Efficacy of Residual Herbicides for Weed Control & Reducing Weed Impacts on Alfalfa Yield & Quality

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Abstract
Annual weeds can impact the economics of alfalfa production by reducing forage yield, and nutritive value or by contaminating hay. Field studies were conducted in Idaho and Nebraska in 2021 and 2022 to evaluate the efficacy of paraquat (Gramoxone®) and residual herbicides [*pendimethalin* (Prowl® H2O); *acetochlor* (Warrant®), and *flumioxazin* (Valor® SX)] on annual weeds in newly established non-glyphosate resistant alfalfa. There were 14 treatments (including the untreated control) arranged in a randomized complete block design with four replications. Alfalfa was harvested multiple times and data was collected on weed control and weed biomass (common lambsquarters [*Chenopodium album*], kochia [*Bassia scoparia*], and Palmer amaranth [*Amaranthus palmeri*]), forage biomass, and forage quality. Weed control (visible control and biomass) was influenced by herbicide treatments. Although weed control was primarily due to the application of paraquat, treatments containing Prowl H2O resulted in slightly better weed control. Generally, herbicide treatments had little impact on alfalfa and total forage yield (alfalfa + weeds). Where there were differences in forage yield due to treatments, it was a result of weed biomass from poor weed control treatments. Herbicide treatments influenced forage quality at the Kimberly location. Treatments that had more weed biomass tended to have slightly better forage quality. At the Scottsbluff location, a combination of slower alfalfa regrowth following paraquat application after the first cutting and slight weed suppression by paraquat resulted in higher forage crude protein and lower fiber at the second cutting. From the regression analyses, weed biomass in forage due to poor or no weed control reduced crude protein and increased fiber concentrations. This in turn reduced the relative feed value. The relationship between the proportion of individual weed species biomass and alfalfa nutritive value was linear for all weed species evaluated and there were differences among weed species.

Introduction

Annual weeds can impact the economics of alfalfa production by reducing forage quality or by contaminating alfalfa hay with unwanted seeds. Weed control programs in alfalfa rely heavily on the ALS-inhibiting herbicides, Raptor® and Pursuit®, for conventional alfalfa and glyphosate in Roundup Ready® alfalfa. Populations of pigweeds (waterhemp and Palmer amaranth) and kochia are currently resistant to both ALS-inhibiting herbicides and glyphosate, and these resistant weed populations are widespread across much of the United States. Consequently, alfalfa producers do not have many effective options for controlling herbicide-resistant weed populations.

In row crops, many farmers have shifted to using overlapping residual herbicide programs to control resistant weeds as effective herbicide options become scarce. The herbicides Chateau® (Group 14), Warrant® (Group 15), and Prowl® H2O (Group 3) are all labeled for use in alfalfa. All three herbicide options provide effective control of pigweeds and have some activity on kochia. In row crops, residual herbicides are used to provide weed control from planting until canopy closure. There has been considerable research in row crops regarding the optimal timings of residual herbicides, however, there is a lack of information on the optimal timing of these herbicides in alfalfa. The goal of this project was to evaluate residual herbicides for weed control in alfalfa.

Materials and Methods

All field studies were established under sprinkler irrigation at the University of Idaho (UI) Kimberly Research and Extension Center, Kimberly, ID, and the University of Nebraska (UNL) Panhandle Research and Extension Center, Scottsbluff, NE.

Experiment 1: *Weed control, forage yield and quality as influenced by weed control treatments in Idaho and Nebraska*

This experiment was two (foliar herbicide) by seven (residual herbicide) factorial randomized complete block design with four replications.

Factor A (foliar herbicide): The foliar herbicide factor consisted of two levels: 1) a check treatment where no herbicide was applied, and 2) application of paraquat (Gramoxone® SL 2.0) at 16 fl oz/A (0.25 lb ai/A) following the first cutting. All paraquat treatments included 0.25 %v/v non-ionic surfactant.

Factor B (residual herbicide program): The second factor comprised seven residual herbicide programs:

Table 1. Residual herbicide treatments used in the study

No.	Level	Product rate	Active ingredient rate (lb ai /A)
1	No residual herbicide		
2	*pendimethalin (Prowl® H2O) after 1st cutting*	2.1 qt/A	2.0
3	*pendimethalin (Prowl® H2O) after 1st and 2nd cutting*	2.1 qt/A	2.0
4	*acetochlor (Warrant®) after 1st cutting*	1.5 qt/A	1.13
5	*acetochlor (Warrant®) after 1st and 2nd cutting*	1.5 qt/A	1.13
6	*flumioxazin (Valor® SX) after 1st cutting*	4 oz oz/A	0.128
7	*flumioxazin (Valor® SX) after 1st and 2nd cutting*	4 oz oz/A	0.128

The soil at Kimberly, ID was a Portneuf silt loam (coarse-silty, mixed, superactive, mesic Durinodic Xeric Haplocalcids) with 23% sand, 58% silt, and 19% clay. In 2021, the soil had a pH of 8.0, organic matter (OM) content of 2.4 %, and a cation exchange capacity (CEC) of 19.8 meq / per 100 g soil. In 2022, the soil had a pH of 8.0, organic matter (OM) content of 2.4 %, and a cation exchange capacity (CEC) of 19.8 meq / per 100 g soil. In 2021, the soil at Scottsbluff, NE was a sandy loam with 1.3% organic matter and a pH of 7.5. In 2022, the soil was sandy loam with 1.2% organic matter and a pH of 7.3.

Conventional alfalfa ("WL354" in Kimberly, ID and "Heritage" in Scottsbluff, NE) was planted into a well-prepared seedbed at a rate of 20 lbs/A on Apr 16, 2021, and Apr 26, 2022, in Kimberly ID, and May 7, 2021, and June 24 (for the 2022 season) in Scottsbluff, NE, using a seed drill. Plots were uniformly irrigated using a sprinkler irrigation system. Individual plot sizes ranged from 10 by 50 ft to 10 by 30 ft depending on the location and year. Different fields were used at each site in 2021 and 2022.

