STRATEGIES FOR WEED MANAGEMENT IN GLYPHOSATE-RESISTANT ALFALFA

A Thesis in
Agronomy

by

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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

May 2012
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ABSTRACT

Proper establishment of an alfalfa (*Medicago sativa* L.) stand is critical for the stand’s productivity and longevity. Producers, through using glyphosate resistant (GR) alfalfa, may now have a tool allowing them the option of clear seeding their alfalfa while applying glyphosate as a selective herbicide without damaging alfalfa growth. The objective of the study was to evaluate the influence of planting dates, harvest intervals, and herbicides on GR alfalfa yield, weed yield, and forage quality. GR alfalfa was seeded into conventionally tilled seedbeds in Pennsylvania in the spring of 2010 and 2011. Yield and quality measurements were made for two planting dates (early and late) and three harvest intervals (25, 30, and 35 day) under three herbicide treatments: no herbicide, imazethapyr, and glyphosate. Alfalfa and weed yield were most influenced by herbicide treatment. Season alfalfa yields were increased and weed yields were decreased by herbicide application. In the first harvest following herbicide application there was some injury from imazethapyr resulting in reduced alfalfa yield compared to the glyphosate plots but the injury was temporary and at the end of the year, alfalfa yield was no different between the two herbicides. Lengthening harvest intervals increased alfalfa yield while weed yield remained unchanged. This lengthening of time between harvests also resulted in higher overall forage yield that contained a higher percentage of alfalfa when no herbicide was used. Planting date had the biggest influence on the weed content. Weed content in both seeding years was higher in the first planting date compared to the second. The emergence period for most of the summer annual weeds better matched the earlier planting date compared to the later. Late tillage performed to prepare the seedbeds also provided additional weed control for the later planting. The quality yield for the season was also impacted greatest by harvest intervals with the longer intervals allowing for greater yields which translated into higher quality yields. The use of herbicides had little effect on seasonal CP yield but application did tend to decrease the amount of ADF in the
forage compared to not being treated. Forage yields and quality yields in the first production year showed no carryover effects from herbicide application or planting date treatments implemented in the seeding year.
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ACKNOWLEDGEMENTS

This thesis is dedicated to the many people who have supported me with advice, guidance, and assistance throughout my collegiate career while pursuing both my bachelors and masters degrees. I would like to thank my parents for their help and encouragement throughout the entire process of completing my degree. Without them this opportunity would not have been possible. Also, my brother for his understanding and forgiveness when I was unable to be there for him during his many activities.

I would like to give an extreme amount of gratitude to Dr. Marvin Hall for being an excellent advisor as well as a mentor especially through the past two plus years as well as before. It was an honor to gain knowledge and expertise from someone who never settled for providing it but was there beside me teaching it. I would like to extend my appreciation to my other committee members Dr. William Curran and Dr. Harold Harpster for their expertise in designing my research. Without them my project would not have been nearly as successful.

In addition, I would like to thank the entire Crop and Soils Sciences department. I have been privileged, over my six years at Penn State, to have been taught by many educators that have excelled in their respective fields and been gracious enough to pass their knowledge along to me.

Finally, I would like to thank Justin Dillon. Without his support and knowledge the completion of my degree would not have been possible. He was an ever present source of expertise and advice that truly enriched my experience. Working alongside him throughout my degree has taught me many valuable lessons and I wish him the best and hope he will continue educating others.
Chapter 1

Literature Reviewed

Introduction

Alfalfa (*Medicago sativa* L.) is a widely grown perennial legume forage commonly used as a high protein component of livestock rations. Alfalfa is the most common hay crop produced in both Pennsylvania and the U.S., accounting for around one third of the total hay production. In 2011 there was 23.3 million hectares of hay farmed in the U.S. and of that 7.8 million were producing alfalfa (NASS, 2011a). At an average yield of 7.6 Mg/hectare the U.S. totaled 59 million Mg of alfalfa produced (NASS, 2011a). In Pennsylvania alone 202,000 hectares of farmland was in alfalfa production (NASS, 2011a). The most common use for alfalfa is feeding dairy cows. It can be fed in several different forms including hay, silage, and greenchop but is always highly desirable due to its high protein and digestible fiber content. In the past 10 years there has been a downward trend in U.S. forage production losing 2.4 million hectares in hay and 1.8 million hectares in alfalfa production (NASS, 2011b). These trends are likely to continue as grain commodity prices increase and interest in producing biofuel crops grows. With minimal gains in yield this loss in acreage has resulted in the U.S. producing 13.9 million fewer Mg of alfalfa annually compared to just 10 years previous (NASS, 2011b). During this same time the number of milk cows have held relatively constant while milk production per cow has increased almost 1,360 kg annually (NASS, 2011c). So there will continue to be an increasing need for high quality alfalfa forage to support this ever rising milk production.
Seeding Rate

Clear seeding is a planting method that provides an alternative to using a companion crop. Clear seeding decreases the competition from companion crops increasing harvested alfalfa yields in the establishment year (Simmons et al., 1992). In Pennsylvania, recommended seeding rate for pure stands of alfalfa is from 16.8 – 20.2 kg ha\(^{-1}\) (Hall, 2010). The higher plant densities associated with seeding rates greater than 17 kg ha\(^{-1}\) were not found to persist beyond 6 months after planting (Hall et al., 2004). Competition between alfalfa plants causes greater mortality for high than for low seeding rates (Kephart et al., 1992). Some thinning of seedlings could be occurring simultaneously with emergence, especially at the higher seeding rates (Hall et al., 2004). Kephart et al. (1992) reported that based on morphological measurements, forage quality should not be affected by seeding rate. Also, seeding rates greater or slightly less than those recommended have been found to result in little to no effect on the life expectancy of an alfalfa stand (Hall et al., 2004). Norris and Ayres (1991) reported in their study conducted in California, that alfalfa stands declined linearly with time and the rate of decline was not affected by irrigation regime or by cutting interval.

Herbicide Treatment

Glyphosate is a broad-spectrum nonresidual herbicide that effectively controls most annual and perennial weed species found in forage production (Gianessi et al. 2002). Orloff et al. (2003) found that weed control with glyphosate was 95% or greater on all weeds species in glyphosate-resistant (GR) alfalfa at three location across California in 2003. GR alfalfa is also tolerant to glyphosate at all stages of growth, increasing the application window compared to other herbicides currently available (Van Deynze et al., 2004). Miller and Alford (2002) found that glyphosate did not injure or reduce GR stands. Weed control was greater with glyphosate than with conventional herbicide treatments, and weed control with glyphosate was influenced by
application timing, but not rate (Miller and Alford, 2002). The commercialization of GR alfalfa enables growers to use glyphosate for broad spectrum weed control in alfalfa, while preserving excellent crop safety (McCordick et al., 2008).

