EFFECTS OF COOL-SEASON AND WARM-SEASON GRASS ON ALFALFA (*Medicago sativa*) PRODUCTION WITH AND WITHOUT INSECT STRESS

By

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INTRODUCTION

Part II of this thesis is a manuscript to be submitted for publication in Weed Technology, a Weed Science Society of America publication.

PART I

LITERATURE REVIEW

LITERATURE REVIEW

Alfalfa (*Medicago sativa* L.) is a perennial forage plant of the family Leguminosae. Most evidence suggests that alfalfa originated near Iran, an area characterized as having cold winters and hot, dry summers (5). Alfalfa grows in variable climatic zones around the world. It is highly adaptive which is due largely to its abilities to fix free nitrogen symbiotically with rhizobium (*Rhizobium meliloti*) bacteria and to become dormant during periods of drought and cold. Alfalfa is most productive on well-drained, slightly alkaline soils (25).

Alfalfa has excellent yield potential and provides nutritious forage with high levels of digestible protein. This, combined with its wide adaptive range, makes it one of the most economically important forage crops in the United States. In Oklahoma, alfalfa is grown annually on approximately 174 000 ha (30). The growing season for alfalfa in Oklahoma is generally from early March until October and typically four to six harvests are taken, utilizing a 28 to 35 day cutting interval. This harvest interval allows the alfalfa to reach 10% bloom which coincides with maximum nutrient yield (39).

Healthy, well-maintained alfalfa stands are competitive with weeds for essential growth resources (21, 40). However, as stands begin to deteriorate with age, spaces once occupied by alfalfa plants become available for the establishment and growth of weeds (31). Woodall (46) reported that when alfalfa stem densities decrease below 20 stems per $0.1 m^2$, the competitive advantage is lost and weeds comprise an increasingly greater proportion of harvest forage.

Weeds are a concern primarily because they decrease alfalfa forage production and quality (8, 9, 12, 17, 20, 33, 41, 45). Alfalfa yields are reduced when competition by weeds reduces available light, temperature, and moisture for alfalfa plants (38, 42). Pritchett and Nelson (34) found that alfalfa plants receiving more light were more vigorous and produced more leaves, while decreasing light intensity resulted in smaller less vigorous plants. Other researchers found that shading by weeds could decrease both topgrowth and rootgrowth of alfalfa (7, 26). Shading can also reduce soil and air temperature which may result in delayed alfalfa growth and reduced forage quality. Jensen et al. (19) reported that alfalfa grown in a warm regime (33°C day/17°C night) reached the 10% bloom stage in one-half the number of days required for that grown in a cool regime (24°C day/4°C night). With adequate moisture levels, forage yields at 10% bloom were similar for both regimes. However, percent protein and acid-detergent fiber were higher in the alfalfa grown at warm temperatures.

Losses of forage quality results with increased content of weeds, because protein content of weeds is typically less than alfalfa (8, 9, 33, 44). Accordingly, Temme et al. (41) reported increases in crude protein (CP) and in vitro digestible dry matter (IVDDM) of forage when several annual broadleaf weeds were controlled with herbicide. Controlling weeds may or may not result in an alfalfa yield response. In some studies, alfalfa forage yields were increased due to weed control (20, 32, 33, 45), but in others, similar or reduced yields resulted because increased productivity of alfalfa plants did not offset elimination of weed biomass (13, 14, 35, 40, 43, 44).

Cool-season annual grasses such as downy brome (*Bromus tectorum* L.) and broadleaf weeds such as henbit (*Lamium amplexicaule* L.) and shepherdspurse [*Capsella bursa-pastoris* (L.) Medicus] are among the first weeds to become a problem in declining alfalfa stands. These cool-season weeds emerge and become established in the fall when alfalfa is not actively growing (17, 40). They often grow unnoticed during winter (20), but become evident during March and April as they grow and mature rapidly before first harvest when not shaded by alfalfa (31, 40). These cool-season annual weeds are generally lower in quality than alfalfa. Many investigators have reported that cool-season weeds reduced crude protein percentages at first harvest (9, 20, 33, 44), and Cords (8) found a high negative correlation between winter annual weed content and percent protein of harvested forage.

Cool-season weeds in established alfalfa can be effectively controlled with applications of herbicides from November through February with little crop injury (27, 32, 40). However, after alfalfa begins active growth, yield reductions have resulted because of herbicide injury to alfalfa.

Summer annual weeds are seldom a problem in mature, healthy alfalfa stands. However, as spaces develop between alfalfa plants, warm-season annual grasses such as foxtail (*Setaria* spp.) and crabgrass (*Digitaria* spp.) and broadleaf weeds such as pigweed (*Amaranthus* spp.) can emerge and grow, especially with abundant rainfall or irrigation. Competition by these weeds can then reduce alfalfa forage yields and at high infestations cause premature stand loss (29). However, warm-season grasses grown in established alfalfa are generally higher in nutrient quality than cool-season weedy grasses (12 to 14% compared with 5 to 9% crude protein, respectively) (6, 33). This means that warm-season grass infestations in thinning alfalfa stands could supplement total forage production without seriously reducing forage quality.

Herbicides that are currently labeled for application on dormant or semi-dormant alfalfa are not very affective for summer annual weed control. Winton and Stritzke (45) suggested that this could be related to the late germination of summer weed seed when herbicide concentrations have dissipated below effective levels in the soil. However, several nonlabeled herbicides applied to dormant alfalfa have shown promise for selective summer annual weed control (15, 16). In Nebraska, dormant applied, labeled alfalfa herbicides were compared with dormant applications of the unlabeled herbicides norflurazon [4-chloro-5-(methylamino)-2-(3-(trifluoromethyl)phenyl)-3(2H)-

pyridazinone], pendimethalin [*N*-(1-ethylpropyl)-3, 4-dimethyl-2,6-dinitrobenzenamine], prodiamine [2, 4-dinitro-N^3, N^3-dipropyl-6-(trifluoromethyl)-1,3-benzenediamine], and imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid}. Summer weed species consisted of common lambsquarters (*Chenopodium album* L.), kochia [*Kochia scoparia* (L.) Schrad.], and yellow foxtail [*Setaria glauca* (L.) Beauv.]. The herbicides did not injure alfalfa and had enough activity against weeds to be useful in alfalfa weed control programs.

In addition to weeds, the alfalfa weevil [*Hypera postica* (Gyllenhal)] poses a serious threat to alfalfa production in Oklahoma. Since entering the state twenty-five years ago, the weevil has become the most widespread foliage-feeding pest on alfalfa in Oklahoma (1). It causes reductions in both forage yields and quality (2, 3, 18). First harvest forage yields were reduced an average of nearly 1000 kg ha^{-1} over five years by alfalfa weevil infestation with significant residual effects occurring in the second crop (1). Liu and Fick (24) reported reduced yields at second harvest in New York due to stubble defoliation after first cut by the alfalfa weevil that delayed regrowth.

Combined stresses from the alfalfa weevil and weeds can cause greater losses in alfalfa yield and stand persistence than stresses caused from the pests occurring individually (4, 10, 11, 23, 28). Woodall (46) found that first harvest yields of alfalfa forage were greatest when both insects and weeds were controlled. Berberet et al. (4) reported that seasonal alfalfa yields were reduced an average of 2000 kg ha^{-1} when only stressed by alfalfa weevil. In these same studies, they found that seasonal alfalfa yields were reduced an average of 400 kg ha^{-1} when only stressed by weeds. However, when alfalfa was stressed by both insects and weeds, seasonal alfalfa yields was reduced by 3700 kg ha^{-1}.

Research in Oklahoma has recently focused on the effects of various harvest management practices on alfalfa productivity and persistence. Latheef et al. (22) examined the effects of taking first harvest of alfalfa at the prebloom stage over several years. They found that seasonal forage yields, stand persistence, and weed colonization were not consistently affected by variable first harvest schedules. Sholar et al. (36, 37) evaluated the effects of repeated fall harvesting between mid-September and late November over several years on stand longevity and forage yields. Some first-harvest yield reductions were noted on first-year stands following fall harvesting treatments. However, total seasonal production was not reduced and no reductions in alfalfa plants and stem numbers were attributable to fall harvest treatments. These studies generally indicate that in Oklahoma alfalfa can be harvested earlier than 10% bloom in the spring and that fall grazing or cutting does not have detrimental effects on seasonal alfalfa production. This allows alfalfa producers to cut early and harvest fall growth as effective pest management practices.