Data collection: Each year, alfalfa was harvested (first harvest prior to herbicide application) using a forage harvester and the biomass was removed immediately to enable herbicide treatment application before alfalfa regrowth. Herbicides were applied using CO_2-pressurized bicycle sprayer delivering 15 gallons per acre at 30 psi with TeeJet 11002DG nozzles in Kimberly ID, and a tractor-mounted sprayer in Scottsbluff, NE. In Scottsbluff, alfalfa (and weeds) was harvested 2 times (following the first herbicide application) a year at approximately 10 to 30% alfalfa bloom stage. At the Kimberly location, alfalfa (and weeds) was harvested only once (following the first herbicide application) a year at approximately 10 to 30% alfalfa bloom stage. This was due to slow regrowth after the second harvest. Therefore, additional data (visible weed control) and a second experiment (Experiment 2) was established at Kimberly to better evaluate the impact of weed biomass on forage quality. In Kimberly, weed control efficacy (by weed species) was visually assessed in each plot on a scale of 0 to 100%, with 0% being no weed control and 100% being complete weed control. Before plot harvest each year, a quadrat (5.4 ft2) was randomly placed within each plot, and aboveground biomass (alfalfa and weeds) within the quadrat area was clipped using rice knives, leaving a stubble of about 4 inches. This was hand separated into weed and alfalfa biomass, and oven-dried to constant weight at 100 F to enable evaluation of alfalfa and weed contribution to total forage yield. Forage yield was determined by harvesting 4 ft by whole plot length at each location using a small plot forage harvester. The fresh weight was measured and adjusted for moisture using composite samples collected from the harvester.

The oven-dried composite samples were ground in a Wiley Mill (Model 4, Thomas Wiley, Laboratory Mill, Thomas Scientific, Swedesboro, NJ) to pass through a 1-mm mesh. Composite samples were scanned for crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) using near-infrared reflectance spectroscopy (NIRS, Foss InfraXact analyzer, Silver Spring, MD).

Experiment 2: *The relationship between weed biomass and forage quality*

There were eight treatments including the untreated check. Treatments comprised pre-emergence incorporated, early postemergence (after 80% alfalfa emergence), and postemergence (third trifoliate alfalfa) herbicide applications (Table 2). These herbicide treatments were chosen to include herbicides that provide poor to excellent control of weeds common at the experimental site. In both years, treatments were arranged in a randomized complete block design with four replications. The individual plot size was 10 x 30 ft. Herbicides were applied following the same procedure described in Experiment 1.

Before plot harvest each year, a quadrat (5.4 ft^2) was randomly placed within each plot, and aboveground biomass (alfalfa and weeds) within the quadrat area was clipped using rice knives, leaving a stubble of about 4 inches. This was hand separated into weed and alfalfa biomass to enable evaluation of alfalfa and weed contribution to total forage accumulation. Composite as well as individual species were oven-dried and ground in a Wiley Mill (Model 4, Thomas Wiley, Laboratory Mill, Thomas Scientific, Swedesboro, NJ) to pass through a 1-mm mesh. Composite samples were scanned for crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) using near-infrared reflectance spectroscopy (NIRS, Foss InfraXact analyzer, Silver Spring, MD). Relative feed value (RFV) and digestible dry matter (DDM) were also estimated for the composite sample. To accurately estimate each species impact on alfalfa forage quality, the individual species samples were weighed in these alfalfa (%) to weed biomass (%) proportions: 0 : 100, 20 : 80, 40 : 60, 60 : 40, 80 : 20, and 100: 0, and sent to Ward Laboratories Inc., Kearney, Nebraska, for wet chemistry analysis of forage nutritive value following standard forage testing procedures.

Table 2. Weed control treatments used in the experiments

Treatment	Rate (g ai/ha)	Commercial product (fl oz product/A)
Untreated	-	-
EPTC[a]	2940	Eptam® 7E (48)
Acetochlor[b]	1260	Warrant® (48)
Imazamox	44	Raptor® (5)
Imazamox[c] + *bromoxynil*[c]	44 + 420	Raptor® + Maestro® 2EC (24)
EPTC fb imazamox	2940 *fb* 44	Eptam® fb Raptor®
EPTC fb imazamox + bromoxynil	2940 *fb* 44 + 420	Eptam® *fb* Raptor® + Maestro® 2EC
acetochlor fb imazamox	1260 *fb* 44	Warrant® *fb* Raptor®

[a]Applied pre-plant incorporated (with 1 inch of irrigation); [b]early postemergence (80% alfalfa emergence), [c]postemergence (3rd trifoliate alfalfa). Postemergence applications included urea ammonium nitrate (2.5 % V/V) and non-ionic surfactant (0.25 %v/v). *fb* = followed by

Data analysis: A linear mixed-effects ANOVA was performed in R statistical language using the lmer function of the lme4 package and convenience functions from the lmerTest package (Kuznetsova et al., 2017; R Core Team, 2020). For each location, paraquat (POST) and residual herbicide treatments were considered fixed-effect, and block and year were considered random effects. Treatment means were separated using Fisher's protected LSD at a 0.05 significant level. To evaluate the relationship between weed biomass proportion and alfalfa nutritive value, linear regression analyses were performed using the *lm* function in R.

