

**Use of Herbicides, Tillage, and Grazing Cattle for
Establishment of Corn in Rotation with Alfalfa and Rye**

by

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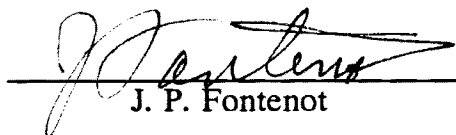
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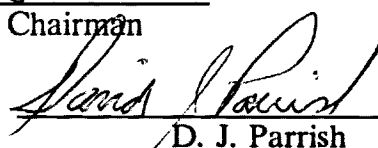
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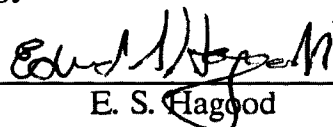
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(ABSTRACT)

Six combinations of grazing, tillage, and herbicides were studied during 2 yr in a randomized block design to determine alfalfa (*Medicago sativa*) survival, corn (*Zea mays*) plant populations and corn growth in an alfalfa-corn rotation. Alfalfa was overseeded with rye (*Secale cereale*) in autumn prior to planting corn in spring of each year. Treatments were 1) non-grazed control with standard chemical treatments for no-till establishment of corn, 2) grazing alfalfa, then grazing rye until corn planting followed by dicamba application, 3) alfalfa grazing plus glyphosate prior to corn planting, 4) treatment 3 plus grazing prior to rye jointing, and 5) alfalfa grazing plus autumn application of glyphosate, 6) alfalfa grazing plus autumn disking (no herbicides). Grazing until corn planting decreased ($P < 0.05$) alfalfa stands and rye biomass, but increased ($P < 0.05$) corn plant populations and soil bulk density compared to shorter grazing periods. Grazing prior to rye jointing increased ($P < 0.05$) soil bulk density and corn plant populations, and decreased ($P < 0.05$) rye biomass compared to no spring grazing. Autumn disking decreased ($P < 0.05$) bulk density, but generally provided less

($P < 0.05$) control of alfalfa compared to autumn application of glyphosate. Autumn disking and glyphosate application (Trts. 5 and 6) increased ($P < 0.05$) rye biomass compared to no autumn treatment (Trts. 3 and 4). Applying glyphosate prior to corn planting (Trts. 3 and 4) improved ($P < 0.05$) corn populations and growth compared to autumn glyphosate or disking (Trts. 5 and 6) and was similar to conventional no-till establishment (Trt. 1). Herbicides were necessary to completely kill alfalfa, but grazing reduced TNC in alfalfa roots and alfalfa plant persistence.

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Chapter I

Introduction

Producing corn (*Zea mays* L.) using sustainable agricultural production techniques is an old concept that is becoming more popular, as preserving our environment has become increasingly important. Farmers have become increasingly dependent on manufactured fertilizers and pesticides, some of which are potentially harmful to the environment. Increasing environmental concerns have brought renewed interest in corn production systems that are less dependent on chemical inputs. Some alternative practices that have been studied for corn production include use of legumes in rotations to provide soil N, use of cover crops to reduce erosion and to prevent leaching of N and minerals through soil, and reduced use of pesticides through tillage and management of the previous crops. Little is known concerning the impact of grazing prior to corn production, although many cover crops and N-fixing legumes could provide excellent feed for ruminants. The objectives of the research were to investigate methods of establishment of corn following alfalfa (*Medicago sativa* L.) that minimize herbicide

requirements. Further objectives were to elucidate the impact of grazing and chemical and mechanical suppression of biomass prior to corn planting on soil fertility, soil compaction, survival of alfalfa, weed encroachment, growth of cover crop, and production of corn.

Chapter II

Review of the Literature

Corn Production

Nearly 30 million hectares of corn are planted in the United States every year (USDA, 1990). Over 40% of the primary nutrients used in agriculture in the United States are applied to corn (USDA, 1990). Greater than 3 billion tons of soil are lost each year due to erosion, and corn land is a major contributor (USDA, 1990). This results in major environmental concerns. Because of concern for our environment and well being, alternative agriculture has begun to play a major role in crop production systems.

Diversity and crop rotations are fundamental parts of sustainable agriculture (Potash and Phosphate Institute, 1989). Price support programs are calculated from the farmers base hectarage and their average yield (Giuther, 1989). If the farmers decrease their base number of ha in order to implement a crop rotation, then their risk is increased; because only half of their crops have a price support, and if the alternative crop fails the financial impact could be severe. Similarly, yield goals will dictate how the farmer will plan a production system. The farmer will tend to produce at a

maximum level to get a maximum support. Therefore, governmental policies, such as price support programs, have encouraged monocropping and by making it difficult for the farmer to diversify (NRC, 1989). Scientists are beginning to play a greater role in developing alternative agriculture programs that the farmers will be able to economically integrate into their way of farming.

Liebhardt et al. (1989) investigated conversion from conventional to low-input methods and its effects on crop production in eastern Pennsylvania. They investigated three different systems: a conventional corn/soybean (*Glycine max* (L.) Merr.) rotation and two low-input systems which utilized oat (*Avena sativa* L.), red clover (*Trifolium pratense* L.), and winter wheat (*Triticum aestivum* L.) in rotation with corn and soybeans. One low-input system utilized cattle manure for nutrients and produced forage crops along with cash grain, while the other system produced a cash grain crop every year and used legumes as a nutrient source. They found that weed competition and insufficient N limited low-input corn yields during the first 4 yr. They concluded that the transition is difficult but feasible, if crop rotations utilize crops that are competitive with weeds and demand less N, such as small grains, soybeans, or legume hay.

The benefits of low-input practices appear to outweigh costs. Ess (1990) found that using certain legume cover crops, such as hairy vetch (*Vicia villosa* Roth) or a mixture of hairy vetch and bigflower vetch (*Vicia grandiflora* W. Koch) reduced cost and energy expenditures associated with N fertilization. In a 5-yr farm study, Lockeretz et al. (1984) compared organic and conventional farms in the corn belt. They found that corn

and soybean yields were not different, but wheat yields were lower in low-input systems. While net returns were similar, energy consumption and soil erosion were lower on the low-input farms. Similarly, in the northern Great Plains, Smolik and Dobbs (1991) found that, while corn yields were generally lower for alternative systems than conventional systems, the net returns were similar and the systems had economic potential.

Tillage practices and herbicide use are important considerations in corn production. Tillage can reduce the amount of herbicides required for adequate weed control. Eadie et al. (1990) achieved excellent weed control in corn by using a banded spray application of metolachlor and atrazine or atrazine alone along with one inter-row cultivation. However, the number of cultivations needed depended on the amount of precipitation. The banded spraying along with cultivation was more economical and reduced the amount of herbicide put into the environment. Similarly, Bicki et al. (1991) found that total amount of herbicide applied was 73% less for banded applications than broadcast and did not significantly reduce yields. However, they found that cultivations required on the banded treatment slightly increased cost over that of the broadcast herbicides. Isensee et al. (1989) studied the impact of tillage practices on pesticide movement through soil. They analyzed for atrazine, alachlor, cyanazine, and carbofuran. They found that tillage practices did not affect pesticide movement during 2 yr, but pesticide concentrations were higher in deep and shallow wells under no-till compared to conventional tillage immediately after application in 1 of the years.

Smith et al. (1992) conducted a study in Wisconsin comparing no-till and conventionally tilled corn in a fall versus spring kill of alfalfa/orchardgrass (*Dactylis glomerata* L.)/bromegrass (*Bromus inermis* Leyss) cover. The no-till fall-killed plots were sprayed with glyphosate; and the spring-killed plots were sprayed with glyphosate for the first, third, and fourth years of the trial and dicamba during the second year of the trial. The conventional-tilled plots were plowed in the fall or spring before planting, followed by two spring diskings. They found that the fall-killed no-till with early spring planting of corn was comparable to conventional till and was much more consistent in growth and yield than spring-killed no-till. The fall-kill of no-till also yielded more grain in 3 of 4 years by 10% during 2 yr and 50% during 1 yr compared to spring-killed no-till.

Alfalfa

Alfalfa is an excellent legume to rotate with corn in Virginia, because it is well adapted to this area. Alfalfa has also been found to fix more N than any other forage legume (Hamdi, 1982). Fox and Piekielek (1988) found no significant corn grain yield response to N fertilizer in the first year following a 3-yr alfalfa stand, 3-yr birdsfoot trefoil (*Lotus corniculatus* L.) stand, or a 2-yr red clover stand. They found N equivalents of the alfalfa, birdsfoot trefoil, and red clover to be 187, 169, and 147 kg/ha, respectively. Benefits of legumes were due mainly to N contribution instead of crop sequence or rotation effect. Similarly, Bruulsema and Christie (1987) found that whole plant N in corn was higher when following alfalfa than clover, which led them to suggest

that alfalfa was more readily mineralized than clover.

Kempen et al. (1990) in a study in California investigated the production of silage corn with reduced tillage into an established alfalfa stand. They removed two cuttings of alfalfa and irrigated for 5 d before applying herbicides to the regrowth. They treated with glyphosate at different rates, glyphosate with metolachlor, or dicamba and cultivated with flat sweeps in the row at corn planting and in the middles after corn emergence. Glyphosate applied at 0.84 kg ai ha⁻¹ was effective in controlling alfalfa prior to corn emergence. In a similar study, Kempen et al. (1991) found glyphosate to be effective in controlling recently mown alfalfa, but better control was seen on actively growing alfalfa. Krall et al. (1989) conducted studies in Wyoming on 6-yr-old irrigated alfalfa and compared alfalfa populations on no-till to plow operations. The no-till was treated with cyanazine, atrazine and dicamba or with metolachlor and atrazine both applied prior to planting corn. The moldboard plowed plots were treated with two operations of roller harrowing with cyanazine and atrazine or with metolachlor and atrazine. They found that alfalfa populations were higher in no-tillage corn than in corn planted into plowed soil, but the alfalfa did not decrease yields compared to the plowed treatments. They saw no difference in silage yields.

Cover Crops

An important management tool in sustainable agriculture is the use of cover crops. Cover crops reduce soil erosion, provide weed control, and scavenge N and other mobile nutrients during high rainfall of winter months (NRC, 1989). Many different cover crops

have potential in Virginia. Winter cereals appear best suited, but some legumes have been used.

Types of cover crops. The most popular cover crops are winter cereals. Their ability to produce high amounts of biomass allows them to be effective in soil conservation, weed competition, and scavenging mobile nutrients. Since they are annuals, once they are cut or harvested, they have very little regrowth (Stoskopf, 1985), which is important; because they do not have to be sprayed prior to planting the following crop. They are also important as a cash crop and have the potential to be double-cropped in areas with long growing seasons with crops such as corn or soybeans.

Cereals are excellent forage crops because of their ease of establishment, very little regrowth, and inexpensive seed (Stoskopf, 1985). They can also lengthen the fall grazing period and allow earlier grazing in the spring, which reduces the number of days of winter feeding. Furthermore, cereals are excellent quality forages, with a crude protein content of 20% to 30%, and produce cattle gains of 1 kg day⁻¹ when grazed (Stoskopf, 1985). The young leafy growth, between 14% and 18% dry matter (DM), has a digestibility of 80% (Stoskopf, 1985).

Rivera (1970) compared the growth of wheat, barley (*Hordeum vulgare* L.), and rye (*Secale cereale* L.) under field conditions in Virginia. He found that leaf area index (LAI) reached a maximum at ear emergence, and decreased as it reached maturity. Wheat had the highest LAI at 5.9, with barley at 3.8, and rye at 2.9. Rye, however, grew more in the first month and had higher forage mass than wheat or barley during

most of the growth cycle. Barley started growing later than rye or wheat, but reached maturity 1 to 2 wk sooner than either of the other forages. In order for corn to be planted at an optimal time, the small grain would need to be harvested by mid-to-late April. On April 23, rye yielded 4000 kg ha⁻¹ with wheat and barley having 50% and 60% less biomass (Rivera, 1970).

Legumes are also important cover crops, because they not only fix N but also scavenge N and other essential plant nutrients. Hoyt and Cole (1989) found that hairy vetch residual N accumulation was close to 200 kg/ha, second only to caley peas (*Lathyrus hirsutus* L.). Hoyt (1990) found that hairy vetch survived better in western North Carolina and produced higher yields than bigflower vetch, Austrian winter pea (*Pisum sativum* subsp. *arvense* (L.) Poir), caley pea, crimson clover (*Trifolium incarnatum* L.), subterranean clover (*Trifolium subterraneum* L.), and berseem clover (*Trifolium alexandrinum* L.). Finally, Hoyt and Cole (1989) found that corn yields were highest following hairy vetch and caley pea as compared to corn yields following subterannean clover, crimson clover, Austrian winter peas, and bigflower vetch. This suggests that hairy vetch could be an important winter cover crop in this area.

Heichel (1984) found that the N contribution to the following non-legume is affected by many factors, such as C:N ratio, degradation by microflora, environmental factors, and soil properties. By using ¹⁵N methods, he found that 15% to 25% of the N produced by the legume would be recovered by the following nonlegume in the first year and possibly 4% in the second year, but a further understanding of this contribution is

needed in order to properly credit the legume.

Sullivan (1990), in Virginia, studied the value of mixing rye and vetch in order to reduce the N fertilizer requirement while providing a ground cover. He compared several combinations of rye, hairy vetch, and bigflower vetch at different seeding rates. He found that mixing the rye and vetch resulted in a higher biomass production than either of these alone. However, he found that corn yields were lower when rye was seeded with vetch compared to vetch alone, probably due to immobilization of N by the rye.

Weed control. Cover crops reduce weeds in the subsequent crop. This is likely due either to a smothering effect on weeds or to allelopathy (Else et al., 1989; Teasdale and Beste, 1990). Teasdale and Beste (1990) found that a rye or hairy vetch cover crop resulted in fewer weeds in a no-till system without residual herbicides when compared to no cover crop. The primary weeds in the no-till systems were annual grasses and carpetweed (*Mollugo verticillata* L.). The weed reductions were due primarily to amount of residue biomass, not to type of cover crop.

Several plant species used as cover crops have been shown to have allelopathic effects on weeds and to reduce total weed biomass. Some mulches in the presence of a corn crop provide good weed control without herbicides or tillage (Else et al., 1989). Rye has been effective in controlling weeds (Rice, 1984; Shilling et al., 1985; Barnes and Putnam, 1986; Else et al., 1989). Shilling et al. (1985) reported that no-tillage with rye mulch reduced the biomass of redroot pigweed (*Amaranthus retroflexus* L.), common

lambsquarters (*Chenopodium album* L.), and common ragweed (*Ambrosia artemisiifolia* L.) by 96, 84, and 83% respectively. According to Barnes et al. (1986), a spring-planted cover crop of rye reduced weed biomass by 90% as compared to unplanted controls. Else et al. (1989) found that a dead rye mulch significantly reduced weed biomass when corn was present. Hairy vetch seeds have also been shown to reduce germination and seedling growth of weeds in many tests (Rice, 1984).

