Fall Applications of Foliar Applied Nitrogen and Potassium and Their Effect on Winter Hardiness

K. Dodson, M.A. Anderson and J. Pick

Summary

With the turf industry's rapid adoption of foliar nutrient programs across Canada, and the continued effort to minimize losses from winterkill, this two year study aimed to leverage the previous research conducted at the PTRC which evaluated the efficacy of fall applied granular N/K,to fall applied foliar treatments. The project would uncover a preferred application strategy of granular or foliars, for the purpose of maximizing winter hardiness and spring green-up on poa reptans greens.

Different rates of nitrogen applied either alone or in combination with the different rates of potassium had a significant impact on the fall color of the turf. The tissue test results in both years of the study reflected consistent absorption of the foliar applied treatments, and relative effectiveness in entering the plant. This somewhat contradicted previous assumptions where lower ambient temperatures limit and translocation. There were no significant differences between the foliar treatments regarding spring green-up, or winter hardiness throughout the winter testing periods, however the relationship of applications to N & K % tissue analysis presented new information when compared to the previous granular study.

Introduction

Currently there is conflicting information on the effects of Nitrogen (N) focused fall fertility programs for improving cold tolerance during the acclimation and spring recovery (deacclimation) time-frames. In general, the literature shows a trend of positive effect for improving frost hardiness during the acclimation period with N applications (Taulavuori, et al., 2004). For example, early research by Carroll (1943) found fall application rates of N directly correlated with cold tolerance, and Carroll and Welton (1939) found high crown hydration levels were associated with increased risk to winter injury. Tompkins et al. (2000) found high rates of N directly correlated with increased crown hydration levels and a reduction is winter survival rates. Whereas, Powell et al. (1967) found fall applied N increased rooting and stimulated photosynthesis rate and carbohydrate production.

Carbohydrate levels are thought to play an important role in preventing direct low-temperature kill to turfgrass crowns (Fry and Huang, 2004). Potassium (K) focused research with respect to cold tolerance has also shown variable results in turfgrass. Marklan and Roberts (1967) found that as K applications increased crown hydration levels decreased in creeping bentgrass, and Hurto and Troll (1980) found that tissue K levels positively correlated with cold tolerance of perennial ryegrass. Whereas Moody and Rossi (2010) found high K levels made creeping bentgrass more susceptible to snow mold injury. The roles of N and K in the plant are well known, and it is understood that when one is limited the nutrient use efficiency of the other is limited (Ebdon et al., 2013). Cold tolerance research with perennial ryegrass has shown some discrepancies with respect to cold tolerance. Hurto and Troll (1980) recommend a 2:1 N:K ratio, while Webster and Ebdon (2005) found that ratios of 1:4 – 2:1 improved winter injury prevention when N was applied at (5-15 $g^{-2}yr^{-1}$) with med – high levels of K (24-22$g^{-2}yr^{-1}$).

A granular-focused N and K trial at the PTRC found that applying 4.88$gNm^{-2}yr^{-1}$ at biweekly rates of 1.22gNm^{-2} in combination with 4.88 – 9.76 gKm^{-2}yr-1 at biweekly rates of 1.22-2.44 gKm^{-2}, during the early fall pre-acclimation period, resulted in optimum cold tolerance levels and good spring recovery on an annual bluegrass putting green. While the results were useful in determining the negative effects of too much or too little N and K applied during the fall acclimation process, the rates were too coarse to fine-tune a foliar-based fertility program.

The current study is focusing on the efficacy of using foliar applied N and K during the early fall pre-acclimation period. Steigler et al. (2013) found that Urea-based N sources had the lowest phytotoxicity potential and greater absorption rates when compared to other N sources, with most of the N being absorbed in the first 4 hours after application. Steigler et al. (2011) also found that applications in cooler weather resulted in greater absorption rates than during the hot summer months. This research suggests that using a foliar-based approach on cool season putting greens in the north may be a more efficient method for ensuring N gets absorbed effectively while minimizing potential loss to non-target areas. The purpose of this study was to observe the effects of foliar applied N and K on cold tolerance during the acclimation stage and deacclimation stage of annual bluegrass putting greens, and to determine if by using the foliar based approach would there be a potential decrease in the total amount of N and K applied in the early fall pre-acclimation period. This two year trial was a follow-up of a previous 2014-2015 granular experiment, “Fall Applications of Nitrogen and Potassium and their effect on winter hardiness of poa reptans”. In the next chapter, we explored the increased potential of using foliar treatments. The initial experiment utilized ammonium sulphate and sulphate of potash through granular application, where this foliar trial would compare Urea Triazone and Potassium Sulphate to compare turf response and N:K interactions.

