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Urea ammonium nitrate as the carrier for preplant burndown herbicides

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Abstract

Preplant weed control is a common practice for many small grain farmers. The timing of these applications often coincides with starter nitrogen (N) fertilizer application. Co-application of the herbicides and N fertilizers, such as urea-ammonium nitrate (UAN), can reduce the number of trips across the field, labor costs, and the costs of N and herbicide applications. However, there is a dearth of information on the effect of herbicide-N fertilizer mixtures on herbicide efficacy. Field studies were conducted in the summer of 2021 and 2022 to evaluate the effect of UAN (32-0-0) rate (0%, 25%, 50%, 75%, and 100% of carrier volume) on the efficacy of three non-selective herbicides (glyphosate [1260 g ae ha^{-1}], paraquat [560 g ai ha^{-1}], and tiafenacil [74 g ai ha^{-1}]). There was no effect of UAN volume on herbicide efficacy. The addition of UAN did not reduce the efficacy of glyphosate, paraquat, or tiafenacil. At 3 weeks after herbicide application, glyphosate efficacy ranged from 92% to 94% (broadleaved weeds) and 97% (grassy weeds). Paraquat efficacy ranged from 63% to 87% (broadleaved weeds) and 87% (grassy weeds). Tiafenacil efficacy ranged from 52% to 74% (broadleaved weeds) and 70% (grassy weeds). Higher application volume may be needed to increase the efficacy of contact herbicides such as paraquat and tiafenacil.

1 | INTRODUCTION

Preplant weed control is a common practice in small grain production to control emerging weeds before planting crops. This application often coincides with starter nitrogen (N) fertilizer application, with liquid urea-ammonium nitrate solution (UAN, 32-0-0) being one of the most common forms of starter fertilizers applied. The co-application of burndown herbicides with liquid UAN as a tank mixture allows farmers to control existing weeds while simultaneously applying their starter fertilizer (Soltani et al., 2012). This reduces the number of trips across a field, thereby reducing labor costs (Soltani et al., 2012). Tank-mixing herbicides with liquid UAN reduces environmental pressure by reducing fuel emissions and soil compactions. Despite these benefits of herbicide tank mixtures, tank mixing of herbicides with other chemicals can result in antagonism or incompatibility issues (Merritt et al., 2020).

An antagonism response is undesirable because it reduces the weed control efficacy by either inhibiting the binding effect of the herbicide or by augmenting the inactivation of metabolic activities, which narrows the weed control spectrum (Green, 1989). However, UAN is commonly used as an adjuvant for most herbicide applications since it mixes well with most herbicides (Tu & Randall, 2001). Several

Abbreviations: UAN, urea-ammonium nitrate; WAT, weeks after treatment.

herbicides, including paraquat and glyphosate, often require a UAN foliar spray adjuvant to optimize herbicide efficacy (Jursík et al., 2016).

There are herbicides such as paraquat, which allow the use of liquid N fertilizers as carriers (Anonymous, 2019). However, some herbicides have restrictions on the proportion of liquid N fertilizers in the carrier volume. For example, for fall applications of bromoxynil plus pyrasulfotole (Huskie), liquid N may not exceed 50% of the carrier volume because UAN's density is greater than water (Anonymous, 2021; Long, 2019). Thus, the volume of UAN may affect nozzle flow rate and, consequently, spray coverage (Klein, 2016). Spray coverage is especially important when using contact herbicides such as paraquat and tiafenacil (Long, 2019). Good coverage is essential for contact herbicides since they have limited mobility within the plant, which plays an important role in weed control efficacy (Shan et al., 2021).

The objective of this study was to evaluate the effect of UAN (32-0-0) rate (0%, 25%, 50%, 75%, and 100% of carrier volume) on the efficacy of three non-selective herbicides (glyphosate, paraquat, and tiafenacil).