Rye

Rye is better adapted to Virginia than wheat because rye can be planted later in autumn, has more autumn growth, and is more winter hardy (Rivera, 1970; Stoskopf, 1985). Also rye tolerates a wide range of pH, soil fertility and moisture levels (Barnes et al., 1986). At corn planting, rye has 50 to 60% more dry matter yield than wheat or barley (Rivera, 1970). Brinsfield (1989) found rye to be a more effective N scavenger compared to spring oat and barley.

Shiple, et al. (1992) found rye to scavenge more N than other cover crops. They compared the uptake of N at three fertilizer rates (0, 168, and 336 kg ha⁻¹) by hairy vetch, crimson clover, cereal rye, annual ryegrass (*Lolium multiflorum* Lam.), and a weed/fallow of chickweed (*Stellaria media* (L.) Cyrillo). Cereal rye and annual ryegrass recovered the most fertilizer N of these treatments, with cereal rye being significantly higher the second year. However, with no fertilizer N, grasses and weeds were similar in total N content. Hairy vetch and crimson clover were similar in N content across all three fertilizer rates, implying that most of their N content was due to N fixation.

Moschler et al. (1967) found higher corn yields and water conservation under a system with rye mulch as compared to spring plowing. The main drawback with a heavy winter cover of rye may be reduced corn populations. Eckert (1988) found that a rye residue increased no-till corn yields on one site in 1 yr which he attributed to moisture conservation. However, rye decreased corn yields in four of twelve treatments because of reduced plant stands. Mitchell and Teel (1977) found no evidence of rye boosting corn yields as compared to a sod with volunteer weeds. They did, however, see reduced stands and suspected it was because of poor seed-soil contact caused by the planter pushing rye residue into the furrow. Sullivan (1990) also found reduced corn emergence where rye, rye/vetch or pure vetch stands were not mechanically incorporated, which he thought was due to poor seed-soil contact.

Raimbault et al. (1990), in a study in Canada compared no rye mulch, rye harvested for silage, and rye chemically killed with different spring tillage systems. They found that a no-till rye mulch system delayed corn development and decreased corn yields by 11% and 17% when compared to rye cover that was harvested as silage and no cover crop. They suggested that the rye had an allelopathic effect on the corn. In a later trial, Raimbault et al. (1991) compared five tillage treatments and early and late rye kill. The tillage treatments included: moldboard plow with secondary tillage, strip tillage, no-till with ripple coulters, no-till with disc furrowers plus plow coulters, and no-till with ripple coulters plus plow coulters. The rye was killed either 2 wk prior to corn planting or immediately prior to corn planting. They found best corn yields with the

early kill of rye and a modified no-till that removed rye residue from the row area. However, the early kill did result in a 60% decrease in rye yield.

Grazing Effects

Grazing alfalfa. Alfalfa is valuable as a cash crop and is a highly nutritious forage. If alfalfa is not needed for hay, grazing is a valuable management tool. However, unless properly managed, grazing can reduce stands and increase weeds (Van Keuren and Martin; 1972, Hamilton, 1983; Allen et al., 1986).

Grazing alfalfa can reduce total seasonal yields (Van Keuren and Martin, 1972). Allen et al. (1986) found that alfalfa grazed by sheep in the summer for more than 7 d at early bloom decreased seasonal yields the following year. However, grazing alfalfa for 2 yr during spring or summer by steers according to recommendations did not reduce alfalfa yield in yr 3 (Wolf and Allen, 1990). Grazing alfalfa for 4 or 6 wk in the summer by sheep increased percentage weeds in the fall; but, by the following spring, percentage weeds had declined (Hamilton, 1983). Alfalfa persistence does decrease with increased grazing frequency and continuous grazing (Brownlee, 1973; Counce et al, 1984). Thus, if alfalfa was to be followed by another crop, it may be advantageous to continuously graze it to decrease the stand persistence and decrease the need for herbicides. However, if grazing results in increased weed populations, the need for herbicides may be increased.

Grazing on cereal grains. Rye has excellent grazing potential also. The management of this forage is critical. Brickbauer et al. (1978) stated that rye for grazing

should be managed as wheat. Worrell et al. (1992) studied the grazing potential of wheat. They compared an ungrazed control with grazing at three different stages: jointing, second node, or flag leaf appearance. They found that grazing did not decrease grain yield unless grazed after the flag leaf appearance during one year, but in another year grain yields were reduced with grazing past jointing. This suggests that it would not be safe to graze past the jointing stage if grain yield is the objective.

Grazing effects on soil bulk density. Krenzer et al. (1989) grazed cattle on wheat pastures until early jointing. They found that animal traffic increased bulk density up to 16% on the surface. The bulk density on a Teller fine sandy loam soil (fine loamy, mixed, thermic Udic Argiustoll) was increased to a depth of 20.3 cm, compared to 12.7 cm on silt loams. The silt loams were a Taloka silt loam (fine, mixed, thermic Mollic Albaqualf) and a Pond Creek silt loam (fine-silty, mixed, thermic Udic Argiustoll)(Krenzer et al., 1989). Thus, compaction may be deep enough that some tillage practices may not eliminate the increased bulk density. Similarly, Worrell et al. (1992) found that soil compaction increased linearly with grazing duration and suggested that this may have contributed to a reduction in wheat grain yield.

Van Havern (1983) studied grazing effects of cattle on soil bulk density of different textured soils of the Central Plains at three different grazing intensities. Stocking rates were 1.66, 1.25, and .73 ha per yearling heifer. He found that coarse-textured soil bulk densities did not increase with increased grazing intensities; but, on fine-textured soils, bulk density increased with increased grazing intensity. Heavily

grazed pastures were 13.4% and 11.8% higher in bulk density than light and moderately grazed pastures. Likewise, Tanner and Mamaril (1959) measured soil compaction on 20 different pastures and compared each pasture to an adjacent hay field or fence row. They found that the coarse silt loam did not compact under animal traffic, but the fine textured soils did increase in compaction after a season of grazing.

In New Zealand Gradwell (1966) studied effects of winter grazing on topsoils. Sheep were grazed on a gleyed pumiceous soil with ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) forages. Soil bulk density increased and large pore content decreased as stocking rate was increased. The high stocking rates also led to closer grazing and damage to plants. Residual effects the following summer were reduced plant growth due to mechanical damage and a reduced capacity of soils to absorb and store water because of slow structural recovery.

Grazing and nutrient cycling. One of the values of grazing is the return of dung and urine back to the pasture system. The size of a urine patch from a sheep has been estimated to average about 290 cm² with a N concentration of .92% (Doak, 1952). Doak also found that the area that showed improved growth was about twice the area actually wetted (645 cm²). The rate of N applied to a urine patch from sheep was estimated to be 484 kg ha⁻¹. A cow wets an area approximately 4,194 cm² and affects an area of 5,484 cm² (Doak, 1952).

The hydrolysis of urea can result in an elevated pH which allows accumulation of nitrites if nitrate formation is inhibited by high pH (Doak, 1952). Nitrite buildup is

caused by high ammonium levels and high pH (Tisdale et al., 1985). Hydrolysis of urea causes both buildup of ammonium and temporary elevation of pH. Nitrite will be produced faster than nitrate when pH is 7.5 to 8.0 (Tisdale et al., 1985). Doak (1952) found soil pH rose from 5.5 to 9.2 under laboratory conditions. Finally, Doak (1952) found that considerable ammonia can be lost to the air from herbage and soil. This is because hydrolysis of urea to ammonium is quick, while nitrite formation is delayed slightly; ammonium will be lost during this delay.

Annual yields of a grassland in New Zealand were higher when nutrients were returned to pasture than when they were not, 15.4 t ha⁻¹ vs. 11.7 t ha⁻¹, respectively (Pearson and Ison, 1987). Grazing provides many benefits as a means of forage removal. These include reduced labor since the animal itself removes the vegetation, and in replacing nutrients that would otherwise be lost if the forage were mechanically harvested and removed.

The overall objective of the research was to establish corn into an alfalfa sod while minimizing chemical and mechanical inputs and integrating grazing by cattle as a management option.

Specific objectives were:

- 1) To determine the influence of chemical and mechanical plant suppression of cover on corn plant populations and initial growth of corn.
- 2) To examine the extent to which grazing can be integrated into plant suppression methods prior to corn planting.

- 3) To determine the effect of various establishment techniques weed populations.
- 4) To determine the influence of suppression methods on soil moisture, compaction, and fertility.

Methods and Materials

Experiments were conducted during 2 yr (1991-92 and 1992-93) at the Virginia Polytechnic Institute and State University Kentland Research Farm located in Montgomery County, Virginia (366 m elevation, 12°30' north latitude, 35°37.5' west longitude) to determine effects of various methods for establishment of corn following alfalfa. Treatments were imposed on an existing stand of 'Cimarron' alfalfa that was established in April 1989 on a Shottower soil. Shottower (fine-loamy, mixed, mesic, Typic Hapludults) is typified by localized accumulations of cobblestones. Alfalfa had been managed as a hay crop prior to this experiment.

Six treatments (Table 1) in a randomized block design with four replicates of each treatment were initiated following the second alfalfa hay harvests in 1991 and 1992. Plots used in 1992 were adjacent to plots used in 1991, so that in each year treatments were applied to alfalfa stands previously managed as hay.

Treatment 1 - This treatment represented a conventional system with no grazing. Alfalfa was harvested for hay on 15 Aug. 1991 and 28 Aug. 1992. Rye was no-till

Table 1. Six grazing, herbicide, and mechanical treatments tested to establish corn following alfalfa in rotation.

Treatment	Time Period		
	July to Oct.	Oct. to Mar.	Mar. to May
		Event	
1) No grazing	Hay harvests	Rye [†]	Herbicides [‡]
2) Maximum grazing	Graze	Disk, rye [†]	Graze
3) No spring grazing	Graze	Rye [†]	Glyphosate [§]
4) Spring grazing	Graze	Rye [†]	Graze, Glyphosate [§]
5) Autumn herbicide kill	Graze	Glyphosate [§] , rye/hairy vetch [¶]	Roll down
6) Autumn disk	Graze	Disk, rye/hairy vetch [¶]	Roll down

[†] Seeding rate of 'Abruzzi' rye was 112 kg ha⁻¹.

[‡] Paraquat (.7 kg ai ha⁻¹), alachlor (3.4 kg ai ha⁻¹), atrazine (1.7 kg ai ha⁻¹), simazine (1.2 kg ai ha⁻¹), compatibility agent, non-ionic surfactant, and esfenvalerate (.05 kg ai ha⁻¹).

[§] Application rate was 2.8 kg ai ha⁻¹.

[¶] Seeding rate of 'Abruzzi' rye was 89.6 kg ha⁻¹ and hairy vetch was 22.4 kg ha⁻¹.

drilled at 112 kg ha⁻¹ on 31 Oct. 1991 and 13 Oct. 1992. Prior to corn planting, vegetation was sprayed with a tank mix of paraquat (1,1'-dimethyl-4,4'-bipyridinium ion; .7 kg ai ha⁻¹), alachlor (2-chloro-2',6'-diethyl-N-(methoxymethyl)-acetanilide; 3.4 kg ai ha⁻¹), atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine; 1.68 kg ai ha⁻¹), simazine (2-chloro-4,6-bis(ethylamino)-s-triazine; 1.23 kg ai ha⁻¹), compatibility agent, non-ionic surfactant, and esfenvalerate ((S)-cyano(3-phenolylphenyl)methyl-(S)-4-chloro-alpha-(1-methylethyl)benzeneacetate; .05 kg ai ha⁻¹). 'Pioneer 3140' corn seed was treated with Agrox dl (diazinon (15%), lindane (25%)) at 2.3 g Agrox kg⁻¹ corn seed and planted at 59,300 seeds ha⁻¹ on 1 May 1992 and 12 May 1993. Dicamba (3,6-dichloro-2-methoxy-benzoic acid) was broadcast post-emergence at .28 kg ai ha⁻¹ on 11 June 1992 and 17 June 1993 to kill alfalfa.

Treatment 2 - Cattle began grazing alfalfa following the second hay cutting when there was sufficient regrowth for grazing (28 July 1991 and 4 Aug. 1992). Grazing continued until 12 Sept. 1991 and 5 Oct. 1992. Alfalfa was disked (22 Oct. 1991 and 13 Oct. 1992) to further suppress it. 'Abruzzi' rye was no-till drilled on 31 Oct. 1991 and 13 Oct. 1992 at a seeding rate of 112 kg ha⁻¹. Grazing of the rye-alfalfa mixture continued as forage was available until corn planting on 1 May 1992 and 12 May 1993. Dicamba was broadcast at .28 kg ai ha⁻¹ immediately prior to corn planting to kill remaining alfalfa.

Treatment 3 - Cattle grazed alfalfa prior to winter as in Treatment 1. Rye was no-till drilled at 112 kg ha⁻¹ on 31 Oct. 1991 and 13 Oct. 1992 after which no more

grazing was allowed. Glyphosate [*N*(Phosphonomethyl)glycine] (2.8 kg ai ha⁻¹) was applied prior to corn planting to kill the vegetation.

Treatment 4 - This system was identical to Treatment 3, except that rye was grazed as available prior to jointing.

Treatment 5 - Cattle grazed alfalfa prior to winter, as in Treatment 1. Glyphosate was broadcast on 22 Oct. 1991 and 13 Oct. 1992 at 2.8 kg ai ha⁻¹ to kill remaining vegetation. A rye/hairy vetch mixture was no-till drilled at 89.6 kg ha⁻¹ and 22.4 kg ha⁻¹, respectively, as a cover crop on 31 Oct. 1991 and 13 Oct. 1992. Immediately prior to corn planting, the cover crop was rolled down with a hand-operated turf roller in yr 1. In yr 2, the cover crop was rolled down using a tractor-operated disk roller.

Treatment 6 - Cattle grazed alfalfa prior to winter as in Treatment 1. The plots were disked (22 Oct. 1991 and 13 Oct. 1992) to suppress alfalfa and weeds. A rye/hairy vetch mixture was no-till drilled on 31 Oct. 1991 and 13 Oct. 1992 as described for Treatment 5. The cover crop was rolled down prior to corn planting as described for Treatment 5. No herbicides were used.

Corn was planted at the same time each year on all plots using an 8-row Kinze corn planter. Plots were 6.1 x 7.6 m. Plots were fenced so that only the grazed plots could be accessed by the cattle. During yr 1, yr 2 plots were fenced, so cattle could not tread on them or graze. During yr 1, alfalfa was grazed by 4 beef heifers with an average weight of 350 kg. They were allowed to graze as forage was available to keep it at an average height of 8 cm. During spring of yr 1 and all of yr 2, holstein cows

with an average weight of 450 kg were used.