Foliar Fall Fertility Results Year One

Summary (year 1):

Low rates of N (0.4-0.8 lbsN/M) and medium rates of K (0.25lbsK/M) produced annual bluegrass plants that had greater cold tolerance rates when compared to plants that were treated with high rates of N or 0lbsK to high rates of K. While the plots that received no N in the fall did express good cold tolerance in the December and March relative cold tolerance tests, they had very low NDVI ratings, and extremely poor spring green-up rates. The preliminary data suggested that aiming for the 0.4-0.8 lbsN/M rate during the pre-acclimation period (late summer early fall) would provide annual bluegrass plants with the nutrition they need while preparing for winter, while still providing a reliable playing surface. It is important to note that plots that did not receive K did not have good tolerance. This emphasizes the need of potassium nutrition for annual bluegrass plants going into winter. This trend is in concurrence with the granular fall fertility trial that was completed in the spring of 2017.

Materials and Methods: (year 1)

An USGA sand-based annual bluegrass putting green that was constructed in 2012 was used to set up individual 1.5 x 0.75m plots at the Prairie Turfgrass Research Centre (PTRC) in Olds, AB. All plots were fertilized biweekly throughout the summer to ensure no deficiencies were present before the onset of the trial. Plots were arranged in a 2-factorial randomized complete block design with 4 replications for a total of 120 individual plots. All plots were fertilized with Urea-Ammonium Nitrate (UAN) (28-0-0) and potassium acetate (K) based upon their treatment number (Table 1) on 20 Aug, 1 Sept, 17 Sept, and 1 Oct, 2016. Soil tests were taken August 15th, 2016 before the onset of the trial and again on October 15th, to evaluate the effects of the foliar program on the soil nutrient profile. Tissue tests were taken on September 15th, and October 15th, 2017 for tissue nutritional status of the plant during the early and late fall acclimation process respectively. Both fertilizer sources were applied at a 4L 100m^{-2} spray rate using an even flat fan, and the applications occurred on days when no precipitation was forecasted for a 24-hour period in order to ensure optimum absorption potential of both nutrients (Steigler et al., 2013).

Table One: Summary of the treatments applied during the pre-acclimation period of 2016

Trt #	N Rate (lbs/M)	K Rate (lbs/M)
1	0	0
2	0.1	0
3	0.2	0
4	0.3	0
5	0.4	0
6	0	0.125
7	0.1	0.125
8	0.2	0.125
9	0.3	0.125
10	0.4	0.125
11	0	0.25
12	0.1	0.25

13	0.2	0.25
14	0.3	0.25
15	0.4	0.25
16	0	0.375
17	0.1	0.375
18	0.2	0.375
19	0.3	0.375
20	0.4	0.375
21	0	0.5
22	0.1	0.5
23	0.2	0.5
24	0.3	0.5
25	0.4	0.5
26	0	0.625
27	0.1	0.625
28	0.2	0.625
29	0.3	0.625
30	0.4	0.625

Year One – Preliminary Results and Discussion:

Cold Tolerance:

There were no statistical differences between the treatments for the October, December and April sampling dates when N and K treatments were explored as a 2-way factorial analysis. There was an interaction effect with the year one deacclimation data taken on March 21, 2017 between N&K suggesting that the uptake of one is reliant on the other one for helping with winter-long cold tolerance (Table Two). When explored further the results were similar to the granular fall fertility study where N rates played a factor in the changes in cold tolerance with the 0.2 lbN/M rate having a greater cold tolerance than the other treatments (Tables 3&4).

Table Two: ANOVA results for the LT_{50} results from the March 21, 2017 deacclimation sampling

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
N Rate (lbs/M)	4	4	26.38333	1.4981	0.2094
K Rate (lbs/M)	5	5	15.17500	0.6893	0.6328
N Rate (lbs/M)*K Rate (lbs/M)	20	20	237.49167	2.6971	0.0007*

Table Three: ANOVA LT_{50} results for N rates from the spring (March 21, 2017) deacclimation sampling when N levels were analyzed separately from K.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	29	279.05000	9.62241	2.1855	0.0027*
Error	90	396.25000	4.40278		
C. Total	119	675.30000			

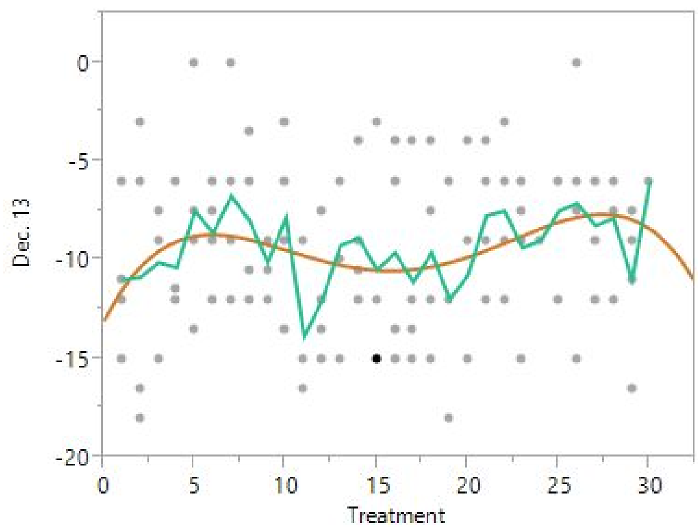
Table Four: Spring (March 21, 2017) cold tolerance values based on Nitrogen rates applied in the fall of 2016. Results followed by different letters within the column are statistically different according to the least square means Student's T-test ($\alpha = 0.05$).