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PART II

EFFECTS OF COOL-SEASON AND WARM-SEASON GRASS ON ALFALFA (*Medicago sativa*) PRODUCTION WITH AND WITHOUT INSECT STRESS

Effects of Cool-Season and Warm-Season Grass on Alfalfa (*Medicago sativa*) Production with and without Insect Stress

MARK W. WAYLAND, JIMMY F. STRITZKE, and RICHARD C. BERBERET[1]

Abstract. Two field experiments were conducted from 1990 through 1993 on established stands of alfalfa at Chickasha and Stillwater, OK, to determine the effects of cool- and warm-season grass with and without insect stress on alfalfa. Treatments evaluated included high and low levels of cool-season grass, warm-season grass, and alfalfa weevil infestations. Downy brome was overseeded in plots designated for high levels of cool-season grass infestation and large crabgrass was overseeded in plots designated for high levels of warm-season grass infestation. Terbacil was used to sustain low levels of cool-season grass and sethoxydim was used to sustain low levels of warm-season grass. Carbofuran was used to reduce the number of naturally occuring weevil larvae to low levels. The effect of cool-season grass in reducing alfalfa production was not consistent and appeared to be influenced by early spring rainfall. Warm-season grass did not reduce alfalfa production until stand density declined below 20 stems per 0.1 m^2. Alfalfa weevil reduced yields more consistently than either cool-season or warm-season grasses. In 1992, combined stresses of the alfalfa weevil and cool-season grass reduced yields of first harvest alfalfa by 1920 kg ha^{-1} (as compared with the pest-free treatment), which was equal to the sum of the loses due to the pest types occurring individually. Individually, residual effects of alfalfa weevil infestation and competition by warm-season grass reduced

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third harvest alfalfa yield in 1992 by 450 and 710 kg ha^{-1}, respectively (as compared with the pest-free treatment). When the pests occurred together, a 1170 kg ha^{-1} alfalfa yield reduction occurred. In 1993, individual stresses of cool-season grass, warm-season grass and alfalfa weevil caused significant alfalfa yield reductions at first harvest (330, 360, and 580 kg ha^{-1}, respectively), with their combined stresses reducing yield by 1480 kg ha^{-1}.

Nomenclature: carbofuran, 2, 2-(dimethyl)-2,3-(dihydro-7 benzofuranyl)-N-methylcarbamate; sethoxydim, 2-[1-(ethoxyimino) butyl]-5-[2-(ethylthio) propyl]-3-hydroxy 2-cyclohexen-1-one; terbacil, 3-tert-butyl-5 chloro-6-methyluracil; downy brome, *Bromus tectorum* L. #[2] BROTE; large crabgrass, *Digitaria sanguinalis* (L.) Scop. # DIGSA; alfalfa, *Medicago sativa* L.; alfalfa weevil, *Hypera postica* (Gyllenhal).

Additional index words: Carbofuran, sethoxydim, terbacil, alfalfa weevil, *Hypera postica, Bromus tectorum*, *Digitaria sanguinalis*, BROTE, DIGSA.

INTRODUCTION

Healthy, well-maintained alfalfa stands are competitive with weeds for essential growth resources (16, 24). However, as stands begin to decline with age, spaces once occupied by alfalfa plants become available for the establishment and growth of weeds (21). Woodall (29) reported that when alfalfa stem numbers decreased below 20 stems per 0.1m^2, weeds were able to compete effectively and became a larger forage component.

Weeds are a concern primarily because they decrease alfalfa forage production and quality (6, 7, 9, 12, 15, 22, 25, 28). When harvested with alfalfa, weeds contribute to the total biomass yield. Consequently, controlling weeds seldom results in total forage yield

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[2]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, revised 1989. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

increases, and may or may not result in greater alfalfa forage yields. In some studies, alfalfa forage yields were increased due to weed control (15, 20, 22, 28), but in others, similar or reduced yields resulted (10, 11, 23, 24, 26, 27). Losses in forage quality results with weed infested forage since protein content of weeds is generally less than that of alfalfa (6, 7, 22, 27).

Cool-season annual grasses such as downy brome and broadleaf weeds such as henbit (*Lamium amplexicaule* L. # LAMAM) and shepherdspurse [*Capsella bursa-pastoris* (L.) Medicus. # CAPBP] often become important pests in declining alfalfa stands. These cool-season weeds emerge and become established in late summer and fall when alfalfa is not actively growing (12, 24). Their growth is minimal during the winter and they often escape detection until March and April when they grow and mature rapidly before first harvest if not shaded by a dense stand of alfalfa (15, 21, 24). Cool-season annual weeds are generally lower in quality than alfalfa. Cords (6) found a high negative correlation between winter annual weed content and crude protein content of alfalfa. Consequently, controlling cool-season weeds in first harvest is important in Oklahoma because this is ordinarily, the most productive harvest.

Summer annual weeds are seldom a problem in mature, healthy alfalfa stands. However, as spaces develop between alfalfa plants, warm-season annual grasses such as foxtail (*Setaria* spp.) and crabgrass (*Digitaria* spp.) and broadleaf weeds such as pigweed (*Amaranthus* spp.) can emerge and grow, particularly with abundant rainfall and irrigation. These weeds can then reduce alfalfa forage yields and cause premature stand loss at high weed infestations (19). Warm-season weedy grasses growing in established alfalfa are generally higher in nutrient quality than cool-season weedy grasses (12 to 14% compared with 5 to 9% crude protein, respectively) (5, 22). For this reason warm-season grass infestations in thinning alfalfa stands can supplement total forage production without seriously reducing quality.

In addition to weeds, the alfalfa weevil can cause reductions in alfalfa forage yields and quality (2, 3, 13). In Oklahoma, first harvest forage yields were reduced an average of nearly 1000 kg ha^{-1} over five years by the alfalfa weevil with significant residual effects occurring in the second crop (1).

While the individual effects of alfalfa weevil, cool-season weeds, and warm-season weeds on alfalfa production have been well documented, information has not been readily available on the interactions of these pests. Recently, researchers found that reductions in alfalfa yield due to stress from weeds and insects were often greater than the sum of the reductions caused by pests occurring individually (4, 8, 17, 18). These researchers, however, did not evaluate the effects of combined cool- and warm-season weed stresses.

Because of the complex nature of the alfalfa pest community, additional research is needed on the effects of pest stresses and their interactions on alfalfa productivity. The objectives of this research were to evaluate the effects of cool- and warm-season grass stress alone and in combination with alfalfa weevil stress on alfalfa production.

MATERIALS AND METHODS

Experiment 1 was initiated in the fall of 1990 on a third-year stand of 'OK08' at the South Central Research Station, Chickasha, OK, on a Dale silt loam (fine-silty, mixed, thermic, Pachic Haplustolls) soil. Experiment 2 was initiated in the fall of 1991 on a fourth-year stand of 'Cimarron' at the North Agronomy Research Station, Stillwater, OK, on an Easpur loam (fine-loamy, mixed, thermic, Fluventic Haplustolls) soil. Soil fertility levels were maintained by periodically testing and applying fertilizer based on recommendations. Irrigation was used on Experiment 1 to supplement rainfall in order to maintain productivity throughout the summer, while Experiment 2 was not irrigated.

The design in both experiments was a randomized complete block with a 2 by 2 by 2 factorial arrangement of main factors; cool-season grass (CSG)[3], warm-season grass (WSG)[3], and alfalfa weevil (AW)[3]. All combinations were replicated four times in 4.6 by 9.1 m plots. Treatment levels included both high and low levels of CSG, WSG, and AW. To help insure uniform weed infestation in high weed density plots, appropriate plots in both experiments were overseeded with downy brome and large crabgrass. Downy brome was overseeded at 10.5 kg ha^{-1} pure live seed in September, prior to the initial growing season of both experiments. Large crabgrass was overseeded in January in the initial year of both experiments at 6.7 kg ha^{-1} pure live seed. During the study, shepherdspurse and henbit invaded the unsprayed CSG plots and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv. # ECHCG] and foxtail (*Setaria* spp.) invaded the unsprayed WSG plots. Low levels of CSG were sustained by applying terbacil at 0.56 kg ai ha^{-1} as a dormant application in February each year. Low levels of WSG were sustained by applying sethoxydim at 0.28 kg ai ha^{-1} during the summer as needed.