Due to dry soil conditions in 1991, rye was irrigated once with 1.3 cm of water on 2 Nov. 1991. Ammonium nitrate was applied at 22.4 kg N ha⁻¹ to rye on all treatments, 31 Oct. 1991 and 29 Oct. 1992. Prior to planting corn, cattle manure from cattle fed corn silage plus poultry litter was applied to all plots. These cattle were part of the ongoing Sustainable Agriculture project at the Kentland Research Farm feedlot. Analysis of this manure is in Appendix Table 1. The cattle manure was applied to all plots at 31 Mg ha⁻¹ on 15 April 1992 and 28 April 1993. Urea ammonium nitrate (UAN) was applied to corn on all treatments at 84 kg ha⁻¹, 29 June 1992 and 112 kg ha⁻¹, 2 July, 1993.

Plant measurements. Plant dry mass was measured at intervals on alfalfa, rye, weeds, and corn. Initial forage mass of alfalfa was determined on 26 July 1991 and 3 Aug. 1992 by clipping two 0.25m² quadrats per plot at a 2.5-cm cutting height and drying at 55°C. Forage mass of alfalfa was also measured prior to rye planting, 11 Oct. 1991 and 8 Oct. 1992. Total forage mass, which consisted almost totally of rye, was measured prior to corn planting by clipping one 0.25 m² quadrat per plot in the same manner as the alfalfa. Forage mass of alfalfa and weeds was determined at the time of corn harvest by clipping and hand separation of 0.25 m² quadrats. Forage mass was reported on a dry matter basis at 55°C. TNC (Total Nonstructural Carbohydrates), percentage N, and corn ear leaf mineral concentrations were reported on a dry matter basis at 110°C.

Alfalfa populations were measured by counting the number of alfalfa crowns in a 0.25 m² quadrat. Two quadrats per plot were counted, initially (30 July 1991 and 3 Aug. 1992), immediately prior to planting rye (11 Oct. 1991 and 8 Oct. 1992), immediately prior to planting corn (28 Apr. 1992 and 5 May 1993), and mid-season after planting the corn (2 July 1992 and 12 July 1993). The number of corn plants emerged in two 6.1-m rows per plot were counted to determine corn plant populations on 10 June 1992 and 24 June 1993.

Plant heights were measured by disk meter with six measurements taken per plot at the time grazing was initiated each summer. Plant heights were measured by disk meter every 2 wk beginning 30 July 1991 and 30 Aug. 1992 and continuing through rye planting to corn planting (1 May 1992 and 6 May 1993). Corn plant heights were taken by measuring to the top of the smallest leaf in the whorl on 2 July 1992 and 12 July 1993. Final corn height at harvest was also determined by measuring from 5 cm above ground level (harvest level) to the top of the tassel.

Stem diameter of the corn was measured on six random plants per plot on 2 July 1992 and 12 July 1993 to help determine overall vigor of plants. The diameter was measured on the long axis (the widest diameter) above the brace roots at the base of the stem.

Alfalfa roots were sampled on 18 Dec. 1991 and 19 Dec. 1992 for total nonstructural carbohydrates. Five plants per plot were removed with a shovel. The top 15.2 cm from the crown of the main taproot were taken, washed and cut into small

pieces to facilitate drying. Roots were dried at 70°C until dry, then ground in a Wiley mill with a 1-mm screen. The total nonstructural carbohydrate content was determined by procedures from Davis (1976) and Smith (1981).

Corn was sampled at silking to measure nutrient status. Eight ear leaves per plot were collected, dried at 55°C, and ground in a stainless steel Wiley mill through a 1-mm screen. Percentage N was determined by micro-Kjeldahl techniques (McKenzie and Wallace, 1954). Mineral concentration was determined by Inductively Coupled Plasma Spectroscopy after wet ashing with 4:2 nitric:perchloric acid by a modification from Westerman (1990).

Corn was harvested from and weighed from 13.7 x 11.4 m to determine total yield for yr 1, on 18 Sept. 1992. Ten plants per plot were weighed in the field. Six plants were subsampled and separated into ear and stalk fractions and dried at 55°C for dry matter determination. Botanical composition in each plot was determined by the Double DAFOR (Dominant, Abundant, Frequent, Occasional, Rare) Method (Brodie, 1985 as modified by Abaye, 1992). Botanical composition was estimated initially (30 July 1991 and 3 Aug. 1992), prior to planting rye (11 Oct. 1991 and 8 Oct. 1992), and prior to planting corn (28 Apr. 1992 and 6 May 1993).

Soil measurements. All plots were sampled to determine initial soil fertility on 26 July 1991 and 3 Aug. 1992. Six cores plot⁻¹ were taken to a depth of 7.6 cm and composited within plots for analysis of pH, organic matter, P, K, Ca, Mg, Zn, Mn, Fe, Al, Cu, and B at the VPI&SU Soil Testing Laboratory (Donohue, 1992). Soil samples

were also taken for fertility analysis prior to rye planting, 11 Oct. 1991 and 8 Oct. 1992. Soils were again sampled to determine soil fertility 8 wk after planting corn (29 June 1992 and 2 July 1993).

Soil bulk density was determined by the core method (Blake and Hartge, 1986) prior to grazing (26 July 1991 and 3 Aug. 1992), after rye planting (18 Dec. 1991 and 19 Dec. 1992), and after corn establishment (2 July 1992 and 12 July 1993). Four cores per plot were taken to a depth of 7.6 cm and dried at 105°C. Soil moisture was calculated from the bulk density samples on 2 July 1992 and 12 July 1993.

Statistical analysis. Data were analyzed as a randomized complete block design using a general linear model (SAS, 1990). A probability level of 0.05 was considered significant. Contrasts were used to determine differences among treatments as follows: 1) No grazing versus grazing (Treatment 1 vs. all other treatments); 2) Spring grazing versus no spring grazing (Treatment 4 vs. Treatment 3); 3) Autumn chemical application versus autumn tillage (Treatment 5 vs. Treatment 6); 4) Long grazing period versus short grazing period (Treatment 2 vs. Treatments. 3, 4, 5, and 6); and 5) Autumn kill of vegetation versus spring kill of vegetation (Treatments 5 and 6 vs. Treatments 3 and 4). Tukey's Studentized Range (HSD) Test (SAS, 1990) was applied to further separate mean differences.

Results

Alfalfa. When treatments were initiated following the second alfalfa hay harvest in each year, more ($P < 0.05$) alfalfa was present in yr 1 compared to yr 2, but within years alfalfa was similar across all treatment plots (Table 2). Immediately prior to planting rye, however, there was more alfalfa present in yr 2, compared to yr 1, but the magnitude of this differed by treatment (year by treatment interaction; $P < 0.05$). By the time rye was planted in October, there was more ($P < 0.05$) alfalfa present in the non-grazed treatment (Trt. 1) compared to the mean of grazed treatments. This occurred even though hay was harvested in September from the non-grazed treatment. Grazing resulted in a lower canopy height of alfalfa during both years compared to that of non-grazed alfalfa (Figures 1 and 2). At the time rye was planted, alfalfa plant heights continued to be higher where alfalfa had been harvested as hay compared to alfalfa that had been grazed (data not shown). There were no differences in alfalfa biomass present among grazed treatments at the time rye was planted in either year (Table 2). At the time corn was harvested in September of yr 1, there tended ($P < 0.07$) to be more alfalfa present in plots where glyphosate was applied in the previous autumn (Trt. 5) compared

Table 2. Influence of grazing, chemical, and mechanical treatments on alfalfa dry mass immediately prior to grazing, prior to planting rye, and at corn harvest.

Date	Event	Grazed						SE
		Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
				Glyphosate (3)	Glyphosate + grazed (4)	Glyphosate (5)	Disked (6)	
Mg ha ⁻¹								
Year 1								
07-30-91 [†]	Pre-grazed	0.77	0.78	0.83	0.68	0.90	0.82	0.06
10-11-91 ^{††}	Pre-rye planting	0.41	0.11	0.17	0.11	0.13	0.12	0.07
09-17-92	Corn harvest							
	Alfalfa ^{†††}	0.02 ^{bl}	0.01 ^b	0.01 ^b	0.00 ^b	0.72 ^a	0.41 ^{ab}	0.11
	Weed ^{†††}	0.51	0.54	0.94	0.52	0.30	0.36	0.15
	Total	0.53	0.54	0.94	0.52	1.02	0.77	0.18
Year 2								
08-04-92 [†]	Pre-grazed	0.67	0.67	0.60	0.58	0.61	0.56	0.07
10-08-92 ^{††}	Pre-rye planting	1.97 ^a	0.25 ^b	0.38 ^b	0.40 ^b	0.22 ^b	0.55 ^b	0.16

^l Means with the same letter in a row are not significantly different at the 0.05 probability level as determined by Tukey's test.

[†] Effect of year (P < 0.05).

^{††} Year by treatment interaction (P < 0.05).

^{†††} The non-grazed treatment (Trt. 1) differs from the mean of grazed treatments (Trts. 2,3,4,5, and 6); P < 0.01).

^l Autumn chemical destruction of alfalfa (Trt. 5) differed for autumn mechanical suppression of alfalfa (Trt. 6; P < 0.07).

[#] Grazing until corn planting (Trt. 2) differed from the mean for shorter grazing periods (Trts. 3,4,5, and 6; P < 0.05).

^{††} The mean of treatments with autumn suppression of standing crop (Trts. 5 and 6) differed from the mean of treatments with spring suppression of standing crop (Trts. 3 and 4; P < 0.05).

^{†††} Grazing prior to rye jointing in spring (Trt. 4) differed from no spring grazing (Trt. 3; P < 0.05).

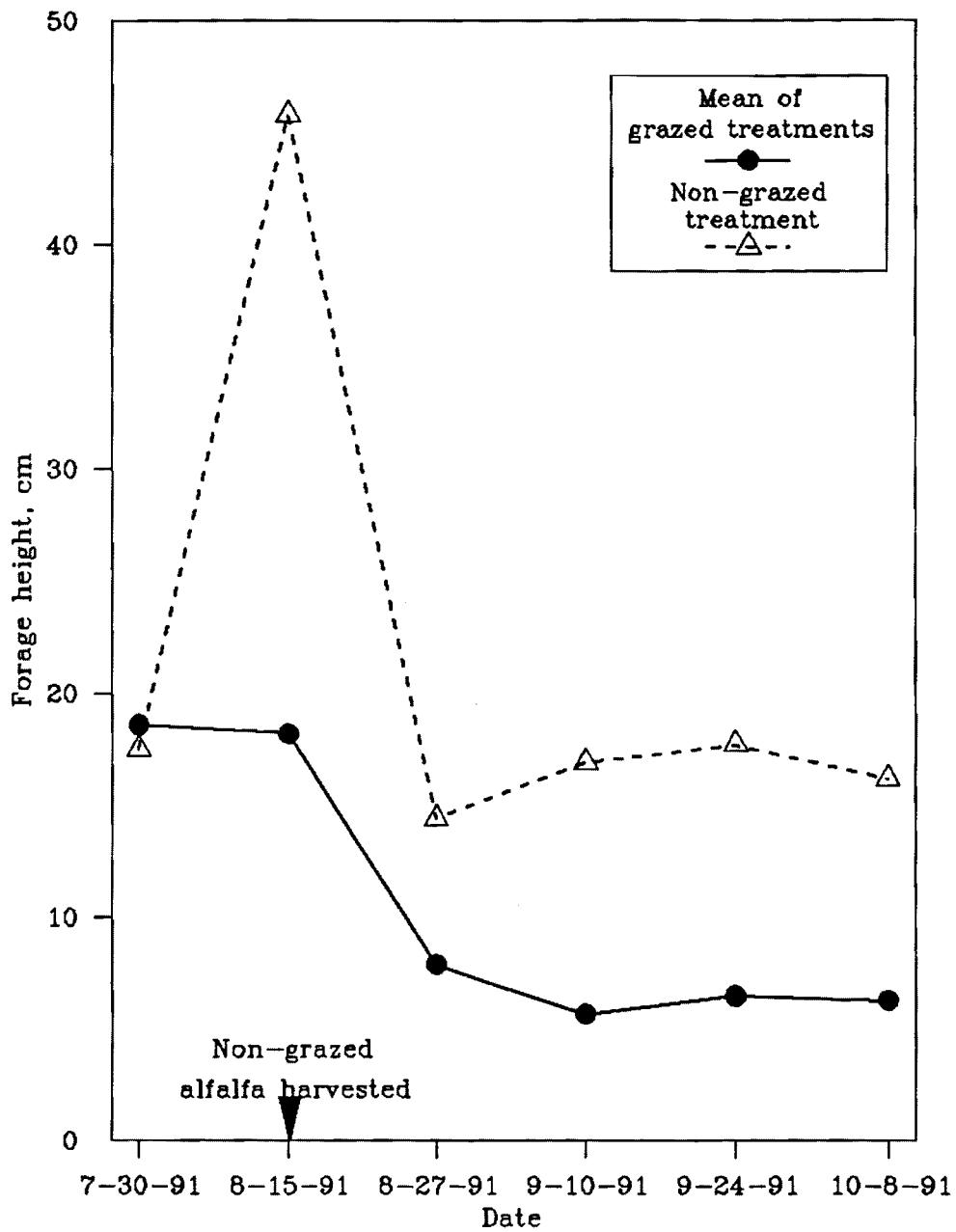


Figure 1. Alfalfa plant heights as influenced by grazing from initiation of grazing following the second hay harvest until grazing was discontinued in October (year 1).