N Rate (lbs/M)	Least Sq Mean
0.1	-5.0625 a
0.3	-5.1042ab
0.4	-5.6250ab
0	-5.9375ab
0.2	-6.2708a

The December sampling date should reflect the greatest cold tolerance of the plants based from previous research performed at the PTRC. When N&K were explored as combined treatments we see a trend where treatments that received applications of K at the 0.25lbsK/M (Trt#s 11-15, with 13 having the best cold tolerance) expressed greater cold tolerance (Fig.1).

Figure One:

LT_{50} results from the Dec. 13th sampling. Treatments numbers are outlined in Table One. The green line represents the areal fit line of the LS means of the LT_{50} results, while the orange line is the best fit line. In general, when N levels were low, and K was at 0.25lbs/M there was a greater cold tolerance in annual bluegrass. Rates of high N and/or high K resulted in a lower cold tolerance.

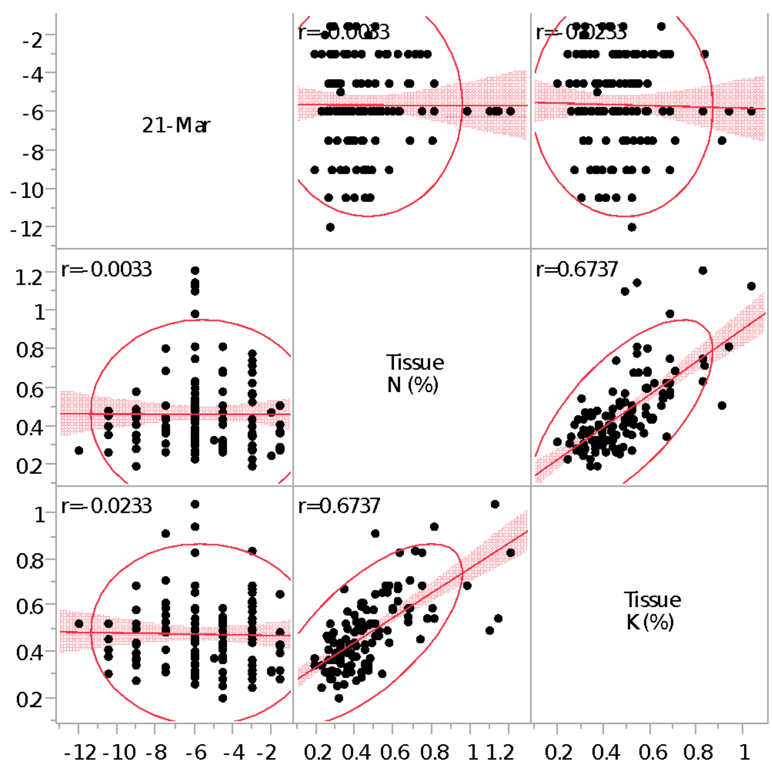


Tissue Nutrient Levels and Cold Tolerance:

At all sampling dates the data presented no strong correlations between cold tolerance and either N or K tissue nutrient status (Fig.2)

Figure 2:

Scatterplot matrix of correlations. An R value that is close to 1 is considered to be a strong correlation, while a value closer to zero is not. The graphs show that there is a weak correlation between tissue N and tissue K content, which suggests that the two nutrients uptake and use in the plant are dependent upon the other, however there was not true correlation (r=0.0033) between the tissue nutrient status from the late fall and the March 21 Cold Tolerance levels.



Work plan for year two:

First year data indicated a weak correlation between N & K tissue content, which would motivate the research team to re-think project scope & methodology. During this re-assessment, principal researcher Katie Dodson would depart, and year two of the project would be completed by Mark Anderston and Jason Pick. For year two, the scope of the project would be reduced from 120 test plots to 64, total of 16 treatments would include tissue tests to be batched due to lack of significant difference found in year 1. Similarly, soil tests would no longer be performed due to statistical indifference recorded in the first year. Rates applied would remain consistent within manufacturers recommendations.

Foliar Fall Fertility Results Year Two

Methodology and Trial Design

The second year was continued on the same site, USGA sand-based Poa reptans (cv. Two Putt) putting green at the Prairie Turfgrass Research Centre (PTRC) in Olds, AB. In preparation for the second fall trial, the green had been aggressively aerated and top dressed in July. A daily light irrigation was carried out throughout the summer to encourage the germination and the establishment of any dormant poa seed present in the green's soil profile. In addition, the green was fertilized on a biweekly basis (13-13-13 granular fertilizer at 0.5 lb/1,000 ft^2 rate), with the last application occurring on July 30th, this ensured that the green was not nutrient deficient prior to the onset of the trial.