Naturally occurring populations of AW were allowed to infest plots that were designated for high levels of infestation. The last harvest was timed early enough to allow 25 to 35 cm of fall growth to provide abundant ovipositional sites. Larval infestation occured during growth of the first crop in March and April. In plots designated for low levels of AW infestation, carbofuran was applied at 1.12 kg ai ha^{-1} in late February or early March to maintain larval numbers below the economic threshold in Oklahoma of 1.0 to 1.5 larvae per stem (2). Chlorpyrifos [o,o-diethyl-o-(3,5,6-trichloro-2-pyridinyl) phosphorothioate] was applied at 0.21 kg ai ha^{-1} when needed as a broadcast treatment over the entire experiment to control the blue alfalfa aphid, [*Acyrthosiphon kondi*

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[3]Abbreviations: CSG = cool-season grass; WSG = warm-season grass; AW = alfalfa weevil.

(Shinji)], and pea aphid [*A. pisum* (Harris)]. All pesticide treatments were applied with a boom sprayer mounted on a tractor calibrated to deliver a total volume of 190 L ha^{-1}.

Weed densities were estimated each December, before the dormant application of terbacil and again in March after herbicide activity occurred, by counting plants of each species in three quadrats (50 by 76 cm) placed randomly in each plot. As the plants had not jointed, leaf length estimates of downy brome were also determined in March by measuring the tallest extended leaf tip of 20 brome plants selected in each of three randomly placed quadrats (50 by 76 cm) in each plot. Alfalfa stem numbers were estimated before each harvest by counting stems in five randomly placed quadrats (15 by 67 cm) per plot. For the first harvest, heights of 20 alfalfa stems were measured in each of three randomly placed quadrats, and for the remaining harvests 20 stems were measured at random in each plot.

Dry weight yields of alfalfa and weeds were determined at first harvest (early May) by hand clipping forage in the three randomly placed quadrats (50 by 76 cm) used for measuring stem height and separating into yield components of alfalfa, downy brome, and broadleaf weeds (primarily shepherdspurse and henbit). Components were dried, weighed, and yields were calculated in kg ha^{-1}.

Subsequent harvests were conducted at 30 to 40 day intervals (10 to 25% bloom) using a self-propelled, flail-type harvester. Before each harvest, percent composition of broadleaf weeds and weedy grasses in forage was visually estimated in each plot. The accuracy of these estimates was verified periodically during the study by hand-separating and weighing weed and alfalfa components from quadrats (50 by 76 cm). Wet forage weights were determined in the field from a 1 by 5 m area in each plot and a 200 to 500 g subsample was oven-dried to determine moisture content. Dry matter yields of alfalfa and weeds were then calculated.

Alfalfa weevil peak larval densities (number per stem) were estimated during the first crop of alfalfa from samples collected by pulling 25 random stems from each plot.

Larvae were then extracted from the plant samples, using standard Berlese funnels. Sample timing was based on the accumulation of Celsius degree days above a developmental threshold temperature of 9.0°C (14).

All data were subjected to analysis of variance procedures. The degrees of freedom for treatments were divided into single degree of freedom orthogonal contrasts to compare main effects and interactions at the 5% level of probability. The observed significance levels listed in the tables are the probabilities of obtaining larger F values if the respective null hypotheses are true. All yield data presented are expressed on an oven-dry weight basis.

RESULTS AND DISCUSSION

Experiment 1. During the first three years of the study, no interaction was significant at the 5% or less level for alfalfa forage yield at any harvest (Table 1). However, in 1993, the WSG by AW interaction had a significance of <0.01 at first harvest. In the presence of AW infestation, alfalfa forage yields with and without WSG stress were similar (2420 and 2590 kg ha^{-1}, respectively). However, when AW was controlled, alfalfa forage yield with WSG stress was 3390 kg ha^{-1} compared to only 2680 kg ha^{-1} without WSG infestation.

It appeared that rainfall in February and March (Table 2) had more impact on competitiveness of downy brome than brome plant density (Table 3). Plant density of downy brome in March varied from a low of 2 per 0.1m^2 in 1992 to a high of 7 in 1993. However, the largest CSG yield resulted in 1990 when there were 4 downy brome plants per 0.1m^2 in overseeded plots compared to none following the terbacil treatment (Table 3). Rainfall in February and March of 1990 was desirable for growth of downy brome (Table 2). At the end of March, leaf length of downy brome averaged 14.7 cm. At first harvest in 1990, downy brome produced an average of 1620 kg ha^{-1} in plots designated for CSG infestation compared to 20 kg ha^{-1} in plots where terbacil had been applied

(Table 4). This amount of downy brome production significantly reduced alfalfa stem numbers from 41 to 37 stems per $0.1m^2$ (Table 5) and alfalfa height was significantly reduced by 2 cm (Table 6). This resulted in a significant reduction in yield of alfalfa forage at first harvest (940 kg ha^{-1}) and for the season (1090 kg ha^{-1}) in comparison with uninfested plots (Table 7).

Limited rainfall in February and March of 1991 and 1992 may have decreased the competitiveness of downy brome. Plant density of downy brome was 8 per 0.01 m^2 by mid-November, but by mid-March of 1991, there were only 3 plants per 0.1 m^2 remaining. In addition, leaf length of downy brome plants the last week in March of 1991 was only 9.1 cm compared to 14.7 cm at the same time the previous year. As a result, downy brome forage production was only 560 kg ha^{-1} in plots designated for CSG infestation compared to 380 kg ha^{-1} in plots in which terbacil was applied (Table 4). Terbacil applied on February 23 of 1991 resulted in poor control of downy brome because one month passed before it was activated by rainfall.

In March of 1992, downy brome plants averaged only 2 per 0.1 m^2 in plots designated for CSG infestation. However, downy brome was better able to compete because the alfalfa stand had declined from 19 stems per 0.1 m^2 in 1991 to only 9 stems per 0.1 m^2 in 1992. Leaf length of downy brome plants during the last week of March in 1992 was 14.7 cm compared to 9.1 cm in 1991. A severe hail storm on April 16 destroyed the first crop of alfalfa and weeds, so the downy brome forage production and effects of CSG on first harvest alfalfa forage yield could not be determined.

Downy brome emergence in the fall of 1992 was delayed because of limited rainfall during September and October. However, sufficient rainfall was received in November that weed counts in late December showed downy brome averaged 4 plants per 0.1 m^2 in plots designated for CSG infestation (Table 3). Downy brome continued to emerge and when counts were taken again in late March of 1993, downy brome plant numbers in CSG plots had increased to 7 plants per $0.1m^2$. Downy brome competition in 1993 did not significantly reduce alfalfa stem numbers or stem height at first harvest (Tables 5 and 6). However, there was a significant alfalfa forage yield reduction at first harvest in the CSG plots (2240 kg ha^{-1} compared to 3300 without CSG).

Warm-season grasses had little affect on productivity of alfalfa during the 1990 and 1991 seasons. Yields of WSG in 1990 for the third, fourth, and fifth harvests when alfalfa stand density averaged over 30 stems per 0.1m^2 (Table 5) were less than 100 kg ha^{-1} (Table 4). Higher yields of WSG resulted in unsprayed plots in 1991 (180, 270, 470 kg ha^{-1}, for third, fourth, and fifth harvests, respectively). The alfalfa yields in plots with WSG were correspondingly decreased, but decreases were not significant at the 5% level (Table 7). However, some of the yield components in 1991 were significantly reduced. Warm-season grass infestation reduced alfalfa stem density at fourth harvest from 19 to 16 plants per 0.01 m^2 and stem height at fifth harvest was reduced from 59 to 56 cm (Tables 5 and 6, respectively).

By 1992, WSG yields had increased to 510, 530, and 490 kg ha^{-1} at third, fourth, and fifth harvests, respectively (Table 4). Average alfalfa stand density in 1992 had decreased to 14 stems per 0.01 m^2 compared to 21 in 1991 (Table 5). Evidently, this decrease in alfalfa stem numbers allowed WSG to be more competitive and yields of alfalfa forage were significantly reduced due to WSG stress by 530, 390, and 640 kg ha^{-1} at third, fourth, and fifth harvests, respectively (Table 7). Total seasonal alfalfa yield was also significantly reduced by 1440 kg ha^{-1} as a result of WSG infestation. The WSG infestation appeared to reduce alfalfa stem height more than stem density, as heights were significantly reduced at fourth and fifth harvests (Table 6) with no reductions occurring in stem density (Table 5).