Project Objectives and Corresponding Results

Project objectives	Project results
1. Evaluate residual herbicide programs and application timing for control of herbicide-resistant weeds	Weed control was primarily due to the application of paraquat and treatments containing Prowl H2O resulted in slightly better weed control than Warrant and Valor SX.
2. Determine the impact of weed control on alfalfa hay yield and quality	Weed control treatments had little impact on alfalfa and total forage yield (alfalfa + weeds). Where there were differences in forage yield due to treatments, it was a result of weed biomass from poor weed control treatments. Reduction in weed biomass due to good weed control increased forage crude protein and reduced forage fiber.
3. Extend research results to stakeholders through field days, workshops, and extension publications	Results were presented during weed tour/field days in Kimberly ID, and Scottsbluff, NE. Results were also presented at hay and forage schools in Idaho and Nebraska.

Results and Discussion

Weed control from herbicide treatments

At the Kimberly location, there was an interaction effect ($P < 0.001$) of POST (paraquat) and residual herbicide treatments on common lambsquarters (Figure 1) and kochia control (Figure 3). Although weed control was primarily due to the application of paraquat, treatments containing Prowl H2O resulted in slightly better weed control (Figures 1 & 2; Table 3). The application of paraquat after the first cutting reduced kochia biomass but common lambsquarters biomass was not affected (Table 3). There were differences in common lambsquarters biomass among the residual herbicide treatments at the second cutting (Table 3).

At the Nebraska location, the application of paraquat after the first cutting did not result in any significant reduction in weed biomass (Tables 4 & 5). However, there were differences in Palmer amaranth and common lambsquarters biomass among the residual herbicide treatments at second cutting (Table 4). Also, there were differences in common lambsquarters biomass among the residual herbicide treatments at third cutting (Table 5), with Prowl H2O providing slightly better weed control.

Impact of herbicide treatments on forage yield

Alfalfa yield was not influenced by herbicide treatments in Kimberly (Table 3). However, alfalfa regrowth was slower following paraquat application after the first cutting and this resulted in forage yield reduction at the second cutting at the Nebraska location (Table 4). Alfalfa and total forage yield (alfalfa + weeds) were not influenced by herbicide treatments at the third harvest (Table 5). Where there were differences in forage yield due to treatments, it was a result of weed biomass from poor weed control treatments (Table 3). For example, at Kimberly, forage yield was greater in the no paraquat treatment due to high weed biomass (Table 3). Thus, weed control is more likely to have a significant impact on forage yield if treatments were applied before the first harvest since weeds tend to have a greater impact on yield at the first harvest.

Impact of herbicide treatments on forage quality

Herbicide treatments influenced CP, ADF, and NDF at the Kimberly location (Table 6). Treatments that had more weed biomass (Table 3) tend to have lower forage CP and higher ADF and NDF (Table 6). At the Scottsbluff location, a combination of slower alfalfa regrowth following paraquat application after the first cutting and slight weed suppression by paraquat resulted in higher forage crude protein and lower fiber (ADF and NDF) at the second cutting (Table 5). However, forage quality was not influenced by weed control treatments at the third cutting (Table 5).

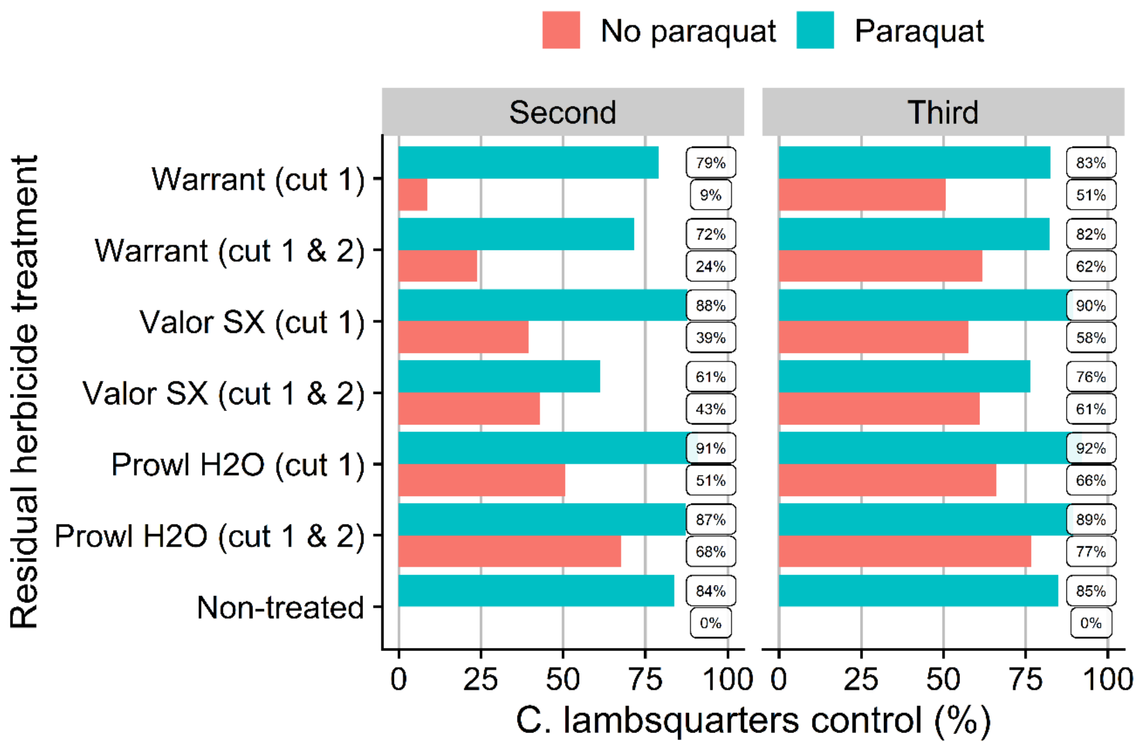

Figure 1 Visible common lambsquarters control at second cutting and four weeks after second cutting (~third cutting) in 2021 and 2022, Kimberly ID. Treatments are described in Table 1.