In late October, the site was prepared for the approaching winter season, Fungicide was applied to the turf and snow fencing was installed to aid in trapping a heavy snow cover.

The trial was laid out as in a Completely Randomized Block Design. With four replications of sixteen fertilizer treatments to generate a total of sixty-four - 1x2 meter plots.

List of Treatments:

1. Untreated Control
2. Foliar nitrogen product 0.5 lb N/1,000sq.ft.only
3. Foliar nitrogen product 1.0 lb N/1,000sq.ft.only
4. Foliar nitrogen product 1.5 lb N/1,000sq.ft.only
5. Foliar potassium product 0.5 lb K/1,000sq.ft.only
6. Foliar potassium product 1.0 lb K/1,000sq.ft.only
7. Foliar potassium product 1.5 lb K/1,000sq.ft.only
8. Foliar nitrogen product 0.5 lb N.+ Foliar potassium product 0.5 lb K/1,000sq.ft.
9. Foliar nitrogen product 0.5 lb N.+ Foliar potassium product 1.0 lb K/1,000sq.ft.
10. Foliar nitrogen product 0.5 lb N.+ Foliar potassium product 1.5 lb K/1,000sq.ft.
11. Foliar nitrogen product 1.0 lb N.+ Foliar potassium product 0.5 lb K/1,000sq.ft.
12. Foliar nitrogen product 1.0 lb N.+ Foliar potassium product 1.0 lb K/1,000sq.ft.
13. Foliar nitrogen product 1.0 lb N.+ Foliar potassium product 1.5 lb K/1,000sq.ft.
14. Foliar nitrogen product 1.5 lb N.+ Foliar potassium product 0.5 lb K/1,000sq.ft.
15. Foliar nitrogen product 1.5 lb N.+ Foliar potassium product 1.0 lb K/1,000sq.ft.
16. Foliar nitrogen product 1.5 lb N.+ Foliar potassium product 1.5 lb K/1,000sq.ft.

Three application rates for each of the liquid foliar fertilizer products was selected based on the manufacturer's directions for use on greens.

The products were:

1. UAN 28-0-0, Liquid Fertilizer
   A slow release urea ammonium nitrate formulation.

Product Rates applied:	Single application delivered:	Total nutrient applied:
Low Rate 5.2 fl oz/1,000 ft^2	0.125 lbs N/ 1000ft^2	0.5 lbs N/ 1000ft^2
Medium Rate 10.4 fl oz/1,000 ft^2	0.250 lbs N/ 1000ft^2	1.0 lbs N/ 1000ft^2
High Rate 15.6 fl oz/1,000 ft^2	0.375lbs N/ 1000ft^2	1.5 lbs N/ 1000ft^2

Applied with 1.5 gallons of water per 1,000 sq. ft. every 14 days

2. Potassium Acetate 0-0-29 Liquid Fertilizer
   Is used as the sole potassium source or it can also be combined with nitrogen sources.

Product Rated applied:	Single application delivered:	Total nutrient applied:
Low Rate 4.3 fl oz/1,000 ft^2	0.125 lbs N/ 1000ft^2	0.5 lbs N/ 1000ft^2
Medium Rate 8.6 fl oz/1,000 ft^2	0.250 lbs N/ 1000ft^2	1.0 lbs N/ 1000ft^2
High Rate 12.9 fl oz/1,000 ft^2	0.375lbs N/ 1000ft^2	1.5 lbs N/ 1000ft^2

Applied with 1.5 gallons of water per 1,000 sq. ft. every 14 days

A total of four applications of the fertilizer treatments were made to their designated plots every fourteen days commencing August 28th and concluding on October 7th, 2019. The applications were made using a three nozzle CO_2 sprayer calibrated to deliver 1.5 U.S gallons per 1,000 sq. ft.

Data Collected During the Application of Treatment Phase

Fall Color Retention

On October 24th, two weeks after the last application of the treatments, the seasonal color retention was assessed for the overall plot color. Seasonal color ratings can be used to differentiate color differences based on nutrient deficiency or environmental stress. This fall turf color rating provided a subjective indicator as to the level of nutrient uptake in response to the fall applications of the nitrogen and the potassium. The color retention score is based on a 1 to 9 scale with 1 being straw brown and 9 being dark green.

NDVI

A color meter, (Field Scout model# TCM 500), as used to generate a normalized difference vegetation index digital score (NDVI) for each plot in order to objectively measure the effect of the treatments on turf quality. a digital image analysis of the impact of the treatments on turf color and density. A NDVI index value of healthy dense turfgrass generally falls between index values of 0.2 to 0.9. However these values will vary depending on the turf species and the season.

Turfgrass Leaf Tissue Analysis

On October 24th, two weeks after the last application of the treatments, turfgrass clippings were also collected from the treated plots. The clipping samples were oven dried at 70°C for 24 hours, then packaged and sent to the Brookside Laboratory for tissue analysis of Nitrogen and Potassium levels.