Although effects of AW were minor in 1990, alfalfa stem density (Table 5) was significantly reduced in the first crop. Alfalfa forage yield was not significantly reduced (Table 7). Peak larval numbers averaged only one per stem and the economic threshold in Oklahoma has been determined to be 1.5 to 2.0 larvae per stem (2).

In 1991, larval numbers peaked the first week of March with 1.8 larvae per stem without insecticides. This resulted in a significant 340 kg ha^{-1} alfalfa yield reduction at first harvest and residual effects leading to 310 and 250 kg ha^{-1} alfalfa yield reductions at second and third harvests, respectively (Table 7). Seasonal yield was also significantly reduced in 1991 by 310 kg ha^{-1}. Alfalfa stem heights were significantly reduced by AW stress at first, second, and third harvests in 1991 (Table 6) with no significant effect on alfalfa stem density at any harvest.

In 1992, peak larval density occurred about March 20 and averaged 6.4 larvae per stem in plots where weevils were not controlled. Just prior to first harvest, however, hail damage destroyed the first crop of alfalfa, so the effects of AW on first harvest yields could not be determined. Residual effects of the AW on alfalfa yields resulted in significant reductions of 420 and 490 kg ha^{-1} for the second and third harvests, respectively (Table 7). Also, total seasonal alfalfa yield (minus the first harvest) was significantly reduced by 1370 kg ha^{-1}. Residual effects of the AW resulted in both reduced alfalfa stem density and height at second harvest. However, neither alfalfa stem density nor height was significantly reduced at third harvest (Tables 5 and 6).

In 1993, peak larval density did not occur until about April 16 when larval numbers averaged 1.9 per stem without insecticides. This resulted in a significant 530 kg ha^{-1} alfalfa yield reduction at first harvest (Table 7). Both stem density and height at first harvest were significantly reduced in 1993 following AW infestation (Tables 5 and 6).

Alfalfa weevil and CSG stresses resulted in significant alfalfa yield reductions individually at first harvest in 1993, but their combined effects were less than additive. Both the stresses of CSG and WSG were not significant in any common year, and the result of their combined effects was not determined (Table 1). Stresses from both AW and WSG caused significant alfalfa yield reductions in 1992 at third harvest and for total seasonal alfalfa yield, but their combined effects were less than additive.

Experiment 2. During 1991 and 1993 there were no interactions significant at the 5% level for alfalfa forage yield at any harvest (Table 8). However, in 1992 the CSG by WSG interaction at first harvest had a significance level of <0.01. Without CSG stress, the first harvest yield of alfalfa without WSG stress was 1214 kg ha^{-1} and increased to 1374 kg ha^{-1} with WSG infestation the previous summer. However, with CSG stress the first harvest yield of alfalfa actually decreased from 957 kg ha^{-1} without WSG stress the previous summer to 780 kg ha^{-1} with the stress. There was a significantly greater amount of downy brome produced at first harvest in plots that had WSG infestation the previous summer (1400 compared to 1130 kg ha^{-1} without WSG). It appeared that having WSG in the plots the previous year resulted in a more favorable environment for downy brome. At the December weed counts, there were significantly more downy brome plants in the plots that were infested with WSG the previous summer (2.4 compared to 1.5 plants per 0.01 m^2 without WSG).

As in Experiment 1, the amount of rainfall received in February and March (Table 9) appeared to have more influence on competitiveness of downy brome than brome plant density (Table 10). Density of downy brome in March varied from 3 plants per 0.1 m^2 in both 1992 and 1993 to 7 in 1991 (Table 10) with the largest CSG yield resulting in 1992 (Table 11). The rainfall accumulation in February and March of 1991 was not sufficient for growth of downy brome. Weed counts taken in early December of 1990 indicated a density of 10 downy brome plants per 0.1 m^2 (Table 10). At the time of weed counts in mid-March of 1991 the numbers had decreased to 7 plants per 0.1 m^2. At the end of March, leaf length of downy brome averaged 5.2 cm. At first harvest in 1991, downy brome produced an average of 470 kg ha^{-1} in plots designated for CSG infestation compared to 10 kg ha^{-1} in plots where terbacil had been applied (Table 11). This amount of downy brome production did not significantly reduce stem density, stem height, or forage yield of alfalfa in 1991 (Tables 12, 13, and 14).

Sufficient rainfall was received during February and March of 1992 for downy brome growth. Downy brome averaged 2 plants per 0.1 m^2 in plots designated for CSG infestation in early December (Table 10) and had increased to 3 per 0.1 m^2 when counts were taken again in March of 1992. Average leaf length estimates in late March of 1992 revealed that downy brome was 16.2 cm compared to only 5.2 cm at the same time the previous year. At first harvest in 1992, downy brome produced an average of 1260 kg ha^{-1} in plots designated for CSG infestation compared to 280 kg ha^{-1} in plots where terbacil had been applied (Table 11). This amount of downy brome production significantly reduced alfalfa forage yield at first harvest (870 compared to 1300 kg ha^{-1} without CSG). Cool-season grass stress had no affect on alfalfa stem density (Table 12) and effect on stem height of alfalfa could not be determined because of a significant CSG by WSG by AW interaction (Table 13).

In March of 1993, downy brome plants averaged only 3 per 0.1 m^2 in plots designated for CSG infestation (Table 10). However, downy brome was competitive with a stand of alfalfa that had decreased from 12 stems per 0.1 m^2 in 1992 to only 9 in 1993. At first harvest in 1993 downy brome produced an average of 410 kg ha^{-1} in plots designated for CSG infestation compared to 10 kg ha^{-1} in terbacil treated plots (Table 11). There was also a 470 kg ha^{-1} of alfalfa forage yield reduction at first harvest with the high CSG stress (Table 14). There was also a significant reduction of alfalfa stems in plots with CSG stress (9 compared to 12 stems per 0.01 m^2 in plots without CSG stress) (Table 12).

Warm-season weedy grasses had little affect on alfalfa productivity during 1991. Yield of WSG for the last three harvests never exceeded 110 kg ha^{-1} (Table 11), when alfalfa stand density was usually above 20 stems per 0.1 m^2 (Table 12). However, by 1992, the average alfalfa stand density had declined to only 15 stems per 0.1 m^2 (Table 12) and alfalfa competitiveness decreased. WSG yields increased to 980 and 510 kg ha^{-1} at third and fourth harvests of 1992, respectively (Table 11) and alfalfa forage yields were significantly decreased by 710 and 780 kg ha^{-1} for third and fourth harvests, respectively (Table 14). There were also significant reductions of alfalfa stems at both harvests and alfalfa stem height at fourth harvest (Tables 13 and 14). At first harvest in 1993 yield of alfalfa forage was significantly reduced by 290 kg ha^{-1} in plots stressed by WSG the previous summer (Table 14). The reduction in alfalfa forage yield resulted from reduced alfalfa stem height (Table 13).

In 1991, peak AW larval density occurred about April 7 at 2.5 larvae per stem without insecticide. This resulted in a significant 450 kg ha^{-1} alfalfa forage yield reduction at first harvest, and a significant 260 kg ha^{-1} reduction occurring at second harvest (Table 14). The stress from AW also significantly reduced total seasonal alfalfa yield by 660 kg ha^{-1}. The main effect of AW appeared to be in reducing alfalfa stem height at first and second harvests (Table 13). However, alfalfa stem density was also reduced by residual effects of AW at second harvest in 1991 when plots with high weevil infestation averaged 34 stems per 0.1 m^2 compared to 38 stems per 0.1 m^2 with no weevil infestation.

In 1992, larval numbers peaked about March 20 at 4.9 larvae per stem without insecticide. This infestation resulted in significant reductions in alfalfa yields of 1490, 1320, and 450 kg ha^{-1} at first, second, and third harvests, respectively (Table 14). Total seasonal yield was also significantly reduced by 3300 kg ha^{-1}. Alfalfa weevil affected both alfalfa stem density and stem height. Stem density was significantly reduced at first, second, and third harvests (Table 12) and stem height was significantly reduced at first and second harvests (Table 13).

Peak larval density occurred about April 20 in 1993, approximately one month later than in 1992. Larval numbers without insecticide averaged 5.3 larvae per stem and significantly reduced first harvest forage yield by 670 kg ha^{-1} (Table 14). The effects of this AW infestation did not reduce alfalfa stem density, but alfalfa stem height was significantly reduced (Table 13).