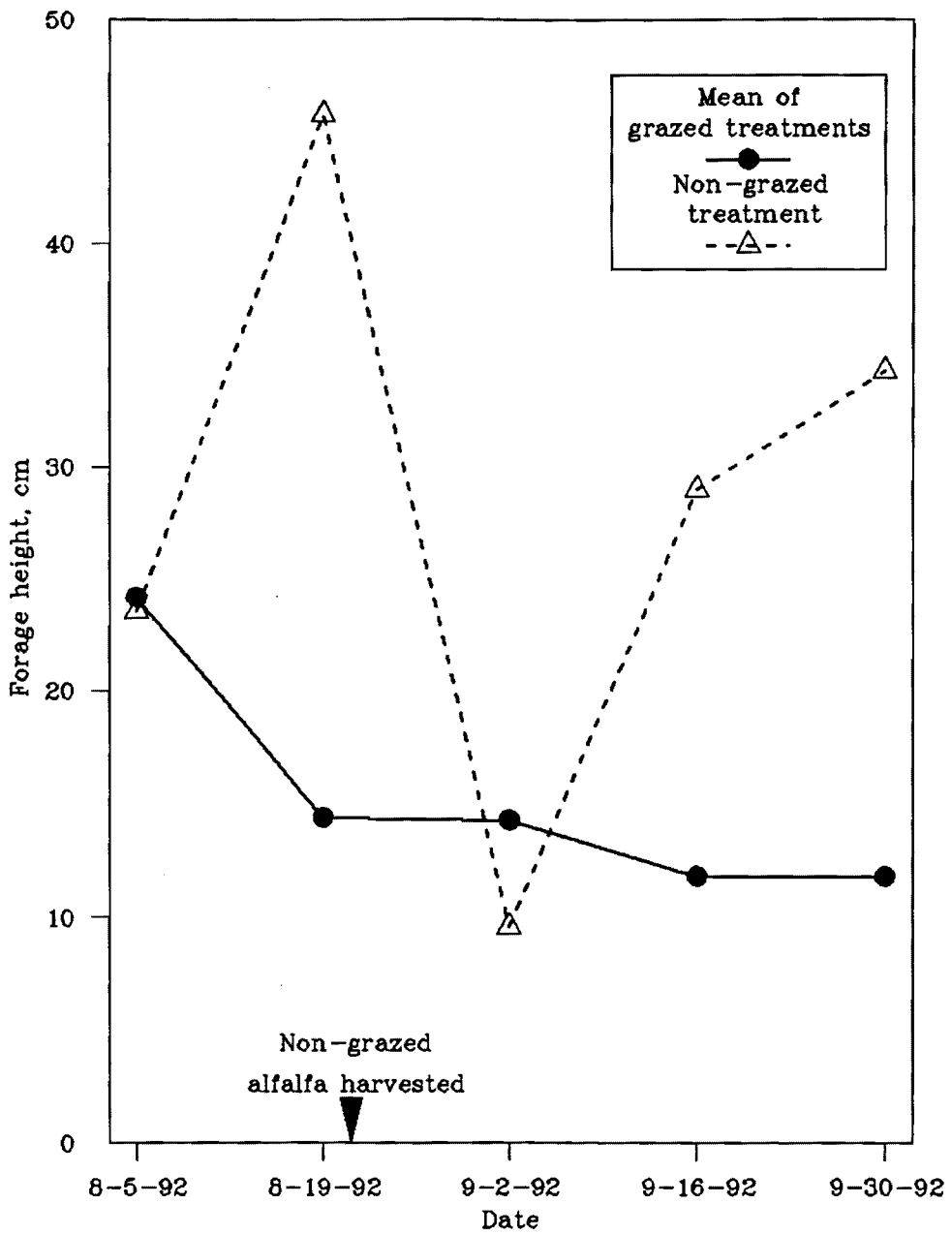


Figure 2. Alfalfa plant heights as influenced by grazing from initiation of grazing following the second hay harvest until grazing was discontinued in October (year 2).

to plots that had been disked in autumn (Trt. 6) prior to planting rye. Grazing until corn was planted (Trt. 2) resulted in less alfalfa present at corn harvest ($P < 0.05$) compared to the mean of the treatments where grazing occurred during a shorter time period (Trts. 3,4,5 and 6); however, this difference was due to alfalfa remaining in treatments that received either autumn application of glyphosate or autumn disking (Trts. 5 and 6) prior to rye planting. There was more ($P < 0.05$) alfalfa remaining at corn harvest for these two treatments compared to plots that received a spring application of glyphosate (Trts. 3 and 4). Virtually no alfalfa was present at the time of corn harvest in Treatments 1, 2, 3, and 4. When corn was harvested, fewer weeds other than alfalfa, were present in treatments that received autumn application of glyphosate or were disked (Trts. 5 and 6), compared to spring application of glyphosate (Trts. 3 and 4). Grazing prior to rye jointing in spring (Trt. 4) tended ($P < 0.07$) to reduce weeds by the time corn was harvested compared to discontinuing grazing the previous autumn (Trt. 3). When weeds and alfalfa were added together, there were no differences among treatments in total weeds.

At the beginning of each experimental year, there were no differences among treatments in number of alfalfa plants, but stand counts differed ($P < 0.05$) by year (Table 3). There were more plants per 0.25 m² present in yr 1 than yr 2 (15.7 vs 7.1, SE=0.6). At the end of the summer grazing season, just prior to rye planting, there were no differences due to treatment in alfalfa stands in yr 1. However, in yr 2, non-grazed alfalfa (Trt. 1) had more ($P < 0.05$) alfalfa plants per 0.25m², compared to grazed

Table 3. Influence of grazing, chemical, and mechanical treatments on survival of alfalfa plants.

Date	Event	Grazed						SE
		Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
				Glyphosate (3)	Glyphosate + grazing (4)	Glyphosate (5)	Disked (6)	
crowns 0.25m ²								
Year 1								
07-30-91 [†]	Pre-grazed	16.0	13.8	17.4	15.9	17.4	13.6	1.4
10-11-91 ^{†‡}	Pre-rye planting	8.3	7.9	10.8	8.1	10.1	10.4	1.0
04-28-92 ^{†‡#}	Pre-corn planting	8.8 ¹	2.8 ^c	7.5 ^{ab}	7.0 ^{abc}	3.5 ^{bc}	3.3 ^{bc}	1.0
07-07-92 ^{†‡##}	Post-corn planting	0.0 ^c	0.0 ^c	1.1 ^{bc}	0.6 ^c	2.5 ^a	2.3 ^{ab}	0.3
Year 2								
08-04-92 [†]	Pre-grazed	8.3	7.4	7.3	7.4	6.3	6.1	0.5
10-08-92 ^{†‡}	Pre-rye planting	7.8 ^a	6.6 ^{ab}	5.6 ^{ab}	5.8 ^{ab}	3.5 ^b	4.3 ^{ab}	0.9
05-05-93 ^{†‡#}	Pre-corn planting	3.0 ^a	1.5 ^{abc}	2.0 ^{ab}	2.3 ^a	0.0 ^c	0.5 ^{bc}	0.4
07-12-93 ^{†‡##††}	Post-corn planting	0.0 ^b	0.0 ^b	0.3 ^b	0.8 ^{ab}	0.5 ^{ab}	1.1 ^a	0.2

¹ Means with the same letter in a row are not significantly different at the 0.05 probability level as determined by Tukey's test.

[†] Effect of year (P < 0.05).

[‡] Year by treatment interaction (P < 0.05).

[‡] The non-grazed treatment (Trt. 1) differs from the mean of grazed treatments (Trts. 2, 3, 4, 5, and 6; P < 0.05).

¹ The mean of treatments with autumn suppression of standing crop (Trts. 5 and 6) differed from the mean of treatments with spring suppression of standing crop (Trts. 3 and 4; P < 0.05).

[#] Grazing until corn planting (Trt. 2) differed from the mean for shorter grazing periods (Trts. 3, 4, 5, and 6; P < 0.09).

^{††} Autumn chemical suppression of alfalfa (Trt. 5) differed from autumn mechanical suppression of alfalfa (Trt. 6; P < 0.05).

alfalfa (Trts. 2, 3, 4, 5, and 6; year by treatment interaction; $P < 0.05$). Immediately prior to planting corn, there were more ($P < 0.05$) alfalfa plants present in yr 1 than yr 2 across all treatments (5.5 vs 1.5, $SE = 0.3$). More ($P < 0.01$) alfalfa plants were present in the non-grazed treatment (Trt. 1) compared to the mean of the grazed treatments (Trts. 2, 3, 4, 5, and 6) in both years. Treatments with autumn destruction of cover crop (Trts. 5 and 6) had fewer alfalfa plants ($P < 0.01$) than treatments that received spring applications of glyphosate (Trts. 3 and 4). At this time, grazing until corn planting (Trt. 2) tended to result in fewer ($P < 0.09$) alfalfa plants per area than the mean of treatments where less grazing time occurred (Trts. 3, 4, 5, and 6). This tended to differ by year (year by treatment interaction; $P < 0.08$). This effect was observed ($P < 0.05$) in yr 1, but not in yr 2.

Nine weeks post corn planting, alfalfa plant populations differed ($P < 0.01$) by year and there was a year by treatment interaction ($P < 0.01$). The non-grazed treatment (Trt. 1) had less (none) alfalfa plants per area ($P < 0.01$) than the mean of the grazed treatments (Trts. 2, 3, 4, 5, and 6) during both years. The treatment with the long grazing period (Trt. 2) also had fewer (none) alfalfa plants ($P < 0.01$) than the mean of the treatments with less grazing (Trts. 3, 4, 5, and 6) during both years. For yr 1, this was largely due to more ($P < 0.01$) alfalfa remaining in plots that received autumn tillage or application of glyphosate (Trts. 5 and 6) compared with treatments that received glyphosate in the spring (Trts. 3 and 4). However, in yr 2, the alfalfa remaining in Treatments 3, 4, 5, and 6 was similar at this time. Also in yr 2, the treatment with

autumn glyphosate application (Trt. 5) had fewer ($P < 0.05$) alfalfa plants 9 wk post corn planting than the treatment that only received an autumn disking of the alfalfa (Trt. 6).

Total Nonstructural Carbohydrates (TNC). Averaged over treatments, TNC in alfalfa roots was similar in both years (Table 4). Grazing (Trts. 2, 3, 4, 5, and 6) lowered ($P < 0.01$) TNC in alfalfa roots by December in both years, compared to concentrations measured in roots of non-grazed alfalfa (Trt. 1). There were no other treatment effects observed.

Rye. Rye biomass at corn planting was similar among all treatments that were not grazed during the time that rye was growing (Trts. 1, 3, 5, and 6; Table 5). Grazing rye until corn planting (Trt. 2) reduced ($P < 0.05$) total rye biomass and plant heights at corn planting for both years (Figures 3 and 4). Grazing only until rye began jointing (Trt. 4) also lowered ($P < 0.05$) biomass and plant heights compared to plots where the rye was not spring grazed in both years (Trt. 3). The mean of treatments that received spring glyphosate application (Trts. 3 and 4) was lower ($P < 0.05$) in rye biomass at the time corn was planted compared to the mean of treatments that received autumn disking (Trt. 6) and autumn application of glyphosate (Trt. 5). During yr 1, this was due to the reduced biomass seen in Treatment 4. However, in yr 2, it was apparent that this was not solely due to the reduction in biomass by grazing.

Percentage N in rye differed by year ($P < 0.05$) and differed in magnitude for the treatments within year (year by treatment interaction; $P < 0.05$). During both years, percentage N was higher ($P < 0.05$) in rye that was grazed until corn planting (Trt.

Table 4. Influence of grazing, chemical and mechanical treatments on total nonstructural carbohydrates in alfalfa roots in December.

Date	Grazed						SE
	Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
			Glyphosate (3)	Glyphosate + grazed (4)	Glyphosate (5)	Disked (6)	
g 100g ⁻¹							
Year 1 [†]							
12-18-91 [†]	21.1	18.1	18.3	18.6	21.1	16.1	1.3
Year 2							
12-19-92 [†]	21.8 ^{a1}	16.7 ^{ab}	18.4 ^{ab}	19.4 ^{ab}	13.8 ^b	17.4 ^{ab}	1.6

¹ Means with the same letter in a row are not significantly different at the 0.05 probability level as determined by Tukey's test.

[†] The non-grazed treatment (Trt. 1) differs from the mean of grazed treatments (Trts. 2,3,4,5, and 6; P<0.01).

Table 5. Influence of grazing, chemical and mechanical treatments on rye dry mass and concentration of nitrogen in rye at corn planting.

Date		System					SE	
		Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
				Glyphosate (3)	Glyphosate + grazed (4)	Glyphosate (5)		Disked (6)
Year 1								
04-28-92	Rye, Mg ha ⁻¹ ††	5.1 ^{a1}	1.5 ^b	5.5 ^a	4.1 ^a	5.5 ^a	4.8 ^a	0.4
	N, % †††	2.1	2.8	2.1	2.3	2.3	2.3	0.2
	Total N, kg ha ⁻¹ ‡	106 ^a	40 ^b	117 ^a	93 ^a	122 ^a	110 ^a	7.0
05-05-93	Rye, Mg ha ⁻¹ †††	4.9 ^{ab}	1.4 ^c	5.0 ^{ab}	3.7 ^{bc}	6.4 ^a	5.4 ^{ab}	0.6
	N, % ††††	2.1 ^{bc}	2.9 ^a	1.9 ^{bc}	2.6 ^{ab}	1.7 ^c	1.6 ^c	0.2
	Total N, kg ha ⁻¹ ‡	101 ^a	35 ^b	95 ^a	95 ^a	106 ^a	83 ^{ab}	11.3

¹ Means with the same letter in a row are not significantly different at the 0.05 probability level as determined by Tukey's test.

† Grazing prior to rye jointing in spring (Trt. 4) differed from no spring grazing (Trt. 3; P < 0.05).

‡ Grazing until corn planting (Trt. 2) differed from the mean for shorter grazing periods (Trts. 3, 4, 5, and 6; P < 0.01).

§ The mean of treatments with autumn suppression of standing crop (Trts. 5 and 6) differed from the mean of treatments with spring suppression of standing crop (Trts. 3 and 4; P < 0.05).

† Effect of year (P < 0.05).

¶ Year by treatment interaction (P < 0.05).

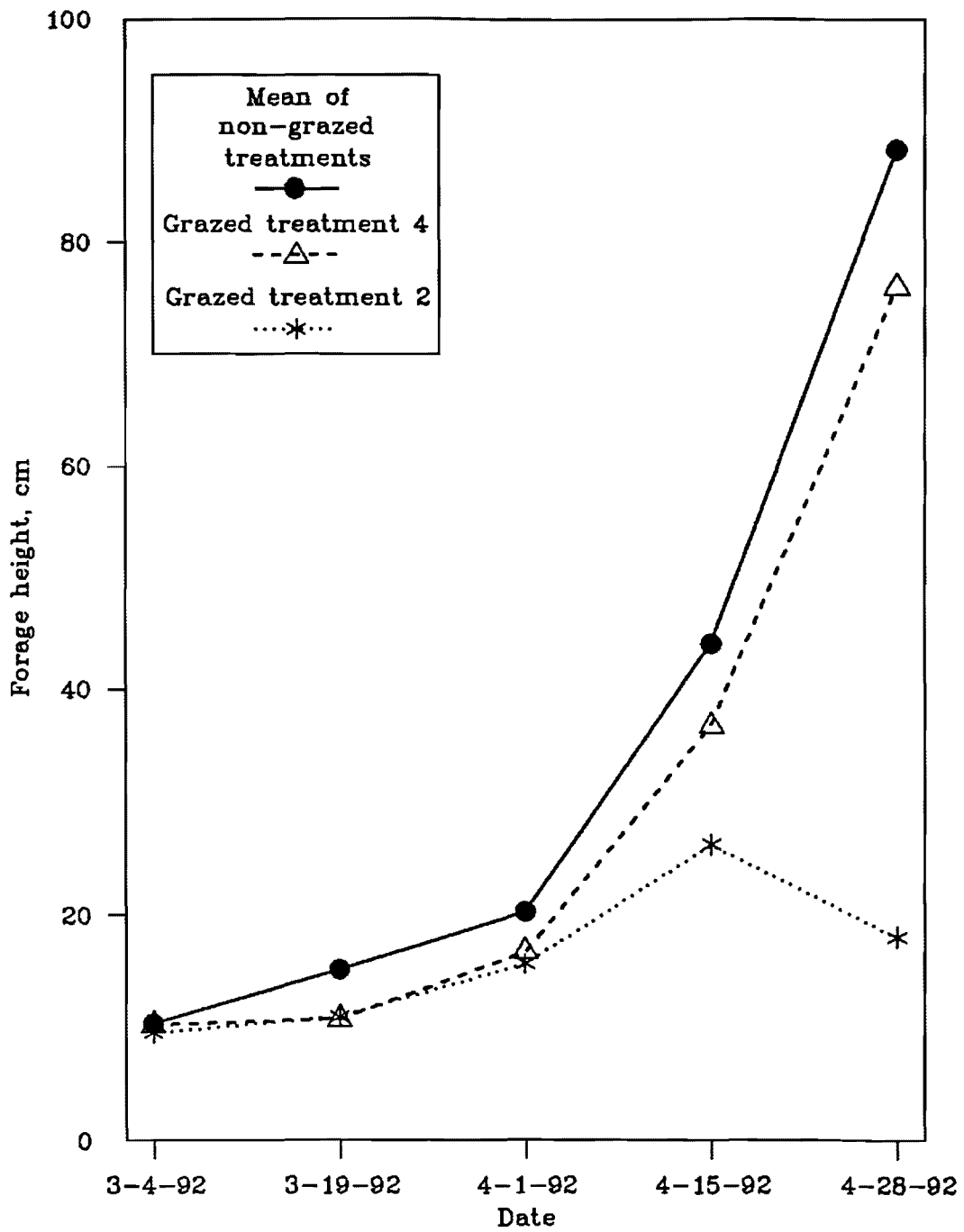


Figure 3. Rye plant heights as influenced by grazing from breaking of rye dormancy in spring until jointing (Trt. 4) or until corn planting (Trt. 2; year 1).

