Evaluation of the Efficacy of Saflufencacil Tank-Mixes and Sequential Applications Applied in Early Fall for the Control of Plantain (*Plantago* spp.) and Field Bindweed (*Convolvulus arvensis*) in Alfalfa Fields

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Abstract: Buckhorn plantain (*Plantago lanceolata*) and field bindweed (*Convolvulus arvensis*) are notoriously difficult to control perennial weeds in alfalfa cropping systems. From 2020-2023, research was conducted to determine if Sharpen®, tank-mixed with Butyrac 200® or Roundup®, and/or sequential applications, could effectively control plantain and field bindweed in the field with little damage to alfalfa yield. This research indicates that Sharpen® tank-mixed with other commercially available herbicides may provide adequate injury to plantain and field bindweed when applied during accelerated weed growth in the fall. Applications of Butyrac 200® tank-mixed with either Sharpen® or Pursuit as well as applications of Roundup® tank-mixed with Sharpen® effectively decreased plantain coverage compared to non-treated control. In one location, Sharpen® tank-mixed with the other herbicides was observed to have some longer residual in the soil to help delay late season seed germination of plantain. Control of field bindweed was improved with sequential applications of Sharpen® alone or tank-mixed with the other herbicides compared to the non-treated control, but none were able to fully prevent the recovery of field bindweed as the growing season progressed. This research also indicates that spring sequential applications of Sharpen® alone or tank-mixed with the other herbicides negatively impacted alfalfa harvest biomass in both Las Cruces and Los Lunas, NM. Herbicide injury and impacts to biomass are increased when Sharpen® is applied to actively growing alfalfa, or Roundup® is applied to non-Roundup Ready® alfalfa. Additionally, Sharpen® does not have a label for a spring application on actively growing alfalfa. However, sequential applications of Sharpen® may be applicable in fallow or grass forage rotational cropping systems, Butyrac 200® may be applied in fall and spring seasons to conventional and Roundup® to Roundup Ready® alfalfa systems to help manage difficult to control perennial weeds.

Introduction: Alfalfa is the third most valuable cash crop in the United States (USDA, 2023) and is the most widely cultivated forage legume worldwide (Hatfield et al. 2017). Furthermore, roughly 40% of the nation's alfalfa crop is grown in 11 of the 17 western states, including New Mexico (Putnam et al., 2001). As of 2018, alfalfa hay remains the most valuable cash crop in the state of New Mexico with an estimated annual gross of just over $177 million (Lauriault et al., 2023). Additionally, hay biomass decreased only slightly (3.62 tons) compared to 3.65 tons in 2020; however, the price of alfalfa increased by 6%, averaging $236 per ton in 2021 for the state (USDA NASS, 2022). The overall value of alfalfa hay is further increased by its essential contributions to livestock production (i.e., meat, milk, textiles), which continues to lead New Mexico in overall agricultural commodities. According to the New Mexico Agricultural Statistics for 2021, the dairy industry contributed approximately $1.26 billion in total milk sales with the other livestock industries netting $1.07 billion in total sales for the State of New Mexico (USDA NASS, 2022). Crop production acreage and the availability of resources for management continue to decline; however, it is still important to maximize biomass and quality of all alfalfa production as much as possible during the growing season to meet the ever-increasing agricultural needs of growers, producers, farmer, ranchers, dairy managers, and industry personnel throughout the state of New Mexico and the western US.

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 initial seeding stages of alfalfa typically have the greatest impact by competing for light, water, space, and nutrients, perennial weeds that populate established alfalfa fields can have a significant impact on biomass through continued competition for resources throughout the life of the stand (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 (Ashigh et al., 2010; Gilbert et al., 1988; Green et al., 2003).

Perennial weed populations are especially difficult to control in perennial crops like alfalfa, because management practices have to address both 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 taproot system that allows the plant to become dormant to survive during non-ideal environmental conditions, then proctors tissue regrowth and re-establishment once conditions become ideal again. 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. (Elmore et al., 2007; Sulser and Whitesides, 2012). Additionally, complex perennial weeds like field bindweed (*Convolvulus arvensis*) have not only a deep and hardy root system, but extensive spreading underground stems in the form of rhizomes, which further complicates management efforts (Uva et al., 1997). Like plantain, field bindweed is a hardy, invasive, drought tolerant perennial weed that is broadly distributed across all the continental western states, and in all 33 New Mexico counties (USDA Plants Database, 2023; Uva et al., 1997). Weed management on both simple and complex 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 hearty root system and spreading rhizomes located deep within the soil (Elmore et al., 2007). Similarly, the use of herbicides to control broadleaf weeds like plantain and field bindweed in a broadleaf crop like alfalfa further complicate any effective management. As a result, there are only a few registered herbicides, such as glyphosate, MCPA, and 2,4-DB that have been reported to cause injury to plantain and field bindweed in alfalfa fields in New Mexico (Beck et al., 2017; Canevari et al., 2007). Furthermore, the continued use of these select few herbicide active ingredients to manage a specific population of weeds like plantain in alfalfa over time, can also lead to the development of herbicide resistance in the target weeds (Beck, 2018; 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 improved control of plantain and field bindweed in alfalfa.