Combined stress of the AW and CSG resulted in reducing first harvest yield of alfalfa in 1992 by 1920 kg ha^{-1} as compared to the pest-free treatment that had received both insecticide and herbicides. AW stress alone reduced yield of first harvest alfalfa forage in 1992 by 1490 kg ha^{-1} and CSG reduced first harvest alfalfa forage yield by 430 kg ha^{-1}. There were also significant reductions of alfalfa forage yields resulting from the individual effects of AW and WSG stress at third harvest in 1992, when reductions of 450 and 710 kg ha^{-1} resulted from both pest types, respectively. Their combined stress resulted in a 1170 kg ha^{-1} alfalfa forage reduction as compared to the pest-free treatment, which was essentially equal to the sum of their individual effects. In 1993, individual stresses of CSG, WSG, and AW caused significant alfalfa yield reductions at first harvest (330, 360, and 580 kg ha^{-1}, respectively), with their combined stresses reducing yield by 1480 kg ha^{-1}.

Interpretive discussion. CSG infestation did not consistently reduce alfalfa production. In Experiment 1, there were significant reductions in alfalfa forage yields at first harvest in 1990 and 1993 associated with CSG infestation, but none in 1991. In Experiment 2, CSG significantly reduced alfalfa forage yield at first harvest only in 1992 and 1993 (Table 14). The competitiveness of downy brome with alfalfa appeared to be influenced primarily by the amount of rainfall received during February and March and was affected little by the density of downy brome plants. Abundant rainfall during late winter and early spring resulted in taller, more vigorous downy brome plants. Under limited rainfall conditions, downy brome plants were not able to grow and compete with the alfalfa.

Initially, WSG infestation had little affect on alfalfa production. In Experiment 1, warm-season weedy grasses did not reduce alfalfa forage yield in the first two years of the study, but by the third year, significant yield reductions of alfalfa resulted in the plots with high densities of WSG at third, fourth, and fifth harvests with a resulting significant reduction in total seasonal yield of alfalfa. Warm-season weedy grasses in Experiment 2 did not reduce alfalfa forage yield during the first year of the study, but by the second year, significant yield reductions of alfalfa resulted at third and fourth harvests in plots with WSG and residual effects resulting at first harvest the next year. The competitiveness of WSG was related to alfalfa stand density in both experiments. Warm-season grass infestation reduced alfalfa forage yields only after alfalfa stem density had fallen below 20 stems per $0.1m^2$. In Experiment 1, warm-season weedy grasses reduced alfalfa forage yield in the third year of the study (fifth year of the alfalfa stand) when average alfalfa stem numbers had decreased from 21 stems per $0.1m^2$ in 1991 to 14 stems per $0.1\ m^2$ in 1992. Likewise, in Experiment 2, WSG reduced alfalfa forage yield in the second year of the study (fifth year of the alfalfa stand) when average alfalfa stem numbers had decreased from 23 stems per $0.1\ m^2$ in 1991 to 15 stems per $0.1\ m^2$ in 1992.

Alfalfa weevil had a more consistent damaging affect on alfalfa than either cool-season or warm-season weedy grasses. In Experiment 1, first harvest alfalfa forage yields in 1991 were significantly reduced by larvae feeding with significant residual reductions occurring at second and third harvests. Hail damage in 1992 prevented the determination of AW effects on first harvest forage yield. However, residual effects resulted in significant reductions at second and third harvests. In 1993, larvae feeding significantly reduced first harvest alfalfa forage yield. In Experiment 2, AW stress caused significant forage yield reductions at first harvest of each year with significant residual reductions occurring at second harvest and second and third harvests of 1991 and 1992, respectively. Alfalfa weevil stress also resulted in significantly reducing total seasonal alfalfa yield in both 1991 and 1992.

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Table 1. AOV (observed significance level) table for dry matter yield of alfalfa associated with three stresses [cool-season grass (CSG), warm-season grass (WSG), and alfalfa weevil (AW)] and their interactions at Chickasha, OK for 1990 through 1993.

Source of variation	Harvest					
	1	2	3	4	5	Total
	------------------observed significance level------------------					
			1990			
CSG	<0.01	0.71	0.27	0.30	0.54	0.02
WSG	0.43	0.31	0.49	0.17	0.12	0.17
AW	0.28	0.91	0.49	0.68	0.83	0.56
CSG x WSG	0.95	0.88	0.94	0.85	0.61	0.93
CSG x AW	0.53	0.47	0.77	0.09	0.75	0.49
WSG x AW	0.89	0.95	0.16	0.39	0.48	0.69
CSG x WSG x AW	0.14	0.23	0.55	0.87	0.71	0.27
			1991			
CSG	0.11	0.70	0.66	0.76	0.07	0.08
WSG	0.13	0.75	0.17	0.45	0.11	0.11
AW	<0.01	0.04	0.06	0.32	0.48	0.04
CSG x WSG	0.07	0.69	0.10	0.66	0.96	0.96
CSG x AW	0.34	0.11	0.90	0.85	0.64	0.36
WSG x AW	0.92	0.33	0.24	0.87	0.87	0.57
CSG x WSG x AW	0.30	0.86	0.22	0.64	0.15	0.40
			1992			
CSG	HD[a]	0.25	0.41	0.39	0.07	0.92
WSG	HD	0.21	0.04	0.04	<0.01	0.01
AW	HD	<0.01	0.04	0.13	0.12	0.01
CSG x WSG	HD	0.74	0.94	0.84	0.55	0.78
CSG x AW	HD	0.78	0.99	0.83	0.68	0.91
WSG x AW	HD	0.23	0.49	0.68	0.34	0.86
CSG x WSG x AW	HD	0.45	0.89	0.62	0.62	0.83
			1993			
CSG	0.05	-[b]	-	-	-	-
WSG	0.22	-	-	-	-	-
AW	<0.01	-	-	-	-	-
CSG x WSG	0.39	-	-	-	-	-
CSG x AW	0.24	-	-	-	-	-
WSG x AW	<0.01	-	-	-	-	-
CSG x WSG x AW	0.14	-	-	-	-	-

[a] HD = Hail damage.

[b] Data were terminated after first harvest.

Table 2. Monthly rainfall (cm) during cool and warm-season grass study, Chickasha, OK, 1989 to 1993.

	30 Year Mean	Year				
Month	1963-1992	1989	1990	1991	1992	1993
January	2.95	3.94	4.88	3.78	2.97	2.29
February	4.14	6.48	12.70	0.13	2.59	3.34
March	6.55	5.11	16.31	3.84	2.29	6.70
April	7.16	0.69	13.23	8.33	23.62	11.48
May	12.37	15.98	14.20	17.07	13.94	21.00
June	9.63	18.54	4.88	9.65	17.07	-
July	5.72	7.98	6.27	8.66	10.80	-
August	7.06	8.10	8.84	9.53	13.03	-
September	9.47	13.46	7.01	25.10	6.48	-
October	8.18	6.20	4.83	8.81	2.79	-
November	5.03	0.15	6.35	4.22	14.49	-
December	3.78	0.51	4.01	13.59	9.75	-
Yearly Total	82.04	87.14	103.51	112.71	119.82	-
Dev. from Mean		+5.10	+21.47	+30.67	+37.78	

Table 3. Orthogonal contrasts for plant density of downy brome associated with three stresses [cool-season grass (CSG), warm-season grass (WSG), and alfalfa weevil (AW)] and their interactions at Chickasha, OK for 1990 through 1993.

	1990	1990-91		1991-92		1992-93	
Orthogonal contrast[a]	3-08	11-15	3-12	12-05	3-12	12-21	3-23
	---plants per 0.1m²---						
CSG / No CSG[b]	4/0**	8/4*	3/3	3/1**	2/1	4/3	7/3**
WSG / No WSG[b]	2/2	8/4*	4/2**	1/1	2/2	3/4	4/5
AW / No AW[b]	1/2	6/7	2/4**	2/1*	3/1*	3/4	5/4
	---observed significance level of interaction---						
CSG x WSG[c]	0.81	0.58	0.03	0.04	0.01	0.89	0.49
CSG x AW[c]	0.21	0.33	0.36	0.02	0.15	0.82	1.00
WSG x AW[c]	0.90	<0.01	0.02	0.41	0.81	0.94	0.14
CSG x WSG x AW[c]	0.97	0.27	0.89	0.43	0.37	0.19	0.51

[a] ** and * denote orthogonal contrast significant at the 1 and 5% levels, respectively. Mean comparisons not followed by an asterisk are not significantly different.

