Title: Evaluation of the Efficacy of Herbicide Tank-Mixes and Sequential Applications for the Control of Plantain (*Plantago* spp.) in Alfalfa

PI: **Leslie Beck**, Department of Extension Plant Sciences; New Mexico State University, MSC 3AE, PO Box 30003, las Cruces, NM 88003; Phone: (575) 646-7082; Fax: (575) 646-8085; lebeck@nmsu.edu

Co PI: Mark Marsalis, Department of Extension Plant Sciences; New Mexico State University, 1036 Miller St. SW, Los Lunas, NM 87301; Phone: (505) 865-7340; Fax: (505) 865-5163; marsalis@nmsu.edu

Leonard Lauriault, Department of Plant & Environmental Sciences; New Mexico State University, 6502 Quay Rd AM 5, Tucumcari, NM 88401; Phone: (575) 461-1620; Fax: (575) 461-1631; lmlaur@nmsu.edu

Abstract: Broadleaf and buckhorn plantain (*Plantago major* and *P. lanceolata*, respectively) are perennial weeds that are notoriously difficult to control in alfalfa cropping systems. Research conducted in 2018 indicated that single applications of commercially available herbicides, including Sharpen®, a newly registered herbicide for broadleaf weed control in alfalfa, proved ineffective for plantain control in the greenhouse. In 2018-2019, field and greenhouse experiments were conducted to determine if Sharpen®, tank-mixed with commercially available products and/or sequential applications, could effectively control plantain with little damage to alfalfa yield. In the greenhouse, applications of Sharpen® combined with Butyrac 200® and a tank-mix of Butyrac 200® + Pursuit® provided almost complete control of broadleaf plantain compared to the non-treated control. However, herbicide injury did not increase with the addition of a sequential application of any herbicide combination compared to the injury observed with the initial applications. In the field, both initial and sequential applications of Sharpen® in combination with Roundup® caused a significant reduction in alfalfa yield for the first harvest date in Las Cruces. However, applications of Sharpen alone or in combination with the other herbicide active ingredients did not significantly affect alfalfa yield at other harvest dates or at Los Lunas compared to the non-treated control, regardless if it was an initial application only, or if a sequential application was added 6 weeks after initial treatment. The varieties used at both locations were not Roundup Ready®. This research indicates that Sharpen® can be tank-mixed with multiple herbicides, especially Butyrac 200® for improved broadleaf plantain weed control with minimal negative effects to alfalfa yield. This research also indicates that sequential applications of Sharpen® in combination with other herbicide treatments was not necessary for increased herbicide injury to broadleaf plantain, although these applications did not have an effect on alfalfa yield unless Roundup® was part of the mixture and a non-Roundup Ready® variety was being treated.

Introduction: As of 2018, alfalfa hay remains the second most valuable cash crop in the state of New Mexico with estimated annual gross receipts of just over $197 million (Lauriault et al., 2018). Additionally, hay yields reflected an increase of 2%, along with an increase in revenue of $29 million, compared to 2017 for the state. Furthermore, the overall value of alfalfa hay is increased by its essential contributions, as feed and forage, to livestock production (i.e., meat, milk, and textiles) which continues to lead New Mexico in overall agricultural commodities. The dairy industry contributed approximately $1.33 billion in total milk sales, and the beef industry grossed $823 million in total sales for the state of New Mexico (USDA NASS, 2018). Crop production acreage and the availability of resources for management continue to decline; however, it is still important to maximize yield and quality of all alfalfa production as much as possible during the growing season to meet the ever-increasing agricultural needs of growers, producers, farmers, ranchers, dairy managers, and industry personnel throughout the state of New Mexico.

As demand for quality alfalfa continues to increase, managing weeds remains a critical and ever-present component of successful production. While weeds that emerge during the seedling stages of alfalfa typically have the greatest impact by competing for light, water, space, and nutrients, late-season weeds that populate established alfalfa fields can have a significant impact on yield through continued competition for resources throughout the growing season (Beck et al., 2017). Additionally, the presence of late-season annual and perennial weeds can lower forage quality, reduce stand longevity, cause premature stand loss or reduction, increase the incidence of disease and insect damage, and create detrimental harvesting issues (Gilbert et al., 1988; Green et al., 2003; Ashigh et al., 2010).

Perennial weed populations are especially difficult to control in perennial crops, like alfalfa, because management practices have to address seed production and vegetative reproductive structures that allow the plant to survive from season to season. Simple perennial weeds like plantain (*Plantago* spp.) have a hardy root system that allows the plant to die back and survive non-ideal environmental conditions throughout the winter, then proctors tissue regrowth and re-establishment once conditions become ideal again in the early spring. Broadleaf plantain (*P. major*) and buckhorn plantain (*P. lanceolata*) are particularly difficult-to-control weeds whose infestations are widespread in alfalfa fields throughout the western U.S., including the state of New Mexico (Elmore et al., 2007; Sulser and Witesides, 2012). Management of these simple perennial weeds must focus primarily on injury to the root system; however, it is difficult for herbicide active ingredients to move effectively enough within the entire plant to injure a healthy root system that extends deep within the soil (Elmore et al., 2007). Similarly, the use of herbicides to control broadleaf weeds like plantain in a broadleaf crop like alfalfa further complicate any effective management. As a result, there are only a few registered herbicides, such as glyphosate and MCPA that have been reported to cause injury to plantain in alfalfa fields in New Mexico (Beck et al., 2017). Additionally, the continued use of these select few herbicide active ingredients to manage a specific population of weeds like plantain in alfalfa over time, can lead to the development of herbicide resistance in the target weeds (Orloff et al., 2009). As a result, research to evaluate the effectiveness of newly registered herbicides, as well as tank-mixes of older traditional herbicides with different active ingredients is greatly warranted for control of plantain in alfalfa.