Core Ideas

- Co-application of urea-ammonium nitrate (UAN) and herbicides can save farmers' time and reduce labor costs.
- Using UAN as the herbicide carrier did not reduce the efficacy of glyphosate, paraquat, and tiafenacil.
- Glyphosate was more effective for broad-spectrum weed control compared to paraquat and tiafenacil.
- Adequate tissue coverage is essential to improve the weed control efficacy of paraquat and tiafenacil.

2 | MATERIALS AND METHODS

Field experiments were conducted at the University of Idaho Kimberly Research and Extension Center, Kimberly, ID (42.549877, −114.349615) in 2021 and 2022 to evaluate the effect of UAN carrier volume on the weed control efficacy of preplant herbicides (glyphosate, paraquat, and tiafenacil). The soil was a Portneuf silt loam (coarse-silty, mixed, superactive, mesic Durinodic Xeric Haplocalcids). The soils at the study site had a pH of about 8.0, organic matter of 1.97%–2.14%, and cation exchange of 18.6 mEq 100 g^{-1} of soil.

The average field location air temperature and relative humidity for the 3 weeks after herbicide spraying in 2021 and 2022 were retrieved from the AgriMet Cooperative Agricultural Weather Network Database (https://www.usbr.gov/pn/agrimet/agrimetmap/twfida.html) and are presented in Figure 1.

The experiment was a 3 × 5 factorial randomized complete block design with four replications. A summary of weed control treatments and herbicide rates used in the study is provided in Table 1. Factor A comprised three non-selective herbicides (glyphosate, paraquat, and tiafenacil); and factor B comprised five rates of UAN (32-0-0): 0%, 25%, 50%, 75%, and 100% of carrier volume (%V/V). This provided 12.3, 25.6, 36.9, and 49.2 kg of N ha^{-1} for the 25%, 50%, 75%, and 100% v/v UAN, respectively. Individual plots were 3 m × 9 m. Herbicides were applied using a CO_2-pressurized bicycle sprayer delivering 144 L ha^{-1} at 207 kPa with TeeJet 11002DG nozzles on June 2, 2021, and September 12, 2022.

The common weeds evaluated were common lambsquarters (*Chenopodium album* L.), kochia (*Bassia scoparia* [L.] A. J. Scott), redroot pigweed (*Amaranthus retroflexus* L.), and barnyardgrass (*Echinochloa crus-galli* [L.] P. Beauv.). Weed heights at the time of herbicide application were as follows: common lambsquarters (12–15 cm), kochia (10–13 cm), redroot pigweed (12–15 cm), and barnyardgrass (8–13 cm).

Weed control efficacy (by weed species) was visually assessed in each plot at 1, 2, and 3 weeks after treatment (WAT) on a scale of 0%–100%, with 0% being no weed control and 100% being complete weed control.

2.1 | Data analysis

All data analyses were performed in R statistical language (version 4.0.2) using the *lme4*, *lmerTest*, and *emmeans* packages (Bates et al., 2015; Kuznetsova et al., 2017; Lenth, 2022; R Core Team, 2022). The effect of UAN carrier volume on weed control efficacy was analyzed using a mixed-effects model where herbicide treatment and UAN carrier volume were considered fixed effects, and year and block were considered random effects. This approach was used because herbicide efficacy is influenced by a myriad of soil and environmental conditions as well as plant factors (size, growth stage, leaf surface characteristics, etc.). The conditions over the 2 years were considered representative of weed control that could be possible within these representative conditions. When the main effect of herbicide treatment was significant, estimated marginal means were calculated from the model, and post hoc Tukey-adjusted pairwise treatment comparisons were performed at an alpha level of 0.05 using the *emmeans* and *multcomp* packages (Hothorn et al., 2008; Lenth, 2022). Where there was a significant effect of UAN or UAN–herbicide interaction, a linear regression analysis was performed, and the marginal coefficient of determination (variance explained by the fixed effect) from the mixed