[b] Orthogonal comparison of means between pest stress and no pest stress.

[c] Main effect interactions.

Table 4. Orthogonal contrasts for dry matter yield of weeds associated with three stresses [cool-season grass (CSG), warm-season grass (WSG), and alfalfa weevil (AW)] and their interactions at Chickasha, OK for 1990 through 1993.

	Harvest					
Orthogonal contrast[a]	1[d]	2[d]	3[e]	4[e]	5[e]	Total[f]
			1990			
			kg ha^{-1}			
CSG / No CSG[b]	1620/20**	11/0**	0/0	0/0	50/60	1690/100**
WSG / No WSG[b]	830/810	4/7	0/0	0/0	90/20*	950/850
AW / No AW[b]	740/910	8/3	0/0	0/0	60/50	810/970
			observed significance level of interaction			
CSG x WSG[c]	0.81	0.34	-	-	0.48	0.93
CSG x AW[c]	0.25	0.14	-	-	0.39	0.49
WSG x AW[c]	0.93	0.82	-	-	0.99	0.69
CSG x WSG x AW[c]	0.62	0.82	-	-	0.92	0.27
			1991			
			kg ha^{-1}			
CSG / No CSG	560/380*	20/10	120/70	200/70*	300/220	1270/770**
WSG / No WSG	680/260**	20/5*	180/10**	270/10**	470/50**	1670/370**
AW / No AW	420/530	14/10	130/60*	180/100	350/160*	1160/880*
			observed significance level of interaction			
CSG x WSG	<0.01	0.42	0.26	0.07	0.55	0.17
CSG x AW	0.34	0.99	0.28	0.26	0.26	0.22
WSG x AW	0.32	0.13	0.09	0.33	0.18	<0.01
CSG x WSG x AW	0.22	0.82	0.49	0.38	0.32	0.02

Table 4. (Continued)

Orthogonal contrast[a]	Harvest 1[d]	2[d]	3[e]	4[e]	5[e]	Total[f]
				1992		
			kg ha^{-1}			
CSG / No CSG	HD[g]	460/200**	230/330	330/220	260/260	1340/1170
WSG / No WSG	HD	220/440**	510/50**	530/30**	490/30**	1770/640**
AW / No AW	HD	420/240*	300/250	300/260	330/190**	1430/980**
			observed significance level of interaction			
CSG x WSG	HD	0.17	0.25	0.40	0.55	0.02
CSG x AW	HD	0.70	0.96	0.57	0.63	0.72
WSG x AW	HD	0.54	0.83	0.98	0.06	0.95
CSG x WSG x AW	HD	0.13	0.85	0.37	0.48	0.04
				1993		
			kg ha^{-1}			
CSG / No CSG	340/0**	-[h]	-	-	-	-
WSG / No WSG	110/230**	-	-	-	-	-
AW / No AW	210/130	-	-	-	-	-
			observed significance level of interaction			
CSG x WSG	<0.01	-	-	-	-	-
CSG x AW	0.09	-	-	-	-	-
WSG x AW	0.46	-	-	-	-	-
CSG x WSG x AW	0.46	-	-	-	-	-

[a] ** and * denote orthogonal contrast significant at the 1 and 5% levels, respectively. Mean comparisons not followed by an asterisk are not significantly different.

Table 4. (Continued)

[b] Orthogonal comparison of means between pest stress and no pest stress.
[c] Main effect interactions.
[d] Cool-season annual grasses.
[e] Warm-season grasses.
[f] Total weed yield includes broadleaf weeds.
[g] HD = Hail damage.
[h] Data were terminated after first harvest.

Table 5. Orthogonal contrasts for stem density of alfalfa associated with three stresses [cool-season grass (CSG), warm-season grass (WSG), and alfalfa weevil (AW)] and their interactions at Chickasha, OK for 1990 through 1993.

	Harvest				
Orthogonal contrast[a]	1	2	3	4	5
			1990		
	---plants per 0.1m^2---				
CSG / No CSG[b]	37/41*	23/22	39/37	38/38	22/25*
WSG / No WSG[b]	38/39	24/22*	39/38	36/40*	21/21
AW / No AW[b]	42/36**	23/23	38/38	37/39	20/23*
	---observed significance level of interaction---				
CSG x WSG[c]	0.96	0.68	0.73	0.99	0.13
CSG x AW[c]	0.50	0.40	0.55	0.84	<0.01
WSG x AW[c]	0.64	0.78	0.59	1.00	0.72
CSG x WSG x AW[c]	0.44	0.44	0.89	0.08	0.24
			1991		
	---plants per 0.1m^2---				
CSG / No CSG	19/19	32/31	23/22	16/19*	16/15
WSG / No WSG	19/19	31/32	22/23	16/19*	15/16
AW / No AW	20/19	31/32	22/23	17/19	15/16
	---observed significance level of interaction---				
CSG x WSG	0.30	0.78	0.18	0.03	0.49
CSG x AW	0.97	0.02	0.54	0.39	0.19
WSG x AW	<0.01	0.33	0.34	0.10	0.69
CSG x WSG x AW	0.81	0.52	0.48	0.11	0.59
			1992		
	---plants per 0.1m^2---				
CSG / No CSG	9/11*	15/14	20/21	16/16	11/11
WSG / No WSG	10/10	13/15*	20/21	15/16	11/12
AW / No AW	9/11*	13/15*	20/21	15/16	11/12
	---observed significance level of interaction---				
CSG x WSG	0.66	0.50	0.42	0.32	0.33
CSG x AW	0.07	0.84	0.92	0.69	0.11
WSG x AW	0.60	0.28	0.15	0.07	0.04
CSG x WSG x AW	0.02	0.82	0.71	0.61	0.10

Table 5. (Continued)

Orthogonal contrast[a]	Harvest 1	2	3	4	5
			1993		
	---plants per $0.1m^2$---				
CSG / No CSG	11/10	-[d]	-	-	-
WSG / No WSG	11/10	-	-	-	-
AW / No AW	10/12*	-	-	-	-
	---observed significance level of interaction---				
CSG x WSG	0.23	-	-	-	-
CSG x AW	0.48	-	-	-	-
WSG x AW	0.51	-	-	-	-
CSG x WSG x AW	0.98	-	-	-	-

[a] ** and * denote orthogonal contrast significant at the 1 and 5% levels, respectively. Mean comparisons not followed by and asterisk are not significantly different.

[b] Orthogonal comparison of means between pest stress and no pest stress.

[c] Main effect interactions.

[d] Data were terminated after first harvest.

Table 6. Othogonal contrasts for stem height of alfalfa associated with three stresses [cool-season grass (CSG), warm-season grass (WSG), and alfalfa weevil (AW)] and their interactions at Chickasha, OK for 1990 through 1993.

	Harvest				
Orthogonal contrast[a]	1	2	3	4	5
			1990		
	-----------------------------cm-----------------------------				
CSG / No CSG[b]	63/65*	45/44	44/44	45/45	49/51
WSG / No WSG[b]	64/63	45/44	45/43	45/44	51/49
AW / No AW[b]	62/65**	44/45	44/44	45/44	50/50
	--------------observed significance level of interaction--------------				
CSG x WSG[c]	0.38	0.76	0.46	0.74	0.46
CSG x AW[c]	0.51	<0.01	0.99	0.79	0.61
WSG x AW[c]	<0.01	0.58	0.21	0.65	0.61
CSG x WSG x AW[c]	0.83	0.31	0.86	0.84	0.46
			1991		
	-----------------------------cm-----------------------------				
CSG / No CSG	48/47	67/67	65/64	60/61	59/60
WSG / No WSG	48/48	68/66	65/64	60/60	59/61*
AW / No AW	44/52**	65/68**	63/66**	60/60	59/60
	--------------observed significance level of interaction--------------				
CSG x WSG	0.65	0.47	0.08	0.35	0.45
CSG x AW	0.15	0.94	0.14	0.46	0.88
WSG x AW	0.63	0.34	0.32	0.65	0.53
CSG x WSG x AW	0.47	0.50	0.37	0.44	0.16
			1992		
	-----------------------------cm-----------------------------				
CSG / No CSG	HD[d]	55/51**	65/63*	70/68	58/57
WSG / No WSG	HD	52/54	64/64	66/71**	56/59**
AW / No AW	HD	51/55**	63/64	69/69	57/58
	--------------observed significance level of interaction--------------				
CSG x WSG	HD	0.14	0.29	0.27	0.37
CSG x AW	HD	0.65	0.41	0.45	0.49
WSG x AW	HD	0.41	0.26	0.39	0.29
CSG x WSG x AW	HD	0.20	0.87	0.43	0.29

Table 6. (Continued)

Orthogonal contrast[a]	Harvest 1	2	3	4	5
			1993		
	--------------cm--------------				
CSG / No CSG	57/59	-[e]	-	-	-
WSG / No WSG	57/59	-	-	-	-
AW / No AW	54/62**	-	-	-	-
	--------------observed significance level of interaction--------------				
CSG x WSG	0.39	-	-	-	-
CSG x AW	0.24	-	-	-	-
WSG x AW	<0.01	-	-	-	-
CSG x WSG x AW	0.14	-	-	-	-

[a] ** and * denote orthogonal contrast significant at the 1 and 5% levels, respectively. Mean comparisons not followed by and asterisk are not significantly different.