Sharpen® (BASF Corporation) has recently acquired a label for broadleaf weed control in dormant-season alfalfa in the 17 western states (BASF Corporation, 2023). 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, ivyleaf morningglory (*Ipomoea hederacea*) and dandelion (*Taraxacum officinale*) during limited (dormant) season growth of alfalfa. Sharpen® was evaluated as a potential herbicide option for late-season broadleaf and buckhorn plantain control in greenhouse evaluations in Las Cruces and crop injury was assessed in alfalfa fields in Los Lunas in from 2017 through 2019. Single applications of the highest rate of Sharpen®

resulted in injury to the plantain, yet plants eventually recovered (Beck et al., 2018). One treatment that was added to the 2017-2018 greenhouse trial was an application of Sharpen® combined with a second active ingredient, which yielded the most herbicide injury to the plantain, but control was still limited (Beck et al., 2018). In 2018, and 2019, additional tank-mixes of Sharpen® with commercially available herbicides, combined with sequential applications approximately 60 days after the initial application were evaluated in greenhouse studies in Los Lunas and Las Cruces (Beck et al., 2019). These mixtures, coupled with sequential applications that also contained Sharpen®, caused noticeable injury to the alfalfa immediately following application. However, the alfalfa was able to recover completely with no visible signs of injury or impact on biomass by the first cutting occurring in the field in spring (Beck et al., 2019). While the tank-mixed and sequential applications of Sharpen® resulted in adequate control of plantain in the greenhouse and no alfalfa injury was observed in separate field experiments, these combinations have yet to evaluate efficacy while plantain is in the field with alfalfa. Additionally, there are other difficult to control perennial weeds, such as field bindweed, with minimal research as to the potential for better-management practices in alfalfa that need to be evaluated. In 2017 and 2018, initial herbicide applications in the field (to alfalfa only) were made in December to take full advantage of slowed alfalfa growth to help minimize potential damage and reductions in biomass the following spring. Since our previous research indicates that these applications caused minimal negative impacts to biomass compared to the non-treated control (Beck et al., 2018 and 2019), research needs to be conducted to evaluate the impacts of Sharpen® applications in earlier fall months (i.e., October) when final harvest cuts are made. This is also the most opportune time for maximum injury from herbicide applications since perennial weeds are actively growing but shifting their growth patterns to ensure survival of the roots from the oncoming winter temperatures (Elmore et al., 2007; Johnson and VanGessel, 2014). Additionally, tank mixes with Sharpen® and commercial herbicide, as well as sequential applications of these mixtures, have yet to be evaluated for field bindweed control in alfalfa fields. As a result, further field research into applications of tank-mixes and sequential applications of Sharpen® combined with other active ingredients to potentially improve plantain and field bindweed control in alfalfa is warranted.

The objectives of this study were to: 1) compare the weed control performance of initial and sequential applications of saflufenacil alone or in combination with commercially available herbicide standards on both plantain and field bindweed under field conditions, and 2) evaluate the effects on alfalfa biomass as a result of the applications of single or multiple applications of saflufenacil alone or in combination with other commercially available herbicide products under field conditions.

Methodology

It should be noted that this research was conducted from 2020 to 2023 during COVID safety and state-wide travel shutdowns and restrictions. As a result, adjustments were made to the initial proposed research timelines for sequential applications and restricted space in field locations from year to year. These adjustments will be described and explained in the Methodology section.

Objective 1: Compare the weed control performance of initial and sequential applications of saflufenacil alone or in combination with commercially available herbicide products for plantain and field bindweed under field conditions

Field studies were conducted during the fall, winter, and spring of 2020-2023 at the New Mexico State University (NMSU) Leyendecker Plant Science Research Center (LSC) near Las Cruces, NM, the NMSU Los Lunas Agricultural Science Center (ASC) at Los Lunas, NM, and at private producer commercial fields located less than 15 miles from the ASC.

For plantain research two private producer commercial fields were utilized. One location (2020-2021) was a 3+ year-old alfalfa field at Los Lunas, NM, and the second location (2021-2022) was a grass pasture at Bosque, NM. Both producer fields were chosen due to high concentrations of plantain populations and were managed using typical procedures for crops grown within that area. The research area at Bosque, NM, was fenced off to prevent any forage grazing in herbicide applied areas as per the instructions on the herbicide treatment labels. The soils at the alfalfa private producer site is an Agua Series (coarse-loamy over sandy, mixed, superactive, calcareous, thermic Typic Torrifluvents) (NCSS, 2023a) while the soil at the grass private producer location is (Brazito Series, mixed, thermic Typic Torripsamments) (NCSS, 2023c). Both fields were irrigated and maintained to provide healthy cropping and weed systems.

For field bindweed research, field locations that were heavily populated by field bindweed infestations were chosen for both replicated years of study at the ASC. The first replicated year took place in 2020-2021. A replicated research study was initiated at the same grass private producer location in Bosque, NM within a seeded tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.) cropping system in 2021. However, the research area was accidentally sprayed over by one of the production technicians at that location during the data collection timing. Therefore, the study had to be terminated and a new replicated research study for field bindweed was initiated in 2022 in a field location at the ASC that was heavily infested with field bindweed. These field bindweed-infested fields were also irrigated and maintained in a manner that mimicked how the surrounding alfalfa fields were managed to keep the field bindweed actively growing during herbicide treatment applications and data collection periods.

The saflufenacil herbicide treatments for both the plantain and the field bindweed study are labeled for use during dormant-season (or slowed) alfalfa growth, thus herbicide treatment applications for both weed populations were initiated after final cutting and during a period of slowed alfalfa growth in mid-October. This is also the best timing for herbicide control of perennial weeds like plantain and field bindweed since the redistribution of carbohydrates to the root system, in preparation for winter, allows for greater translocation of systemic herbicides, and more effective control (Marsalis et al., 2008; Reiter, 2020).