Sharpen® (BASF Corporation) has recently acquired a supplemental label for broadleaf weed control in dormant-season alfalfa in the state of New Mexico (BASF Corporation, 2018). The active ingredient in Sharpen® is saflufenacil, which causes plant cell membrane damage and eventually plant death by inhibiting the production of protoporphyrinogen-oxidase (herbicide group 14). Specifically, Sharpen® can offer contact burn-down control of perennial broadleaf weeds including, but not limited to, field bindweed (*Convolvulus arvensis*) and dandelion (*Taraxacum officinale*) during limited (dormant) season growth of alfalfa. Sharpen® was assessed as a potential herbicide option for late-season broadleaf and buckhorn plantain control in greenhouse evaluations in Las Cruces, and crop injury assessed in alfalfa fields in Los Lunas in 2017 and 2018. Single applications of the highest rate of Sharpen® resulted in injury to the plantain, yet the plants eventually recovered (data not shown). One treatment that was added to the 2017-2018 greenhouse trial was an application of Sharpen® in combination with a second active ingredient, which yielded the most herbicide injury to the plantain, but limited control (data not shown). As a result, further research into applications of Sharpen®, as well as tank-mixes and sequential applications of Sharpen® combined with other active ingredients to potentially improve plantain control in alfalfa is warranted. The objectives of this study were to: 1) Compare the weed control performance of initial and sequential applications of Sharpen® alone or in combination with commercially available herbicide standards under greenhouse conditions, and 2) evaluate the effects of alfalfa yield as a result of the applications of single or multiple applications of Sharpen® alone or in combination with other commercially available herbicide products. Should the results indicate that Sharpen® alone, or tank-mixed, provides acceptable control of plantain and equivalent crop safety compared to the non-treated control, we will take action to include plantain as a target weed in the most up-to-date product label.

Materials and Methods: In 2018, a field research trial was established to evaluate the development of herbicide injury symptoms, as well as any negative impacts on yield, in a mature alfalfa stand. Due to the lack of a uniform infestation of the target weeds needed for a comparative research study in the field, research was also initiated in the greenhouse in 2018 to evaluate the efficacy of saflufenacil (Sharpen®) on broadleaf and buckhorn plantain control when combined with other commercially available herbicides, as well as sequential applications for enhanced control.

Field Study: Field trials were initiated at New Mexico State University's Agricultural Science Center (ASC) at Los Lunas, NM and the Leyendecker Plant Sciences Research Center (LSC) at Las Cruces, NM. Herbicide trials were initiated in December 2018 to evaluate any negative impacts of herbicide treatments to alfalfa growth and yield. The soil at the ASC site is a Vinton Series (Sandy, Mixed, Thermic Typic Torrifluvents with 1.5% organic matter) (NCSS, 2019b) while the soil at the LSC site is an Armijo series (Fine, Smectitic, Thermic Chromic Haplotorrerts with 1.3% organic matter) (NCSS, 2019a). The fields at both locations had previously been prepared for alfalfa using typical procedures including tillage, seeding, irrigation, etc. The alfalfa at the ASC field was an established (6+ years), healthy stand of Reward II (Fall dormancy rating = 4, dormant; NAFA, 2008, 2019), and the alfalfa at the LSC field was an established (4+ years) healthy stand of TMA 990 Brand (Fall dormancy rating = 9, non-dormant; NAFA, 2019) (Lauriault et al., 2008, 2009, 2011; Dyna-Gro, 2019). Neither alfalfa variety was Roundup Ready®. The herbicide treatments for the study are labeled for use in dormant-season alfalfa growth. However, due to warmer temperatures throughout the southern regions of New Mexico, especially Las Cruces, alfalfa tends to display slowed-growth effects rather than true dormancy, thus herbicide applications must be made early enough for the alfalfa to recover during slowed fall/winter-growth and spring regrowth (Lauriault et al., 2009, 2011). As a result, herbicide applications were initiated on December 5, 2019, at LSC and December 12, 2019, at ASC after the final cutting and during a period of slowed growth starting in late November. This is also the best timing for herbicide control of perennial weeds like plantain since the redistribution of carbohydrates to the root system, in preparation for winter, allows for greater translocation of systemic herbicides and more effective control (Johnson and VanGessel, 2014).

The experimental design at both locations was a randomized complete block design and four replications of thirteen total treatments using a plot size of 10 ft x 10 ft. All treatments consisted of an initial application of the following herbicide combinations: saflufenacil (Sharpen®) alone at 2 fl oz/A; saflufenacil (2 fl oz/A) + 2,4-DB Amine (Butyrac 200®) at 3 qts/A; saflufenacil (2 fl oz/A) + imazethapyr (Pursuit®) at 6 fl oz/A; saflufenacil (2 fl oz/A) + imazamox (Raptor®) at 6 fl oz/A; and saflufenacil (2 fl oz/A) + glyphosate (Roundup PowerMax®) at 44 oz/A, which was included to assess potential control of plantain in Roundup Ready® alfalfa systems. An additional treatment combination of Butyrac 200® (3 qts/A) + Pursuit® (6 fl oz/A) was added to the study to reflect an herbicide combination commonly used by alfalfa growers in New Mexico as a comparison. A non-treated control (NTC) was included for comparison as well. Each treatment contained the tank-mixes mentioned above at either a single initial application or an initial application coupled with a sequential application 6 weeks after the initial treatment (WAIT) for a total of 13 treatments. Treatments were applied using a CO_2-powered backpack sprayer equipped with a 4-nozzle boom with 11002 VS TeeJet Flat-fan nozzles calibrated to deliver 20 GPA at 207 kPa. The alfalfa fields were not irrigated for 24 hours after the initial application to allow herbicide treatments to dry. Throughout the duration of the study, fields were flood-irrigated as needed to maintain alfalfa growth and health.

In 2019, alfalfa injury (%) due to herbicide applications was evaluated visually every two weeks for approximately 18 WAIT at LSC and 23 WAIT at ASC. Evaluations were assessed on a percent scale where 0 equals no injury to alfalfa, and 100 equals death of alfalfa plants. Additionally, weed percent coverage (%) was estimated visually every two weeks for approximately 16 WAIT at LSC and 23 WAIT at ASC on a percent scale where 0 equals no weed populations within the treated plot, and 100 equal equals complete weed population coverage within the treated plot. No broadleaf or buckhorn plantain weeds were located within the field trials at either location. The predominant weed species within the entire alfalfa fields throughout the duration of the trials at both locations included annual sowthistle (*Sonchus oleraceus*) and prickly lettuce (*Lactuca serriola*), and specifically shepherd's purse (*Capsella bursa-pastoris*) and jungle rice (*Echinochloa colona*) at the LSC location where daytime winter-season temperatures were more mild compared to the ASC location. For the most part, field plots remained relatively weed-free throughout the duration of the trial at both locations. Alfalfa was harvested on April 9 (19 WAIT) and June 6, 2019 (24 WAIT) at LSC, and on June 20 (27 WAIT) and July 6, 2019 (30 WAIT) at ASC to assess any treatment effects on yield. Alfalfa was harvested using hand-clipped fresh forage to collect weights from a 10.56 ft^2 area within each plot. Samples from each plot were collected and weighed prior to drying in a forced-air oven at 52°C until a constant weight to convert field weights to dry matter (DM) yield. Herbicide injury, by rating WAIT, and DM yield data were subjected to pairwise comparisons amongst treatments using analysis of variance (PROC Mixed) in SAS (Version 9.4, SAS Institute Inc.) and treatment means were separated using Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$.