[b] Orthogonal comparison of means between pest stress and no pest stress.

[c] Main effect interactions.

[d] HD = Hail damage.

[e] Data were terminated after first harvest.

Table 7. Orthogonal contrast for dry matter yield of alfalfa at various harvests associated with three stresses [cool-season grass (CSG), warm-season grass (WSG), and alfalfa weevil (AW)] at Chickasha, OK for 1990 through 1993.

Orthogonal contrast[a]	Harvest 1	2	3	4	5	Total
	----------	----------	----------	kg ha^{-1}	----------	----------
				1990		
CSG	1950 b	3000 a	2620 a	1800 a	2600 a	11970 b
No CSG	2890 a	3050 a	2840 a	1740 a	2540 a	13060 a
WSG	2470 a	3090 a	2790 a	1810 a	2660 a	12820 a
No WSG	2370 a	2960 a	2660 a	1720 a	2480 a	12190 a
AW	2350 a	3040 a	2660 a	1780 a	2560 a	12390 a
No AW	2490 a	3020 a	2800 a	1760 a	2580 a	12650 a
				1991		
CSG	2130 a	3470 a	3020 a	2710 a	3130 a	14460 a
No CSG	2330 a	3520 a	3070 a	2770 a	3670 a	15360 a
WSG	2140 a	3520 a	2950 a	2660 a	3160 a	14430 a
No WSG	2320 a	3470 a	3140 a	2810 a	3660 a	15400 a
AW	2060 b	3340 b	2920 b	2640 a	3310 a	14270 b
No AW	2400 a	3650 a	3170 a	2840 a	3520 a	15580 a
				1992		
CSG	HD[b]	1540 a	3380 a	2830 a	2340 a	10090 a
No CSG	HD	1640 a	3180 a	2660 a	2540 a	10020 a
WSG	HD	1650 a	3020 b	2550 b	2120 b	9340 b
No WSG	HD	1530 a	3550 a	2940 a	2760 a	10780 a
AW	HD	1380 b	3040 b	2600 a	2360 a	9380 b
No AW	HD	1800 a	3530 a	2890 a	2530 a	10750 a
				1993		
CSG	2240 b	-[c]	-	-	-	-
No CSG	3300 a	-	-	-	-	-
WSG	2910 a	-	-	-	-	-
No WSG	2640 a	-	-	-	-	-
AW	2510 b	-	-	-	-	-
No AW	3040 a	-	-	-	-	-

[a] Observations for each orthogonal contrast followed by the same letter are not significantly different at the 5% level. Comparisons only valid within the same column.

[b] HD = Hail damage.

[c] Data were terminated after first harvest.

Table 8. AOV (observed significance level) table for dry matter yield of alfalfa associated with three stresses [cool-season grass (CSG), warm-season grass (WSG), and alfalfa weevil (AW)] and their interactions at Stillwater, OK for 1991 through 1993.

Source of variation	Harvest					
	1	2	3	4	5	Total
	-----------------observed significance level-----------------					
			1991			
CSG	0.23	0.36	0.08	0.91	0.45	0.47
WSG	0.55	0.94	0.06	0.52	0.46	0.17
AW	<0.01	<0.01	0.04	0.48	0.49	0.03
CSG x WSG	0.38	0.36	0.68	0.62	0.96	0.41
CSG x AW	0.25	0.45	0.39	0.98	0.08	0.62
WSG x AW	0.54	0.77	0.55	0.27	0.61	0.65
CSG x WSG x AW	0.46	0.51	0.79	0.79	0.27	0.86
			1992			
CSG	<0.01	0.49	0.07	0.21	NH[a]	0.50
WSG	0.92	0.98	<0.01	<0.01	NH	0.10
AW	<0.01	<0.01	<0.01	0.88	NH	<0.01
CSG x WSG	<0.01	0.51	0.07	0.71	NH	0.26
CSG x AW	0.90	0.74	0.96	0.78	NH	0.45
WSG x AW	0.59	0.25	0.77	0.75	NH	0.69
CSG x WSG x AW	0.12	0.64	0.69	0.17	NH	0.63
			1993			
CSG	<0.01	-[b]	-	-	-	-
WSG	<0.01	-	-	-	-	-
AW	<0.01	-	-	-	-	-
CSG x WSG	0.88	-	-	-	-	-
CSG x AW	0.08	-	-	-	-	-
WSG x AW	0.74	-	-	-	-	-
CSG x WSG x AW	0.59	-	-	-	-	-

[a] NH = No harvest.

[b] Data were terminated after first harvest.

Table 9. Monthly rainfall (cm) during cool and warm-season grass study, Stillwater, OK, 1990 to 1993.

	30 Year Mean	Year			
Month	1963-1992	1990	1991	1992	1993
January	3.02	4.70	2.46	1.98	5.69
February	4.32	9.70	0.15	3.78	6.27
March	6.93	18.21	2.49	2.41	6.10
April	7.77	14.94	7.95	8.97	8.30
May	13.31	12.19	17.88	6.91	9.47
June	9.91	2.57	10.16	20.32	-
July	6.83	3.68	1.14	5.97	-
August	7.70	9.14	3.58	21.59	-
September	10.19	9.73	14.48	6.91	-
October	6.58	3.15	10.82	4.11	-
November	6.10	4.45	6.91	16.89	-
December	3.94	2.51	12.95	8.86	-
Yearly Total	86.60	94.97	90.97	108.70	
Dev. from Mean		+8.37	+4.37	+22.10	

Table 10. Orthogonal contrasts for plant density of downy brome associated with three stresses [cool-season grass (CSG), warm-season grass (WSG), and alfalfa weevil (AW)] and their interactions at Stillwater, OK for 1990 through 1993.

	1990-91		1991-92		1992-93	
Orthogonal contrast[a]	12-06	3-13	12-10	3-11	12-18	3-16
	----------plants per $0.1 m^2$----------					
CSG / No CSG[b]	10/1**	7/1**	2/1**	3/1**	2/2	3/0**
WSG / No WSG[b]	6/5	4/4	1/1	2/2	3/2	2/2
AW / No AW[b]	5/6	4/4	1/1	2/2	3/2	2/2
	----------observed significance level of interaction----------					
CSG x WSG[c]	0.09	0.79	<0.01	0.09	0.08	0.53
CSG x AW[c]	1.00	0.14	0.17	<0.01	0.10	0.12
WSG x AW[c]	0.02	0.24	0.74	0.04	0.48	0.55
CSG x WSG x AW[c]	0.02	0.05	0.67	0.33	0.33	0.28

[a] ** and * denote orthogonal contrast significant at hte 1 and 5% levels, respectively. Mean comparisons not followed by an asterisk are not significantly different.

[b] Orthogonal comparison of means between pest stress and no pest stress.

[c] Main effect interactions.

Table 11. Orthogonal contrasts for dry matter yield of weeds associated with three stresses [cool-season grass (CSG), warm-season grass (WSG), and alfalfa weevil (AW)] and their interactions at Stillwater, OK for 1991 through 1993.