Bradley et al., (2010) found glyphosate application provided good control of weeds regardless of alfalfa seeding rate. Weed control with glyphosate was more consistent across growing conditions and weed species compared to imazamox and imazamox + clethodim treatments (McCordick et al., 2008). Imazamox and imazethapyr caused minor injury to alfalfa seedlings, which increased with the addition of bromoxynil or 2,4DB to either herbicide (Wilson and Burgener, 2009). When applied at the same timing, imazamox provided similar levels of annual broadleaf weed control as glyphosate, while 2, 4-DB plus sethoxydim provided similar levels of annual grass and broadleaf weed control as glyphosate (Bradley et al., 2010). Neither glyphosate nor the conventional herbicide treatments reduced alfalfa stem density between the first and last annual harvests, but 2, 4-DB plus sethoxydim resulted in the most visual injury to seedling alfalfa stands and lowered initial yields at all locations (Bradley et al., 2010). Therefore these results suggest that, depending on the weed species in question, imazamox or 2, 4-DB plus sethoxydim could be used in rotation with glyphosate over time in a GR alfalfa system to prevent the evolution of GR weeds, or manage GR weed species that have already evolved (Bradley et al., 2010). The results from these trials also indicate that similar or higher levels of annual grass and broadleaf weed control can be achieved with glyphosate compared to conventional herbicide systems in spring-seeded GR alfalfa (Bradley et al., 2010).

**Herbicide Timing/Rate**

Orloff et al., (2003) found that the best time to apply glyphosate was at the three- to four-trifoliate stage. Early applications (unifoliate to two-trifoliate) allowed later germination of weeds, requiring a second application prior to the first harvest. Later applications (six- to nine-
trifoliate) allowed greater weed competition at early alfalfa growth stages that could potentially reduce first harvest yield. Dillehay et al., (2011) reported weed density was critical for determining critical period for herbicide application and ranged from the 0.5 to 7th trifoliate growth stage. The higher the weed density the earlier the critical period started but had no effect on when the critical period ended. Under low weed densities a critical period may not exist (Dillehay et al., 2011).

Orloff et al. (2003) also reported that 1.68 kg ae/ha rate of glyphosate resulted in more rapid week kill compared to 0.84 kg ae/ha, but was generally not needed. A single 0.84 kg/ha application of glyphosate at the unifoliate growth stage controlled 67% of the weed population (Wilson and Burgener, 2009). Increasing the glyphosate rate to 1.25 kg/ha and delaying the application until alfalfa had reached the two-trifoliate growth stage further improved weed control to 83% (Wilson and Burgener, 2009). Applying two applications of glyphosate at 1.12 kg/ha at the two- and eight-trifoliate growth stages resulted in 87% weed control but increased herbicide costs. Wilson and Burgener (2009) reported that 0.84 kg/ha of glyphosate applied at the unifoliate growth stage controlled 69% of final common lambsquarters population where delaying application until the two-trifoliate stage with a rate of 1.25 kg/ha provided 86% reduction when compared to the no-herbicide treatment. The improvement in weed control was probably the result of more of the common lambsquarters population being exposed to herbicide at the later date and the increase in the glyphosate rate from 0.84 to 1.25 kg/ha. Further delaying glyphosate treatment until the four-trifoliate growth stage did not result in an improvement in common lambsquarters control (Wilson and Burgener, 2009).

Yield

McCordick et al. (2008) found alfalfa yield was highest for the glyphosate treatment in both clear seeding and oat companion crop establishment systems. Alfalfa stunting was observed
at the first harvest where imazamox + clethodim were applied, which likely reduced the alfalfa yields. There were no differences between glyphosate and imazamox treatments at the second and third harvests, the seasonal alfalfa yields however were reflective of the first harvest suggesting that the seasonal alfalfa yields are significantly impacted by weed control systems implemented before the first harvest (McCordick et al., 2008). Bradley et al. (2010) also found alfalfa yields were similar or higher in the glyphosate treatment compared to the other herbicide programs and annual forage yields were highest for the untreated control plots. The increase in total forage yields are likely due to higher weed biomass in the untreated compared to the herbicide-treated plots (Wilson and Burgener, 2009). Dillehay and Curran (2010) found alfalfa plots receiving an herbicide application provided 26% higher cumulative alfalfa yield for the establishment year compared to untreated check plots.

**Weed Competition**

New alfalfa seedlings and older, thinning stands are susceptible to weed encroachment (Fischer et al., 1988). Herbicides do not need to be used during alfalfa establishment when weed density is low (Brothers et al., 1994). However, use of herbicides may be justified where weed density is severe. Bradley et al. (2010) stated weed infestations are more likely to be a problem in spring-seeded compared to fall-seeded alfalfa, as summer annual weeds often emerge at the same time as the newly seeded alfalfa. Weed competition can have serious negative effects on alfalfa growth and yield since seedling alfalfa is not a vigorous competitor with weeds emerging shortly after seeding (Fischer et al., 1988). The early-season weed suppression provided by all herbicide treatments allowed more alfalfa plants to become established compared to nontreated areas (Wilson and Burgener, 2009). Weed management is important for decreasing competition with alfalfa and for increasing alfalfa yield and quality during the establishment year (Hall et al.,
Competition, provided by weeds or companion crops, reduces the total season alfalfa yield compared with alfalfa seeded alone and when the weeds are managed with herbicides (Sheaffer et al., 1988). In addition, some weed infestations can reduce forage quality and palatability depending on the species and quantity of weeds present thus reducing the value of the forage (Hall et al., 1995, Brothers et al., 1994).

Sheaffer et al. (1988) determined that herbicides are necessary for weed control and are advantageous for first-year yields of clear-seeded alfalfa. In general, glyphosate provided excellent control of emerged weeds decreasing weed biomass about 10-fold at the first harvest (Dillehay et al., 2009). The greatest impact from the glyphosate application occurred in the first harvest (Dillehay et al., 2009). In the second harvest of the first year, glyphosate application increased alfalfa yield and decreased weed content. This can be beneficial if weeds are of inferior nutritive value, influence the flavor of milk or meat, cause palatability problems, or are poisonous to livestock (Wilson and Burgener, 2009). Wilson and Burgener (2009) also reported that weeds were most competitive with the first forage harvest and reduced relative feed value, crude protein, and value (dollars per kg) of forage compared to forage that had been treated with herbicides. Dowdy et al. (1993) observed a 30 to 47% increase in alfalfa plant density over a 5-yr time period as a result of weed removal with herbicide applications. Wilson and Burgener (2009) found that GR alfalfa treated with glyphosate or non-GR alfalfa treated with one of several post-emergent herbicides produced stands with approximately 26% more plants per m$^2$ than an untreated control in Nebraska.