Initial herbicide treatments were applied on the 6th of Oct. 2020 for both plantain and field bindweed studies at the private alfalfa field and the ASC at Los Lunas, NM; on 1st of Nov. 2021 for plantain in the grass pasture in Bosque, NM; and 21st of Oct. 2022 for field bindweed at the ASC in Los Lunas, NM. Sequential applications were initially supposed to be applied approximately 60 days after the initial herbicide treatment; however, the state of New Mexico was under a governor-mandated shut down (including travel) in the weeks prior to, during, and following the proposed sequential application period in 2020. As a result, the sequential application timing for all locations and target weeds was adjusted to include a spring application once the weeds began actively growing from underground root systems. Like fall applications, this is also one of the best application timings for herbicides on difficult to control perennial weeds because of the active growth to produce leaves and begin photosynthesizing following winter dormancy (Canevari et al., 2017; Elmore et al., 2007; Johnson and VanGessel, 2014). Spring sequential herbicide treatments were applied 28 weeks after the initial treatment (WAIT) on the 16th of Apr. 2021 for both plantain and field bindweed studies at the private alfalfa field and the ASC in Los Lunas, NM; 12th of Apr. 2022 for plantain in the forage pasture in Bosque, NM; and 3rd of May 2023 for field bindweed at the ASC in Los Lunas, NM.

The experimental design at all three locations was a randomized complete block design with plot sizes of 10 ft x 10 ft and four replications of thirteen total treatments. Herbicide treatments were the labeled rates of the following herbicides: saflufenacil (Sharpen®) alone or in combination with: dimethylamine 4-(2,4-dichlorophenoxy) (Butyrac 200®, Albaugh, INC.), imazamox (Raptor®, BASF Corp.), or imazethapyr

(Pursuit®, BASF Corp.). A treatment of saflufenacil + glyphosate (e.g., Roundup®) was included to assess potential control of plantain and field bindweed in Roundup Ready® alfalfa systems. A treatment of Butyrac 200® + Pursuit® was also included to assess potential control of plantain and field bindweed based on common tank-mix applications made by alfalfa producers in NM (NMSU Extension clientele conversations). Each of the treatments were applied initially (6 treatments), or in combination with a sequential application of the same treatments listed above (6 treatments) the following spring once green-up began. A non-treated control was included for comparison for a total of 13 treatments. There were space limitations for the 2022-2023 field bindweed study at the ASC, therefore the Butyrac 200® + Pursuit® initial and sequential treatments were excluded from the trial due to previous data indicating limited to no significant enhancement of weed control with the addition of the Pursuit® to the tank. Therefore, the 2022-2023 field bindweed study had 11 total treatments, including the non-treated control. Treatments were applied using a CO_2-powered backpack sprayer equipped with a 4-nozzle boom with 11002 VS TeeJet Flat-fan nozzles (Teejet Technologies, Wheaton, IL) calibrated to deliver 20 GPA at 207 kPa. Research trial fields were not irrigated for approximately 24 hours after each application to allow the herbicide treatments to dry.

At both locations, plantain and field bindweed populations were assessed and evaluated visually prior to herbicide applications in the fall and spring. Plantain and field bindweed coverage (%) within each treatment plot were assessed visually on a percent scale relative to the non-treated control, where 0% indicated no presence of living plantain or field bindweed and 100% indicated complete coverage of the weed throughout the plot. Once initial herbicide treatment applications were made, each treatment plot was assessed visually on a percent scale relative to the non-treated control where 0% indicated no herbicide injury to plantain or field bindweed, and 100% indicated complete coverage of herbicide injury symptoms for the weed located within the plot. Once herbicide treatments were applied, data collections of weed coverage (%) and herbicide injury (%) were assessed every two weeks for approximately 36 weeks after the initial treatment (WAIT) or until herbicide weed control or injury symptoms were no longer visible.

Objective 2: Evaluate the effects on alfalfa biomass as a result of the applications of single or multiple applications of saflufenacil alone or in combination with other commercially available herbicide products under field conditions

In 2021-2022, studies to evaluate the impacts of Sharpen® tank mixes and sequential applications on alfalfa biomass were conducted simultaneously in alfalfa stands at the ASC in Los Lunas, NM and at the LSC in Las Cruces, NM. The soil at the ASC site is a Vinton Series (Sandy, Mixed, Thermic Typic Torrifluvents) (NCSS, 2023d) while the soil at the LSC site is an Armijo series (Fine, Smectitic, Thermic Chromic Haplotorrert) (NCSS, 2023b). The fields at both locations had previously been prepared for alfalfa using typical procedures including tillage, seeding, irrigation, cutting, 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, initial herbicide treatments were made on 1st Nov. 2021 at ASC and on 14th Dec. 2021 at the LSC after the final cutting and during a period of slowed growth starting in late October and November. Sequential herbicide applications were made to both alfalfa locations in the spring following the initiation spring growth by the weeds to replicate the herbicide treatments for the plantain and field bindweed locations. As a result, spring sequential herbicide applications were made on 12th Apr. 2022 at the ASC and 6th Apr. 2022 at the LSC fields.

The experimental design at both locations was a randomized complete block design with plot sizes of 10 ft x 10 ft and four replications of the same 12 herbicide treatments listed previously. A non-treated control was also included for comparison for a total of 13 treatments. Treatments were applied using the same spray equipment as described above. Alfalfa fields were not irrigated for approximately 24 hours after applications to allow the herbicide treatments to dry. Throughout the duration of the study, fields were irrigated as needed to maintain alfalfa growth and health.

