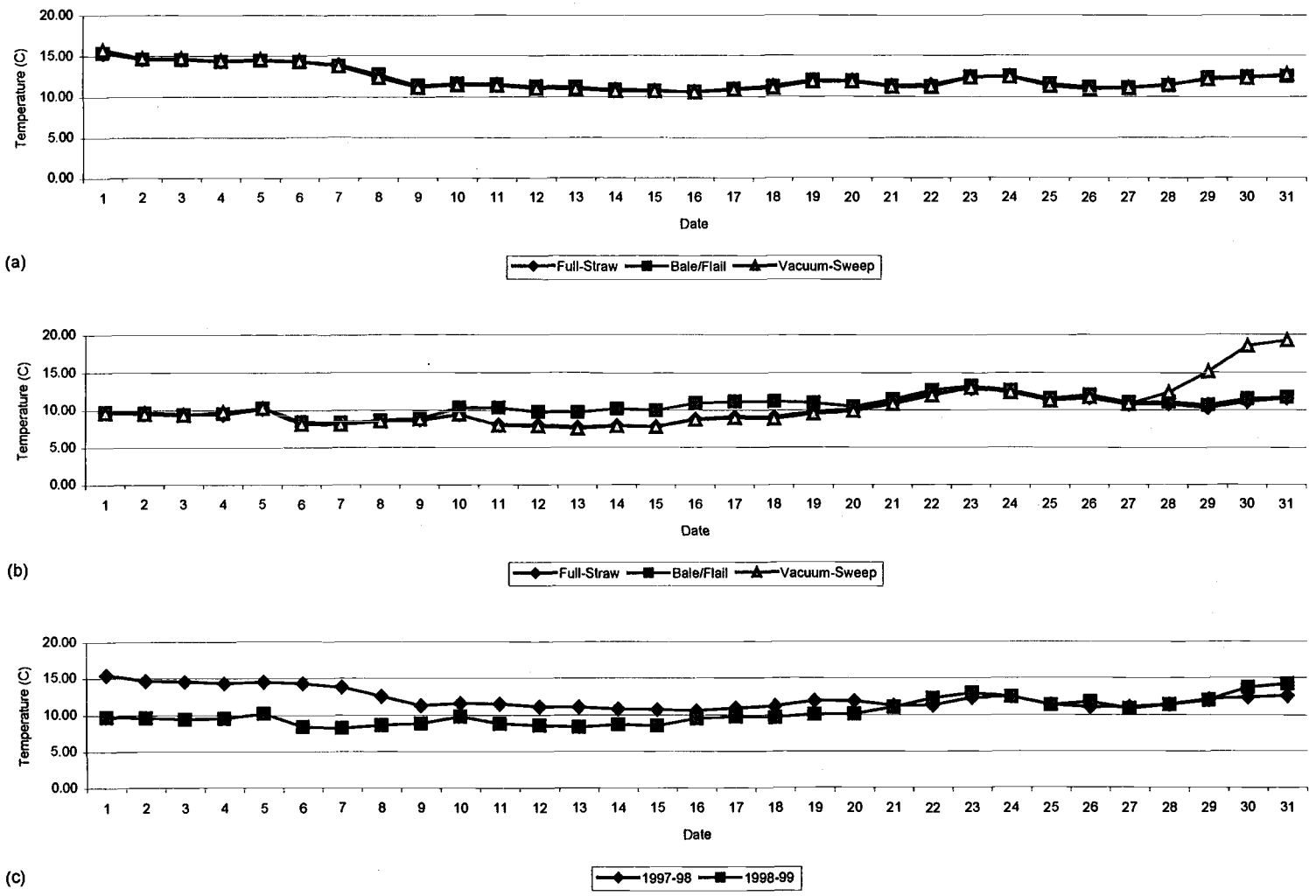

Figure A-9. Average daily soil temperature for May in a) 1997-98, b) 1998-99, and c) treatment means for 1997-98 and 1998-99.

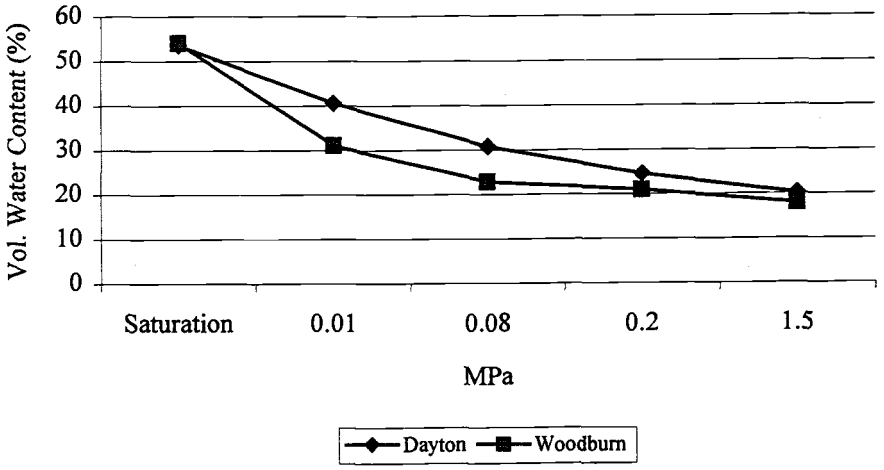

Figure A-10. Water retention curves for Dayton and Woodburn soil types.