Data Collected During the Cold Tolerance Testing Phase

LT_{50} Value Determination

Typically, the freezing tolerance of turfgrass species is measured as the LT_{50}, or lethal temperature 50%, the temperature at which 50% of the plants die due to freezing injury.

Turf cores were collected from the field and tested at three different times throughout the winter period. The first collection was on November 18th (early winter), while the turfgrass was acclimating or in its hardening phase.

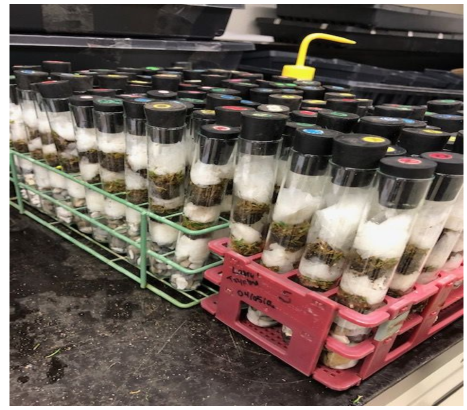


Image right: *collected samples subjected to cold temperature testing*

The second collection of turf cores occurred on January 21st (mid-winter) when the turfgrass were believed to be fully hardened. The last turf sampling was on April 21st after the snow cover had melted and the turfgrass was in the process of dehardening and beginning to break winter dormancy.

Image left*: Re-growth following LT50 testing*

Sub-samples were extracted from each turf core and along with a moisten paper nucleator were placed in test tubes. The individual tubes were allowed to acclimatize in the chiller for a minimum of twelve hours at -2 ^{0}C prior to the commencement of the testing phase. The temperature was then decreased in a step-wise fashion by 2^{0}C/hour. Once the selected temperature range was reached, a test tube for each treatment was removed before the temperature was further decreased by 2^0 C. Following the freeze test, turf plugs were thawed for 12 hours before being planted into plug trays and transferred to a greenhouse for four weeks. After four weeks, the re-growth of the turfgrass plugs was rated for survival in order to establish LT50 values.

Data Collected During the Spring Green -up Phase

Spring Green-up Color Rating

Spring green-up is the initial seasonal appearance of green leaves originating from dormant axillary buds as spring temperatures and moisture conditions become favorable for growth. The color score is based on a 1 to 9 scale with 1 being straw brown and 9 being dark green. The field color assessments were conducted on April 28th, May 12th and May 26th respectively.

NDVI

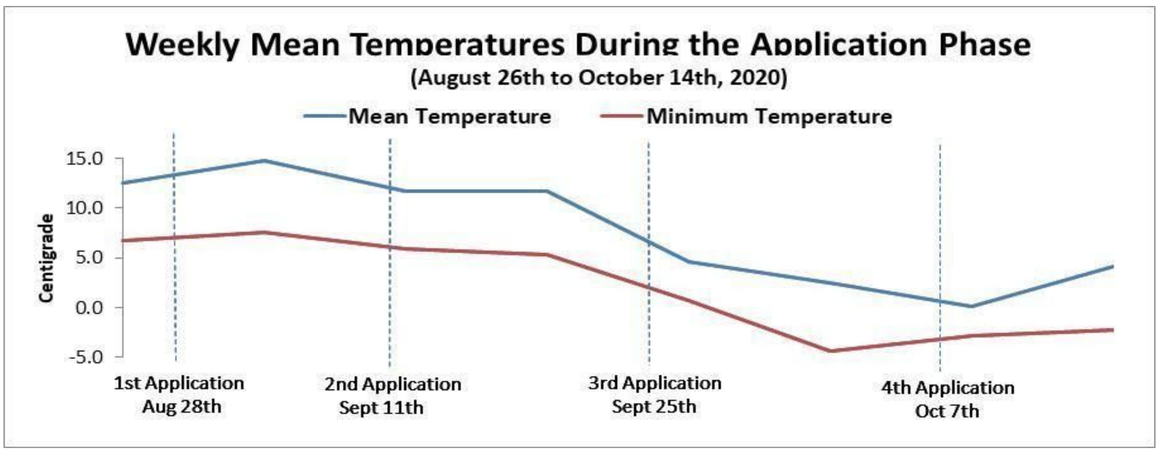
A normalized difference vegetation index score (NDVI) was also conducted each time a spring green-up color rating was performed. The NDVI rating objectively measured the effect of the treatments on the turf ability to break winter dormancy.

The color meter, (Field Scout model# TCM 500), was used again to generate a digital image analysis of the impact of the treatments on turf color and density. A NDVI index value of healthy dense turfgrass generally falls between 0.2 to 0.9. However these values will vary depending on the turf species and the seasonal weather conditions.