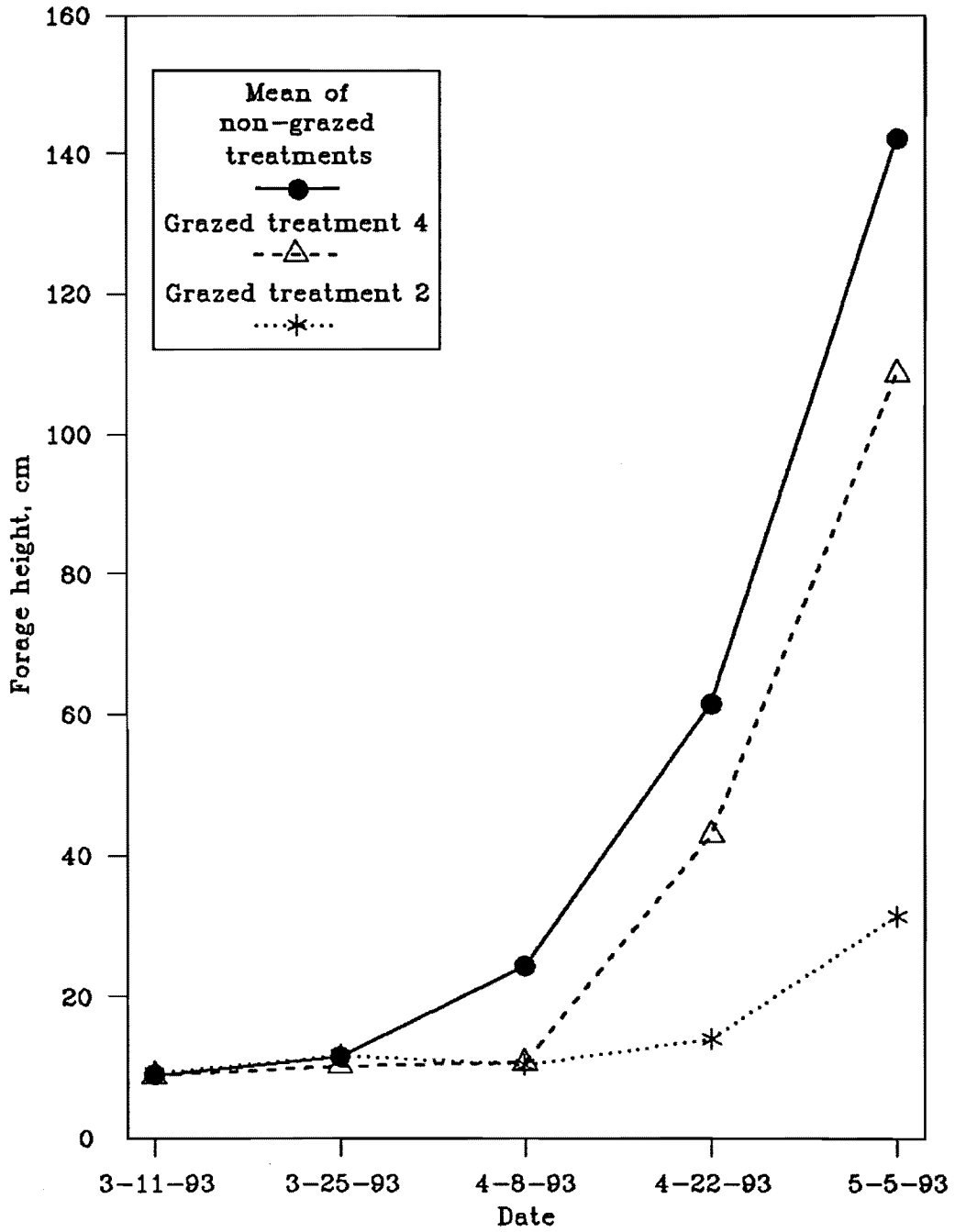


Figure 4. Rye plant heights as influenced by grazing from breaking of rye dormancy in spring until jointing (Trt. 4) or until corn planting (Trt. 2; year 2).

2) than the mean of the other grazed treatments (Trts. 3, 4, 5, and 6; Table 5). During yr 2 only, percentage N in the treatment that was grazed until rye began jointing in spring (Trt. 4) was higher compared to the treatment that was similar but not spring grazed (Trt. 3). Also during yr 2, the mean percentage N of treatments that received autumn disking or autumn glyphosate application (Trts. 5 and 6) was lower ($P < 0.05$) than the mean of treatments that received spring glyphosate application at corn planting (Trts. 3 and 4).

Total N in biomass, which was calculated by multiplying the dry matter by the percentage N, did not differ by year (Table 5). Total N in rye that was grazed until corn planting (Trt. 2) was lower ($P < 0.05$) than the mean of the other grazed treatments (Trts. 3, 4, 5, and 6).

Corn Plant Populations. Corn plant populations differed ($P < 0.05$) by year, with higher populations observed across all treatments in yr 2 compared to yr 1 (Table 6). In both years, grazing rye until corn planting (Trt. 2) resulted in higher ($P < 0.01$) corn plant populations than the mean of the treatments with shorter grazing periods (Trts. 3, 4, 5, and 6). Also, the mean of treatments with glyphosate application prior to corn planting (Trts. 3 and 4) had higher ($P < 0.01$) populations compared to the mean of treatments with autumn glyphosate application and autumn disking (Trts. 5 and 6)

Corn Plant Heights and Diameters. Nine weeks after corn planting, corn heights and diameters differed by year (treatment by year interaction; $P < 0.05$; Table 6). In both years, corn plant heights in plots with the extended grazing treatment (Trt. 2)

Table 6. Influence of grazing, chemical, and mechanical treatments on corn plant populations, heights and stalk diameters 9 weeks post-planting.

Date	Item	Grazed						SE
		Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
				Glyphosate (3)	Glyphosate + grazing (4)	Glyphosate (5)	Disking (6)	
Year 1								
06-10-92	Population, no. per 6m row ^{†††}	13.3 ^{bc1}	21.6 ^a	14.3 ^{bc}	17.6 ^{ab}	9.5 ^c	9.9 ^c	1.2
07-07-92	Height, cm ^{††††}	62.5 ^b	71.8 ^{ab}	66.3 ^{ab}	75.4 ^a	44.2 ^c	39.3 ^c	2.1
	Diameter, cm ^{††††}	2.96 ^a	2.35 ^b	3.23 ^a	3.22 ^a	1.25 ^c	1.24 ^c	0.1
Year 2								
06-24-93	Population, no. per 6m row ^{†††}	23.1	24.4	22.9	25.1	17.1	20.1	1.8
07-12-93	Height, cm ^{†††††}	161.9 ^a	76.5 ^b	172.5 ^a	177.9 ^a	94.5 ^b	73.2 ^b	5.6
	Diameter, cm ^{†††††}	2.89 ^{ab}	1.55 ^d	3.09 ^{ab}	3.19 ^a	2.63 ^b	2.07 ^c	0.1

¹ Means with the same letter in a row are not significantly different at the 0.05 probability level as determined by Tukey's test.

[†] Effect of year (P < 0.05).

[‡] Grazing until corn planting (Trt. 2) differed from the mean for shorter grazing periods (Trts. 3,4,5, and 6; P < 0.01).

[§] The mean of treatments with autumn suppression of standing crop (Trts. 5 and 6) differed from the mean of treatments with spring suppression of standing crop (Trts. 3 and 4; P < 0.01).

[¶] Year by treatment interaction (P < 0.05).

[#] Grazing prior to rye jointing in spring (Trt. 4) differed from no spring grazing (Trt. 3; P < 0.01).

^{††} The non-grazed treatment (Trt. 1) differs from the mean of grazed treatments (Trts. 2,3,4,5, and 6; P < 0.01).

^{†††} Autumn chemical suppression of alfalfa (Trt. 5) differed from autumn mechanical suppression of alfalfa (Trt. 6; P < 0.05).

differed ($P < 0.01$) from the mean of the treatments that received less grazing (Trts. 3, 4, 5, and 6). In yr 1, corn plants were taller ($P < 0.05$) when rye had been grazed until corn was planted (Trt. 2). However, in yr 2, this result was reversed and plants were shorter ($P < 0.05$) for this treatment, compared to the mean of other grazed treatments. In yr 1, grazing until rye jointing also resulted in taller corn plants compared to no spring grazing (Trt. 4 vs. 3) and there was a similar trend in yr 2. In both years, autumn destruction of the alfalfa (Trts. 5 and 6) resulted in shorter ($P < 0.05$) corn plant heights compared to the mean of treatments that received spring glyphosate application (Trts. 3 and 4). In yr 2, autumn application of glyphosate resulted in taller corn ($P < 0.05$) than where plots were disked on autumn. Also in yr 2, corn heights on the non-grazed (Trt. 1) plots differed from the mean of grazed treatments, but the actual corn plant heights for this treatment were numerically intermediate.

Corn stalk diameters also differed by year and a treatment by year interaction was observed ($P < 0.05$; Table 6). During both years, the mean of treatments with autumn glyphosate and disking (Trts. 5 and 6) was smaller ($P < 0.01$) in diameter than the mean of treatments that received spring glyphosate application (Trts. 3 and 4). Also during both years, the the stalk diameters for the non-grazed treatment (Trt. 1) differed ($P < 0.01$) from the diameters of mean of the other treatments (Trts. 2, 3, 4, 5, and 6), but as was observed for corn plant heights, the values were numerically intermediate for this treatment. For yr 2, further effects were seen. Stalk diameters in the extended grazing treatment (Trt. 2) were smaller ($P < 0.01$) than the stalk diameters from corn of

mean of the shorter grazing periods (Trts. 3, 4, 5, and 6). Furthermore, corn plants that grew where autumn glyphosate was applied to alfalfa (Trt. 5) had larger ($P < 0.05$) diameter stalks than corn where an autumn disking had occurred (Trt. 6) in yr 2 but no such difference occurred in yr 1.

Corn N and Mineral Concentrations. Percentage N in the corn ear leaf at silking differed ($P < 0.05$) by year (3.4 vs 3.1, $SE = .1$; Tables 7 and 8). Grazing until corn planting (Trt. 2) resulted in lower ($P < 0.05$) percentage N compared to the mean of treatments with less grazing (Trts. 3, 4, 5, and 6). Mineral concentrations of P, K, Ca, Mg, Zn, Cu, Na, and S all differed by year ($P < 0.05$), but differences among treatments were not consistent over years (year by treatment interaction; $P < 0.05$) for K, Ca, Mg, Fe, Cu, and S. No treatment differences were observed for Zn, Mn, or Na.

Corn grown where the rye cover crop was grazed until corn planting (Trt. 2) had lower ($P < 0.05$) P concentrations in ear leaf for both years compared to the mean of treatments that were grazed for shorter durations (Trts. 3, 4, 5, and 6). During yr 2, corn grown in Treatment 2 was also lower ($P < 0.05$) in K, Ca, Fe, and S compared to the other treatments.

Between the treatments that were rolled down in the spring (Trts. 5 and 6), ear leaf P was higher ($P < 0.05$) in the treatment that received an autumn glyphosate application (Trt. 5) compared to the treatment that received only an autumn disking (Trt. 6) during both years. In yr 2, corn grown where glyphosate was applied in autumn (Trt. 5) was also higher ($P < 0.05$) in Ca, Fe, Cu, and S than corn grown following disking

Table 7. Influence of grazing, chemical, and mechanical treatments on nitrogen and mineral concentrations in corn-ear leaf at silking on 19 July 1992 (Year 1).

Nutrient	Grazed						SE
	Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
			Glyphosate (3)	Glyphosate + grazing (4)	Glyphosate (5)	Disked (6)	
N, g 100g ^{-1†‡}	3.5	3.2	3.4	3.2	3.5	3.5	0.1
P, g 100g ^{-1†‡}	0.30	0.29	0.29	0.29	0.31	0.29	0.01
K, g 100g ^{-1††‡‡}	1.82 ^{a†}	1.69 ^a	1.83 ^a	1.85 ^a	1.40 ^b	1.45 ^b	0.05
Ca, g 100g ^{-1†††}	0.40	0.41	0.39	0.40	0.44	0.44	0.01
Mg, g 100g ^{-1††††}	0.29 ^b	0.34 ^{ab}	0.32 ^{ab}	0.33 ^{ab}	0.38 ^a	0.36 ^{ab}	0.02
Zn, mg kg ^{-1†}	39.7	33.3	32.9	33.2	41.1	36.0	2.2
Mn, mg kg ⁻¹	48.6	49.6	49.0	47.3	42.9	39.0	3.6
Fe, mg kg ^{-1††}	106.7	102.8	100.4	97.1	106.2	106.9	2.6
Cu, mg kg ^{-1†††}	9.0	8.7	8.3	8.3	9.5	9.7	0.4
Na, mg kg ^{-1†}	6.0	6.6	6.6	7.9	7.4	9.5	1.1
S, g 100g ^{-1††††}	0.21	0.21	0.21	0.20	0.21	0.21	0.01

¹ Means with the same letter in a row are not significantly different at the 0.05 probability level as determined by Tukey's test.

[†] Effect of year ($P < 0.05$).

[‡] Grazing until corn planting (Trt. 2) differed from the mean for shorter grazing periods (Trts. 3,4,5, and 6; $P < 0.05$).