Quality

In forage crops where the entire herbage is harvested, reduction in quality can be the major source of loss and is more difficult to quantify than is yield reduction (Cords, 1973). Cords
(1973) reported a high negative correlation existed between weed content and protein percentage of harvested forage. Reasons include the weeds, having a lower average protein content than alfalfa; and winter annual weeds are quite mature by the time alfalfa is ready for harvest in the spring.

Increasing maturity of alfalfa is another source of loss in forage production. The decline in total herbage quality associated with the passage of time appears mostly to be due to changes in the chemical composition of stems and a decrease in leaf protein (Onstad and Fick, 1983). When legumes mature the leaf: stem ratio declines because stem material accumulates at a faster rate than leaves, and lower leaves senesce and die (Aman and Nordkvist, 1983). This is important to forage quality because stems contain more cell wall material than leaves, and cell walls are less digestible by ruminants than are cell soluble components (Buxton and Brasche, 1991). In addition, as stems mature, they accumulate higher concentrations of cell wall material and the degradability of these cell walls by ruminant’s decreases while little change happens in leaves (Buxton and Brasche, 1991, Albrecht et al., 1987). Cell wall lignin increased linearly with cell wall concentration, indicating that a consequence of a greater cell wall concentration in alfalfa stems was a more lignified cell wall (Sanderson and Wedin, 1988). This in conjunction with the low crude protein (CP) and in vitro true digestibility (IVTD) values for stems in older samples emphasizes again the importance of high leaf content for good alfalfa forage quality (Kalu and Fick, 1981). This confirms that digestibility of alfalfa decreases with maturity as a result of increased concentration of cell wall material (CWM) in stems, decreased stem digestibility, and increased proportions of stems (Albrecht et al., 1987). Improving the forage quality of alfalfa will require alterations in one or both of these maturation events, but given the large contribution of stems to alfalfa yield, changing the impact of maturation on stem quality may have the largest potential benefit (Jung and Engels, 2002).
**Harvest Interval**

Harvest interval is one management technique commonly used that can directly impact forage quality. Over four alfalfa cultivars and four growth periods, forage quality declined from the first to the final sampling time (Albrect et al., 1987 and Hall et al., 2000). The CP concentrations and in vitro dry matter digestibility (IVDMD) decreased by 28 and 43 g kg\(^{-1}\), respectively while the ADF and NDF concentrations increased by 35 and 46 g kg\(^{-1}\), respectively, from the first to last sampling time. Forage yield is also affected by cutting interval. Griffin et al., (1994) reported ADF concentrations increased and in situ dry matter digestibility (ISDMD) and CP decreased with increasing alfalfa maturity. Alfalfa harvested four times yielded 7% (0.8 Mg ha\(^{-1}\)) more per year than when harvested five times, and 28% (3.1 Mg ha\(^{-1}\)) more than when harvested six times (Kallenbach et al., 2002). In each year tested, the annual average ADF and NDF was highest when harvested four times, intermediate when harvested five times, and lowest when harvested six times (Kallenbach et al., 2002). In a consistent manner, CP was highest when harvested six times, intermediate when harvested five times and lowest when harvested four times (Kallenbach et al., 2002). These researchers also reported that while harvesting more frequently improved forage quality it had little impact on plant density.

**Economics**

Wilson and Burgener (2009) found gross economic return over the first production year was calculated to be $1,151/ha in nontreated, $1,239/ha for single glyphosate application at two-trifoliate, and $1,222/ha for single treatment with imazamox. When herbicide was applied to alfalfa at the two-trifoliate growth stage, the net return from using glyphosate with a GR alfalfa variety or utilizing imazamox with a conventional alfalfa variety were similar at $742 and $743/ha, respectively, which suggests the two technologies were similar (Wilson and Burgener,
2009). However combining imazamox with 2,4-DB to obtain improved weed control resulted in alfalfa injury, which reduced the net return to $688/ha.

With the reintroduction of GR alfalfa a renewed interest has been brought forth into how this technology could influence the yield and quality of alfalfa. Previous research on alfalfa has mainly focused on harvest intervals and weed populations and the resulting yield and quality. There has also been abundant research on alfalfa yield and quality using selective alfalfa herbicides. With the introduction of this new GR technology the ability to selectively control weeds in alfalfa and specifically during establishment warranted further evaluation. The influence of glyphosate coupled with GR alfalfa productivity research needed to be performed comparing selective alfalfa herbicides to glyphosate across planting dates, harvest intervals, and weed pressures to achieve a true measure of its impact. Following this the opportunity to make conclusions on how glyphosate applied to GR alfalfa influences resulting yield and quality compared to selective herbicides would be possible.
References


Chapter 2

Strategies for Weed Management in Glyphosate-resistant Alfalfa

Introduction

Alfalfa (*Medicago sativa* L.) is a crucial component of rations for many livestock species. It provides large amounts of protein and digestible nutrients along with ample fiber content. A high yielding alfalfa stand will normally have a life span of four to eight years but successful establishment is an imperative first step. Weed competition is especially damaging to alfalfa during the establishment period since seedling alfalfa is not a vigorous competitor with weeds emerging shortly after seeding resulting in serious negative effects on alfalfa growth and yield (Fischer et al., 1988). Under high weed density, weeds can compete with the alfalfa for available resources such as light, water, and nutrients. Under severe cases this can cause crop failure by preventing the alfalfa seedlings from becoming established. To maintain high quality alfalfa forage, one challenge comes from weeds invading the alfalfa stand. Previous research has shown that when weeds are controlled with glyphosate [N-(phosphonomethyl)glycine], forage quality at the first harvest and for the entire seeding year increases (Hall et al., 2010).