Results and Discussion

Evaluation of the Application Phase

Diagram:1



Weather conditions

We can presume the ability of the plant to translocate applied nutrients and systemics are greatly reduced when the plant is not actively growing. As the fall ambient temperatures gradually drop, we would expect to see reduced translocation compared to midsummer. This year, the PTRC also received an early snowfall on Sept 24 which may have compounded this physiological response. With severe low temperatures over this same period, the snow was not cleared to ensure adequate insulation, remaining on the surface until October 5thbefore melting off again just in time for the final applications on October 7th. The hardening process interrupted, we would expect this to have a negative effect on translocation of applied N & K. (Diagram 1.)

Table 1: Fall Turf Color Ratings and NDVI Values

Nitrogen/Potassium Treatments:	Fall Turf Color Rating	NDVI Value
1.5lbs N/ 1000 sq ft.	6.2a	0.757a
1.0lbs N + 0.5lbs K / 1000 sq ft.	6.0ab	0.757a
1.5lbs N + 0.5lbs K/ 1000 sq ft.	6.0ab	0.753a
1.0lbs N/ 1000 sq ft.	6.0ab	0.753a
1.5lbs N + 1.5lbs K/ 1000 sq ft.	6.0ab	0.739a

1.0lbs N + 1.0lbs K/ 1000 sq ft.	6.0ab	0.735a
0.5lbs N + 0.5lbs K/ 1000 sq ft.	5.7b	0.751a
0.5lbs N/ 1000 sq ft.	5.7b	0.734a
0.5lbs N + 1.0lbs K/ 1000 sq ft.	5.7b	0.734a
1.5lbs N + 1.0lbs K/ 1000 sq ft.	5.7b	0.724a
1.0lbs N + 1.5lbs K/ 1000 sq ft.	5.5b	0.726a
0.5lbs N + 1.5lbs K/ 1000 sq ft.	5.5b	0.717a
Untreated Control	5.0c	0.731a
0.5lbs K/ 1000 sq ft.	5.0c	0.700a
1.0lbs K/ 1000 sq ft.	5.0c	0.708a
1.5lbs K/ 1000 sq ft.	5.0c	0.684a
$LSD_{0.05}$ =	0.4	n/s

*Values with the same letter suffix are not statistically different from each other.

Fall Color Retention

The different rates of nitrogen applied either alone or in combination with the different rates of potassium had a significant impact on the fall color of the turf. As the rates of N increased and the color of the turf improved, we can conclude that the plant is processing the additional N, as chlorophyll and this suggests it's being utilized and/or stored. In contrast, applications of K ranging from low to high rates did not produce any significant difference. (Table 1.)

NDVI

While there was no significant difference between the treatments, there is trend that as the rate of potassium increases the overall NDVI value appears to be reduced. This implies albeit slight, a gradually negative response to increasing rates of K above .5lbs/1000sqft. Therefore we might conclude, that balanced with N or alone, applications of K above 0.5lbs/K/1000sqft will result in negative color response in fall and spring. (Table 1.)

Table 2a: Fall Leaf Tissue Nutrient Levels

Nitrogen Treatments:	Leaf Tissue Analysis Results			
	% N	Change in % N content compared to the Control Treatment	% K	Change in % K content compared to the Control Treatment
1.5lbs N + 0.5lbs K/ 1000 sq ft.	3.55a	+15.6%	1 .83bc	+ 0.0%
1.5lbs N + 1.0lbs K/ 1000 sq ft.	3.52a	+14.6%	2.01ab	+ 9.8%
1.0lbs N/ 1000 sq ft.	3.52a	+14.6%	1.81c	- 1.0%
1.0lbs N + 1.0lbs K/ 1000 sq ft.	3.51a	+14.3%	1.90bc	+ 3.8%
1.5lbs N/ 1000 sq ft.	3.48a	+13.3%	1.76c	- 3.8%
1.5lbs N + 1.5lbs K/ 1000 sq ft.	3.44ab	+12.0%	2.06a	+12.5%
1.0lbs N + 0.5lbs K/ 1000 sq ft.	3.38ab	+10.1%	1.87bc	+ 2.2%

1.0lbs N + 1.5lbs K/ 1000 sq ft.	3.28abc	+ 6.8%	2.04a	+11.4%
0.5lbs N + 1.5lbs K/ 1000 sq ft.	3.20bc	+ 4.2%	1.95bc	+ 6.6%
0.5lbs N/ 1000 sq ft.	3.10c	+ 9.7%	1.88bc	+ 2.7%
1.0lbs K/ 1000 sq ft.	3.09c	+ 0.6%	2.04ab	+11.5%
0.5lbs N + 1.0lbs K/ 1000 sq ft.	3.07c	+ 0.0%	1.95bc	+ 6.6%
Untreated Control	3.07c	--------	1.83bc	---------
0.5lbs N + 0.5lbs K/ 1000 sq ft.	3.04cd	- 0.9%	1.94bc	+ 6.0%
0.5lbs K/ 1000 sq ft.	2.88cd	- 6.2%	1.90bc	+ 3.8%
1.5lbs K/ 1000 sq ft.	2.77d	- 9.7%	2.11a	+15.3%
$LSD_{0.05}$ =	0.29		0.12	

*Values with the same letter suffix are not statistically different from each other.