Greenhouse Study: A greenhouse study was initiated on September 7, 2018, when broadleaf and buckhorn plantain were seeded in potting soil at the LCS Greenhouse in Las Cruces, NM. On November 8, 2018, germinated seedlings of both broadleaf and buckhorn plantain were transplanted into individual cone-tainers filled with potting soil for further maturation. Plants were irrigated daily to allow for healthy growth and development throughout the trial.

The experimental design was a randomized complete block design with each cone-tainer having a single plant as the experimental unit and four replications of twelve total treatments, applied to each plantain species. On January 7, 2019, the same twelve initial herbicide treatments and applications rates that were used in the field trials were also applied in the greenhouse. Like the field trials, six of the treatments also received a sequential application on February 7, 2019 (4 WAIT). A NTC was also included for comparison for a total of thirteen treatments. The duration between the initial and sequential applications in the greenhouse differed from that of the field trials due to more ideal growing conditions that allowed the plantain plants to recover more quickly from the initial application. In contrast, the sequential applications in the field trials were made 6 WAIT to allow for some recovery, and a better evaluation of the potential for sequential tank-mixes to cause additional damage to the alfalfa yield. Treatments were applied using the same spray equipment as the field studies. Cone-tainers were not watered for 24 hours following the treatment applications, and were irrigated as needed throughout the study to maintain plantain growth and health.

Beginning 1 WAIT, broadleaf and buckhorn plantain injury (%) due to herbicide applications was evaluated visually once a week until 6 WAIT when plantain began to recover from herbicide injury. Evaluations were assessed on a percent scale where 0 equals no injury to plantain, and 100 equals death of plantain plants. Dark green color index (DGCI) was calculated using digital photographs. One photograph per plant was taken weekly until 6 WAIT using a constructed light box with mounted LED lamps to provide uniform lighting conditions and camera lens height for all the photographs taken (Karcher and Richardson, 2003). A Canon PowerShot SX700 HS (Canon Inc., Tokyo, Japan) camera was set to a shutter speed of 1/10, an aperture of f/4.0, an ISO of 200, and a normal focus lens, and used to take digital images. SigmaScan Pro 5 software package (Systat Software Inc., San Jose, CA) was used to calculate DGCI following methods described by Richardson et al. (2001). The entire picture frame was used to calculate DGCI without excluding bare spots (Karcher and Richardson, 2003), which was then used to calculate percent green cover (cover), or the amount of green pixels in each image, within the software to determine the appearance of herbicide injury in comparison to healthy green plant tissue. Starting at 6 WAIT, above and below-ground tissue was harvested for broadleaf and buckhorn plantain by cone-tainer. Below-ground tissue was washed to remove potting soil contaminants. Plant samples were then oven-dried and weighed by container. Visual herbicide injury, percent green cover, and broadleaf plantain root dry weight data were subjected to pairwise comparisons amongst treatments using analysis of variance (PROC Mixed) in SAS and treatment means were separated using Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$.

Project Objectives and Corresponding Results:

1. Compare the weed control performance of initial and sequential applications of Sharpen® alone or in combination with commercially available herbicide standards for plantain under greenhouse conditions.
2. Evaluate the effects of alfalfa yield as a result of initial or sequential applications of Sharpen® alone or in combination with other commercially available herbicide standards.

1. Sharpen® tank-mixed with Butyrac 200® may provide adequate injury to control broadleaf plantain; however, sequential applications were not needed for increased injury. This research continues.
2. Sharpen® tank-mixed with other commercially available herbicides may be applied in semi-dormant alfalfa with minimal affects to yield. However, caution should be approached when applying Sharpen® + Roundup® where alfalfa fall dormancy does not allow for slowed-growth during the winter months and the alfalfa variety is not Roundup Ready®. Sharpen® would be a viable candidate for late-season residual control of winter annual weeds.

Results and Discussion:

<u>Field Study:</u> Average visual estimates for weed percent coverage (%) did not yield any noticeable difference amongst treatments as the study area was relatively clean of weed populations on the treatment application dates at both locations (Data not shown). However, the final weed coverage rating date (23 WAIT) at the ASC location indicated that initial and sequential herbicide applications of any treatment that contained Sharpen®, as well the sequential applications of Butyrac 200® + Pursuit® provided residual late-season annual weed control when significantly higher populations of prickly lettuce and annual sowthistle were observed in in the NTC and the initial Sharpen® + Roundup® treatments (Image 1 and Figure 1).

In the weeks following the initial and sequential applications, there was significantly greater herbicide injury (%) to the alfalfa at both the LSC and ASC locations with herbicide treatments that contained Sharpen® or in combination with other herbicide active ingredients compared to the NTC and the Butyrac® 200 + Pursuit® treatments (Tables 1 and 2). However, the alfalfa recovered to the point of no visible injury to any of the herbicide treatments compared to the NTC by 18 WAIT at both locations, with the exception of the initial only, and the initial + sequential applications of Sharpen® + Roundup®. This is not unexpected since the alfalfa varieties used in the field studies at both locations were not Roundup Ready®. The injury observed for all treatments that included Sharpen® following the initial and sequential applications is an indication that the herbicide treatments were made while there was still active (although reduced) growth of the alfalfa on the initial application dates of December 5, 2019 at LSC, and December 12, 2019 at ASC. This growth was observed in the initial damage of the alfalfa plants treated with Sharpen® and Roundup®, which only causes injury to green, actively growing plant tissue (BASF Corporation, 2019; Monsanto Company, 2019).

Average DM yield observed for the first harvest (19 WAIT) at LSC resulted in a significant reduction of alfalfa yield in treatments applied with Sharpen® + Roundup® compared to the NTC (Figure 2). Average yield for the second harvest date (24 WAIT) at LSC and both harvest dates (27 and 30 WAIT) at ASC did not result in significant differences among the herbicide treatments, including those that contained Sharpen® (Figures 2 and 3). The significant drop in yield with the first harvest date at LSC is indicative of the differences in the dormancy ratings of the two alfalfa varieties between both locations and the milder winter temperatures experienced at the LSC location compared to the ASC location which is located approximately 175 miles north. The initial herbicide applications at LSC were made to alfalfa that did have some slowed growth, but was considerably more active than the ASC alfalfa, thus adequate recovery time needed to limit any reductions in the first yield was not met by 19 WAIT (Image 2). In contrast, while herbicide injury was observed following herbicide treatments, there was adequate time for recovery to limit the negative effects on yield for all other harvest dates at both locations. Additionally, a sequential application 6 WAIT at both locations did not affect the yield at 24 WAIT at LSC or for both harvest dates (27 and 30 WAIT) at the ASC location.