Glyphosate resistant (GR) alfalfa can enhance the farmers’ ability to manage and eliminate weed competition from their fields. The incorporation of the GR gene into alfalfa provides excellent protection against herbicide injury throughout the life of the crop. Miller and Alford (2002) found that glyphosate did not injure or reduce GR stands. Economically, glyphosate is relatively inexpensive to apply on a per hectare basis compared to some conventional alfalfa herbicides. Perhaps the biggest benefit of planting GR alfalfa is the flexibility it offers. In conventional alfalfa, herbicides have specific application timings and
even under correct usage can cause temporary injury to the alfalfa. GR alfalfa has been found to be tolerant to glyphosate at all stages of growth, increasing the application window compared to other herbicides currently available (Van Deynze et al., 2004). Glyphosate may also offer increased benefits when multiple applications of an herbicide are necessary or if perennial weeds are a problem (Dillehay and Curran, 2010).

When establishing alfalfa, weed infestations are more likely to be a problem in spring-seeded compared to fall-seeded alfalfa, as summer annual weeds often emerge at the same time as the newly seeded alfalfa (Bradley et al., 2010). Little research has been done on altering the timing of the alfalfa planting date in the spring with the goal of avoiding peak weed emergence. This could be a useful tactic because weed infestations can reduce forage quality and palatability depending on the species and quantity of weeds present (Hall et al., 1995, Brothers et al., 1994).

In forage crops where the entire herbage is harvested, reduction in quality can be the major source of loss and is more difficult to quantify than is yield reduction (Cords, 1973). The harvest interval is of critical importance with alfalfa production. Extending the harvest interval can increase yield but also reduce total herbage quality due to changes in the chemical composition of stems and a decrease in leaf protein (Onstad and Fick, 1983). The alfalfa stems become less digestible with time, and they increase in proportion compared to leaves (Albrecht et al., 1987). It has been shown that alfalfa harvested four times per year provided 7% more alfalfa yield than when harvested five times, and 28% more than when harvested six times (Kallenbach et al., 2002). Additional harvests per year can decrease the alfalfa yield while increasing the quality by harvesting alfalfa of a lower maturity (Hall et al., 2000, Kallenbach et al., 2002).

Studies evaluating alfalfa yield and quality have mostly been performed either on seedings accompanied by a companion crop such as Oats (Avena sativa L.) or treated with a
conventional alfalfa herbicide. Others have measured the tolerance of GR alfalfa at different timings and rates but few studies have looked into the interplay of quality and yield of GR alfalfa compared to conventional alternatives. Therefore the objectives of this study were to evaluate how altering planting dates, harvest intervals, and application of herbicides would influence weed and alfalfa growth. The resulting influence of these management strategies on yield and quality could be used to find the optimum combination to maximize production goals.

**Materials and Methods**

In the spring of 2010 and 2011, an early and late spring planting of GR and non-GR alfalfa was made into a conventionally tilled seedbed at the Russell E. Larson Agricultural Research Center near Rock Springs, PA. The soil was a Hagerstown Silt Loam (Fine, mixed, semiactive, mesic Typic Hapludalfs) soil and the planting was done with a Carter (Brookston, IN) seeder at 20 kg ha\(^{-1}\) of pure live seed (PLS). Soil pH, and fertility levels were in the optimum range for alfalfa production before planting and were maintained during the course of the study.

In 2010, seedings of ‘FG R43M708’ (glyphosate tolerant) and ‘FG 43Q124’ (conventional) were made on April 13 and May 7. Six days after the 1\(^{st}\) harvest of the May 7 seeding a second application of glyphosate at 1.6 kg ae/ha was made.

In 2011, ‘DKA41-18RR’ (glyphosate tolerant) and ‘Persist II’ (conventional) were seeded with a carter seeder on May 7 and May 26. Due to low precipitation, these plots were irrigated on July 19 with 3.18 cm of water using a travelling gun.

Within each seeding time the experimental design was a randomized complete block in a split-plot arrangement with four replicates. Whole plots were three harvest intervals (25, 30, and
35 days), sub-plots were three herbicide treatments [no herbicide, imazethapyr at 0.105 kg ae/ha, and glyphosate 1.6 kg ae/ha], and two alfalfa varieties. Sub-plots were 1.83m by 4.6 m in size.

Statistical analysis was done comparing the yield and quality of the conventional and GT alfalfa varieties under the no herbicide and imazethapyr treatments for genetic differences or influence from the incorporation of the glyphosate tolerant gene. There were no differences between either of the varieties over the two years in yield or quality so analysis was run on the GT variety only to maintain equal observations for each treatment.

Herbicides were applied with a CO₂-pressurized backpack sprayer with air induction 11002-VS TeeJet flat-fan nozzles (Wheaton, IL) calibrated to deliver 187 L/ha at 207 kPa. Herbicide application to the plots was performed when alfalfa seedlings were at the 3rd to 4th trifoliate growth stage at the previously stated rates along with all appropriate adjuvants. The first harvest of the year was collected on the entire planting area separately for each planting date when the alfalfa reached 1/10 bloom to ensure ample energy reserves present in the roots. Then the harvest interval treatments followed.

Prior to harvest, each plot was visually assessed for weed content. A 0.28 m² area was sampled down to a height of 5 cm from each plot when weed content was greater than 5% or 50 g kg⁻¹ of forage. This sample was separated into alfalfa and weed proportions and dried at 60 °C for 48 hours for dry matter (DM) determination. The total harvests per year (three) were the same for each harvest interval treatment during the seeding year. In 2011 we harvested the 2010 seeding year four times and this was constant across all treatments. At each harvest, forage from a 1.0 m x 4.6 m strip within each plot was collected using a Carter flail type harvester (Brookston, IN). Subsamples from each plot were collected and dried for 48 hours at 60°C to determine forage DM. The dried subsamples were then used for quality analysis. Potato leafhoppers were monitored and managed with 0.23 L ha⁻¹ of Lambda-cyhalothrin.
Quality yield for all plots was calculated for each harvest. To find the yield of each quality component the total kg ha\(^{-1}\) of crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) produced in each harvest was the product of DM yield multiplied by the concentration of the quality constituents. Total yield is the sum of alfalfa yield plus weed yield, within a single harvest. Weed content was less than 50 g kg\(^{-1}\) of the total forage in plots treated with herbicides so in these plots total yield and alfalfa yield are the same. Season total yield and quality yield is the sum of all harvests over the entire year.

The year after establishment, four harvests were collected from each treatment over the year and the three cutting intervals were continued. The following results only include the first production year for the 2010 seeding this study will be continued next year to collect the first production year data from the 2011 seeding year. Season total DM yield and quality yield were determined using the same procedures as in the seeding years.

Quality analysis was done through near infrared spectroscopy (NIRS) and analyzed for CP, NDF, and ADF by Forage Genetics International (West Salem, WI). Statistical analysis was conducted using PROC GLM and PROC MIXED procedures in SAS version 9.1 (Cary, NC).