	Harvest					
Orthogonal contrast[a]	1[d]	2[d]	3[e]	4[e]	5[e]	Total[f]
			1991			
			$kg\ ha^{-1}$			
CSG / No CSG[b]	470/10**	30/1**	60/80	0/0	50/40	610/130**
WSG / No WSG[b]	260/220	18/10	110/40**	0/0	90/10**	480/280**
AW / No AW[b]	280/200*	20/10*	70/80	0/0	60/30*	430/320*
			observed significance level of interaction			
CSG x WSG[c]	0.35	0.52	0.34	-	0.99	0.72
CSG x AW[c]	0.04	0.05	0.38	-	0.45	0.12
WSG x AW[c]	0.39	0.39	0.55	-	0.02	0.11
CSG x WSG x AW[c]	0.54	0.60	0.45	-	0.54	0.32
			1992			
			$kg\ ha^{-1}$			
CSG / No CSG	1260/280**	610/440	430/560*	250/270	NH[g]	2650/1530**
WSG / No WSG	790/760	600/450	980/10**	510/10**	NH	3220/1240**
AW / No AW	900/640**	910/150**	540/450	330/190	NH	3030/1430**
			observed significance level of interaction			
CSG x WSG	<0.01	0.76	0.02	0.86	NH	<0.01
CSG x AW	0.41	0.87	0.24	0.74	NH	<0.01
WSG x AW	0.60	0.37	0.12	0.20	NH	1.00
CSG x WSG x AW	0.02	0.90	0.22	0.71	NH	1.00

Table 11. (Continued)

Orthogonal contrast	Harvest 1[d]	2[d]	3[e]	4[e]	5[e]	Total[f]
	1993					
	kg ha^{-1}					
CSG / No CSG	410/3**	-[h]	-	-	-	-
WSG / No WSG	200/210	-	-	-	-	-
AW / No AW	240/170	-	-	-	-	-
	observed significance level of interaction					
CSG x WSG	0.82	-	-	-	-	-
CSG x AW	0.13	-	-	-	-	-
WSG x AW	0.84	-	-	-	-	-
CSG x WSG x AW	0.78	-	-	-	-	-

[a] ** and * denote orthogonal contrast significant at the 1 and 5% levels, respectively. Mean comparisons not followed by an asterisk are not significantly different.

[b] Orthogonal comparison of means between pest stress and no pest stress.

[c] Main effect interactions.

[d] Cool-season annual grasses.

[e] Warm-season grasses.

[f] Total weed yield includes broadleaf weeds.

[g] NH = No harvest.

[h] Data were terminated after first harvest.

Table 12. Orthogonal contrasts for stem density of alfalfa associated with three stresses [cool-season grass (CSG), warm-season grass (WSG), and alfalfa weevil (AW)] and their interactions at Stillwater, OK for 1991 through 1993.

Orthogonal contrast[a]	Harvest 1	2	3	4	5
			1991		
			plants per 0.1m^2		
CSG / No CSG[b]	17/18	36/36	27/27	13/15	23/22
WSG / No WSG[b]	18/17	37/35	28/27	14/15	23/23
AW / No AW[b]	18/18	34/38*	26/28	14/14	22/23
			observed significance level of interaction		
CSG x WSG[c]	0.39	0.69	0.83	0.51	0.39
CSG x AW[c]	<0.01	0.68	0.06	0.47	0.85
WSG x AW[c]	0.53	0.17	0.25	0.61	0.19
CSG x WSG x AW[c]	0.23	0.06	0.90	0.31	0.13
			1992		
			plants per 0.1m^2		
CSG / No CSG	12/11	17/18	17/17	15/15	NH[d]
WSG / No WSG	12/11	18/17	15/20**	13/14**	NH
AW / No AW	10/13**	16/19**	16/19*	15/15	NH
			observed significance level of interaction		
CSG x WSG	0.81	0.95	0.63	0.81	NH
CSG x AW	0.42	0.36	0.67	0.10	NH
WSG x AW	<0.01	0.97	0.31	0.90	NH
CSG x WSG x AW	0.22	0.62	0.94	0.29	NH
			1993		
			plants per 0.1m^2		
CSG / No CSG	9/12*	-[e]	-	-	-
WSG / No WSG	10/10	-	-	-	-
AW / No AW	10/11	-	-	-	-
			observed significance level of interaction		
CSG x WSG	0.22	-	-	-	-
CSG x AW	0.21	-	-	-	-
WSG x AW	<0.01	-	-	-	-
CSG x WSG x AW	0.13	-	-	-	-

Table 12. (Continued)

[a] ** and * denote orthogonal contrast significant at the 1 and 5% levels, respectively. Mean comparisons not followed by and asterisk are not significantly different.

[b] Orthogonal comparison of means between pest stress and no pest stress.

[c] Main effect interactions.

[d] NH = No harvest.

[e] Data were terminated after first harvest.

Table 13. Orthogonal contrasts for stem height of alfalfa associated with three stresses [cool-season grass (CSG), warm-season grass (WSG), and alfalfa weevil (AW)] and their interactions at Stillwater, OK for 1991 through 1993.

Orthogonal contrast[a]	Harvest 1	2	3	4	5
			1991		
			cm		
CSG / No CSG[b]	40/39	58/59	44/44	28/28	40/38**
WSG / No WSG[b]	40/39	59/57*	44/44	28/27	39/39
AW / No AW[b]	35/45**	56/60**	44/44	28/28	39/39
		observed significance level of interaction			
CSG x WSG[c]	0.28	0.21	0.52	0.86	0.30
CSG x AW[c]	0.40	0.05	0.72	0.94	0.91
WSG x AW[c]	0.76	0.13	0.02	0.68	0.06
CSG x WSG x AW[c]	0.54	0.26	0.33	0.23	0.82
			1992		
			cm		
CSG / No CSG	30/31	60/60	51/52	39/39	NH[d]
WSG / No WSG	30/31	60/61	51/52	37/41**	NH
AW / No AW	18/43**	55/65**	51/52	39/39	NH
		observed significance level of interaction			
CSG x WSG	0.25	0.55	0.59	0.23	NH
CSG x AW	0.02	0.43	0.95	0.33	NH
WSG x AW	0.80	0.25	0.74	0.84	NH
CSG x WSG x AW	<0.01	0.82	0.27	0.55	NH
			1993		
			cm		
CSG / No CSG	52/53	-[e]	-	-	-
WSG / No WSG	51/54**	-	-	-	-
AW / No AW	47/58**	-	-	-	-
		observed significance level of interaction			
CSG x WSG	0.33	-	-	-	-
CSG x AW	0.68	-	-	-	-
WSG x AW	<0.01	-	-	-	-
CSG x WSG x AW	0.07	-	-	-	-

Table 13. (Continued)

[a] ** and * denote orthogonal contrast significant at the 1 and 5% levels, respectively. Mean comparisons not followed by and asterisk are not significantly different.

[b] Orthogonal comparison of means between pest stress and no pest stress.

[c] Main effect interactions.

[d] NH = No harvest.

[e] Data were terminated after first harvest.

Table 14. Orthogonal contrasts for dry matter yield of alfalfa at various harvests associated with three stresses [cool-season grass (CSG), warm-season grass (WSG), and alfalfa weevil (AW)] at Stillwater, OK for 1991 through 1993.

Orthogonal contrast[a]	Harvest 1	2	3	4	5	Total
	kg ha^{-1}					
			1991			
CSG	2050 a	2560 a	2150 a	880 a	1180 a	8820 a
No CSG	2180 a	2500 a	2350 a	870 a	1090 a	8990 a
WSG	2150 a	2530 a	2360 a	850 a	1170 a	9060 a
No WSG	2090 a	2530 a	2140 a	890 a	1090 a	8740 a
AW	1890 b	2400 b	2210 a	900 a	1170 a	8570 b
No AW	2340 a	2660 a	2290 a	850 a	1090 a	9230 a
			1992			
CSG	870 b	2700 a	2090 a	1470 a	NH[b]	7130 a
No CSG	1300 a	2840 a	2320 a	1780 a	NH	8240 a
WSG	1080 a	2770 a	1850 b	1240 b	NH	6940 a
No WSG	1090 a	2770 a	2560 a	2020 a	NH	8440 a
AW	340 b	2110 b	1980 b	1610 a	NH	6040 b
No AW	1830 a	3430 a	2430 a	1650 a	NH	9340 a
			1993			
CSG	1650 b	-[c]	-	-	-	-
No CSG	2120 a	-	-	-	-	-
WSG	1740 b	-	-	-	-	-
No WSG	2030 a	-	-	-	-	-
AW	1550 b	-	-	-	-	-
No AW	2220 a	-	-	-	-	-

[a] Observations for each orthogonal contrast followed by the same letter are not significantly different at the 5% level. Comparisons only valid within the same column.

[b] NH = No harvest.

[c] Data were terminated after first harvest.

VITA 2

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Master of Science

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