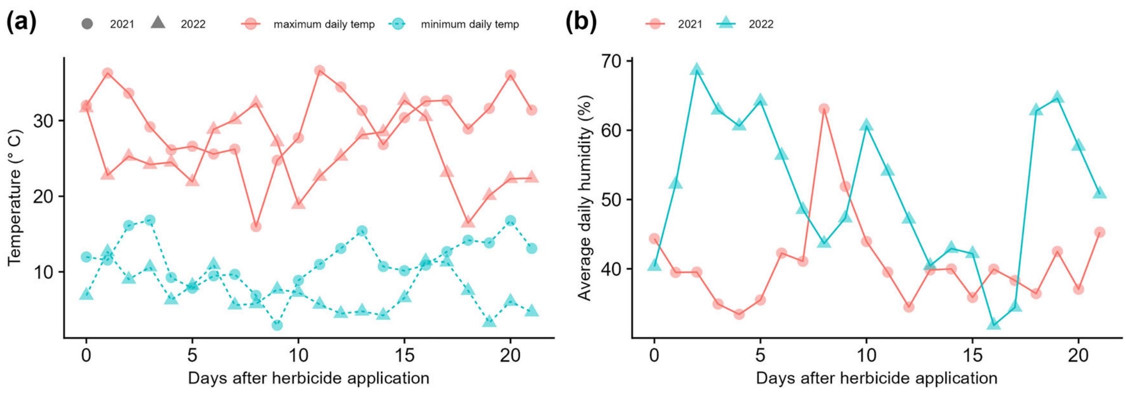

FIGURE 1 Air temperatures (a) and relative humidity (b) 0–21 days after herbicide application in 2021 and 2022, Kimberly, ID. Cumulative precipitation was negligible in 2021 (0.25 mm) and 2022 (0.75 mm). Data from the AgriMet Cooperative Agricultural Weather Network Database (https://www.usbr.gov/pn/agrimet/agrimetmap/twfida.html). Herbicides were applied on June 2, 2021 and September 12, 2022.

TABLE 1 Weed control treatments, herbicide rates, and urea-ammonium nitrate (UAN) volumes used in the study in 2021 and 2022 in Kimberly, ID.

Treatment	Rate	Description
Herbicide, g ai or ae/ha		
Glyphosate[a]	1260	–
Paraquat[b]	560	–
Tiafenacil[c]	74	–
UAN (32-0-0)[d], %v/v		
None (no UAN)	0	100% water carrier, 0% UAN
Low	25	25% UAN, 75% water
Medium	50	50% UAN, 50% water
High	75	75% UAN, 25% water
Very high (no water)	100	100% UAN, 0% water

[a]Roundup PowerMax, Bayer CropScience. The glyphosate-only (0% UAN) contained Ammonium sulfate (Alliance, WinField Solutions, St. Paul, MN) at 2.5% v/v as a water conditioner. The rate of glyphosate is in gram acid equivalent per hectare.
[b]Gramoxone SL 2.0 Syngenta Crop Protection, LLC. Treatment contained nonionic surfactant (Preference, WinField Solutions) at 0.25% v/v.
[c]Reviton, HELM Agro. Treatment contained methylated seed oil (MSO Concentrate with Leci-Tec, Loveland Products, Inc) at 1% v/v.
[d]Agrium U.S. Inc. (a subsidiary of Nutrien Ltd.).

model was obtained using the multi-model inference (*MuMIn*) package (Bartoń, 2023).

3 | RESULTS AND DISCUSSION

The study area is semi-arid, characterized by cold winters and springs followed by warm and dry summers (Figure 1). Ambient temperatures were generally warmer in 2021 than in 2022 (Figure 1a) because herbicides were applied on June 2, 2021, and September 12, 2022. In addition, relative humidity remained above 50% for only 2 days in 2021 and for 10 days after herbicide application in 2022 (Figure 1b).

The UAN carrier volume did not reduce the efficacy of glyphosate, paraquat, and tiafenacil on common lambsquarters within 3 weeks after herbicide application (Table 2). However, there were differences in common lambsquarters control among the herbicides. At 1 WAT, glyphosate provided better common lambsquarters control than tiafenacil, while glyphosate was more effective than both paraquat and tiafenacil for common lambsquarters control at 2 and 3 WAT.