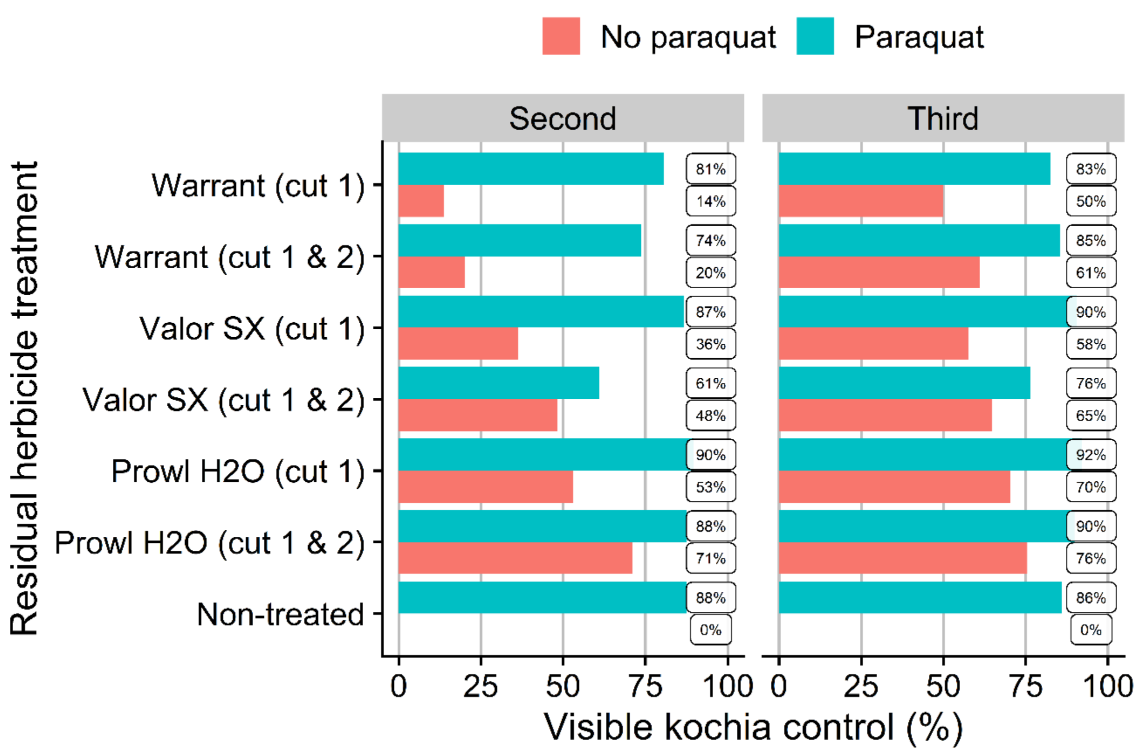

Figure 2 Visible kochia control at second cutting and four weeks after second cutting (~third cutting) in 2021 and 2022, Kimberly ID. Treatments are described in Table 1.

Table 3. Weed biomass and forage yield as influenced by postemergence (POST) and residual herbicide treatments at second cutting in 2021 and 2022, Kimberly, Idaho, USA

Factor		Lamb[1]	Kochia[1]	Biomass Total weed	Alfalfa	Total forage
		------------------ Biomass (ton/A) -----------------------				
POST		*P = 0.36*	***P < 0.001***	***P = 0.03***	*P = 0.97*	***P = 0.002***
	No paraquat	0.25 a[2]	0.05 a	0.30 a	0.85 a	1.19 a
	Paraquat	0.20 a	0.0 b	0.20 b	0.85 a	1.0 b
Residual		*P* = **0.03**	*P = 0.09*	*P* = **0.008**	*P = 0.25*	*P* = **0.03**
	Non-treated	0.31 a	0.07 a	0.37 a	0.90 a	1.25 a
	Prowl® H2O, 1st cut	0.13 bc	0.03 a	0.16 bc	0.88 a	1.01 b
	Prowl® H2O, 1st & 2nd cut	0.10 c	0.0 a	0.10 c	0.90 a	1.94 b
	Warrant®, 1st cut	0.23 a-c	0.04 a	0.27 ab	0.85 a	1.10 ab
	Warrant®, 1st & 2nd cut	0.28 ab	0.03 a	0.30 ab	0.92 a	1.24 a
	Valor SX®, 1st cut	0.25 ab	0.0 a	0.26 ab	0.71 a	1.0 b
	Valor SX ®, 1st & 2nd cut	0.27 ab	0.0 a	0.26 ab	0.77 a	1.06 ab
POST * Residual		*P = 0.18*	*P = 0.10*	*P = 0.06*	*P = 0.75*	*P = 0.89*

[1] Lamb; common lambsquarters (Chenopodium album); kochia (Bassia scoparia)

[2]Within columns for each factor, means followed by the same letters are not different according to Fisher's protected LSD at the 0.05 significance level.

Table 4. Weed biomass and forage yield as influenced by postemergence (POST) and residual herbicide treatments at second cutting in 2021 and 2022, Scottsbluff, Nebraska, USA

Factor		Lamb[1]	Palmer[1]	Biomass Total weed	Alfalfa	Total forage
		------------------ Biomass (ton/A) -----------------------				
POST		*P = 0.09*	*P = 0.25*	*P = 0.24*	***P = 0.01***	***P = 0.01***
	No paraquat	0.32 a[2]	0.32 a	1.12 a	2.19 a	2.30 a
	Paraquat	0.23 a	0.24 a	0.89 a	1.91 b	1.99 b
Residual		***P < 0.001***	***P = 0.02***	***P = 0.03***	*P = 0.13*	***P = 0.04***
	Non-treated	0.61 a	0.37 ab	1.36 a	2.27 a	2.94 a
	Prowl® H2O, 1st cut	0.16 d	0.16 b	0.85 bc	1.93 a	1.99 bc
	Prowl® H2O, 1st & 2nd cut	0.13 d	0.30 ab	0.75 c	1.88 a	1.90 c
	Warrant®, 1st cut	0.30 c	0.16 b	1.10 ab	2.31 a	2.36 ab
	Warrant®, 1st & 2nd cut	0.33 bc	0.15 b	1.08 a-c	2.12 a	2.22 a-c
	Valor SX®, 1st cut	0.34 bc	0.34 a	1.0 bc	2.03 a	2.13 a-c
	Valor SX ®, 1st & 2nd cut	0.44 b	0.45 a	0.90 bc	1.82 a	1.91 bc
POST * Residual		*P = 0.22*	*P = 0.62*	*P = 0.49*	*P = 0.82*	*P = 0.89*