At both locations, alfalfa was assessed visually prior to herbicide applications in the fall and spring. Alfalfa coverage (%) was assessed visually on a percent scale relative to the non-treated control, where 0% indicated no presence of living alfalfa and 100% indicated complete alfalfa coverage throughout the plot. Once initial herbicide treatment applications were made, each plot was assessed visually on a percent scale relative to the non-treated control, where 0% indicated no herbicide injury to alfalfa and 100% indicated complete coverage of herbicide injury symptoms for alfalfa located within the plot. Once herbicide treatments were applied, data collections of weed coverage (%) and herbicide injury (%) were assessed every two weeks for approximately 36 WAIT or until herbicide weed control or injury symptoms were no longer visible. During the following spring season, alfalfa biomass was harvested by treatment to assess biomass effects for up to two harvest events at both locations. The first harvest took place on 1st June 2022 at the ASC and on 2nd May 2022 at the LSC, while the second harvest took place on 12th July 2022 at the ASC and on 20th June 2022 at the LSC. At both locations, aboveground biomass within 0.37 m^2 was clipped and dried in a forced-air oven at 52°C until a constant weight to convert field weights to dry matter (DM) biomass.

Alfalfa total biomass data were pooled across sites and analyzed using SAS Proc MIXED (SAS, 2013) to compare the effects of site and herbicide treatment and their interaction. Replicate within site was considered random. When the F-test for the effect of herbicide treatment or the site x treatment interaction was significant ($P<0.05$), lsmeans were separated with least significant differences using the PDMIX800 macro (Saxton, 1998). Due to differences in bindweed and plantain weed stand and injury rating dates, those data were analyzed within site for the effects of herbicide and rating date and their interaction, using the repeated statement in SAS Proc GLM (SAS, 2013). Within rating dates, herbicide treatment means were separated using least significant differences at $P<0.05$.

Project Objectives and Corresponding Results:

1. Compare the weed control performance of initial and sequential applications of saflufenacil alone or in combination with commercially available herbicide standards on both plantain and field bindweed under field conditions.
2. Evaluate the effects on alfalfa biomass as a result of the applications of single or multiple applications of saflufenacil alone or in combination with other commercially available herbicide products under field conditions.

1. Sharpen® tank-mixed with Butyrac 200® or Roundup® applied in the fall may provide adequate injury to control plantain and field bindweed. Similarly, Butyrac 200® tank-mixed with Pursuit also provided effective control of plantain. Fall applications combined with sequential spring applications with Sharpen® tank-mixed with the other commercially available herbicides improved control of field bindweed. This research continues.
2. Sharpen® alone or tank-mixed with Butyrac 200® may be applied in semi-dormant alfalfa with minimal affects to yield; however, applications of Roundup® to non-Roundup Ready® alfalfa can negatively impact biomass. Applications of herbicide treatments in the spring during active alfalfa growth negatively impacted biomass.

Results and Discussion:

Weed injury caused by herbicides

Plantain Study: At both sites (private alfalfa field at Los Lunas and private grass pasture at Bosque), while average visual percentage estimates for injury caused by herbicide treatments did yield significant results, particularly with Butyrac 200® and Roundup® tank-mix treatments with Sharpen® and/or Pursuit®, they were not indicative of overall weed control abilities of the treatments (Data not shown).

Bindweed Study: In both studies at ASC, while average visual percentage estimates for injury caused by herbicide treatments did yield significant results, particularly with Sharpen® and Roundup® alone or tank-mix treatments, they were not indicative of overall weed control abilities of the treatments (Data not shown).

Herbicide effects on weed coverage

Plantain Study: The final weed coverage (%) rating date at the private producer alfalfa field in Los Lunas indicated that all herbicide treatments applied alone or in combination with Sharpen® either initially (1X) or sequentially in the spring (2X) decreased plantain weed coverage compared to the non-treated control with the exception of Sharpen® alone (1X), respectively (Table 1). Starting from 31 WAIT to the end of the study, Sharpen® alone 2X significantly decreased plantain weed coverage compared to the non-treated control indicating a need for a sequential application in the spring to be comparably effective at managing plantain compared to commercially available herbicide treatments such as Butyrac 200®, respectively. While Sharpen® is not labelled for application on actively growing alfalfa in the spring, this may be an option for plantain control in fallow fields or in grass crop rotations as permitted by the label. By 33 WAIT, plantain percentages increased for most all herbicide treatments, with the exception of Butyrac 200® + Pursuit® 1X or 2X and Sharpen® + Roundup® 2X, due to lack of residual herbicide activity and the spring germination of plantain from seeds within the soil seedbank in late spring.

Applications of Butyrac 200® alone 1X or 2X, or tank-mixed with Sharpen® or Pursuit® 1X or 2X significantly decreased plantain coverage compared to the non-treated control and Sharpen® alone throughout the duration of the trial (Table 1); however, by the end of the study the addition of a sequential spring application (2X) did not significantly improve plantain control compared to a 1X application of the same treatments whether Butyrac 200® was applied alone or tank-mixed with Sharpen® or Pursuit®. Although the results were not significant, trends indicated that throughout the study, treatments of Butyrac 200® tank mixed with either Sharpen® or Pursuit® (1X or 2X) reduced plantain coverage compared to applications of Butyrac 200® alone 1X or 2X.