As a result, applications of Sharpen® alone or in combination with other commercially available herbicides may be viable candidates for inclusion in a late-season weed control program even when applied on slowed green growth of mature alfalfa crop stands during the fall months. However, applicators should be cautious when using active ingredients like Roundup® in non-Roundup Ready® alfalfa varieties that are less dormant allowing for >6.0” growth during the winter “dormant” period.

<u>Greenhouse Study:</u> Prior to the initial herbicide treatment application, the buckhorn plantain began to develop symptoms of necrosis at the leaf tips which progressed throughout the length of the entire leaf. Within a short amount of time, the entire study of buckhorn plantain was completely necrotic, and thus data (both visual and digital) could not be collected. The cause of the damage to the buckhorn is still unknown as other buckhorn plants located elsewhere in the greenhouse displayed the same symptoms and eventual death. Additionally, the broadleaf plantain was healthy and robust at the initiation of the herbicide treatments, but within a week or two (about the time herbicide injury started to show) the non-treated plants started to develop multiple symptoms of stress most likely associated with roots being too mature and robust for continued growth of the above ground tissue at the time the trial was initiated. Visual ratings for herbicide injury differentiated herbicide symptoms from the stress symptoms which allowed for the data collection of injury. The software that determines DGCI was not able to make this distinction, thus the digital images did not yield any significant results or measurable trends between the NTC and herbicide treatments (Data not shown). Due to the lack of comparable or living plant tissue from both broadleaf and buckhorn plants, root and shoot dry weights could not be collected. As a result, the greenhouse study on both broadleaf and buckhorn plantain will be repeated in the greenhouse in the fall/winter of 2019/2020 to hopefully yield publishable results. At that time, a report discussing the results of the second greenhouse trial will also be sent to the National Alfalfa & Forage Alliance.

Visual ratings data for percent weed injury (%) in the broadleaf plantain indicated that initial applications of Sharpen® + Butyrac 200® provided early (1 WAIT) injury symptoms to broadleaf plantain compared to the other herbicide treatments (Table 3). Additionally, the initial only and initial + sequential applications of Sharpen® + Butyrac 200® provided the highest percentages of weed injury throughout the study (up to 6 WAIT) compared to other herbicide treatments. Results also indicated that by 6 WAIT, all herbicide combinations and application timings that contain Sharpen® and a mixture of Butyrac 200® + Pursuit® provided significantly greater herbicide injury symptoms compared to the NTC. However, injury data collected from 4 to 6 WAIT indicate that herbicide injury to plantain did not increase with the addition of a sequential application. Also the initial applications of Butyrac 200® combined with either Sharpen® or Pursuit® was the only treatment to provide levels of herbicide injury to the broadleaf plantain where recovery would not be expected at 6 WAIT. Additionally, the initial applications of these treatments performed comparatively to the addition of a sequential application for these treatments at 6 WAIT. Thus, the visual data indicated that while the herbicide treatments where Butyrac 200® is combined with either Sharpen® or Pursuit® provided the greatest broadleaf plantain weed control compared to other herbicide combinations, sequential applications were not necessary for increased herbicide injury beyond the resulting damage of the initial applications of the herbicide combinations. A repeat of the greenhouse plantain study is necessary in fall 2019 to determine if these results are also reflected in the digital image analysis data, and whether these trends would be reflected in buckhorn plantain as well.

Conclusions: This research indicates that applications of Sharpen® tank-mixed with other commercially available herbicides may provide adequate injury to broadleaf plantain, especially when combined with Butyrac 200. Additionally, single or sequential applications of Sharpen® alone or in combination with other commercially available herbicides did not negatively affect alfalfa yield except when Roundup® was part of the tank-mix when applied to non-Roundup Ready® alfalfa. Thus tank-mixes of Sharpen® may be great candidates for broadleaf plantain control with little negative effects on alfalfa yield. However, further research is still needed to determine the ideal tank-mix rates to maximize weed injury, as well as whether additional combinations of Butyrac 200® with Sharpen® can provide better broadleaf plantain control compared to Butyric 200® tank-mixed with other herbicide active ingredients. The greenhouse data also seemed to indicate that sequential applications were not needed for improved broadleaf plantain control, although this study warrants a repeated trial to determine if these results can be validated and whether they would apply to buckhorn plantain as well. This research continues.

Acknowledgements: Funding for this study was provided by the U.S. Alfalfa Farmer Research Initiative of the National Alfalfa & Forage Alliance.

Image 1. Observations of treatment plots applied with Sharpen® tank-mixes (upper left corner of photograph) that are clean of weed contaminants compared to non-treated areas surrounding the treatment plots on May 21, 2019. Predominant weeds that were present in the NTC plots and areas surrounding the trial included annual sowthistle (*Sonchus oleraceus*) and prickly lettuce (*Lactuca serriola*). Treatment applications were made initially on December 12, 2019, and sequential applications on January 22, 2019, at the New Mexico State University Agricultural Science Center at Los Lunas, NM.

Image 2. Alfalfa injury observed on January 3, 2019, in response to herbicide applications that were made initially on December 5, 2019, and sequentially on January 15, 2019, at the New Mexico State University Leyendecker Plant Sciences Center at Las Cruces, NM.