[1] Lamb; common lambsquarters (Chenopodium album); Palmer; Palmer amaranth (Amaranthus palmeri)

[2]Within columns for each factor, means followed by the same letters are not different according to Fisher's protected LSD at the 0.05 significance level.

Table 5. Weed biomass and forage yield as influenced by postemergence (POST) and residual herbicide treatments at third cutting in 2021 and 2022, Scottsbluff, Nebraska, USA

Factor		Lamb[1]	Palmer[1]	Total weed	Alfalfa	Total forage
		------------------ Biomass (ton/A) -----------------------				
POST		*P = 0.24*	*P = 0.78*	*P = 0.67*	*P = 0.22*	*P = 0.13*
	No paraquat	0.32 a[2]	0.20 a	0.93 a	2.04 a	2.19 a
	Paraquat	0.30 a	0.17 a	0.90 a	1.90 a	2.0 a
Residual		***P = 0.03***	*P = 0.13*	*P = 0.58*	*P = 0.47*	*P = 0.27*
	Non-treated	0.61 a	0.37 a	1.09 a	2.15 a	2.39 a
	Prowl® H2O, 1st cut	0.27 c	0.01 a	0.85 a	1.94 a	1.99 a
	Prowl® H2O, 1st & 2nd cut	0.14 c	0.10 a	0.85 a	1.90 a	1.94 a
	Warrant®, 1st cut	0.26 c	0.18 a	0.88 a	2.13 a	2.22 a
	Warrant®, 1st & 2nd cut	0.33 bc	0.16 a	0.97 a	2.01 a	2.18 a
	Valor SX®, 1st cut	0.46 a-c	0.09 a	0.91 a	1.92 a	2.06 a
	Valor SX ®, 1st & 2nd cut	0.43 a-c	0.40 a	0.84 a	1.73 a	1.87 a
POST * Residual		*P = 0.49*	*P = 0.81*	*P = 0.96*	*P = 0.95*	*P = 0.98*

[1] *Lamb; common lambsquarters (Chenopodium album); Palmer; Palmer amaranth (Amaranthus palmeri)*

[2] *Within columns for each factor, means followed by the same letters are not different according to Fisher's protected LSD at the 0.05 significance level.*

Table 6. Forage crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (ADF) as influenced by postemergence (POST) and residual herbicide treatments at second cutting in 2021 and 2022, Kimberly, Idaho, USA

		Second cutting		
Factor		CP	ADF	NDF
		------------------ % -------------------		
POST		***P = 0.001***	*P = 0.09*	***P = 0.003***
	No paraquat	21 b[1]	29 a	36 a
	Paraquat	23 a	28 a	33 b
Residual		***P = 0.02***	***P = 0.02***	***P = 0.006***
	Non-treated	21 c	32 a	39 a
	Prowl® H2O, 1st cut	23 a	26 c	32 c
	Prowl® H2O, 1st & 2nd cut	23 a	27 bc	33 c
	Warrant®, 1st cut	22 b	30 ab	37 ab
	Warrant®, 1st & 2nd cut	21 c	29 a-c	35 bc
	Valor SX®, 1st cut	23 a	27 bc	34 bc
	Valor SX ®, 1st & 2nd cut	22 b	28 a-c	35 bc
POST * Residual		*P = 0.37*	*P = 0.55*	*P = 0.88*

[1] *Within columns for each factor, means followed by the same letters are not different according to Fisher's protected LSD at the 0.05 significance level.*

Table 7. Forage crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (ADF) as influenced by postemergence (POST) and residual herbicide treatments at second and third cutting in 2021 and 2022, Scottsbluff, Nebraska, USA

Factor	Second cutting CP	ADF	NDF	Third cutting CP	ADF	NDF
	----------	----------	---------- %	----------	----------	----------
POST	***P = 0.03***	***P = 0.03***	***P = 0.03***	*P = 0.15*	*P = 0.19*	*P = 0.54*
No paraquat	23 b[1]	37 a	44 a	22 a	35 a	40 a
Paraquat	25 a	33 b	40 b	22 a	33 a	39 a
Residual	*P = 0.29*	*P = 0.27*	*P = 0.11*	*P = 0.19*	*P = 0.64*	*P = 0.39*
Non-treated	22 a	39 a	45 a	22 a	33 a	39 a
Prowl® H2O, 1st cut	25 a	33 a	39 a	23 a	33 a	38 a
Prowl® H2O, 1st & 2nd cut	26 a	31 a	36 a	21 a	34 a	41 a
Warrant®, 1st cut	23 a	36 a	43 a	23 a	34 a	39 a
Warrant®, 1st & 2nd cut	25 a	33 a	40 a	22 a	34 a	40 a
Valor SX®, 1st cut	23 a	37 a	45 a	21 a	36 a	42 a
Valor SX ®, 1st & 2nd cut	23 a	36 a	43 a	23 a	33 a	39 a
POST * Residual	*P = 0.37*	*P = 0.55*	*P = 0.71*	*P = 0.70*	*P = 0.59*	*P = 0.87*

[1]*Within columns for each factor, means followed by the same letters are not different according to Fisher's protected LSD at the 0.05 significance level.*