**Results and Discussion**

**Weather**

The 30-year average temperature and precipitation at The Russell E. Larson Agricultural Experiment Station near Rock Springs, PA for April through October is 15.9 °C and 69 cm of rain (Figure 2-1. and Figure 2-2.). During the 2010 growing season, temperatures consistently averaged 1 to 2°C above normal for each month and precipitation was at or below normal for all months with the exception of September. In 2011, the temperature was again consistently 1 to 2
°C above normal. The rainfall, on the other hand, was much more variable. Over the growing season, rainfall was 16.6 cm above average, and highly variable from month to month.

First Harvest Yield

For 2010 and 2011 there was a planting date by herbicide treatment interaction in the first harvest for both weed yield and total yield (Table 2-1.). In both years the interaction is a result of differences in weed yield. The early planting date had a higher weed yield than the late planting date when no weed control was used. There were no weeds in the herbicide treated plots in either planting date (Figure 2-3. and Figure 2-4.). The total yield of the first harvest was also influenced by the weed yield. The higher amount of weeds gave a higher total yield for the no herbicide treatment over the glyphosate and imazethapyr treatments in the early planting date. In the late planting date a lower amount of weeds resulted in no difference in total yield between the no herbicide and glyphosate treatments. The late planting date in 2010 also had lower alfalfa yield in the imazethapyr treatment resulting in lower total yield compared to the no herbicide and glyphosate for the first harvest (Figure 2-3.). For the 2011 seeding year the weed yield was very low. The late planting date had such a low weed yield it resulted in no difference in total yield for the late planting date across herbicide treatments where the no herbicide treatment was higher in the early planting date with the additional weeds (Figure 2-4.).

Alfalfa

In 2010 the late planting date yielded 485 kg ha\(^1\) more alfalfa compared to the early date and there was no significant difference in 2011 between planting dates (Table 2-2.). The additional alfalfa yield from the late planting could be partially attributed to lower weed biomass.
at the late planting date. There was no difference in either year from harvest interval in the first harvest because all plots within a planting date were harvested on the same day. Weed control with the herbicide treatments was excellent in 2010. When averaged over harvest interval, the glyphosate treatment resulted in 708 kg ha\(^{-1}\) more alfalfa in the first harvest than the imazethapyr treatment and 943 kg ha\(^{-1}\) more than the no herbicide treatment (Table 2-2.). Wilson and Burgener (2009) also found imazethapyr to cause minor injury to alfalfa seedlings, which increased with the addition of bromoxynil or 2,4DB. Dillehay and Curran (2010) reported imazethapyr cause 10% chlorosis of alfalfa leaves within 7 days of application but disappeared by 14 days and did not affect alfalfa yield or quality. The no herbicide treatment had reduced alfalfa yield due to the increased weed competition. In 2011, there was no difference in alfalfa yields for the first harvest between any of the treatments (Table 2-2.). This could be a result of the very dry weather after planting which limited growth and provided very low alfalfa yields and minimized potential weed competition. Dillehay and Curran (2010) in a 2005 study reported drought conditions reduced weed competition resulting in no short or long-term effects on alfalfa yield.

**Weeds**

The majority of the weeds present in the plots were giant foxtail (*Setaria faberi* Herrm.), yellow foxtail (*Setaria glauca* L.), common lambsquarters (*Chenopodium album* L.), and redroot pigweed (*Amaranthus retroflexus* L.). Weed yield in the first harvest was higher for the early planting date compared to the late in both 2010 and 2011 seeding years (Table 2-2.). This was likely the result of tillage before the later planting eliminating weeds that had germinated in the time between the early and late plantings. Planting three weeks later meant weeds germinating over those three weeks would be present in the early planting but would have been controlled
through tillage preparing for the late seeding. Harvest interval again had no influence on the first-harvest weed yields because all plots within a planting date were harvested on the same day.

Glyphosate and imazethapyr did an excellent job controlling weeds. Consequently weed content was less than 50 g kg\(^{-1}\) of the total herbage so sub-samples were not collected from the herbicide treated plots. Similar results have been reported where glyphosate provided excellent control of emerged weeds decreasing weed biomass about 10-fold at the first harvest (Dillehay et al., 2009). It has also been found that similar or higher levels of annual grass and broadleaf weed control can be achieved with glyphosate compared to conventional herbicide systems in spring-seeded GR alfalfa (Bradley et al., 2010). In the no herbicide plots, weed yield provided almost as much biomass as alfalfa in 2010 and about one third the alfalfa yield in 2011 (Figure 2-3 and Figure 2-4.). McCordick et al., (2008) reported there were no significant differences between glyphosate and imazamox treatments at the second and third harvests, the seasonal alfalfa yields however were reflective of the first harvest suggesting that the seasonal alfalfa yields are significantly impacted by weed control systems implemented before the first harvest.

**Total Herbage**

There was no difference between planting dates in total herbage yield for the first harvest in either year (Table 2-2.). Weeds effectively replaced any yield loss in alfalfa associated with increased weed infestation in the earlier planting. In both studies, total herbage yield was greatest when no herbicides were applied because of the additional weed yield.
Season Total Yield

In 2010 and 2011 there was a planting date by herbicide treatment interaction for the season total weed yield. There was also a planting date by herbicide treatment interaction for total yield in 2010 (Table 2-1.). These interactions are again a result of the early planting date having higher amounts of weeds compared to the later. In 2010 and 2011 the season total weed yield was higher in the early than the late planting date in the no herbicide treatments where there were no weeds in the herbicide treated plots (Figure 2-3.). The difference in 2010 in total season yield was due to the higher amount of weeds in the early planting date which increased the no herbicide yield compared to the herbicide treated plots. The late planting date had a lower amount of weeds and the no herbicide treatment had a similar yield to glyphosate but more than imazethapyr, but in each planting date the rankings stayed the same (Figure 2-3.).