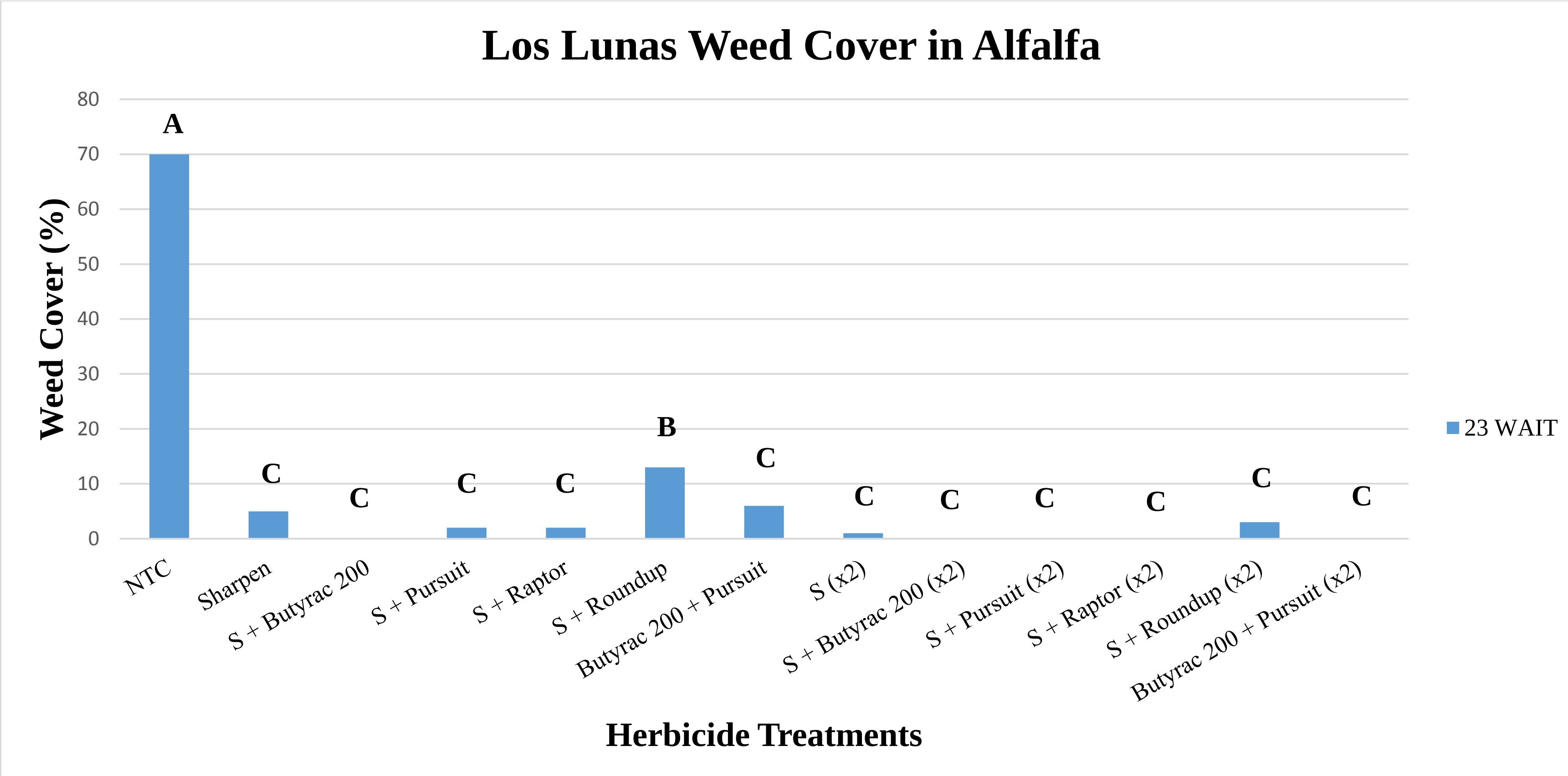

Figure 1. Weed percent cover (%) in response to applications of initial and sequential tank-mixes of Sharpen® combined with other commercially available herbicides at the New Mexico State University Agricultural Science Center at Los Lunas, NM. Initial applications were made on December 12, 2018, and sequential applications were made on January 22, 2019 (6 WAIT). Bars having the same letters are not significantly different at $\alpha = 0.05$, LSD = 6.52; NTC = non-treated control; WAIT = weeks after initiation of treatment; S = Sharpen®; x2 = sequential application of herbicide treatment 6 WAIT; LSD = least significant difference. Predominant weeds that were present in NTC plots included annual sowthistle (*Sonchus oleraceus*) and prickly lettuce (*Lactuca serriola*).