Table 2b: Fall Leaf Tissue Nutrient Levels

Potassium Treatments:	Leaf Tissue Analysis Results			
	% K	Change in % K content compared to the Control Treatment	% N	Change in % N content compared to the Control Treatment
1.5lbs K/ 1000 sq ft.	2.11a	+15.3%	2.77d	- 9.7%
1.5lbs K + 1.5lbs N/ 1000 sq ft.	2.06a	+12.5%	3.44ab	+12.0%
1.5lbs K + 1.0lbs N/ 1000 sq ft.	2.04ab	+11.4%	3.28abc	+ 6.8%
1.0lbs K/ 1000 sq ft.	2.04ab	+11.5%	3.09c	+ 0.6%
1.0lbs K + 1.5lbs N/ 1000 sq ft.	2.01ab	+ 9.8%	3.52a	+14.6%
1.5lbs K + 0.5lbs N/ 1000 sq ft.	1.95bc	+ 6.6%	3.20bc	+ 4.2%
1.0lbs K + 0.5lbs N/ 1000 sq ft.	1.95bc	+ 6.6%	3.07c	+ 0.0%
0.5lbs K + 0.5lbs N/ 1000 sq ft.	1.94bc	+ 6.0%	3.04cd	- 0.9%
1.0lbs K + 1.0lbs N/ 1000 sq ft.	1.90bc	+ 3.8%	3.51a	+14.3%
0.5lbs K/ 1000 sq ft.	1.90bc	+ 3.8%	2.88cd	- 6.2%
0.5lbs N/ 1000 sq ft.	1.88bc	+ 2.7%	3.10c	+ 9.7%
0.5lbs K + 1.0lbs N/ 1000 sq ft.	1.87bc	+ 2.2%	3.38ab	+10.1%
0.5lbs K + 1.5lbs N/ 1000 sq ft.	1 .83bc	+ 0.0%	3.55a	+15.6%
Untreated Control	1.83bc	---------	3.07c	--------
1.0lbs N/ 1000 sq ft.	1.81c	- 1.0%	3.52a	+14.6%
1.5lbs N/ 1000 sq ft.	1.76c	- 3.8%	3.48a	+13.3%
$LSD_{0.05}$ =	0.12		0.29	

Turfgrass Leaf Tissue Analysis

While turfgrasses require at least 16 nutrients for normal growth and development. Some nutrients are needed in large amounts, while other nutrients are only needed in minute quantities. Both nitrogen and potassium are nutrients that turfgrass species require in larger amounts. Seasonal tissue testing provides an accurate evaluation of nutrient movement into the turf tissues and the turf's ability to uptake those nutrients.

Nitrogen
A component of nucleic acids, amino acids, proteins, chlorophyll, and coenzymes, nitrogen affects shoot and root growth, density, color, disease resistance, and stress tolerance. For Nitrogen, the tissue analysis sufficiency range is: 2.75-4.2% as expressed as a percentage on a dry weight basis.

Potassium
Activates enzymes used in protein, sugar, and starch synthesis. Important in maintaining turgor pressure in plants, it affects drought tolerance, cold hardiness, and disease resistance. For Potassium, the tissue analysis sufficiency range is: 1.0-2.5% as expressed as a percentage on a dry weight basis.

The turfgrass plots were maintained and fertilized from spring through mid- August, reflective and typical for a poa golf green to ensure a dense and healthy canopy. No applications were made to the testing site beyond July 30th, ensuring all entered the testing period with an equivalent baseline of N/P/K.

Comparing sole applications of N and K, there was no significant difference in the percent of each nutrient available between the high and the mid treatment rates, there was significant difference when the high and mid rates were compared to the low treatment rate. (Tables 2a & 2b.)

However, the tissue test results reflected consistent absorption of the foliar applied treatments, increasing consistently between 3-5% as rates increased each .5lb step in both N&K. This illustrates the applications were effective in entering the plant, somewhat contradicting the general assumptions regarding ambient temperatures and translocation. (Tables 2a & 2b.)