Alfalfa

Season total alfalfa yields were not different between the early and late planting date in 2010 (Table 2-3.). In 2011, however, there was greater alfalfa yield from the late planting date compared to the early. In both years, extending the harvest interval increased season total alfalfa yield (Table 2-3.). Also in both years, application of a herbicide increased alfalfa yield compared to treatments where no herbicide was applied. Removing competition, provided by weeds or companion crops, has been found to reduce the total season alfalfa yield compared with alfalfa seeded alone with an herbicide (Sheaffer et al., 1988). McCordick et al. (2008) also found alfalfa yield was highest when glyphosate was used in both clear seeding and oat companion crop establishment systems.
**Weeds**

Both years had the same trends with respect to season total weed yield (Table 2-3.). The early planting date had greater weed yield than the late. Harvest interval had no effect on weed yield and the no herbicide plots had greater weed yield than the herbicide treated plots (Table 2-3.). In 2010, the weed yield was greatest at the first harvest and declined in subsequent harvests in plots under the no herbicide treatment. The early planting decreased from 2779 to 937 to 538 kg ha$^{-1}$, and the late planting date from 1546 to 649 to 292 kg ha$^{-1}$ for the first, second, and third harvest respectively when a herbicide was no applied. In 2011, however, weed yield was 225, 440, and 160 kg ha$^{-1}$ in the early planting date and 31, 46, and 13 kg ha$^{-1}$ for the late planting date for the first, second, and third harvest respectively for the no herbicide plots. Dillehay et al., (2009) reported that the greatest impact from a glyphosate application occurs in the first harvest. The 2010 findings would agree with their result. With 2011 being extremely dry during and after planting, the limited moisture in the upper layer of soil could have delayed weed germination later into summer. Dillehay et al., (2011) also reported in their study drought conditions reduced weed establishment and vigor resulting in little competition from weeds.

**Total Herbage**

Season total herbage yield was greater for the early planting in 2010 and the later planting in 2011 (Figure 2-5.). In 2011, it was extremely dry through the first harvest resulting in the early planting date being harvested only one week before the late planting date. After the late planting date was harvested the plots received precipitation promoting faster regrowth for the late compared to the early planting date. In both years the 25 day harvest interval had the lowest season total yield (Figure 2-6.). Depending on the length of the growing season, a shorter harvest
interval could provide the opportunity for an additional harvest each year that would provide additional yield.

Averaged over both planting dates in 2010, the no herbicide treatment had greater season total herbage yield than the herbicide treated plots due to weeds (Figure 2-7.). Bradley et al. (2010) also found alfalfa annual yields were similar or higher in the glyphosate treatment compared to the other herbicide programs and annual forage yields were highest for the no herbicide plots. The increase in total forage yields are likely due to higher weed biomass in the untreated compared to the herbicide-treated plots (Wilson and Burgener, 2009, Dillehay et al., 2009, Dillehay and Curran, 2010). In 2011, there was a much smaller weed population compared to 2010 so in 2011 there was no difference in total herbage yield for the year between herbicide treatments (Figure 2-7.). Sheaffer et al. (1988) and Hall et al., (1995) determined that herbicides are necessary for weed control and are advantageous for first-year yields of clear-seeded alfalfa. Conversely, Brothers et al., (1994) found herbicides do not need to be used during alfalfa establishment when little weed pressure is present.

**Season Quality Yield**

There was one planting date by herbicide treatment interaction for season total ADF yield in 2011. This again is tied back to differences in weed content between early and late spring planting dates (Table 2-4.). The early planting date had a higher amount of weeds that, due to their higher fiber content than alfalfa, resulted in higher ADF for the no herbicide plots compared to the herbicide treated plots (Figure 2-8.). In the late planting date there was a much lower amount of weeds that didn’t result in any difference between treatments (Figure 2-8.).

Averaged over herbicide treatments and harvest intervals in 2010, the early planting date provided greater total yield of CP, ADF, and NDF compared to the late planting date (Table 2-5.).
The opposite trends were found in 2011, with the late planting date having higher yields of CP and NDF with ADF not being significantly higher (Table 2-5.). In both years the season quality yield directly corresponded to season total yield in regards to planting date. It is important to remember that total yield is an important factor in the quality yield. A forage with lower yields and higher quality can have similar quality yields to a forage with lower quality but a higher yield.

For the harvest interval treatment in both years, the total season yield of CP, ADF and NDF trended higher as harvest interval was extended (Table 2-5.). This can be directly attributed to DM yields increasing as the harvest intervals increased.

There was no herbicide treatment effect on season CP yield in 2010, but the ADF and NDF values followed the ranking; glyphosate = imazethapyr < no herbicide (Table 2-5.). This result shows the additional weeds in the no herbicide treatment didn’t affect CP but did increase the fiber content. In 2011 the glyphosate treatment had the highest CP yield with the no herbicide having the lowest. Imazethapyr was in the middle but not different from glyphosate or no herbicide (Table 2-5.). Data from 2011 tends to agree with Bradley et al., (2010) that harvested forage in the herbicide treatments generally had greater CP content than untreated forage and application of glyphosate resulted in similar or higher forage CP content compared to conventional herbicide treatments. The same findings from Bradley et al., (2010) would disagree with the 2010 seeding year results. Season total ADF was also higher in the no herbicide and lower in glyphosate and imazethapyr for both years. Season total NDF in 2011 was not different between any of the herbicide treatments (Table 2-5.). In respect to the no herbicide treated plots generally having higher ADF and NDF values compared to the treated plots it appears some weed infestations can reduce forage quality and palatability depending on the species and quantity of weeds present thus reducing the value of the forage (Hall et al., 1995, Brothers et al., 1994). It
also appears that weed control by either glyphosate or alternative herbicide increased forage quality of the total herbage at the first harvest and for the entire seeding year (Hall et al., 2010).

**First Production Year Yield**

The 2010 seeding year allowed data collected in 2011 to be evaluated for treatment “carry over” into the first production year. There were no treatment interactions for the first production year (Table 2-6.). Planting date and herbicide treatment had no affect on DM yield in the first production year. However, harvest intervals of 25, 30, and 35D during the first production year resulted in increasingly greater yields (Table 2-7.).

There were no differences between the early and late planting dates for seasonal yield of ADF or NDF but the late planting date did yield higher CP compared to the early planting date (Table 2-7). There was a very clear relationship across all measurements with the 25D harvest interval yielding the lowest CP, ADF, and NDF followed by 30D and finally the 35D harvest interval yielding the highest. In the three different herbicide treatments there were no differences in CP, ADF, or NDF yields as a result of herbicide treatment in the seeding year. This is perhaps the biggest finding that application of herbicides during the seeding year had no effect on yield or quality in the first production year. Brothers et al. (1994) also reported no observed differences in forage quality in the year after establishment where alfalfa was seeded with and without use of herbicides. Dillehay and Curran (2010) reported no difference in quality in the first year of established alfalfa along with no differences in alfalfa, weed, or total forage yield from herbicides applied during the establishment year.
Conclusions

In both years, season-total alfalfa yields were increased and weed yields were decreased by herbicide application. In the first harvest following herbicide application the imazethapyr did injure the alfalfa reducing alfalfa yield compared to the glyphosate plots but the injury was temporary and at the end of the year alfalfa yield was not different between the two herbicides. As harvest intervals were lengthened, alfalfa yield increased but weed yield remained unchanged, resulting in a forage that was a higher percentage of alfalfa in the longer compared to the shorter harvest intervals. However this observation only applies to the no herbicide plots since the herbicide treated plots were weed free.