Throughout the duration of the trial, applications of Roundup® alone 1X or 2X, or tank-mixed with Sharpen® 1X or 2X significantly decreased plantain coverage compared to the non-treated control (Table 1). Sequential applications of Sharpen® + Roundup® 2X indicated some residual control of germinating plantain seedlings at 33 and 35 WAIT compared to sequential applications of Roundup® alone 2X, indicating the potential benefits of tank-mixing herbicides with non-residual control with herbicides that have some extended control of germinating weed seedlings later in the growth season. However, spring applications of Roundup® to non-Roundup Ready® (RR) alfalfa may lead to exacerbated injury and decreased biomass of alfalfa crops throughout the growing season (Beck et al., 2019). Additionally, Sharpen® is not labelled for application on actively growing alfalfa in the spring, therefore Roundup® applications are only suggested for use in RR® alfalfa, and tank-mixes for spring applications with Sharpen® are only recommended for fallow fields to control difficult perennial weeds like plantain.

The final weed coverage (%) rating date (36 WAIT) at the private producer grass pasture field in Bosque (Table 2) indicated that sequential applications (2X) of all herbicide treatments with the exception of Sharpen® alone 2X significantly decreased plantain coverage compared to the non-treated control. However, no treatment, with the exception of Roundup® alone 2X, was able to prevent replacement of plantain coverage through late-season germination from seed stored in the soil seedbank beyond 35WAIT. Since Roundup® has no residual activity, it may be that plantain seedling germination was slow or delayed in these particular plots throughout the spring growth season. Starting at 32 WAIT, applications of Butyrac 200® alone or in combination with either Sharpen® or Pursuit (1X or 2X), and Roundup® alone or in combination with Sharpen® (1X) significantly decreased plantain coverage compared to the untreated control (Table 2). All 2X treatments, except Sharpen® 2X, significantly reduced plantain coverage compared to their 1X counterpart.

As a result, applications of Sharpen® tank mixed with other commercially available herbicides may be a viable candidate for inclusion in a late-season fall-applied plantain control program. However, the lack of a label allowing for Sharpen® applications to actively growing alfalfa in the spring may limit the usefulness of sequential spring applications of Sharpen® tank-mixes outside of fallow or grass-forage cover crop fields.

Field Bindweed Study: However, the final weed coverage (%) rating date at the ASC in Los Lunas, NM indicated that all herbicide treatments applied alone or in combination with Sharpen® either initially (1X) or sequentially in the spring (2X) decreased bindweed coverage compared to the non-treated control with the exception of Sharpen® alone (1X) or in combination with Butyrac 200® (1X), respectively (Table 3). According to the data, it seems that tank-mixing Sharpen® with the other commercially available products, as well as a sequential application in the spring, did not improve field bindweed control compared to the commercially available products alone 1X. Applications that were made with Roundup® significantly reduced the population of field bindweed compared to the non-treated control towards the end of the study; however, no treatment managed to prevent some regrowth or recovery of field bindweed in the plots beginning at 33 WAIT. Otherwise, non-significant trends showed that Roundup® alone 1X or tank-mixed with Sharpen® 1X had the least amount of regrowth or recovery of the field bindweed at 33 and 35 WAIT, respectfully. In this study, tank mixing Pursuit with Butyrac 200® provided significantly better bindweed control at the single fall application. Roundup® applied 2X did not provide any better control of bindweed than the 1X fall application.

Just prior to the treatment applications (28 WAIT), observations for field bindweed coverage indicated that Roundup® alone or in combination with Sharpen® 1X or 2X, along with Butyrac 200® alone 1X or 2X had significantly lower percentages of field bindweed visible on the soil surface following the fall applications and the winter months (Table 4). At 32 WAIT (4 weeks following the spring herbicide application) applications of Roundup® alone 1X or 2X, and Butyric 200® alone 2X or tank-mixed with Sharpen® 2X indicated the lowest percentages of field bindweed coverage compared to the non-treated control. However, no treatment was able to prevent the regrowth/recovery of field bindweed as the trial progressed throughout the growing season (36 WAIT). Results indicated that Roundup® alone 1X or 2X, and Butyrac 200® alone 2X or tank-mixed with Sharpen® 2X had the least amount of field bindweed recovery and regrowth by the end of the trial; and while not different from each other, these treatments provided nearly 50% or more bindweed reduction from the non-treated control.

As a result, applications of Sharpen® tank mixed with other commercially available herbicides may be a viable candidate for inclusion in a late-season fall-applied field bindweed control program. However, the lack of a label allowing for Sharpen® applications to actively growing alfalfa in the spring may limit the usefulness of sequential spring applications of Sharpen® tank-mixes except for fallow or grass hay and pasture fields. Additionally, while sequential spring applications delayed the recovery and regrowth of field bindweed in the plots compared to the non-treated control, no herbicide treatment combination was able to completely prevent some recovery of the field bindweed. Therefore, several seasons of herbicide applications at fall and spring application timings may be necessary for effective long-term control.

Alfalfa Biomass Study: Average visual estimates for alfalfa coverage (%) and herbicide injury (%) did not yield any noticeable differences amongst treatments in the study outside of treatment applications that contained Roundup® and/or Sharpen®, which was expected based on past research (Beck et. al., 2019), and were not indicative of overall impacts to alfalfa harvest biomass (Data not shown). The site, treatment, and site x treatment effects were all significant for total alfalfa biomass. The interaction resulted from differences in magnitude among treatments between locations as well as some minor, though not biologically significant changes in rank among treatments between sites. On average, the 1X treatments including only Sharpen®, Butyrac 200®, and Pursuit, either alone or in mixtures produced biomass that was not different from the non-treated control for both ASC and LSC locations (Figure 1). All treatments including Roundup ®alone (1X) and all 2X treatments had significantly reduced total alfalfa biomass compared to the non-treated control. Reduced biomass with the sequential Butyrac 200® treatments resulted from 1st cutting reductions. However, by the 2nd cut, those treatment plots had recovered and were not different from the non-treated control (data not shown).