[§] Autumn chemical suppression of alfalfa (Trt. 5) differed from autumn mechanical suppression of alfalfa (Trt. 6; $P < 0.05$).

[†] Year by treatment interaction ($P < 0.05$).

[#] The non-grazed treatment (Trt. 1) differs from the mean of grazed treatments (Trts. 2,3,4,5, and 6; $P < 0.05$).

^{††} The mean of treatments with autumn suppression of standing crop (Trts. 5 and 6) differed from the mean of treatments with spring suppression of standing crop (Trts. 3 and 4; $P < 0.05$).

Table 8. Influence of grazing, chemical, and mechanical treatments on nitrogen and mineral concentrations in corn-ear leaf at silking on 30 July 1993 (Year 2).

Nutrient	Grazed						SE
	Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
			Glyphosate (3)	Glyphosate + grazed (4)	Glyphosate (5)	Disked (6)	
N, g 100g ^{-1†‡}	3.1 ^{ab}	2.9 ^b	3.0 ^{ab†}	3.1 ^{ab}	3.3 ^a	3.0 ^{ab}	0.1
P, g 100g ^{-1†‡‡}	0.25 ^{ab}	0.23 ^b	0.26 ^a	0.26 ^a	0.26 ^{ab}	0.23 ^b	0.01
K, g 100g ^{-1†††}	1.73 ^{ab}	1.58 ^b	1.78 ^{ab}	1.93 ^a	1.73 ^{ab}	1.81 ^{ab}	0.07
Ca, g 100g ^{-1†††††}	0.42 ^a	0.36 ^b	0.41 ^a	0.42 ^a	0.39 ^{ab}	0.34 ^b	0.01
Mg, g 100g ^{-1††††}	0.33	0.32	0.31	0.29	0.26	0.25	0.02
Zn, mg kg ^{-1†}	33.1	26.8	32.8	33.8	32.7	29.5	2.1
Mn, mg kg ⁻¹	48.4 ^{ab}	36.0 ^b	48.9 ^a	49.6 ^a	44.0 ^{ab}	46.4 ^{ab}	2.8
Fe, mg kg ^{-1†††††}	102.8 ^{ab}	92.1 ^b	111.4 ^a	106.9 ^a	110.2 ^a	94.1 ^b	2.6
Cu, mg kg ^{-1†††}	8.4	7.8	8.0	9.1	8.8	7.3	0.4
Na, mg kg ^{-1†}	15.0	15.2	14.7	14.3	16.9	15.2	2.6
S, g 100g ^{-1††††}	0.18 ^{ab}	0.16 ^b	0.18 ^{ab}	0.19 ^a	0.19 ^a	0.17 ^{ab}	0.01

¹ Means with the same letter in a row are not significantly different at the 0.05 probability level as determined by Tukey's test.

[†] Effect of year ($P < 0.05$).

[‡] Grazing until corn planting (Trt. 2) differed from the mean for shorter grazing periods (Trts. 3,4,5, and 6; $P < 0.05$).

[§] Autumn chemical suppression of alfalfa (Trt. 5) differed from autumn mechanical suppression of alfalfa (Trt. 6; $P < 0.05$).

[¶] Year by treatment interaction ($P < 0.05$).

[#] The non-grazed treatment (Trt. 1) differs from the mean of grazed treatments (Trts. 2,3,4,5, and 6; $P < 0.05$).

^{††} The mean of treatments with autumn suppression of standing crop (Trts. 5 and 6) differed from the mean of treatments with spring suppression of standing crop (Trts. 3 and 4; $P < 0.05$).

in autumn (Trt. 6).

Less consistency in mineral concentration was observed where the non-grazed control (Trt. 1) that received herbicide applications in the spring was compared to the mean of all other treatments that were grazed. During yr 1, corn in Treatment 1 was higher ($P < 0.05$) in concentration of K but lower ($P < 0.05$) in Mg compared to the other treatments,. For yr 2, Treatment 1 was higher ($P < 0.05$) in Ca than the mean of the grazed treatments, but no other effects of this treatment were observed in the second year.

When treatments that received autumn glyphosate and autumn disking (Trts. 5 and 6) and were also rolled down in the spring were compared to the treatments that were killed by spring glyphosate application (Trts. 4 and 7), treatment effects differed by year. During yr 1, corn from Treatments 5 and 6 were higher ($P < 0.05$) in concentrations of Ca, Mg, Fe, Cu, and S, but lower ($P < 0.05$) in K compared to corn from Treatments 3 and 4. However, during yr 2, concentrations of Ca, Mg, and Fe were lower ($P < 0.05$) in corn from Treatments 5 and 6 compared to Treatments 3 and 4 which is opposite of the effect observed in yr 1.

Corn Harvest. Corn harvest data for yr 1 are presented here (Table 9). Corn height at harvest from the non-grazed treatment (Trt. 1) was taller ($P < 0.05$) and had a higher dry matter yield than the mean of the other treatments (Trts. 2, 3, 4, 5, and 6). However, this was due to the reduced corn plant heights and yields resulting from Treatments 5 and 6. Numerically, the non-grazed control (Trt. 1) was similar to results

Table 9. Influence of grazing, chemical, and mechanical treatments on plant height, percentage dry matter, dry matter yield, and percentage ear of corn at harvest in yr 1.

Date	Variable	Grazed						SE
		Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
				Glyphosate (3)	Glyphosate + grazed (4)	Glyphosate (5)	Disked (6)	
Year 1								
09-18-92	Height, m ^{††}	2.8 ^{ab}	2.4 ^{bc}	2.8 ^a	2.8 ^a	2.3 ^{cd}	2.0 ^d	0.2
	Dry matter, % [‡]	42.4 ^{ab}	40.8 ^{abc}	43.6 ^a	42.6 ^{ab}	38.9 ^{bc}	37.1 ^c	0.9
	Yield, Mg ha ^{-1†††}	23.1 ^a	23.9 ^a	23.0 ^a	25.7 ^a	8.6 ^b	9.9 ^b	2.0
	Percentage ear ^{††}	55.3 ^{bc}	63.5 ^a	52.0 ^c	52.7 ^c	60.8 ^{ab}	57.3 ^{abc}	1.7

[†] Means with the same letter in a row are not significantly different at the 0.05 probability level as determined by Tukey's test.

^{††} The non-grazed treatment (Trt. 1) differs from the mean of grazed treatments (Trts. 2,3,4,5, and 6; P<0.05).

[‡] Autumn chemical suppression of alfalfa (Trt. 5) differed from autumn mechanical suppression of alfalfa (Trt. 6; P<0.05).

^{†††} The mean of treatments with autumn suppression of standing crop (Trts. 5 and 6) differed from the mean of treatments with spring suppression of standing crop (Trts. 3 and 4; P<0.01).

^{††††} Grazing until corn planting (Trt. 2) differed from the mean for shorter grazing periods (Trts. 3,4,5, and 6; P<0.01).

obtained with spring application of glyphosate (Trts. 3 and 4). The corn plant heights, percentage dry matter, and yield for the mean of treatments that received spring glyphosate application (Trts. 3 and 4) were higher ($P < 0.01$) than the mean of treatments receiving autumn cover destruction (Trts. 5 and 6). Among these treatments autumn glyphosate application (Trt. 5) resulted in taller ($P < 0.05$) corn plants than autumn disking (Trt. 6). At corn harvest, yield and percentage ear were higher ($P < 0.01$) when maximum grazing (Trt. 2) was imposed, compared to the mean of the treatments with less grazing (Trts. 3, 4, 5, and 6), due primarily to the lower performance of corn that received autumn disking or glyphosate followed by spring roll down of rye (Trts. 5 and 6). However, visual observation of corn growth prior to harvest in yr 2 indicate that this result may not be consistent between years.

Soil Bulk Density. Soil bulk density differed from yr 1 to yr 2 (effect of year; $P < 0.05$), but treatment effects were similar for both years (Table 10). Soil bulk density was not different among any of the treatments at the initiation of summer grazing of alfalfa for both years. Bulk density taken in Dec. and 9 wk after corn planting was lower ($P < 0.05$) for the autumn disked treatment (Trt. 6) compared to the autumn glyphosate killed treatment (Trt. 5). The extended grazing treatment (Trt. 2), which was also disked in autumn, tended to be lower ($P < 0.06$) in bulk density than the mean of the other grazed treatments (Trts. 3, 4, 5, and 6) when measured during winter. However, when measured 9 wk after corn was planted, soil bulk density was higher ($P < 0.05$) were grazing continued until corn was planted (Trt. 2) compared to the mean of shorter

Table 10. Influence of grazing, chemical and mechanical treatments on soil bulk density, prior to grazing, in December, and 8 weeks post-planting of corn.

Date	Event	Grazed						SE
		Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
				Glyphosate (3)	Glyphosate + grazed (4)	Glyphosate (5)	Disked (6)	
g cm ⁻³								
Year 1								
07-30-91 [†]	Pre-grazed	1.33	1.34	1.36	1.37	1.31	1.34	0.03
12-18-91 ^{††††}	Winter	1.24 ^{ab†}	1.15 ^b	1.27 ^{ab}	1.29 ^a	1.25 ^{ab}	1.17 ^{ab}	0.03
07-02-92 ^{††††#}	Post-corn planting	1.29 ^{ab}	1.32 ^a	1.28 ^{ab}	1.34 ^a	1.26 ^{ab}	1.23 ^b	0.02
Year 2								
08-04-92 [†]	Pre-grazed	1.26	1.25	1.24	1.25	1.30	1.29	0.02
12-19-92 ^{††††}	Winter	1.25 ^{ab}	1.19 ^b	1.30 ^a	1.29 ^a	1.31 ^a	1.19 ^b	0.02
07-12-93 ^{††††#}	Post-corn planting	1.22	1.25	1.22	1.26	1.25	1.18	0.02

[†] Means with the same letter in a row are not significantly different at the 0.05 probability level as determined by Tukey's test.

[†] Effect of year (P < 0.05).

[‡] Autumn chemical suppression of alfalfa (Trt. 2) differed from autumn mechanical suppression of alfalfa (Trt. 6; P < 0.05).

[§] Grazing until corn planting (Trt. 1) differed from the mean for shorter grazing periods (Trts. 2, 4, 5, and 6; P < 0.06).

[¶] The mean of treatments with autumn suppression of standing crop (Trts. 2 and 6) differed from the mean of treatments with spring suppression of standing crop (Trts. 4 and 5; P < 0.01).

[#] Grazing prior to rye jointing in spring (Trt. 5) differed from no spring grazing (Trt. 4; P < 0.05).

grazing periods (Trts. 3, 4, 5, and 6). Soil bulk density for the mean of treatments with autumn cover kill (Trts. 5 and 6) was lower ($P < 0.01$) at both dates than the mean of treatments that received spring glyphosate application (Trts. 3 and 4). Soil bulk density was also higher ($P < 0.05$) where rye was grazed until jointing (Trt. 4) compared to the similar treatment that received no spring grazing (Trt. 3) when measured 9 wk after corn was planted. Furthermore, grazing one time during spring prior to rye jointing (Trt. 4) resulted in numerical soil bulk density values that were higher than those observed when grazing was maximized (Trt. 2).

Soil Moisture. Soil moisture differed ($P < 0.05$) by year, but did not differ among any treatment in either year (Table 11). Soil moisture averaged 28.5 and 26.1 g 100 g⁻¹ (SE=0.4) for yr 1 and 2, respectively.

Soil Fertility. Soil fertility that was measured at the initiation of grazing of alfalfa differed ($P < 0.05$) by year, but did not differ among treatments (Appendix Tables 2 and 5). At the time rye was planted, mineral concentrations again differed ($P < 0.05$) by year, but did not differ among treatments (Appendix Tables 3 and 6). The only treatment difference that occurred at this time was the treatment that received no spring grazing of rye (Trt. 3) which was higher in B compared to the treatment that did receive spring grazing prior to rye jointing in spring.

Nine weeks post corn planting, treatment differences in soil fertility were observed (Appendix Tables 4 and 7). Differences due to year ($P < 0.05$) were observed for pH, organic matter, Zn, Mn, Fe, Al, Cu, and B. The pH was higher across all

Table 11. Influence of grazing, chemical and mechanical treatments on percentage soil moisture determined 9 weeks post-planting of corn.

Date	Grazed						SE
	Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
			Glyphosate (3)	Glyphosate + grazed (4)	Glyphosate (5)	Disked (6)	
%							
Year 1							
07-07-92 [†]	29.4	28.0	29.0	27.2	28.6	28.7	0.8
Year 2							
07-12-93 [†]	25.3	25.3	26.4	24.7	28.3	26.7	1.3

[†] Effect of year (P < 0.05).

treatments in yr 1, compared to yr 2 (6.8 vs 6.7, SE=0.02), while organic matter was higher in yr 2 compared to yr 1 (4.0 vs 4.3, SE=0.06). Manganese, Fe, Al, and Cu were higher in yr 1, while Zn and B were higher in soils during yr 2.

The most consistent differences occurred between the treatment that was grazed until rye began jointing (Trt. 4), which was lower ($P < 0.05$) in Ca and Mg during both years compared to the similar treatment that was not spring grazed (Trt. 3). Also, grazing until corn was planted (Trt. 2) resulted in higher ($P < 0.05$) concentrations in soil Mn and B during both years.

Discussion

The lack of differences in alfalfa biomass and plant populations at the time grazing began in each year was expected, since no previous treatments had been applied (Tables 2 and 3). The influence of grazing on alfalfa biomass present at the time rye was planted was similar between the 2 yr with the non-grazed treatment having more alfalfa biomass present than the grazed treatments, even though the years differed greatly in the amount of rainfall. Over all treatments, alfalfa plant populations were lower for yr 2 compared to yr 1 at all dates measured. This was probably due to a combination of increasing age of the stand and the extreme moisture stress alfalfa received during the summer of 1991. Alfalfa was in its third growing season when this experiment was initiated. Year 2 of the experiment had an excellent growing season with 62.2 cm of rainfall from June through Oct. compared to yr 1, when only 17.3 cm were recorded in this interval.

The grazing-induced reduction in alfalfa plant numbers observed immediately prior to planting corn during both years is in agreement with Brownlee (1973), who found that increasing grazing frequency decreased alfalfa survival. Grazing had little effect on alfalfa populations prior to planting rye in yr 1. This may have been partially

due to the dry weather and lack of alfalfa growth which shortened grazing periods. This may also have been due to drought-induced dormancy of alfalfa. Barnes and Sheaffer (1985) found that alfalfa does become dormant under severe drought. Dormancy lasts until moisture increases enough for growth. During yr 2, grazing reduced alfalfa plant numbers by the time rye was planted. Alfalfa grew actively during yr 2. The extended grazing period may have exhausted more TNC reserves from alfalfa plants decreasing their persistence in yr 2. However, when measured in Dec., the TNC was not different between years (Table 4), only among treatments. The non-grazed treatment remained higher in TNC content than the grazed treatments for both years. Wolf and Allen (1990) found TNC in alfalfa roots, where alfalfa had been grazed for 40 d in spring or 21 d in summer, was similar to alfalfa managed for hay, when measured at the end of the growing season in Oct. Regardless of whether or not dormancy of alfalfa reduced the effects of grazing, TNC was reduced in alfalfa roots in Dec. and alfalfa plant populations were reduced by the time corn was planted, compared to non-grazed plots and this was consistent over both years.