Kochia control was different among herbicide treatments at 2 and 3 WAT (Table 2). Paraquat and tiafenacil were as effective as glyphosate for kochia control at 1 WAT, but glyphosate provided better control at 2 and 3 WAT. Contact herbicides such as paraquat and tiafenacil are fast-acting, producing visible results within 2 days after application (Altland et al., 2003). Because contact herbicides are not translocated within the plant, plant tissues not completely covered by the spray droplets tend to green up within 1 week or 2

TABLE 2 Visible common lambsquarters (*Chenopodium album*), kochia (*Bassia scoparia*), redroot pigweed (*Amaranthus retroflexus*), and barnyardgrass (*Echinochloa crus-galli*) weed control within 3 weeks after herbicide treatment in 2021 and 2022 as influenced by herbicides and urea-ammonium nitrate (UAN) carrier volume, Kimberly, ID.

	Common lambsquarters, percentage visible control			Kochia, percentage visible control			Redroot pigweed, percentage visible control			Barnyardgrass, percentage visible control			
Factor	**1 WAT**[a]	**2 WAT**	**3 WAT**	**1 WAT**	**2 WAT**	**3 WAT**	**1 WAT**	**2 WAT**	**3 WAT**	**1 WAT**	**2 WAT**	**3 WAT**	
Herbicide	$p = 0.32$	$p < 0.001$	$p < 0.001$	$p = 0.08$	$p < 0.001$	$p < 0.001$	$p = 0.4$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	
Glyphosate	87a[b]	93a	94a	93a	96a	92a	89a[b]	96a	92a	88ab	98a	97a	
Paraquat	83ab	78b	72b	96a	79b	63b	92a	81b	78b	93a	91b	87b	
Tiafenacil	81b	81b	74b	92a	68c	52c	90a	80b	74b	85b	79c	70c	
UAN rate (%v/v)[c]	$p = 0.19$	$p = 0.66$	$p = 0.79$	$p = 0.15$	$p = 0.023$	$p = 0.41$	$p = 0.86$	$p = 0.62$	$p = 0.16$		$p < 0.001$	$p = 0.29$	$p = 0.91$
0	79	79	77	88	81	69	90	85	82	90	84	88	84
25	85	87	84	96	86	72	91	88	83	91	89	90	85
50	85	85	81	96	81	68	90	85	81	90	89	87	85
75	85	83	78	95	80	69	90	86	80	90	91	89	84
100	84	86	80	93	76	67	89	84	80	89	91	92	84
Herbicide * UAN	$p = 0.90$	$p = 0.14$	$p = 0.14$	$p = 0.15$	$p = 0.07$	$p = 0.77$	$p = 0.76$	$p = 0.47$	$p = 0.90$		$p < 0.001$	$p = 0.054$	$p = 0.17$

Abbreviation: WAT, weeks after treatment.

[a]Weeks after herbicide treatment application.

[b]Within columns for each factor, means followed by the same letters are not different according to Tukey's HSD at the 0.05 significance level.

[c]The 0% UAN means water was used as herbicide carrier.

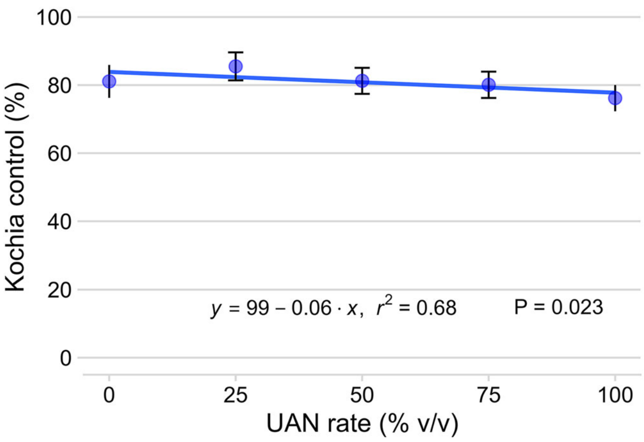

FIGURE 2 Urea-ammonium nitrate (UAN) rate effect on Kochia (*Bassia scoparia*) control at week 2 after herbicide application, in 2021 and 2022 in Kimberly, ID. The 0% UAN means water was used as herbicide carrier.