Experiment 2: The relationship between weed biomass and forage quality

The linear model of the relationship between weed biomass and forage nutritive value showed that a percentage increase in weed biomass reduced forage CP by 0.1%, DDM and TDN by 0.03% and RFV by 0.06% (Figure 3). The reduction in DDM, TDN, RFV were due to increased ADF and NDF with an increase in weed biomass (Figure 3). The reduction in CP and RFV was likely due to the presence of weeds such as shepherd's-purse, and green foxtail which tend to have lower CP concentrations compared to alfalfa (Bosworth et al., 1980; Temme et al., 1979)

Relationship between weed biomass proportion and forage nutritive value

From the nutritive value analysis of individual weed species, we observed that kochia and common lambsquarters had similar CP concentrations as alfalfa (Figure 4). Thus, increasing proportions of kochia and common lambsquarters biomass did not decrease the CP of the forage. Conversely, an increasing proportion of field bindweed, shepherd's-purse, and green foxtail biomass decreased CP of the forage because these species had significantly lower CP concentrations compared to alfalfa (Figure 4A). In a previous study, Temme et al. (1979) reported that shepherd's-purse had 3% less CP than alfalfa when harvested at the bud stage and 23% less CP compared to alfalfa when harvest was delayed until flowering. Similarly, CP concentration in *S. pumila* (Poir.) Roem. & Schult, a grassy weed closely related to green foxtail, was 18% less than alfalfa when harvested at the bud stage and 32% less when harvest was delayed until flowering (Temme et al., 1979). This suggests that delaying alfalfa harvest may result in further reduction in forage nutritive value due to weeds.

Acid detergent fiber concentration was lower in common lambsquarters compared to alfalfa, thus increasing the proportion of common lambsquarters decreased ADF concentration of the forage (Figure 4B). However, increasing proportions of kochia and field bindweed biomass did not affect the ADF of the forage as these weed species had similar ADF concentrations as alfalfa (Figure 4B). Only shepherd's-purse, and green foxtail increased ADF concentration with an increasing proportion of biomass (Figure 4B). Kochia, common lambsquarters, and field bindweed had similar NDF concentrations as alfalfa, and thus, increasing the biomass proportion of these weed species did not affect NDF concentration of alfalfa forage (Figure 4C). On the contrary, shepherd's-purse, and green foxtail had significantly lower NDF concentrations than alfalfa and thus, increasing the biomass proportion of these weed species linearly increased NDF concentration of alfalfa forage (Figure 4C). This was expected as weeds such as shepherd's-purse, and foxtails (*Setaria* spp) tend to have higher fiber concentration compared to alfalfa (Cosgrove & Barrett, 1987; Temme et al., 1979). In a previous study, higher amounts of weed biomass was correlated with higher NDF (Frost et al., 2008). In these instances, weed control may increase forage nutritive value (Cosgrove & Barrett, 1987).

Common lambsquarters had a greater concentration of TDN than alfalfa, and therefore increasing the proportion of common lambsquarters linearly increased the TDN concentration of alfalfa forage (Figure 4D). Kochia and field bindweed had similar TDN concentrations as alfalfa and thus, increasing the biomass proportion of these weed species did not affect TDN concentration of alfalfa forage (Figure 4D). shepherd's-purse and green foxtail on the other hand linearly decreased alfalfa TDN with increasing biomass proportions. Like TDN (Figure 4D), only common lambsquarters had greater RFV than alfalfa, resulting in a linear increase in RFV with an increasing proportion of alfalfa biomass (Figure 4E). Kochia and field bindweed had similar RFV as alfalfa, and thus, increasing the biomass proportion of these weed species did not affect the RFV of alfalfa forage (Figure 4E). An increasing proportion of Shepherd's-purse and green foxtail linearly decreased alfalfa RFV (Figure 4E).

Nitrate accumulation in weed biomass

Nitrate in hay may persist after harvest and curing. Generally, forage with nitrate concentration of 0 to 3,000 ppm (parts per million, on dry matter basis) is safe for cattle; 3,000 to 5,000 ppm is safe for non-pregnant cattle but low risk for pregnant cattle. Hay with 5000 to 10,000 ppm nitrate concentration presents a moderate risk of toxicity to cattle and may cause mid to late-term abortions, reduce milk production, and weak calves. Nitrate concentrations > 10,000 ppm is potentially toxic for all cattle, and could lead to acute toxicity, abortions, and even death (Strickland et al., 2017). Even at 100% biomass proportion, field bindweed and green foxtail had nitrate concentrations < 2,500 mg kg^{-1} (Figure 3), making these weeds safe for cattle consumption. At 60% or greater biomass proportion, kochia and Shepherd's-purse had ≥3,000 ppm which means these present some risk to pregnant cows if consumed in high quantities. Only common lambsquarters had nitrate concentrations exceeding 5,000 ppm, making it a moderately toxic weed to livestock at high biomass proportions (Figure 3). It must be noted that conditions which may reduce plant growth (e.g., drought) are likely to increase nitrate accumulation and the risk of livestock poisoning (Bolan & Kemp, 2003; Hall, 2018; Olson et al., 2002). Thus, under stressed conditions, nitrate concentration may be higher at reduced weed biomass.