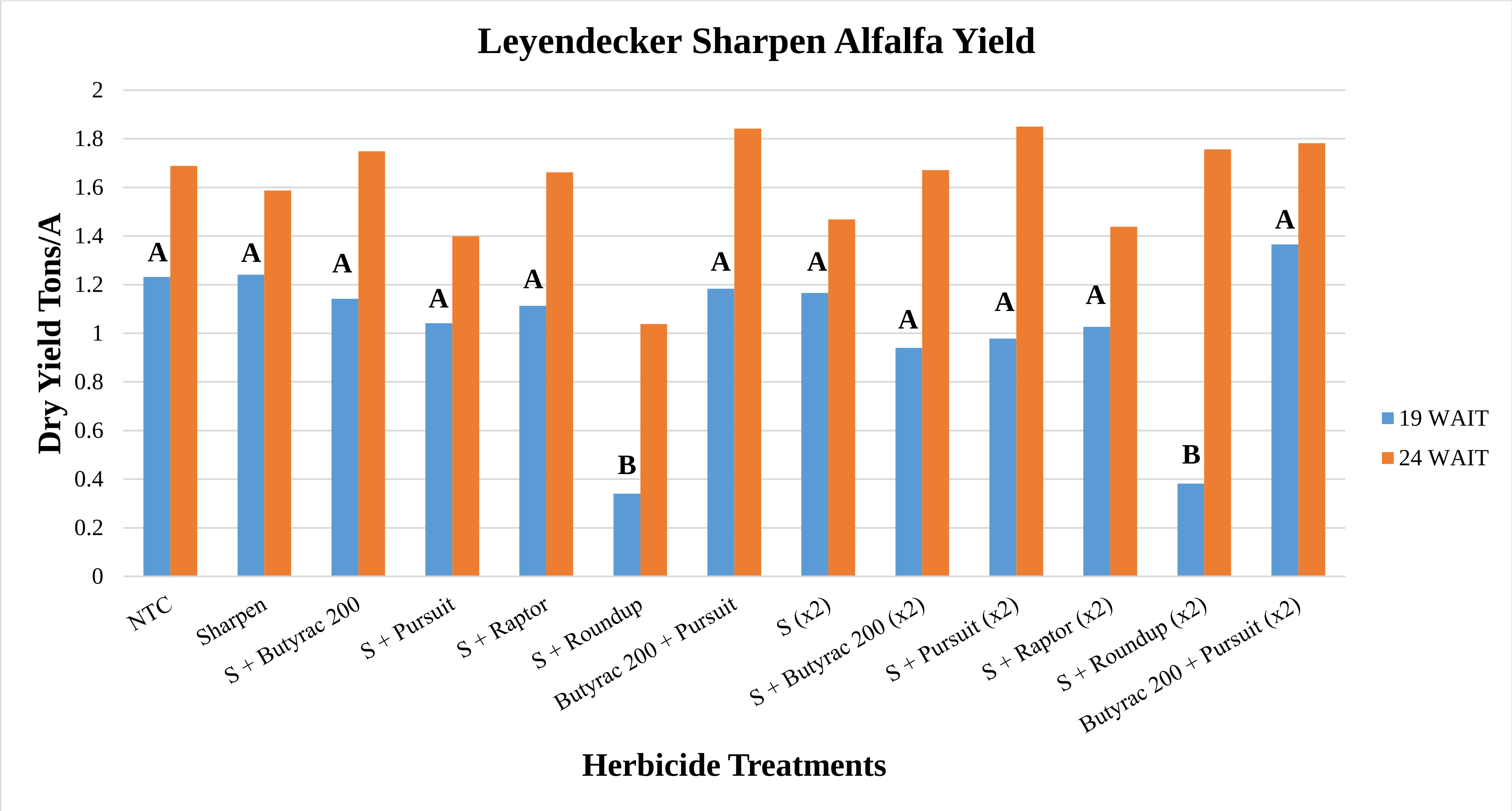

Figure 2. Alfalfa dry matter (DM) yield for 2 cuttings in 2019 in response to applications of initial and sequential tank-mixes of Sharpen® combined with other commercially available herbicides at the New Mexico State University Leyendecker Plant Sciences Center at Las Cruces, NM. Initial applications were made on December 12, 2018, and sequential applications were made on January 22, 2019 (6 WAIT). Bars having the same letters are not significantly different at $\alpha = 0.05$, LSD = 0.7 (19 WAIT) and 0.5 (24 WAIT); NTC = non-treated control; WAIT = weeks after initiation of treatment; S = Sharpen®; x2 = sequential application of herbicide treatment 6 WAIT; LSD = least significant difference.

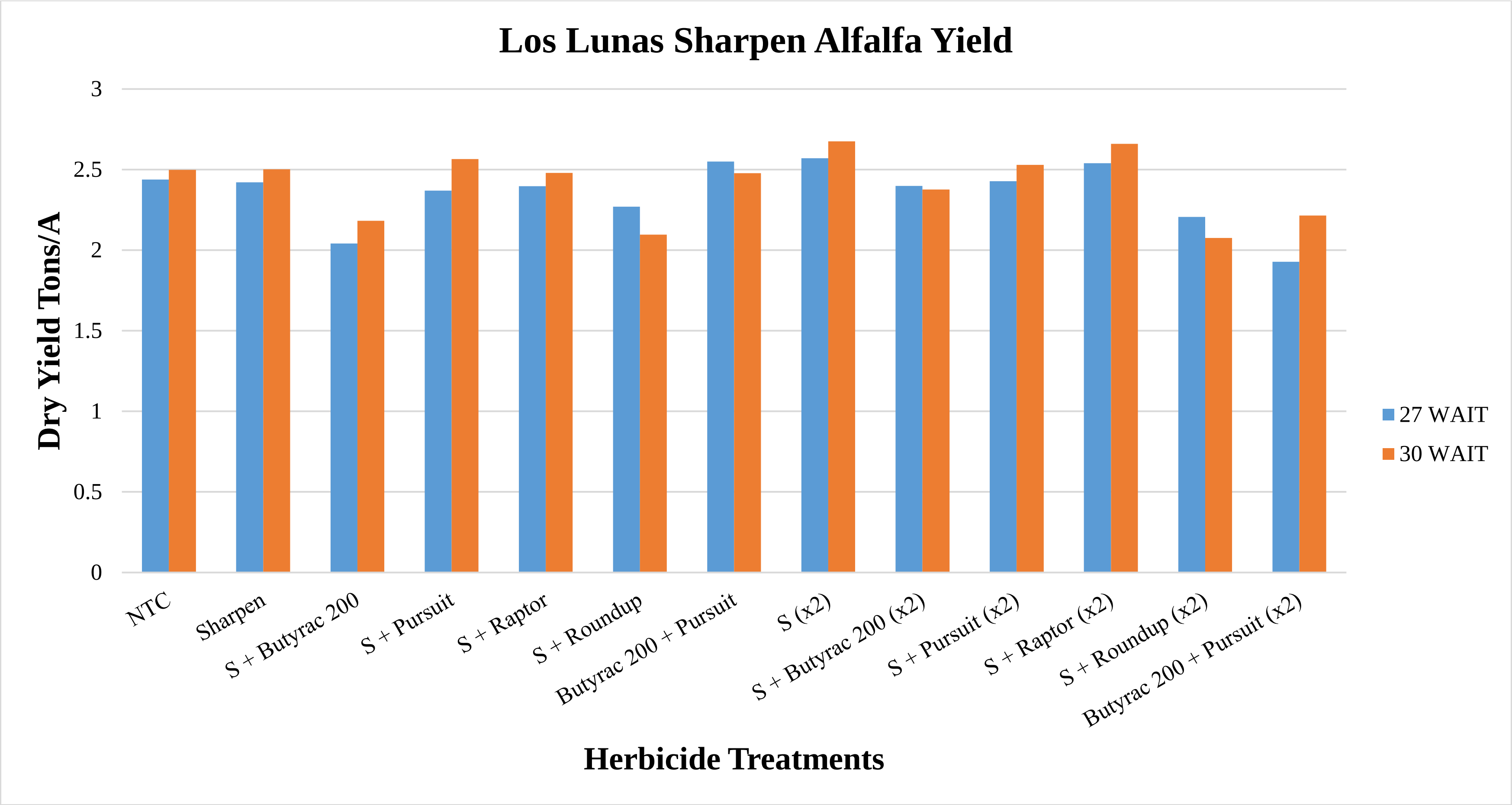

Figure 2. Alfalfa dry matter (DM) yield for 2 cuttings in 2019 in response to applications of initial and sequential tank-mixes of Sharpen® combined with other commercially available herbicides at the New Mexico State University Agricultural Science Center at Los Lunas, NM. Initial applications were made on December 5, 2018, and sequential applications were made on January 15, 2019 (6 WAIT). Within cutting data are not significantly different according to Fisher's LSD test (α = 0.05), LSD = 0.7 (27 WAIT) and 0.6 (30 WAIT); NTC = non-treated control; WAIT = weeks after initiation of treatment; S = Sharpen®; x2 = sequential application of herbicide treatment 6 WAIT; LSD = least significant difference.

Table 1. Percent alfalfa injury (%) observed visually in the field in response to herbicide applications that were made initially on December 5, 2019, and sequentially on January 15, 2019, at the New Mexico State University Leyendecker Plant Sciences Center at Las Cruces, NM.