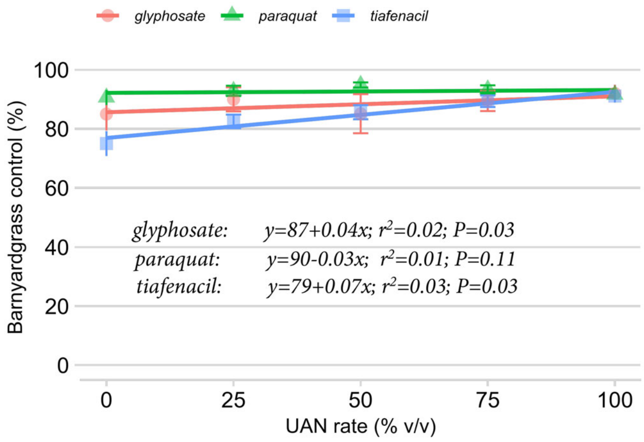

FIGURE 3 Urea-ammonium nitrate (UAN) rate and herbicide interaction effect on barnyardgrass (*Echinochloa crus-galli)* control at week 1 after herbicide application in 2021 and 2022 in Kimberly, ID. The 0% UAN means water was used as herbicide carrier.

weeks after herbicide application. Thus, incomplete coverage results in less weed control efficacy, and this is seen in kochia control from paraquat and tiafenacil at 2 and 3 WAT compared to glyphosate (Qasem, 2011). This is particularly important when controlling larger weeds or weeds at high densities (Shan et al., 2021; Zollinger et al., 2006). Kochia control was also influenced by UAN carrier volume at 2 WAT, where kochia control decreased with increasing UAN volume (Table 2 and Figure 2). The regression analysis showed that with every 10% increase in UAN volume, kochia control decreased by 0.6%. At 3 WAT, there was no effect of UAN volume on kochia control.

Only the effect of herbicide treatment was significant for redroot pigweed control at 2 and 3 WAT (Table 2). Paraquat and tiafenacil provided similar control of redroot pigweed as glyphosate 1 WAT. While redroot control with glyphosate increased after 1 WAT, control by paraquat and tiafenacil decreased after 1 WAT. At 1 WAT, there was a significant herbicide × UAN volume effect on barnyardgrass control. The regression analysis showed that barnyardgrass control using glyphosate and tiafenacil increased linearly as UAN volume increased (Figure 3), but barnyardgrass control using paraquat was not influenced by UAN volume. There was no effect of UAN volume on barnyardgrass control at 2 and 3 WAT. Among the three herbicides, tiafenacil consistently provided the least control of barnyardgrass relative to the other two herbicides.

Three weeks following herbicide application, glyphosate efficacy ranged from 92% to 94% for broadleaved weeds control and 97% for grassy weeds control when averaged across UAN volumes (Table 2). This suggests that even when glyphosate is applied with UAN, effective weed control can still be maintained. Paraquat efficacy ranged from 63% to 78% for broadleaved weeds control and 87% for grassy weeds control (3 WAT; Table 2). Similarly, tiafenacil efficacy ranged from 52% to 74% for broadleaved weeds control and 70% for grassy weeds control. These results suggest that paraquat and tiafenacil applied with or without UAN may benefit from mixtures with other effective herbicides.