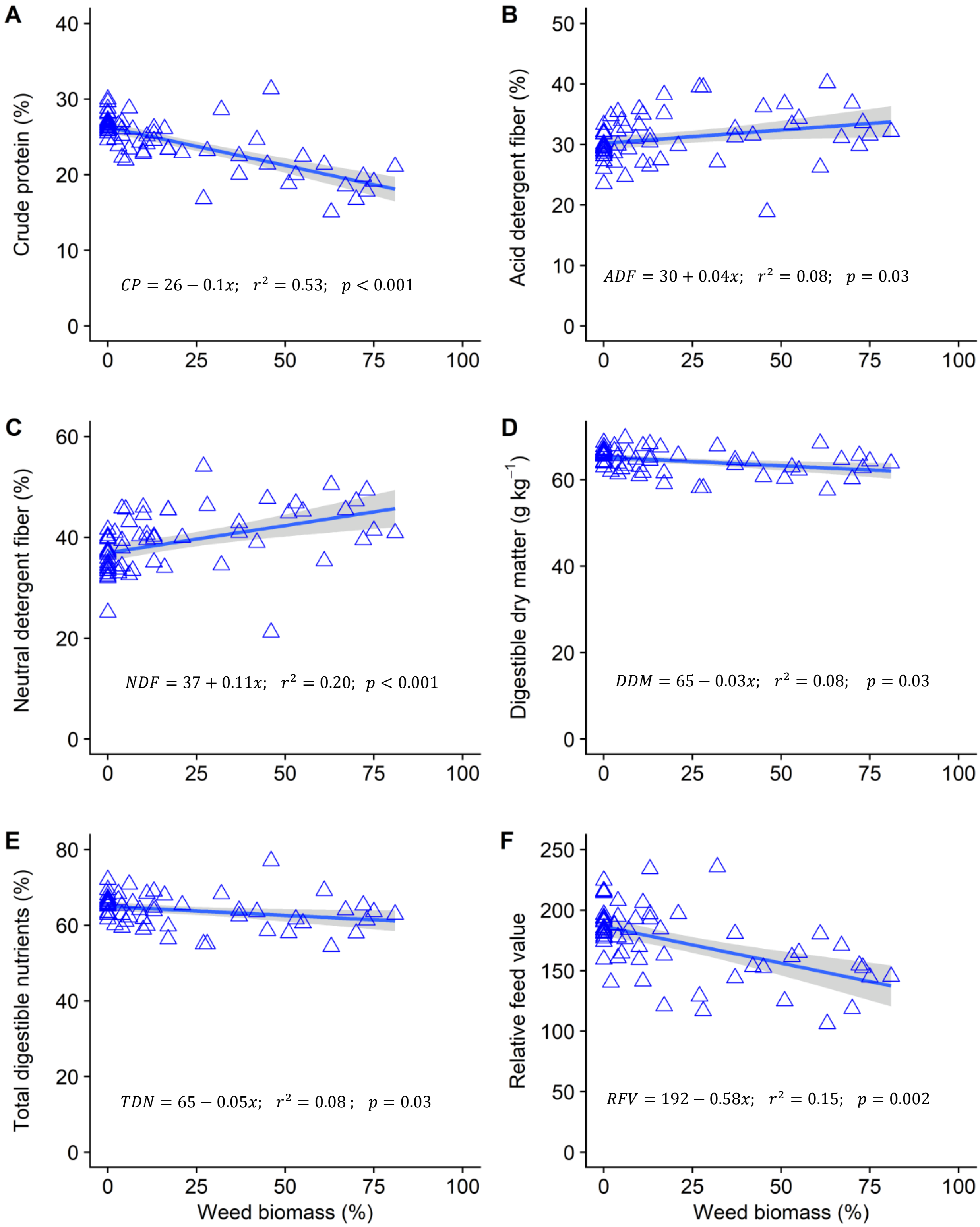

Figure 3. Linear relationships between weed biomass proportion and alfalfa forage nutritive value at first harvest in Kimberly, ID USA.