	Rate		Leyendecker Alfalfa Injury %			
Treatment		6 WAIT[y]	4 WAIT	6 WAIT	13 WAIT	18 WAIT
NTC[y]	--	--	2.5 d[z]	0.0 d	0.0 f	5.0 c
Sharpen	2 oz/A	--	90.0 b	70.0 b	57.5 d	5.0 c
Sharpen + Butyrac 200	2 oz/A + 3 qts/A	--	90.0 b	71.3 b	57.5 d	5.0 c
Sharpen + Pursuit	2 oz/A + 6 oz/A	--	92.5 ab	73.8 b	57.5 d	5.0 c
Sharpen + Raptor	2 oz/A + 6 oz/A	--	92.5 ab	75.0 b	61.3 cd	5.0 c
Sharpen + Roundup	2 oz/A + 44 oz/A	--	95.8 a	100.0 a	95.0 a	55.0 b
Butyrac 200 + Pursuit	3 qts/A + 6 oz/A	--	12.5 c	15.0 c	10.0 ef	5.0 c
Sharpen	2 oz/A	2 oz/A	91.3 ab	96.3 a	72.3 bc	5.0 c
Sharpen + Butyrac 200	2 oz/A + 3 qts/A	2 oz/A + 3 qts/A	92.5 ab	97.5 a	71.3 bc	5.0 c
Sharpen + Pursuit	2 oz/A + 6 oz/A	2 oz/A + 6 oz/A	88.8 b	98.8 a	67.5 bcd	5.0 c
Sharpen + Raptor	2 oz/A + 6 oz/A	2 oz/A + 6 oz/A	93.8 ab	96.3 a	75.0 b	5.0 c
Sharpen + Roundup	2 oz/A + 44 oz/A	2 oz/A + 44 oz/A	93.8 ab	100.0 a	95.0 a	60.0 a
Butyrac 200 + Pursuit	3 qts/A + 6 oz/A	3 qts/A + 6 oz/A	7.5 cd	20.0 c	17.0 f	5.0 c
LSD[y] value			5.4	6.5	11.4	4.0

[y]NTC = non-treated control; WAIT = weeks after initiation of treatment; LSD = least significant difference

[z]Within columns, means followed by the same letter are not significantly different according to Fisher's LSD test (α=0.05)

Table 2. Percent alfalfa injury (%) observed visually in the field in response to herbicide applications that were made initially on December 12, 2019, and sequentially on January 22, 2019, at the New Mexico State University Agricultural Science Center at Los Lunas, NM.

			Los Lunas Alfalfa Injury				
	Rate		%				
Treatment		6 WAIT[y]	4 WAIT	6 WAIT	13 WAIT	18 WAIT	23 WAIT
NTC[y]	--	--	8.8 c[z]	8.5 b	20.0 B	0.0 B	0.0 B
Sharpen	2 oz/A	--	97.3 a	95.0 a	12.5 BCD	0.0 B	0.0 B
Sharpen + Butyrac 200	2 oz/A + 3 qts/A	--	96.5 a	91.3 a	8.8 D	0.0 B	0.0 B
Sharpen + Pursuit	2 oz/A + 6 oz/A	--	96.5 a	93.8 a	15.0 BCD	0.0 B	0.0 B
Sharpen + Raptor	2 oz/A + 6 oz/A	--	98.0 a	95.0 a	10.0 CD	0.0 B	0.0 B
Sharpen + Roundup	2 oz/A + 44 oz/A	--	95.8 a	95.0 a	91.3 A	66.3 A	27.5 A
Butyrac 200 + Pursuit	3 qts/A + 6 oz/A	--	11.3 bc	48.8 b	17.5 BC	0.0 B	0.0 B
Sharpen	2 oz/A	2 oz/A	98.0 a	95.0 a	16.3 BCD	0.0 B	0.0 B
Sharpen + Butyrac 200	2 oz/A + 3 qts/A	2 oz/A + 3 qts/A	98.3 a	93.8 a	12.5 BCD	0.0 B	0.0 B
Sharpen + Pursuit	2 oz/A + 6 oz/A	2 oz/A + 6 oz/A	98.3 a	93.8 a	17.5 BC	0.0 B	0.0 B
Sharpen + Raptor	2 oz/A + 6 oz/A	2 oz/A + 6 oz/A	98.0 a	95.0 a	15.0 BCD	0.0 B	0.0 B
Sharpen + Roundup	2 oz/A + 44 oz/A	2 oz/A + 44 oz/A	95.8 a	93.8 a	93.8 A	71.3 A	40.0 A
Butyrac 200 + Pursuit	3 qts/A + 6 oz/A	3 qts/A + 6 oz/A	13.8 b	47.5 b	16.3 BCD	0.0 B	0.0 B
LSD[y] value			3.4	24.4	7.8	21.0	19.8

[y]NTC = non-treated control; WAIT = weeks after initiation of treatment; LSD = least significant difference

[z]Within columns, means followed by the same letter are not significantly different according to Fisher's LSD test (α=0.05)

Table 3. Percent broadleaf plantain injury (%) observed visually in the greenhouse in response to herbicide applications that were made initially on January 7, 2019, and sequentially on February 7, 2019, at the New Mexico State University Leyendecker Plant Sciences Center at Las Cruces, NM.

	Rate		Broadleaf Plantain Injury %			
Treatment		4 WAIT[y]	1 WAIT	2 WAIT	4 WAIT	6 WAIT
NTC[y]	--	--	0.0 d[z]	0.0 f	0.0 d	15.0 c
Sharpen	2 oz/A	--	3.7 cd	15.0 de	42.5 b	47.5 b
Sharpen + Butyrac 200	2 oz/A + 3 qts/A	--	17.5 b	45.0 a	88.8 a	98.8 a
Sharpen + Pursuit	2 oz/A + 6 oz/A	--	3.8 cd	10.0 ef	32.5 bc	45.0 b
Sharpen + Raptor	2 oz/A + 6 oz/A	--	5.0 cd	21.3 cde	42.5 b	50.0 b
Sharpen + Roundup	2 oz/A + 44 oz/A	--	7.5 c	22.5 cde	47.5 b	47.5 b
Butyrac 200 + Pursuit	3 qts/A + 6 oz/A	--	2.5 cd	28.8 bc	77.5 a	95.0 a
Sharpen	2 oz/A	2 oz/A	1.3 d	25.0 cd	45.0 b	52.5 b
Sharpen + Butyrac	2 oz/A + 3 qts/A	2 oz/A + 3 qts/A	23.8 b	40.0 ab	88.0 a	100.0 a
Sharpen + Pursuit	2 oz/A + 6 oz/A	2 oz/A + 6 oz/A	1.3 d	17.5 cde	22.5 c	45.0 bc
Sharpen + Raptor	2 oz/A + 6 oz/A	2 oz/A + 6 oz/A	5.0 cd	20.0 cde	42.5 b	55.0 b
Sharpen + Roundup	2 oz/A + 44 oz/A	2 oz/A + 44 oz/A	5.0 cd	21.3 cde	40.0 bc	45.0 b
Butyrac 200 + Pursuit	3 qts/A + 6 oz/A	3 qts/A + 6 oz/A	5.0 cd	18.8 cde	70.0 a	97.5 a
LSD[y] value			5.8	12.8	19.2	27.4