Conclusions: This research indicates that applications of Sharpen® tank-mixed with other commercially available herbicides may provide adequate injury to plantain and field bindweed when applied during accelerated weed growth in the fall leading up to winter temperatures. Applications of Butyrac 200® tank-mixed with either Sharpen® or Pursuit®, as well as applications of Roundup® tank-mixed with Sharpen® effectively decreased plantain coverage compared to the non-treated control. Fall combined with spring applications of the herbicide treatments in combination with Sharpen® were observed to have some longer residual in the soil to help delay late season seed germination of plantain from seed built up in the seedbank at the private alfalfa field in 2021.This research also indicated that there was some improved control of field bindweed with sequential applications of Sharpen® alone or tank-mixed with other commercially available herbicides compared to the non-treated control, but none were able to fully prevent the recovery of field bindweed as the growing season progressed. More research may be needed to determine better management strategies to provide extended control for both plantain germinating seedlings, and field bindweed recovery/regrowth throughout the growing season.

Additionally, spring sequential applications of Sharpen® alone or tank-mixed with other commercially available herbicides negatively impacted alfalfa harvest biomass in both Las Cruces and Los Lunas, especially when the herbicide applied was Roundup®. Additionally, Sharpen® does not have a label for a spring application on actively growing alfalfa. Herbicide injury and impacts to biomass are increased when Sharpen® is applied to actively growing alfalfa, or Roundup® is applied to non-RR® alfalfa. However, sequential applications of Sharpen® may be applicable in fallow or grass forage rotational cropping systems, and Roundup® may be applied in fall and spring seasons to RR® alfalfa systems to help manage difficult to control perennial weeds.

This research shows that timing is essential in providing increased herbicide control of difficult-to-control perennial weeds like plantain and field bindweed. Fall application timings of Sharpen® alone or tank-mixed with other commercially available products did help to decrease coverage of plantain and bindweed in the field and have minimal impacts on spring alfalfa harvest in this research and also in previous research (Beck et al., 2019), although other measures may be needed to provide extended control throughout the spring growing season. Butyrac 200® showed promise as an effective option for reducing both plantain populations and bindweed competition with both single and sequential applications. The effect of tank mixing Pursuit on improving performance was inconsistent. Treatments containing Butyrac 200® provided better control of plantain than Roundup® when applied only once in the fall. Both fall and spring applications of Butyrac 200® alone or tank mixed with Pursuit® may provide effective plantain control and field bindweed suppression within an alfalfa cropping system with minimal impacts to the biomass depending on the levels of slowed growth and spring green-up, as well as favorable environmental conditions throughout the growing season. Roundup® provided superior bindweed suppression than Butyrac 200® with just one fall application; although there was no difference between the two with sequential applications. Spring applications of Sharpen® alone or in combination with other commercially available products may be reserved for fallow or grass hay and pasture fields. This research continues.

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Table 1. Percent plantain coverage (%) observed visually in response to herbicide applications that were made initially on 6th Oct. 2020, and sequentially on 16th Apr. 2021, at the private producer alfalfa field in Los Lunas, NM.

	Application and Rate		Plantain Coverage (%)					
Treatment	**Initial**	**Sequential**	**0 WAIT[y]**	**10 WAIT**	**27 WAIT**	**31 WAIT**	**33 WAIT**	**35 WAIT**
NTC[y]			48.8	52.5	15 ab[z]	72.5 a	77.5 a	77.5 a
Sharpen (S)	2 oz/A		67.5	67.5	21.3 a	72.5 a	77.5 a	77.5 a
S + Butyrac 200	2 oz/A + 3 qts/A		40	32.5	1.3 cd	10 c	16.3 cde	17.5 def
S + Roundup	2 oz/A + 44 oz/A		56.3	55	1.3 cd	2.5 c	13.8 cde	32.5 bcd
Butyrac 200 + Pursuit	3 qts/A + 6 oz/A		65	67.5	3 cd	8.8 c	12.5 de	15 def
Butyrac 200	3 qts/A		63.8	67.5	2.5 cd	12.5 c	20 cde	28.8 cde
Roundup	44 oz/A		46.3	48.8	0 d	1.3 c	27.5 bcd	45 bc
Sharpen	2 oz/A	2 oz/A	35	37.5	11.3 abc	37.5 b	48.8 b	50 bc
S + Butyrac 200	2 oz/A + 3 qts/A	2 oz/A + 3 qts/A	42.5	42.5	1.3 cd	3.8 c	10 de	15 def
S + Roundup	2 oz/A + 44 oz/A	2 oz/A + 44 oz/A	48.8	51.3	0 d	0 c	1.3 e	3.8 f
Butyrac 200 + Pursuit	3 qts/A + 6 oz/A	3 qts/A + 6 oz/A	43.8	46.3	1.3 cd	5 c	6.3 de	6.3 ef
Butyrac 200	3 qts/A	3 qts/A	72.5	73.8	8.8 bcd	12.5 c	21.3 cde	31.3 bcd
Roundup	44 oz/A	44 oz/A	48.8	50	1.3 cd	1.3 c	35 bc	52.5 b
LSD[y] value			-----	-----	10.4	16.5	21.5	23.6

[Y]NTC = non-treated control; WAIT = weeks after initial 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 plantain coverage (%) observed visually in response to herbicide applications that were made initially on 1th Nov. 2021, and sequentially on 12th Apr. 2022, at the private producer forage pasture in Bosque, NM.