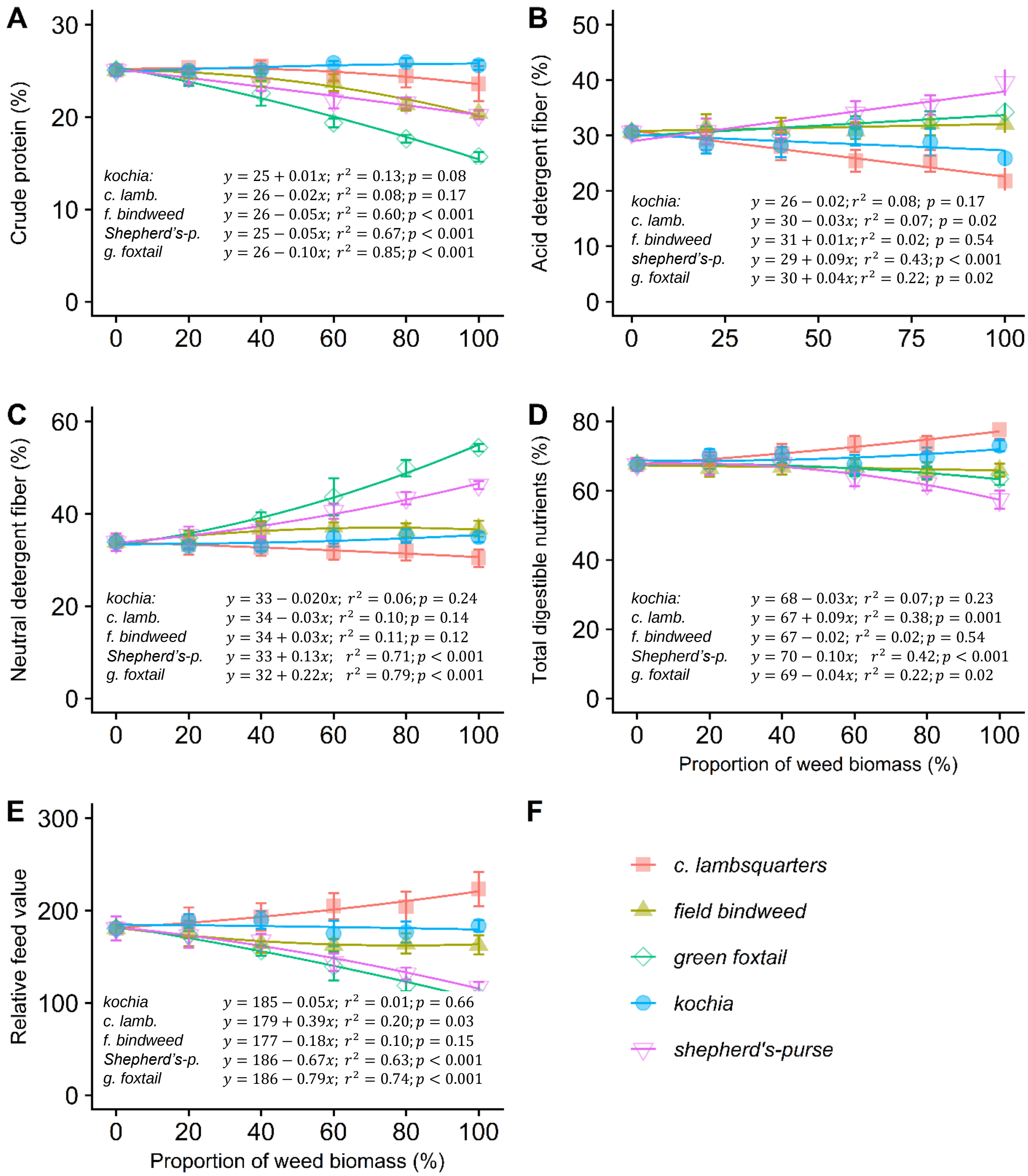

Figure 4. Linear relationship between the biomass proportion of individual weed species (kochia, *Bassia scoparia*; common lambsquarters, *Chenopodium album*; field bindweed, *Convolvulus arvensis*; shepherd's-purse, Capsella bursa-pastoris, and green foxtail, Setaria viridis) and alfalfa nutritive value in Kimberly, ID USA.

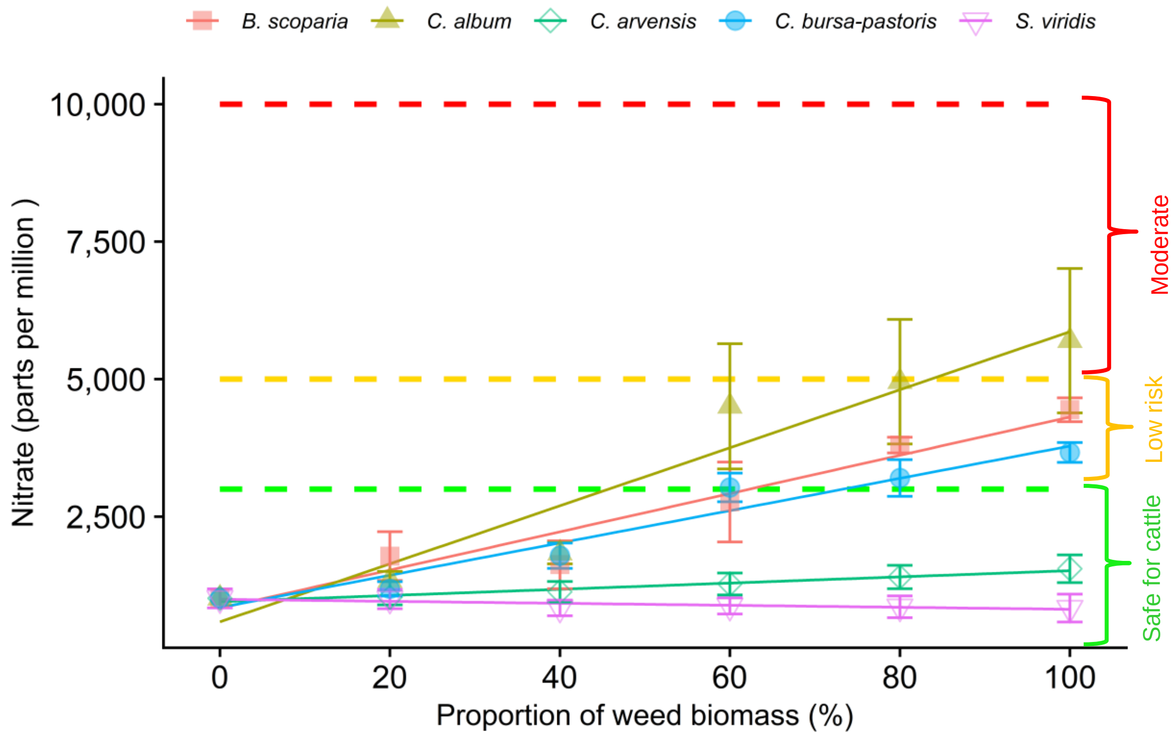

Figure 5. Relationship between biomass proportion of individual weed species (kochia, *Bassia scoparia* $y = 833 + 35x; \quad r^2 = 0.70; \quad p < 0.001$; common lambsquarters, *Chenopodium album* $y = 586 + 53x; \quad r^2 = 0.57; \quad p < 0.001$; field bindweed, *Convolvulus arvensis* ($y = 954 + 5.6x; \quad r^2 = 0.24; \quad p = 0.01$); shepherd's-purse, *Capsella bursa-pastoris* $y = 847 + 29x; \quad r^2 = 0.83; \quad p < 0.001$, and green foxtail, *Setaria viridis* $y = 996 - 1.8x; \quad r^2 = 0.04; \quad p = 0.38$) and alfalfa forage nitrate accumulation in Kimberly, ID USA. Generally, forage with 0 to 3,000 ppm (parts per million, on dry matter basis) is safe for cattle; 3,000 to 5,000 ppm is safe for non-pregnant cattle but low risk for pregnant cattle; 5000 to 10,000 ppm nitrate concentration present moderate risk of toxicity to cattle; and > 10,000 ppm is potentially toxic for all cattle.

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