[y]NTC = non-treated control; WAIT = weeks after initiation of treatment; LSD = least significant difference

[z]Within columns, means followed by the same letter are not significantly different according to Fisher's LSD test (α=0.05)

References:

Ashigh, J., J. Wanstall, and F. Sholedice (2010) Troublesome weeds of New Mexico. New Mexico Department of Agriculture. Retrieved from http://www.nmda.nmsu.edu/wp-content/uploads/2012/04/troublesome_weeds_nm.pdf.

BASF Corporation (2019) Sharpen® herbicide label. Retrieved from http://www.cdms.net/ldat/ld99E019.pdf.

Beck, L., M. Marsalis, and L. Lauriault (2017) Managing weeds in alfalfa. New Mexico State University Cooperative Extension Service. Guide A-325. Retrieved from https://aces.nmsu.edu/pubs/_a/A325.pdf.

Dyna-Gro Seed (2019) TMA 990 Brand product information. Retrieved from https://dynagro-matrix-manager-prod.s3.amazonaws.com/techsheet_pdfs/alfalfa/9RM%20TMA%20990%20Brand%2007-11-2019.pdf.

Elmore, C., D. Cudney, and M. McGiffen (2007) Pests in gardens and landscapes: Plantains. University of California Integrated Pest Management Program. Publication 7478. Retrieved from http://ipm.ucanr.edu/PMG/PESTNOTES/pn7478.html.

Gilbert, R.G., R.N. Peaden, and W.P. Ford (1988) Verticillium wilt of alfalfa. Washington State University Cooperative Extension. Bulletin EB1506. Retrieved from https://research.wsulibs.wsu.edu/xmlui/bitstream/handle/2376/6726/eb1506.pdf?sequence=1&isAllowed=y.

Green, J., M. Marshall, and J. Martin (2003) Weed control in alfalfa and other forage legume crops. University of Kentucky Cooperative Extension Service. Guide AGR-148. Retrieved from http://www2.ca.uky.edu/agcomm/pubs/agr/agr148/agr148.pdf.

Johnson, Q., and M. VanGessel (2014) Perennial weed control. University of Delaware Cooperative Extension Service. WF-1. Retrieved from http://www.rec.udel.edu/weed_sci/FactSheets_08/WF1-PERE_08.pdf.

Karcher, D., and M. Richardson (2003) Quantifying turfgrass color using digital image analysis. Crop Sci. 43:943–951. doi:10.2135/cropsci2003.9430.

Lauriault, L., F. Contreras-Govea, and M. Marsalis (2009) Assessing alfalfa stands after winter injury, freeze damage, or any time renovation is considered in New Mexico. New Mexico State University Cooperative Extension Service. Circular 644. Retrieved from http://aces.nmsu.edu/pubs/_circulars/CR644.pdf.

Lauriault, L., I. Ray, C. Pierce, O. Burney, R. Flynn, M. Marsalis, M. O'Neill, A. Cunningham, C. Havlik, and M. West (2018) The 2017 New Mexico Alfalfa Variety Test Report. New Mexico State University Agricultural Experiment Station. Retrieved from http://aces.nmsu.edu/pubs/variety_trials/AVT17.pdf.

Lauriault, L., I. Ray, C. Pierce, R. Flynn, M. Marsalis, M. O'Neill, and T. Place (2008) The 2008 New Mexico Alfalfa Variety Test Report. New Mexico State University Agricultural Experiment Station. Retrieved from http://aces.nmsu.edu/pubs/variety_trials/avt07.pdf.

Lauriault, L., I. Ray, S. Thomas, C. Sutherland, J. Ashigh, F. Contreras-Govea, and M. Marsalis (2011) Selecting alfalfa varieties for New Mexico. New Mexico State University Cooperative Extension Service. Circular 654. Retrieved from http://aces.nmsu.edu/pubs/_circulars/CR654.pdf.

Monsanto Company (2019) Roundup PowerMax® herbicide label. Retrieved from http://www.cdms.net/ldat/ld8CC002.pdf.

NAFA. 2008, Alfalfa variety ratings 2008. National Alfalfa and Forage Alliance. 2008 Edition retrieved from https://aces.nmsu.edu/pubs/variety_trials/var08.pdf.

NAFA. 2019. Alfalfa variety ratings 2019.National Alfalfa and Forage Alliance. 2019 Edition retrieved from https://www.alfalfa.org/pdf/2019_Alfalfa_Variety_Leaflet.pdf.

NCSS (2019a) Armijo Series. National Cooperative Soil Survey. Retrieved from https://soilseries.sc.egov.usda.gov/OSD_Docs/A/ARMIJO.html.

NCSS (2019b) Vinton Series. National Cooperative Soil Survey. Retrieved from https://soilseries.sc.egov.usda.gov/OSD_Docs/V/VINTON.html.

Orloff, S., D. Putnam, M. Canevari, and W. Lanini (2009) Avoiding weed shifts and weed resistance in Roundup Ready® alfalfa systems. University of California Division of Agriculture and Natural Resources. Publication 8362. Retrieved from https://anrcatalog.ucanr.edu/pdf/8362.pdf.

Richardson, M., D. Karcher, and L.C. Purcell (2001) Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884–1888. doi:10.2135/cropsci2001.1884.

Sulser, A., and R. Whitesides (2012) Buckhorn plantain. Utah State University. Extension Pub. AG/Weeds/2008-01pr. Retrieved from https://digitalcommons.usu.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=2300&context=extension_curall.

USDA NASS (2018) United States Department of Agriculture, National Agriculture Statistics Service State Agriculture Overview: New Mexico. Retrieved from https://www.nass.usda.gov/Statistics_by_State/New_Mexico/Publications/Annual_Statistical_Bulletin/2017/2017-NM-AG-Statistics.pdf.

Keywords: alfalfa, weed control, broadleaf plantain, *Plantago major*, buckhorn plantain, *Plantago lanceolata*, dormant-season application, herbicide tank-mixes, sequential applications, herbicide injury, crop yield