	Application and Rate		Plantain Coverage (%)				
Treatment	**Initial**	**Sequential**	**0 WAIT**[y]	**28 WAIT**	**32 WAIT**	**34 WAIT**	**36 WAIT**
NTC[y]			60	70	72.5 a[z]	72.5 a	88.8 a
Sharpen (S)	2 oz/A		65	66.3	68.8 a	67.5 a	81.3 ab
S + Butyrac 200	2 oz/A + 3 qts/A		63.8	66.3	22.5 b	22.5 b	65 abc
S + Roundup	2 oz/A + 44 oz/A		67.5	67.5	2.8 d	3 cd	71.3 abc
Butyrac 200 + Pursuit	3 qts/A + 6 oz/A		62.5	68.8	21.3 bc	20 b	52.5 cd
Butyrac 200	3 qts/A		60	62.5	15 bcd	15 cb	50 d
Roundup	44 oz/A		72.5	76.3	2.8 d	3.5 cd	90 a
Sharpen	2 oz/A	2 oz/A	63.8	62.5	70 a	63.8 a	72.5 ab
S + Butyrac 200	2 oz/A + 3 qts/A	2 oz/A + 3 qts/A	56.3	58.8	19.3 bc	14.3 cb	25 e
S + Roundup	2 oz/A + 44 oz/A	2 oz/A + 44 oz/A	52.5	51.3	2 d	0.5 d	20 fe
Butyrac 200 + Pursuit	3 qts/A + 6 oz/A	3 qts/A + 6 oz/A	50	56.3	8.8 cd	5.5 cd	23.8 e
Butyrac 200	3 qts/A	3 qts/A	63.8	68.8	8 cd	5.3 cd	18.8 ef
Roundup	44 oz/A	44 oz/A	61.3	67.5	2 d	0.5 d	1.8 f
LSD[y] **Value**			-----	-----	13.5	13.1	19.8

[Y]NTC = non-treated control; WAIT = weeks after initial 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 field bindweed coverage (%) observed visually in response to herbicide applications that were made initially on 6th Oct. 2020, and sequentially on 16th Apr. 2021, at the New Mexico State University Agricultural Science Center at Los Lunas, NM.

	Application and Rate		Field Bindweed Coverage (%)					
Treatment	**Initial**	**Sequential**	**0 WAIT[y]**	**4 WAIT**	**6 WAIT**	**27 WAIT**	**33 WAIT**	**35 WAIT**
NTC[y]			62.5	70	70.5	55	80 a	78.8 a
Sharpen (S)	2 oz/A		72.5	73.8	73.8	56.3	81.3 a	81.3 a
S + Butyrac 200	2 oz/A + 3 qts/A		63.8	61.3	61.3	26.3	68.8 a	77.5 a
S + Roundup	2 oz/A + 44 oz/A		58.8	52.5	52.5	3.8	17.5 de	17.5 cd
Butyrac 200 + Pursuit	3 qts/A + 6 oz/A		61.3	61.3	61.3	2.5	22.5 de	22.5 cd
Butyrac 200	3 qts/A		61.3	60	60	15	47.5 b	47.5 b
Roundup	44 oz/A		57.5	57.5	57.5	3.8	13.8 e	13.8 d
Sharpen	2 oz/A	2 oz/A	52.5	46.3	46.3	37.5	45 bc	47.5 b
S + Butyrac 200	2 oz/A + 3 qts/A	2 oz/A + 3 qts/A	55	51.3	51.3	21.3	35 bcd	35 bc
S + Roundup	2 oz/A + 44 oz/A	2 oz/A + 44 oz/A	65	65	65	3.8	28.8 bcde	30 bcd
Butyrac 200 + Pursuit	3 qts/A + 6 oz/A	3 qts/A + 6 oz/A	47.5	47.5	47.5	10	25 cde	25 cd
Butyrac 200	3 qts/A	3 qts/A	62.5	63.8	63.8	12.5	27.5 bcde	27.5 dc
Roundup	44 oz/A	44 oz/A	58.8	61.3	61.3	3.8	21.3 de	22.5 cd
LSD[y] Value			----	----	----	----	20.6	19.8

[Y]NTC = non-treated control; WAIT = weeks after initial 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 4. Percent field bindweed coverage (%) observed visually in response to herbicide applications that were made initially on 1st Nov. 2021 and sequentially on 12th Apr. 2022 at the New Mexico State University Agricultural Science Center at Los Lunas, NM.

	Application and Rate		Field Bindweed Coverage (%)					
Treatment	**Initial**	**Sequential**	**0 WAIT[y]**	**3 WAIT**	**28 WAIT**	**32 WAIT**	**34 WAIT**	**36 WAIT**
NTC[x]			66.3	66.3	61.3 a[z]	81.3 a	76.3 a	82.5 a
Sharpen (S)[y]	2 oz/A		57.5	57.5	51.3 ab	80 a	75 a	87.5 a
S + Butyrac 200	2 oz/A + 3 qts/A		56.3	61.3	47.5 b	70 a	66.3 ab	82.5 a
S + Roundup	2 oz/A + 44 oz/A		52.5	56.3	27.5 c	70 a	67.5 a	82.5 a
Butyrac 200	3 qts/A		47.5	45	17.5 cd	35 cd	45 cd	61.3 b
Roundup	44 oz/A		52.5	55	8.8 de	26.3 de	22.5 e	41.3 c
Sharpen	2 oz/A	2 oz/A	63.8	63.8	46.3 b	41.3 bc	38.8 cde	62.5 b
S + Butyrac 200	2 oz/A + 3 qts/A	2 oz/A + 3 qts/A	55	57.5	42.5 b	21.3 e	27.5 de	42.5 c
S + Roundup	2 oz/A + 44 oz/A	2 oz/A + 44 oz/A	50	53.8	26.3 c	48.8 b	47.5 bc	71.3 ab
Butyrac 200	3 qts/A	3 qts/A	51.3	48.8	21.3 c	16.3 e	23.8 e	33.8 c
Roundup	44 oz/A	44 oz/A	61.3	65	6.3 e	15 e	21.3 e	37.5 c
LSD[x] Value			----	----	11.1	12.5	19.3	18.4