The efficacy of contact herbicides is improved when application volume is increased, as this improves coverage (Bouse et al., 1990). The paraquat label recommends that for complete coverage of foliage when application volume is less than 187 L ha^{-1}, target weeds must not be larger than 15 cm (Anonymous, 2019). Similarly, although the minimum recommended spray volume for ground application of tiafenacil is 93.5 L ha^{-1}, it is recommended that application volume is increased to 140 L ha^{-1} or more when targeting larger weeds or dense weed populations (Anonymous, 2023). For spring-seeded small grains, it is often recommended that about 40% of the N needed is applied preplant, and this can range from 22 to 33 kg N ha^{-1} (Horneck et al., 2010; Marshall et al., 2020). Although these recommendations depend on the yield goal and residual N concentration (Mahler & Guy, 1992), this was within the range of N applied with the various rates of UAN in this study. This means that where less N rate is desired, farmers can reduce the volume of UAN and increase the volume of water. Similarly, where higher N rates are desired, either the volume of UAN can be increased or a larger nozzle orifice can be used to enable higher application volume, which would also provide good coverage of contact herbicides while meeting the preplant N needs.

Regarding potential fuel, time, and cost savings, Klein and McClure (2022) estimated that, at about \$1 L^{-1} of fuel, fuel cost for either fertilizer or herbicide application was \$0.9 ha^{-1}, while current labor costs are estimated to be about \$2.3 ha^{-1}, based on hourly wages of \$25. Thus, applying UAN and preplant herbicides together could save farmers more than \$3 ha^{-1}, depending on labor and fuel cost.

4 | CONCLUSIONS

Using UAN as the carrier for the application of glyphosate, paraquat, and tiafenacil for preplant weed control did not reduce the efficacy of these herbicides for the control of broadleaf and grassy herbicides. Applying UAN and preplant herbicides together could save farmers more than \$3 ha^{-1}, depending on labor and fuel costs. Glyphosate provided better weed control than paraquat and tiafenacil within 3 weeks after herbicide application. Further research is needed to determine if a higher carrier volume of UAN or UAN plus water improves the coverage of paraquat and tiafenacil and if that results in improved efficacy.

AUTHOR CONTRIBUTIONS

Kaone L. Mookodi: Data curation; investigation; writing—original draft; writing—review and editing. **Jared A. Spackman**: Writing—review and editing. **Albert T. Adjesiwor**: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; supervision; writing—original draft; writing—review and editing.

CONFLICT OF INTEREST STATEMENT

Products for research and funding unrelated to this research have previously been provided to the University of Idaho by manufacturers of products used in this research, including, Bayer CropScience, HELM Agro, and Syngenta Crop Protection, LLC.

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REFERENCES

Altland, J. E., Gilliam, C. H., & Wehtje, G. (2003). Weed control in field nurseries. *HortTechnology*, *13*(1), 9–14. https://doi.org/10.21273/HORTTECH.13.1.0009

Anonymous. (2019). Gramoxone SL 2.0. Syngenta Crop Protection, LLC. https://www.cdms.net/ldat/ldAGR031.pdf

Anonymous. (2021). *Huskie herbicide*. Bayer CropScience LP. https://www.cdms.net/ldat/ld8EU016.pdf

Anonymous. (2023). *Reviton herbicide*. Helm Agro US, Inc. https://www.cdms.net/ldat/ldH62016.pdf

Bartoń, K. (2023). *MuMIn: Multi-model inference*. R package version 1.47.5. https://CRAN.R-project.org/package=MuMIn

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Bouse, L. F., Kirk, I. W., & Bode, L. E. (1990). Effect of spray mixture on droplet size. *Transactions of the ASAE*, *33*(3), 0783–0788. https://doi.org/10.13031/2013.31401

Green, J. M. (1989). Herbicide antagonism at the whole plant level. *Weed Technology*, *3*(2), 217–226. https://doi.org/10.1017/S0890037X00031717

Horneck, D. A., Hart, J. M., Flowers, M. D., Kutcher, L. K., Wysocki, D. J., Corp, M. K., & Bohle, M. (2010). *Nutrient management guide: Irrigated soft white wheat*. Oregon State University Extension Service. https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em9015.pdf

Hothorn, T., Bretz, F., & Westfall, P. (2008). Simultaneous inference in general parametric models. *Biometrical Journal*, *50*(3), 346–363.