Disking and application of glyphosate in autumn reduced alfalfa plant crown numbers in both years by the time corn was planted, but were more effective when moisture was adequate. Glyphosate is most effective when alfalfa is actively growing (Kempen et al., 1991). This probably explains why treatment with glyphosate (Trt. 5) showed visible signs of killing alfalfa in yr 2, whereas in yr 1, glyphosate had little visible effect on the alfalfa. At corn planting, alfalfa control by autumn application of

glyphosate was virtually 100 percent in yr 2.

Dicamba or glyphosate applied in spring both provided excellent control of alfalfa (Trts. 1, 2, 3, and 4). Alfalfa was a major weed problem in yr 1 on corn plots that received an autumn application of glyphosate or autumn disking (Trts. 5 and 6), combined with a rolldown of rye in spring. Although total weed biomass at harvest was not different among treatments, 71 and 53% of weed biomass for these treatments consisted of alfalfa, while alfalfa content was negligible in treatments that received herbicides in the spring. When visual evaluations by the Double DAFOR Method (Brodie, 1985 as modified by Abaye, 1992) were performed to estimate relative frequency of weeds, less alfalfa was seen in yr 2 compared to yr 1. Thus, when alfalfa was visually evaluated in June of yr 2 alfalfa frequency was observed to be "occasional" for Treatments 5 and 6, compared to yr 1, when frequency of alfalfa on Treatments 5 and 6 was "abundant". Thus, alfalfa should not be as prominent a weed in yr 2 on Treatments 5 and 6 at harvest.

Rye and hairy vetch were planted in late Oct. for yr 1, because of the dry growing season and in mid-Oct. for yr 2. Originally, the rye and hairy vetch were to be grazed in the fall for several of the treatments. However, the rye only grew to an average of 10 cm before ceasing growth due to cold weather. The hairy vetch was planted on treatments which were autumn disked (Trts. 2 and 6) and received autumn application of glyphosate (Trt. 5). However, the hairy vetch just emerged with an average height of 3 cm before winter and did not produce a significant amount of

biomass even at corn planting. Overall, there was not enough biomass to graze in autumn. The rye and hairy vetch remained at this height with no fluctuation until mid-March for both years. In the Mountain-Valley region of Virginia, little growth of rye or hairy vetch is expected during autumn and winter.

By visual evaluation, hairy vetch remained only occasional to frequent in occurrence prior to corn planting and was estimated to be less than 10% of the total biomass present at corn planting. Therefore, hairy vetch was not considered to be a contributing factor in treatment effects.

Rye was seeded at a lower rate on treatments that received autumn disking and autumn application of glyphosate than for the conventional treatment and the treatments that received spring applications of glyphosate (Trts. 1, 3, and 4). However, the treatments that received autumn disking or autumn glyphosate on the alfalfa (Trts. 5 and 6) were higher ($P < 0.05$) in rye biomass at corn planting than the treatments that received spring glyphosate (Trts. 3 and 4). Treatment 4 biomass was reduced by grazing, but when compared by Tukey's test, Treatment 5 was numerically higher in biomass than Treatment 3, which was not grazed and was planted with a higher rate of rye. This could be due to the reduced vigor of the alfalfa, that could no longer compete as effectively with the rye. Also, some of the alfalfa was killed and may have begun to mineralize and contribute extra N to the rye.

The grazing-induced reduction in rye biomass at the time corn was planted (Table 5) was anticipated. However grazing even under the more prolonged and intense grazing

imposed during yr 2, did not completely kill rye, and some regrowth occurred after grazing was discontinued.

The higher percentage N in the remaining rye following grazing until corn was planted (Trt. 2) could have been due to a change in morphology of the rye so that more leaf than stem was sampled. Leaves generally have a higher percentage N than stems (Olson, 1982). Percentage N in the rye was highest for the maximum grazed treatment (Trt. 2). Also, the grazing animals may have contributed to the increased N through recycling of N in urine and feces. Doak (1952) found improved growth of forages for an area nearly twice the size of a urine patch. Furthermore, under grazing and defoliation, regrowth of rye would have resulted in a younger growth stage. Percentage N is known to decrease with advancing maturity (Olson, 1982).

In yr 1, plots that were grazed only until rye began jointing (Trt. 4) did not differ in percentage N, but these plots were grazed only for 1 d. In yr 2, rye was continuously grazed as forage was available until jointing and did have a higher percentage N, although not as high as the maximum grazed treatment. The longer grazing time and more effective removal of the rye cover in yr 2 probably altered rye morphology and contributed to recycling of N.

When N was expressed as uptake or kg N ha^{-1} , total N was lowest in rye that was grazed until corn planting. This meant that less N was tied up in the above ground biomass. This would indicate that less N would have to be released from biomass to be available for corn growth during the growing season. Furthermore, grazing would be

expected to recycle N back to soil through urine and feces. Nitrogen in urine is largely present as urea and should be readily available for corn growth. However, percentage N in the corn ear leaf at silking was lower ($P < 0.05$) in corn where grazing continued until corn planting (Trt. 2), compared to the other grazed treatments. Sampling the corn ear leaf at silking is a recommended sampling technique to determine the nutrient status of corn, as it is correlated to soil, fertilizer availability, and yield (Westerman, 1990).

This lower percentage N in the ear leaf was consistent over both years and occurred in spite of applications of manure and 100 kg N ha^{-1} applied as fertilizer N. Lower N in ear leaf at silking appeared to indicate that less N was available for corn growth. In yr 2, corn for this treatment was short and stunted compared to its higher productivity in yr 1. Stressed plants can show a higher concentration of minerals even in the presence of a deficiency due to concentration effects, but this did not occur. Since the N was not tied up in rye biomass, and did not appear to be present in the soil within the active root area, or at least was not taken up, it may have been subject to loss through leaching or volatilization. The fate of N under these conditions needs further investigation. Although not significantly different, N concentrations in ear leaf samples of corn where spring grazing occurred prior to rye jointing (Trt. 4), was numerically lower compared to corn grown when spring grazing did not occur (Trt. 3). Whether or not the increased soil compaction that resulted from spring grazing for the two spring-grazed treatments could have influenced N availability and uptake by corn is not clear. The increased number of corn plants per area that resulted from spring grazing could

have been a factor, since there were more plants present to use a given supply of N.

Mineral concentrations in corn ear leaf at silking were somewhat variable, but some consistent effects were observed. Maximum grazing prior to corn planting resulted in lower P concentration in the corn ear leaf for both years. This treatment as discussed above also resulted in reduced N concentration. Phosphorus would not be lost through leaching or volatilization as would N, thus plant uptake of these minerals appeared somehow limited, perhaps through surface soil compaction caused by the increased grazing in these treatments. The autumn disked treatment (Trt. 6) also resulted in lower ($P < 0.05$) P than plots that received autumn glyphosate application (Trt. 5). The maximum grazed treatment (Trt. 2) was also disked in autumn and was numerically similar to the autumn disked treatment (Trt. 6). Grazing during spring prior to rye jointing resulted in similar soil compaction as was observed for the maximum grazed treatment (Trt. 2), and more compaction than the similar non spring grazed treatment (Trt. 3). No difference in ear leaf P concentration was found between Treatments 3 and 4. Thus, increased soil bulk density was probably not the cause. The non-grazed conventional treatment was not different in corn ear leaf mineral concentration when compared to all the other grazed treatments and was numerically similar to the plots that received spring glyphosate application.

Mineral concentrations decrease with increasing physiological maturity (Westerman, 1990). Since the corn plants on the treatments that received a spring roll down of rye were later maturing compared to the other treatments, it is reasonable that

they should contain higher concentrations of some nutrients. During both years, silking occurred approximately 1 wk later on plots that received spring roll down compared to plots that did not. Other differences observed in mineral concentration in the ear leaf at silking were inconsistent and no conclusions were drawn.

The lack of differences for soil bulk density at the beginning of the trial was expected since this land had been treated as hay land prior to the beginning of the trial. It was also expected that surface soil bulk density would decrease with disking as was seen on the maximum grazed treatment (Trt. 2) and the treatment that received no herbicides (Trt. 6) for both years. At 9 wk post-corn planting the autumn disked treatment that had no spring grazing (Trt. 6) had the same surface soil bulk density as was observed 7 mo prior to this. Other mechanical operations such as the roll down and planting did not significantly increase the surface bulk density. The other fall disked treatment (Trt. 2) did show an increase in soil bulk density from Dec. to July due to grazing. The only differences between these two treatments was spring grazing that occurred for treatment 2 and an application of dicamba. However, this increase in bulk density appeared to be due to grazing. It is interesting to note that when soil bulk density was measured 9 wk post corn planting, the bulk density was effectively the same where plots were grazed in spring (Trts. 2 and 4). This occurred even though Treatment 2 was grazed an average of 2 and 11 d for yrs 1 and 2, respectively, and Treatment 4 was grazed for only 1/2 and 3 days, respectively. The higher soil moisture in spring as compared to summer probably increased the susceptibility of the soil to compaction. It

is also interesting to note that this increase in soil bulk density did not prevent corn plant emergence, since these two treatments were highest in plant populations. Increase in soil bulk density due to grazing has been reported by Krenzer et al. (1989), Worrell et al. (1992), and Van Havern (1983).

Soil moisture as measured in this experiment was not a good indicator of moisture available to corn plants for growth. Under the drier conditions of yr 2, corn in the conventional treatment showed signs of leaf roll before this was observed for corn in Treatments 3 and 4, even though there was no indicated difference in soil moisture. Only the surface soil moisture was measured along with the bulk density measurement at 9 wk post-planting. During yr 1, moisture was adequate throughout the growing season. During yr 2, 1.3 cm of rain fell during the week prior to sampling. Thus a more adequate measure of soil moisture, taken more frequently and at deeper levels may have been helpful.

The dominant weeds observed throughout the experiment on the treatment plots were wild mustard (*Brassica kaber* (DC.) Wheeler), horsenettle (*Solanum carolinense* L.), and common chickweed. Warm-season grassy weeds were also a dominant weed type seen throughout corn growth. Warm season grasses observed were nimblewill (*Muhlenbergia schreberi* J.F. Gmelin), bermudagrass (*Cynodon dactylon* (L.) Pers.), and large crabgrass (*Digitaria sanguinalis* (L.) Scop.). Cool-season grasses observed were tall fescue (*Festuca arundinacea* Schreb.), Kentucky bluegrass (*Poa pratensis* L.), and orchardgrass.

Grazing did increase corn plant populations in both years (Table 6). This was probably due to the decrease of above ground biomass. The corn planter had difficulty cutting through the heavy rye cover on non-spring grazed plots. Poor seed-soil contact was observed on several of the plots. Decreased corn populations were also reported by Eckert (1988), Mitchell and Teel (1977), and Sullivan (1990) in response to higher cover crop biomass. It is interesting to note that corn populations were improved even when spring grazing of rye occurred prior to jointing and was of very short duration. Grazing in yr 1 and 2 for this treatment lasted for 1/2 and 3 d, respectively.

The lower plant stands in our experiment that occurred in treatments with high rye biomass could also have been caused by an allelopathic effect of rye on the corn. Allelopathy by a rye cover crop was suspected by Raimbault et al. (1990) as a factor in reduced corn plant stands. Barnes and Putnam (1986) also discussed allelopathic effects of rye inhibiting corn growth in heavy soils.

During yr 1, corn plants from plots that received autumn glyphosate or autumn disking of alfalfa (Trts. 5 and 6) remained short and stunted throughout the growing season. This appeared to be due to extreme competition for light and moisture from the rolled down rye and the unkilld alfalfa. The rye was rolled down in yr 1 with a hand-operated turf roller. The roller did not damage the base of the stem, the rye did not remain flattened, and did not die until mid-June. Rye competed with corn for light, moisture, and nutrients. In yr 2, rye was rolled down with a tractor-operated disk roller developed by the Agricultural Engineering Dept. Year 2 roll down was very successful

in that the rye remained flattened, but it still did not die quickly and apparently continued to remove moisture and nutrients from the soil. Although somewhat better than in yr 1, corn growth on these two treatments during yr 2 was also short and stunted even though the roll down technique was successful in keeping the rye down. Thus, the poorer corn growth observed for these two treatments was not just due to the failure of the roll down procedure in yr 1.

Growth of corn following autumn glyphosate or disking (Trt. 5 and 6) appeared to reflect competition from both alfalfa and rye. In yr 1, there were no differences in alfalfa plant numbers and rye biomass and corn growth did not differ between these two treatments. There were fewer ($P < 0.05$) alfalfa plant crowns present post-corn planting in yr 2 compared to yr 1 in both treatments. However, in yr 2, glyphosate was more effective than disking in reducing alfalfa plant number. There was no difference in either year in production of rye biomass between these two treatments. Thus, the greater corn plant heights and stem diameters observed in July of yr 2 for corn grown following glyphosate in autumn appeared to result from reduced competition by alfalfa (Tables 1, 3, and 4).

In comparison, there was less ($P < 0.05$) rye biomass present in both years where no autumn treatment was applied and rye was killed by glyphosate application immediately prior to corn planting (Trts. 3 and 4). A slight reduction of rye biomass may be beneficial, because corn plant populations for these two treatments were greater, as were corn heights and diameters taken 9 wk post- corn planting. Furthermore, these

plots did not experience the moisture stress that the spring roll down treatments experienced during yr 2 (Trts. 5 and 6), which experienced leaf roll sooner during times of drought stress (visual observation). Corn heights differed a great deal from yr 1 to yr 2 across all treatments. This was likely because, the spring in yr 1 was very cool, whereas in yr 2, spring was much warmer.

The three most successful treatments were the non-grazed control (Trt. 1) and the two treatments where glyphosate was spring applied to kill the rye (Trts. 3 and 4). When mean separations (Tukey's Studentized Range Test) were performed, Treatments 1, 3, and 4 did not differ statistically. Furthermore, Treatments 1, 3, and 4 did not differ in corn plant populations, corn heights, and corn diameters (Tukey's Test; $P > 0.05$). Although these treatments were not statistically different, the non-grazed control (Trt. 1) was numerically lower in corn plant populations, heights, and stem diameters. Furthermore, when limited precipitation during the growing season of yr 2 began to stress corn plants, corn leaves began to exhibit leaf roll on the conventional treatment (Trt. 1) before corn grown with Treatments 3 or 4. This was observed more than once during the growing season as intermittent precipitation resulted in several wet-dry cycles. This strongly suggested that corn grown by conventional technology was more drought prone than corn grown with spring applications of glyphosate.