Planting date had the biggest influence of any treatment on weed content. Weed content in both seeding years was higher in the early compared to the late planting date. In this research there were a large number of summer annual weeds present so the early planting matched the typical emergence time period for those weeds better than the late planting. Another factor is that when the plots were tilled and prepared, the seedbed in the later planting had three weeks of weed germination and growth removed that was not controlled in the early planting.

Planting date had an inconsistent affect on quality yield which was dependent mostly on the alfalfa yield. As the harvest interval was extended CP, ADF, and NDF season yields increased because of the increasing yield over the time period. The effect of herbicide treatments was also inconsistent for the total quality yield for the year. In both seeding years herbicide treatments had similar CP yields but the use of a herbicide reduced fiber yields compared to not controlling weeds with herbicides.

Forage yields and quality yields in the first production year showed no carryover from practices implemented during the seeding year.
References


Figure 2-1. Average monthly temperature (°C) at the Russell E. Larson Agricultural Research Center near Rock Springs, PA.
Figure 2-2. Cumulative monthly rainfall (cm) at the Russell E. Larson Agricultural Research Center near Rock Springs, PA.
Figure 2-3. Effects of herbicide treatment and planting date on alfalfa, weed and total herbage yield (alfalfa + weeds) for the first harvest and the cumulative yield for the 2010 seeding year. Treatment abbreviation is: PD = planting date. Values are the means of three harvest intervals. Within the same planting date and harvest, alfalfa means with the same lowercase letter inside bars, weed means with the same lowercase letters above the bars, and total herbage yields with the same uppercase letters above the bars are not different at $P \leq 0.05$. 


Figure 2-4. Effects of herbicide treatment and planting date on alfalfa, weed and total herbage yield (alfalfa + weeds) for the first harvest and the cumulative yield for the 2011 seeding year. Treatment abbreviation is: PD = planting date. Values are the means of three harvest intervals. Within the same planting date and harvest, alfalfa means with the same lowercase letter inside bars, weed means with the same lowercase letters above the bars, and total herbage yields with the same uppercase letters above the bars are not different at $P \leq 0.05$. 
Figure 2-5. Effects of planting date on alfalfa, weed and total herbage yield (alfalfa + weeds) for the seasonal total yield. Treatment abbreviation is: PD = planting date. Values are the means of three harvest intervals and three herbicide treatments. Within the same year, alfalfa means with the same lowercase letter inside bars, weed means with the same lowercase letters above the bars, and total herbage yields with the same uppercase letters above the bars are not different at $P \leq 0.05$. 

![Bar chart showing effects of planting date on alfalfa, weed and total herbage yield (alfalfa + weeds) for the seasonal total yield. Treatment abbreviation is: PD = planting date. Values are the means of three harvest intervals and three herbicide treatments. Within the same year, alfalfa means with the same lowercase letter inside bars, weed means with the same lowercase letters above the bars, and total herbage yields with the same uppercase letters above the bars are not different at $P \leq 0.05$.](image-url)
Figure 2-6. Effects of harvest interval on alfalfa, weed and total herbage yield (alfalfa + weeds) for the seasonal total yield. Treatment abbreviations are: 25D = 25 day harvest interval, 30D = 30 day harvest interval, and 35D = 35 day harvest interval. Values are the means of two planting dates and three herbicide treatments. Within the same year, alfalfa means with the same lowercase letter inside bars, weed means with the same lowercase letters above the bars, and total herbage yields with the same uppercase letters above the bars are not different at $P \leq 0.05$. 
Figure 2-7. Effects of herbicide treatment on alfalfa, weed and total herbage yield (alfalfa + weeds) for the seasonal total yield. Values are the means of two planting dates and three harvest intervals. Within the same year, alfalfa means with the same lowercase letter inside bars, weed means with the same lowercase letters above the bars, and total herbage yields with the same uppercase letters above the bars are not different at $P \leq 0.05$. 
Figure 2-8. Effects of herbicide treatment and planting date on cumulative season total ADF yield for the 2011 seeding year. Treatment abbreviation is: PD = planting date. Values are the means of three harvest intervals. Within the same planting date and harvest, alfalfa means with the same lowercase letter inside bars, weed means with the same lowercase letters above the bars, and total herbage yields with the same uppercase letters above the bars are not different at $P \leq 0.05$. 

ADF Yield

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Early PD</th>
<th>Late PD</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Herbicide</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>Imazethapyr</td>
<td>B</td>
<td>A</td>
</tr>
</tbody>
</table>

- ADF Yield
Table 2-1. Effects of treatments on alfalfa, weed, and total herbage (alfalfa + weeds) over seeding year in 2010 and 2011.

<table>
<thead>
<tr>
<th></th>
<th>2010 1st Harvest</th>
<th>Seeding Year Total</th>
<th>2011 1st Harvest</th>
<th>Seeding Year Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alfalfa</td>
<td>Weeds</td>
<td>Total</td>
<td>Alfalfa</td>
</tr>
<tr>
<td>Planting Date (PD)*</td>
<td>*</td>
<td>*</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Harvest Interval (HI) NA</td>
<td>NA</td>
<td>NA</td>
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<td>NA</td>
</tr>
<tr>
<td>PD x HI Herbicide Treatment (TRT) ns</td>
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<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>PD x TRT</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>HI x TRT</td>
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<td>NA</td>
<td>NA</td>
<td>NS</td>
</tr>
</tbody>
</table>

* Significant treatment and interactions p ≤ 0.05

NA, no applicable measurement for that treatment

ns, not significantly different p ≤ 0.05
Table 2-2. Effects of treatments on first harvest alfalfa, weed, and total yield (alfalfa + weeds) for 2010 and 2011 seeding years.