Jursík, M., Kolářová, M., Soukup, J., & Žďárková, V. (2016). Effects of adjuvants and carriers on propoxycarbazone and pyroxsulam efficacy on Bromus sterilis in winter wheat. *Plant, Soil and Environment*, *62*(10), 447–452.

Klein, R. N. (2016). *Setting the sprayer flow rate for non-water solutions*. Cropwatch. https://cropwatch.unl.edu/2016/setting-sprayer-flow-rate-non-water-solutions

Klein, R. N., & McClure, G. (2022). *2022 Nebraska crop budgets*. EC872. University of Nebraska Extension. https://cropwatch.unl.edu/Budgets/2022/2022-nebraska-crop-budgets-010322.pdf

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software*, *82*, 1–26. https://doi.org/10.18637/jss.v082.i13

Lenth, R. (2022). *emmeans: Estimated marginal means, aka least-squares means*. R package version 1.7.5. The University of Iowa. https://CRAN.R-project.org/package=emmeans

Long, J. M. (2019). *Using water to calibrate sprayers for fertilizers and other liquid solutions*. Oklahoma Cooperative extension Service BAE-1293. https://extension.okstate.edu/fact-sheets/print-publications/bae/using-water-to-calibrate-sprayers-for-fertilizers-and-other-liquid-solutions-bae-1293.pdf

Mahler, R. L., & Guy, S. O. A. (1992). *Northern Idaho Guide*: Spring wheat. https://digital.lib.uidaho.edu/utils/getfile/collection/ui_ep/id/30490.pdf?_ga=2.46553511.1234716478.1689699399-181492096.1681835716

Marshal, J. M., Rogers, C. W., Rashed, A., Walsh, L. X., & Adjesiwor, A. (2020). Southern Idaho guide: Soft white spring wheat quick facts. https://www.uidaho.edu/-/media/UIdaho-Responsive/Files/Extension/topic/cereals/scse/publications/SI-Wheat-Quick-Facts-SWS.pdf

Merritt, L. H., Ferguson, J. C., Brown-Johnson, A. E., Reynolds, D. B., Tseng, T.-M., & Lowe, J. W. (2020). Reduced herbicide antagonism of grass weed control through spray application technique. *Agronomy*, *10*(8), 1131. https://doi.org/10.3390/agronomy10081131

Qasem, J. R. (2011). Herbicides applications: Problems and considerations. In A. Kortekamp (Ed.), *Herbicides and environment*. IntechOpen.

R Core Team. (2022). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.r-project.org/

Shan, C., Wang, G., Wang, H., Xie, Y., Wang, H., Wang, S., Chen, S., & Lan, Y. (2021). Effects of droplet size and spray volume parameters on droplet deposition of wheat herbicide application by using UAV. *International Journal of Agricultural and Biological Engineering*, *14*(1), 74–81. https://doi.org/10.25165/j.ijabe.20211401.6129

Soltani, N., Shropshire, C., & Sikkema, P. H. (2012). Urea ammonium nitrate as the carrier for herbicides in winter wheat. *American Journal of Plant Sciences*, *3*(3), 417. https://doi.org/10.4236/ajps.2012.33050

Tu, M., & Randall, J. M. (2001). Adjuvants. In M. Tu, C. Hurd, & J. M. Randall (Eds.), *Weed control methods handbook*. The Nature Conservancy. https://www.invasive.org/gist/products/handbook/methods-handbook.pdf

Zollinger, R. K., Christoffers, M., Endres, G., Gramig, G., Howatt, K., Jenks, B., Kegode, G. O., Lym, R. G., Messersmith, C. G., Thostenson, A. A., & Valenti, H. H. (2006). *North Dakota weed control guide*. North Dakota State University Extension Service Publication W-253. https://library.ndsu.edu/ir/handle/10365/9502

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