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

[y]Butyrac 200® + Pursuit® treatment removed due to space limitations in replicated trial and lack of data to suggest the addition of Pursuit improved weed control greater than Butyrac 200® alone

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

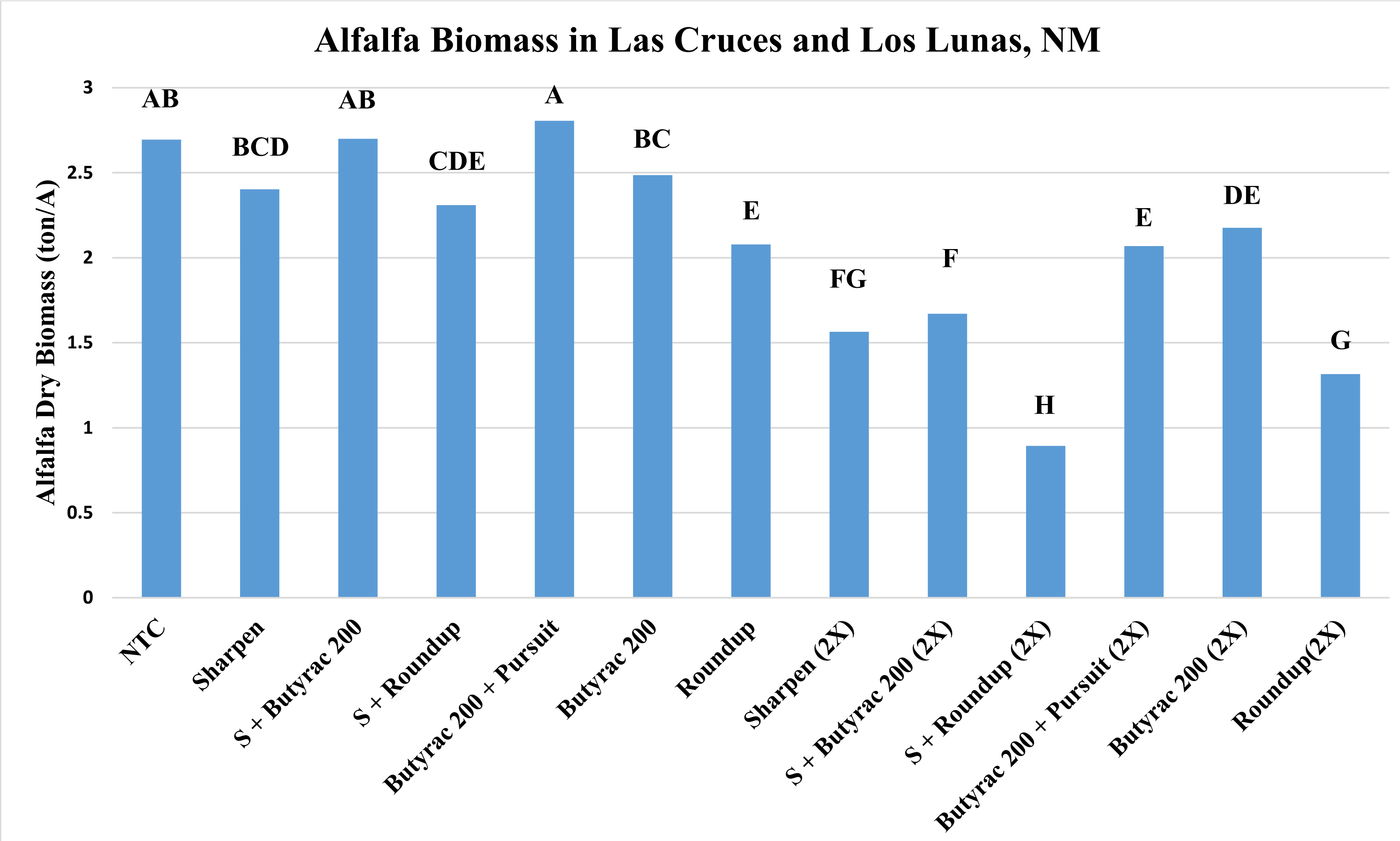

Figure 1. Alfalfa dry biomass weights (ton/A) in response to applications of initial and sequential tank-mixes of Sharpen® combined with other commercially available herbicides at the New Mexico State University (NMSU) Leyendecker Plant Sciences Center at Las Cruces, NM and the NMSU Agriculture Science Center at Los Lunas, NM from 2021-2022. Initial applications were made in the fall following final harvest cut, and in the spring to coincide with spring alfalfa and weed green-up. Chart represents total biomass for both locations and both cuttings averaged across both locations. Bars having the same letters are not significantly different at $\alpha = 0.05$, LSD = 0.30; NTC = non-treated control; S = Sharpen®; 2X = sequential application of herbicide treatment in the spring; LSD = least significant difference.

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