<table>
<thead>
<tr>
<th>Treatment §</th>
<th>Seeding Year First Harvest DM Yield (kg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
</tr>
<tr>
<td>Early PD</td>
<td>2670 B</td>
</tr>
<tr>
<td>Late PD</td>
<td>3155 A</td>
</tr>
<tr>
<td>25D HI</td>
<td>2705 A</td>
</tr>
<tr>
<td>30D HI</td>
<td>2772 A</td>
</tr>
<tr>
<td>35D HI</td>
<td>3262 A</td>
</tr>
<tr>
<td>No Herbicide</td>
<td>2520 B</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>3464 A</td>
</tr>
<tr>
<td>Imazethapyr</td>
<td>2755 B</td>
</tr>
</tbody>
</table>

§ PD, planting date; 25D HI, 25 day harvest interval.

Within the same column (alfalfa, weeds, total) and treatment row (PD, HI, herbicides) yields with the same letter are no different at $P \leq 0.05$. 
Table 2-3. Effects of treatments on season total alfalfa, weed, and total yield (alfalfa + weeds) for 2010 and 2011 seeding years.

<table>
<thead>
<tr>
<th>Treatment §</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seeding Year</td>
<td>Season Total DM Yield (kg ha(^{-1}))</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>Weeds</td>
</tr>
<tr>
<td>Early PD</td>
<td>9301 A</td>
<td>1418 A</td>
</tr>
<tr>
<td>Late PD</td>
<td>8680 A</td>
<td>844 B</td>
</tr>
<tr>
<td>25D HI</td>
<td>6728 C</td>
<td>1050 A</td>
</tr>
<tr>
<td>30D HI</td>
<td>9111 B</td>
<td>1151 A</td>
</tr>
<tr>
<td>35D HI</td>
<td>11133 A</td>
<td>1191 A</td>
</tr>
<tr>
<td>No Herbicide</td>
<td>7764 B</td>
<td>3393 A</td>
</tr>
<tr>
<td>Glyphosate</td>
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<td>0 B</td>
</tr>
<tr>
<td>Imazethapyr</td>
<td>9316 A</td>
<td>0 B</td>
</tr>
</tbody>
</table>

§ PD = planting date; 25D HI = 25 day harvest interval.

Within the same column (alfalfa, weeds, total) and treatment row (PD, HI, herbicides) yields with the same letter are no different at \( P \leq 0.05 \).
Table 2-4. Effects of treatments on CP, ADF, and NDF season total yield for 2010 and 2011 seeding years.

<table>
<thead>
<tr>
<th></th>
<th>2010 Seeding Year Season Total</th>
<th>2011 Seeding Year Season Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CP</td>
<td>ADF</td>
</tr>
<tr>
<td>Planting Date (PD)</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Harvest Interval (HI)</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>PD x HI</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Treatment (TRT)</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>PD x TRT</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>HI x TRT</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>PD x HI x TRT</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

* Significant treatment and interactions $P \leq 0.05$

ns, not significantly different $P \leq 0.05$
Table 2-5. Effects of treatments on season total CP, ADF, and NDF yield for 2010 and 2011 seeding years.

<table>
<thead>
<tr>
<th>Treatment §</th>
<th>2010 Seeding Year</th>
<th>Season Total Quality Yield (kg ha(^{-1}))</th>
<th>2011 Seeding Year</th>
<th>Season Total Quality Yield (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg/ha</td>
<td>CP</td>
<td>ADF</td>
<td>NDF</td>
<td>CP</td>
</tr>
<tr>
<td>Early PD</td>
<td>2515</td>
<td>A</td>
<td>2724</td>
<td>A</td>
</tr>
<tr>
<td>Late PD</td>
<td>2260</td>
<td>B</td>
<td>2250</td>
<td>B</td>
</tr>
<tr>
<td>25D HI</td>
<td>1898</td>
<td>C</td>
<td>1861</td>
<td>C</td>
</tr>
<tr>
<td>30D HI</td>
<td>2422</td>
<td>B</td>
<td>2515</td>
<td>B</td>
</tr>
<tr>
<td>35D HI</td>
<td>2843</td>
<td>A</td>
<td>3086</td>
<td>A</td>
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<td>No Herbicide</td>
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<td>A</td>
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<tr>
<td>Glyphosate</td>
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<td>A</td>
<td>2334</td>
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<td>Imazethapyr</td>
<td>2290</td>
<td>A</td>
<td>2198</td>
<td>B</td>
</tr>
</tbody>
</table>

§ PD = planting date; 25D HI = 25 day harvest interval.

Within the same column (CP, ADF, NDF) and treatment row (PD, HI, herbicides) yields with the same letter are no different at \( P \leq 0.05 \).
Table 2-6. Effects of treatments on CP, ADF, and NDF season total yield in 2011 production year for 2010 seeding year.

<table>
<thead>
<tr>
<th>First Production Year</th>
<th>Seeding Year Season Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DM Yield</td>
</tr>
<tr>
<td>Planting Date (PD)</td>
<td>ns</td>
</tr>
<tr>
<td>Harvest Interval (HI)</td>
<td>*</td>
</tr>
<tr>
<td>PD x HI</td>
<td>ns</td>
</tr>
<tr>
<td>Treatment (TRT)</td>
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<tr>
<td>PD x TRT</td>
<td>ns</td>
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<tr>
<td>HI x TRT</td>
<td>ns</td>
</tr>
<tr>
<td>PD x HI x TRT</td>
<td>ns</td>
</tr>
</tbody>
</table>

* Significant treatment and interactions $P \leq 0.05$

ns, not significantly different $P \leq 0.05$
Table 2-7. Effects of treatments on season total dry matter (DM), CP, ADF, and NDF yield in 2011 production year for 2010 seeding year.

<table>
<thead>
<tr>
<th></th>
<th>Total DM Yield (kg ha⁻¹)</th>
<th>Total Quality Yield (kg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>CP</td>
</tr>
<tr>
<td>Early PD</td>
<td>8582</td>
<td>1920</td>
</tr>
<tr>
<td>Late PD</td>
<td>8675</td>
<td>1996</td>
</tr>
<tr>
<td>25D HI</td>
<td>7562</td>
<td>1859</td>
</tr>
<tr>
<td>30D HI</td>
<td>8813</td>
<td>1950</td>
</tr>
<tr>
<td>35D HI</td>
<td>9512</td>
<td>2065</td>
</tr>
<tr>
<td>No Herbicide</td>
<td>8582</td>
<td>1956</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>8730</td>
<td>1967</td>
</tr>
<tr>
<td>Imazethapyr</td>
<td>8575</td>
<td>1952</td>
</tr>
</tbody>
</table>

§ PD = planting date; 25D HI = 25 day harvest interval.

Within the same column (DM, CP, ADF, NDF) and treatment row (PD, HI, herbicides) yields with the same letter are no different at $P \leq 0.05$. 