Although Treatments 1, 3, and 4 were generally similar, the spring grazed treatment (Trt. 4) numerically had the highest yield. Spring grazing prior to rye jointing (Trt. 4) appears to have potential for improving corn production. Only glyphosate was

used for biomass and weed control, compared to Treatment 1 where six herbicides were applied for control of biomass and weeds with similar results. Treatment 4 also allowed potential to integrate cattle into the system for summer grazing the alfalfa and spring grazing the rye. Both alfalfa and rye are high quality forages. A final and better comparison may be observed when the second year's corn is harvested. Grazing until corn was planted (Trt. 2) was successful in yr 1, and results were numerically similar to Treatments 1, 3, and 4. However, in yr 2, with greater moisture stress during the corn growing season, Treatment 1 resulted in inferior corn growth.

Conclusions

Six systems were tested for viability in a sustainable agricultural system that integrated grazing as a management option. Grazing alfalfa resulted in a decrease in alfalfa biomass, a decrease in root TNC in Dec., and fewer alfalfa plants present when corn was planted the following spring. Rye did not produce enough biomass in autumn to be grazeable. Furthermore, rye biomass at the time corn was planted was decreased by grazing, even when the rye was only grazed for 1 d prior to rye jointing in spring.

Fall disking with spring roll down of rye (Trt. 6) reduced alfalfa plant populations but did not completely eliminate alfalfa. Growth of corn was not successful. Application of glyphosate in autumn with roll down of rye in spring gave similar results to autumn disking in yr 1. A single application of glyphosate in autumn apparently will not provide effective kill of alfalfa and weeds if moisture has been limiting. Furthermore, the spring roll down of rye cover with no herbicide in spring may limit corn production, unless rye can be more rapidly killed by the mechanical operation or corn planting is delayed until rye begins senescing. Furthermore, both autumn disking and autumn glyphosate application resulted in the greatest rye biomass by corn planting. Planting into a heavy rye cover was not conducive to good corn stands. Modifying the no-till drill to more

effectively cut through the rye or spring grazing to reduce biomass may be useful. Maximizing grazing, by grazing until corn planting reduced ground cover enough that weed encroachment and moisture conservation could be a problem in dry years, especially with no residual weed control. Although this treatment was successful in yr 1 when moisture was adequate, it resulted in failure in yr 2 when moisture was limiting. The most effective systems utilized herbicides for total cover crop and weed kill in spring. However, the best corn growth was accomplished by allowing grazing of rye until jointing in spring. This minimized herbicide use to a one-time application of glyphosate to rye in spring at corn planting and provided enough rye cover for moisture conservation while improving weed control, corn emergence, and corn silage yield (yr 1). In conclusion, corn can be successfully established into an alfalfa-rye rotation using grazing and one application of glyphosate in spring. The resultant corn growth and weed suppression are at least as good as and may be better than that achieved by conventional no-till technology with higher chemical inputs and no opportunity for grazing.

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Appendix

Appendix Table 1. Nutrients applied
in manures to corn.

Nutrient	Year 1	Year 2
	kg ha ⁻¹	
N	162	120
P ₂ O ₅	127	91
K ₂ O	129	143
Ca	72	55
Mg	34	44
S	16	15
Zn	1	1

Appendix Table 2. Influence of grazing, chemical, and mechanical treatments on soil fertility, 30 July 1991 prior to initiation of grazing.

Item	Grazed						SE
	Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
			Glyphosate (3)	Glyphosate + grazed (4)	Glyphosate (5)	Disked (6)	
pH [†]	6.7	6.7	6.7	6.6	6.6	6.8	0.81
Organic matter, g 100g ^{-1†}	4.4	4.5	4.5	4.3	4.5	4.8	0.18
P, mg kg ^{-1†}	8.1	9.9	8.0	9.4	8.4	9.1	0.85
K, mg kg ^{-1†}	30.2	29.7	26.5	28.8	31.6	31.8	2.63
Ca, mg kg ^{-1†}	342.5	335.1	329.6	326.5	322.8	332.1	14.0
Mg, mg kg ^{-1†}	83.9	86.7	84.6	86.2	82.7	82.8	3.78
Zn, mg kg ⁻¹	3.5	3.5	3.6	3.3	3.0	3.1	0.39
Mn, mg kg ^{-1†}	13.0	14.4	12.9	12.0	13.6	12.9	1.15
Fe, mg kg ⁻¹	1.5	1.4	1.5	1.5	1.5	1.8	0.14
Al, mg kg ⁻¹	55.7	53.6	56.7	52.0	53.0	48.8	2.45
Cu, μ kg ^{-1†}	62	67	61	63	66	60	8
B, μ kg ^{-1†}	309	289	291	307	323	366	20

[†] Effect of year ($P < 0.05$).

Appendix Table 3. Influence of grazing, chemical, and mechanical treatments on soil fertility, 11 Oct. 1991, at rye planting.

Item	System						SE
	Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
			Glyphosate (3)	Glyphosate + grazed (4)	Glyphosate (5)	Disked (6)	
pH [†]	6.5	6.4	6.6	6.6	6.4	6.5	0.07
Organic matter, g 100g ^{-1†}	4.9	4.8	5.0	4.8	4.9	4.8	0.23
P, mg kg ^{-1†}	8.3	11.1	9.8	8.2	10.4	9.8	1.07
K, mg kg ⁻¹	27.8	31.9	26.6	37.9	30.0	31.7	3.66
Ca, mg kg ^{-1†}	338.7	356.5	361.6	364.7	358.9	347.2	14.8
Mg, mg kg ^{-1†}	86.3	86.2	91.1	96.8	90.5	86.8	3.94
Zn, mg kg ⁻¹	3.6	3.2	3.9	3.6	3.0	3.1	0.25
Mn, mg kg ^{-1†}	16.3	22.6	15.6	14.8	20.8	18.5	2.40
Fe, mg kg ^{-1†}	2.8	2.2	2.2	2.0	2.5	2.8	0.33
Al, mg kg ^{-1†}	57.3	57.9	59.7	55.5	59.0	56.0	3.51
Cu, µg kg ^{-1†}	43	41	41	37	42	46	3
B, µg kg ^{-1†}	223	235	286	240	256	258	19

[†] Effect of year (P < 0.05).

[‡] Grazing prior to rye jointing in spring (Trt. 5) differed from no spring grazing (Trt. 4; P < 0.05).

Appendix Table 4. Influence of grazing, chemical, and mechanical treatments on soil fertility, 29 June 1992, 9 wk after corn planting.

Event	Grazed						SE
	Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
			Glyphosate (3)	Glyphosate + grazed (4)	Glyphosate (5)	Disked (6)	
pH ^{††}	6.8	6.8	6.8	6.8	6.9	6.9	0.06
Organic matter, g 100g ^{-1†}	3.8	4.1	4.1	3.9	4.1	4.0	0.13
P, mg kg ⁻¹	6.6	8.0	9.0	7.1	6.0	6.1	1.10
K, mg kg ^{-1†#}	32.7	38.5	36.0	38.6	22.7	21.2	2.92
Ca, mg kg ^{-1††}	298.4	305.5	308.3	273.6	305.5	301.0	10.1
Mg, mg kg ^{-1††}	71.7	73.9	77.5	70.1	78.5	73.7	2.66
Zn, mg kg ^{-1†}	2.9	2.7	3.1	2.2	2.9	2.8	0.31
Mn, mg kg ^{-1†#}	11.3	14.2	10.9	9.4	11.5	11.5	0.83
Fe, mg kg ^{-1†}	1.8	1.9	1.8	1.9	1.7	2.0	0.15
Al, mg kg ^{-1†}	62.5	58.4	58.7	53.0	54.6	53.5	2.72
Cu, µg kg ^{-1††}	60	68	68	63	60	60	4
B, µg kg ^{-1†#}	174	191	184	154	183	181	67

[†] Effect of year ($P < 0.05$).

[‡] The non-grazed treatment (Trt. 1) differs from the mean of grazed treatments (Trts. 2,3,4,5, and 6; $P < 0.05$).

[§] The mean of treatments with autumn suppression of standing crop (Trts. 5 and 6) differed from the mean of treatments with spring suppression of standing crop (Trts. 3 and 4; $P < 0.05$).

[†] Year by treatment interaction ($P < 0.05$).

[#] Grazing until corn planting (Trt. 2) differed from the mean for shorter grazing periods (Trts. 3,4,5, and 6; $P < 0.05$).

^{††} Grazing prior to rye jointing in spring (Trt. 4) differed from no spring grazing (Trt. 3; $P < 0.05$).

Appendix Table 5. Influence of grazing, chemical, and mechanical treatments on soil fertility, 03 Aug. 1992, prior to initiation of grazing.

Event	Grazed						SE
	Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
			Glyphosate (3)	Glyphosate + grazed (4)	Glyphosate (5)	Disked (6)	
pH [†]	6.9	6.8	7.0	6.8	6.9	6.9	0.07
Organic matter, g 100g ^{-1†}	3.6	3.8	4.0	3.7	3.7	3.8	0.15
P, mg kg ^{-1†}	5.9	4.8	5.7	4.3	5.3	5.3	0.72
K, mg kg ^{-1†}	24.9	25.0	24.7	25.5	24.7	27.6	2.76
Ca, mg kg ^{-1†}	299.6	299.8	325.2	271.9	313.4	304.7	13.8
Mg, mg kg ^{-1†}	73.8	78.1	80.5	66.6	80.9	76.5	4.05
Zn, mg kg ⁻¹	2.7	3.4	3.0	2.3	3.3	3.2	0.55
Mn, mg kg ^{-1†}	6.6	7.0	7.8	6.1	7.6	7.0	0.28
Fe, mg kg ⁻¹	1.6	1.4	1.3	1.5	1.6	1.4	0.10
Al, mg kg ⁻¹	52.4	54.7	52.4	48.6	51.7	48.8	1.62
Cu, µg kg ^{-1†}	50	48	53	47	55	48	4
B, µg kg ^{-1†}	215	230	243	200	237	230	13

[†] Effect of year (P < 0.05).

Appendix Table 6. Influence of grazing, chemical, and mechanical treatments on soil fertility, 10 Oct. 1992, at rye planting.

Event	Grazed						SE
	Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
			Glyphosate (3)	Glyphosate + grazed (4)	Glyphosate (5)	Disked (6)	
pH [†]	7.1	7.1	7.2	7.0	7.2	7.1	0.07
Organic matter, g 100g ^{-1†}	4.3	4.1	4.3	4.2	4.4	4.2	0.18
P, mg kg ^{-1†}	7.0	5.7	6.6	5.8	7.0	6.4	0.56
K, mg kg ⁻¹	20.5	18.4	24.5	30.3	24.3	37.6	4.37
Ca, mg kg ^{-1†}	327.3	330.3	346.5	326.0	346.1	326.8	14.3
Mg, mg kg ^{-1†}	77.5	80.8	84.5	71.8	91.0	77.8	4.76
Zn, mg kg ⁻¹	3.3	4.2	4.0	3.1	4.4	4.0	0.73
Mn, mg kg ^{-1†}	9.8	10.1	11.1	9.3	10.1	10.8	0.62
Fe, mg kg ^{-1†}	1.5	1.45	1.2	1.6	1.5	1.3	0.11
Al, mg kg ^{-1†}	45.8	47.7	46.5	44.9	45.1	45.2	1.27
Cu, µg kg ^{-1†}	48	57	49	54	51	51	4
B, µg ,kg ^{-1‡}	220	223	260	213	242	243	11

[†] Effect of year (P<0.05).

[‡] Grazing prior to rye jointing in spring (Trt. 4) differed from no spring grazing (Trt. 3; P<0.05).

Appendix Table 7. Influence of grazing, chemical, and mechanical treatments on soil fertility, 12 July 1993, 9 wk after corn planting.

Event	Grazed						SE
	Non-grazed control (1)	Maximum grazed (2)	Spring suppression		Autumn suppression		
			Glyphosate (3)	Glyphosate + grazed (4)	Glyphosate (5)	Disked (6)	
pH ^{†††}	6.6	6.8	6.7	6.6	6.7	6.8	0.08
Organic matter, g 100g ^{-1†}	4.2	4.4	4.5	4.2	4.3	4.4	0.15
P, mg kg ⁻¹	6.9	6.9	5.9	4.8	6.0	7.3	0.82
K, mg kg ^{-1†}	25.6	27.1	26.3	32.2	29.0	35.9	3.70
Ca, mg kg ^{-1#}	286.1	321.2	311.6	287.7	298.8	316.6	8.52
Mg, mg kg ^{-1##}	65.1	79.3	76.5	67.7	72.2	76.1	3.56
Zn, mg kg ^{-1†}	3.2	3.9	3.6	2.8	3.4	4.0	0.69
Mn, mg kg ^{-1†††}	8.5	10.1	10.0	8.2	8.8	10.2	0.35
Fe, mg kg ^{-1†}	1.5	1.3	1.1	1.4	1.3	1.3	0.13
Al, mg kg ^{-1†}	46.9	51.6	48.5	46.2	47.3	50.3	1.15
Cu, µg kg ^{-1†††}	54	59	44	45	51	52	4
B, µg ,kg ^{-1†††}	208	283	238	214	212	222	16

[†] Effect of year (P<0.05).

[‡] The non-grazed treatment (Trt. 1) differs from the mean of grazed treatments (Trts. 2,3,4,5, and 6; P<0.05).

[§] The mean of treatments with autumn suppression of standing crop (Trts. 5 and 6) differed from the mean of treatments with spring suppression of standing crop (Trts. 3 and 4; P<0.05).

[†] Year by treatment interaction (P<0.05).

[#] Grazing prior to rye jointing in spring (Trt. 4) differed from no spring grazing (Trt. 3; P<0.05).

^{††} Grazing until corn planting (Trt. 2) differed from the mean for shorter grazing periods (Trts. 3,4,5, and 6; P<0.05).

Vita

The author was born in the small town of Buckhannon, WV. She grew up with an inborn love of animals, especially horses. From the time she was old enough to sit up, her father and mother took her riding. She has lived on the back of a horse ever since. She grew up and lived in the same house until her fateful departure to Virginia Tech in 1987 following her high school graduation. She has one brother, Travis, who is more interested in mechanical pursuits, than horses. She was extremely lucky to grow up with two wonderful parents, Dempsey and Barbara Lane, who have engaged in a loving and stable marriage for 27 years. While at Virginia Tech, the author originally planned to devote her love of animals to becoming a veterinarian. However, she decided to pursue a more production oriented career. So she switched to a production option in Animal Science and received her B.S. degree with this in May of 1991. As an undergraduate the author was active in the Block and Bridle club and held the office of reporter. She also received a scholarship to participate in an undergraduate research project. This wasn't too bad, so she decided to expand this production orientation to include an M.S. degree in Agronomy, also at Virginia Tech under the guidance of Dr. Vivien Allen. Her life for the past two years, you have just read. She joined the

American Forage and Grassland Council to further her interests. She now plans to pursue happiness with her husband Whit, whom she met while working on her M.S. degree.