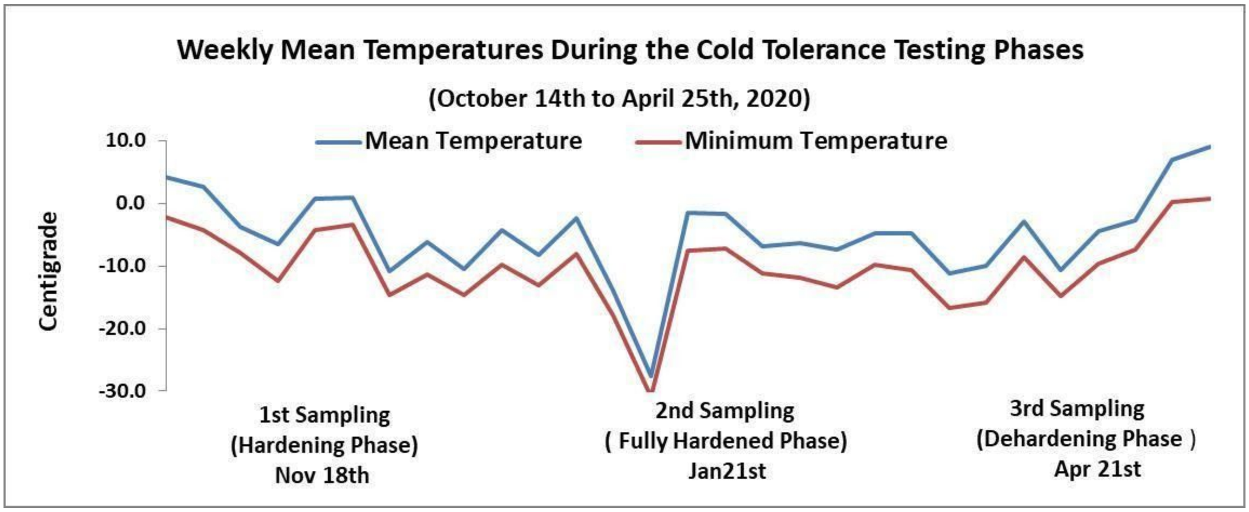
Comparing sole applications of N and K, indicated that nitrogen when applied alone resulted in lowered % K in the turf tissue and that potassium when applied alone resulted in lowered % N in the turf tissue. (Tables 2a & 2b.)

The treatments that combined either a mid or a high rate of nitrogen (1.0lbs to 1.5lbs N/ 1000 sq ft.) with a mid or a high rate of potassium (1.0lbs to 1.5lbs K/ 1000 sq ft.) were found to produce a higher percentage of each nutrient in the turf tissue. (Tables 2a & 2b.)

The treatments that combined either a a high rate of nitrogen (1.5lbs N/ 1000 sq ft.) with a mid or a high rate of potassium (1.0lbs to 1.5lbs K/ 1000 sq ft.) were found to produce the higher percentage of each nutrient in the turf tissue. (Tables 2a & 2b.)

Evaluation of the Cold Tolerance Phase: Foliar treatments

Diagram 2:



Weather conditions:

The snow fences installed in November ensured that an insulating snow layer was present throughout the winter. This insulating snow layer provided protection for the turf from direct cold temperatures. When the first set of turf cores were collected on November 18th, the insulating snow layer measured 6 inches in depth, the sand green was observed to be relatively unfrozen. By the second sampling date, January 21st, the insulating snow layer measured 10-12 inches in depth and the sand green totally frozen. By the last sampling date, April 21st, the snow layer had completely melted way. (Diagram 2.)

Table 3: Cold Tolerance Assessment (LT_{50} Value)

Nitrogen/Potassium Treatments:	Nov 18th	Jan 21st	Apr 21st
Untreated Control	-7.5a	-7.0a	-6.5a
0.5lbs N/ 1000 sq ft.	-8.5a	-7.0a	-8.0b
1.0lbs N/ 1000 sq ft.	-8.5a	-6.5a	-8.0b
1.5lbs N/ 1000 sq ft.	-8.0a	-6.5a	-6.0a
0.5lbs K/ 1000 sq ft.	-7.0a	-7.5a	-7.2a
1.0lbs K/ 1000 sq ft.	-7.5a	-6.5a	-7.2a
1.5lbs K/ 1000 sq ft.	-8.5a	-7.5a	-7.2a
0.5lbs N + 0.5lbs K/ 1000 sq ft.	-8.0a	-6.5a	-7.5a
0.5lbs N + 1.0lbs K/ 1000 sq ft.	-7.0a	-6.0a	-6.5a
0.5lbs N + 1.5lbs K/ 1000 sq ft.	-7.0a	-6.0a	-6.0a
1.0lbs N + 0.5lbs K/ 1000 sq ft.	-7.0a	-8.0a	-7.0a
1.0lbs N + 1.0lbs K/ 1000 sq ft.	-8.0a	-7.5a	-6.5a
1.0lbs N + 1.5lbs K/ 1000 sq ft.	-7.0a	-7.5a	-7.2a
1.5lbs N + 0.5lbs K/ 1000 sq ft.	-7.5a	-7.0a	-6.0a

1.5lbs N + 1.0lbs K/ 1000 sq ft.	-8.5a	-7.0a	-6.0a
1.5lbs N + 1.5lbs K/ 1000 sq ft.	-7.0a	-7.5a	-7.2a
$LSD_{0.05}$ =	n/s	n/s	n/s

*Values with the same letter suffix are not statistically different from each other.

Freezing Tolerance

Throughout the winter testing period, there were no significant differences, between the treatments, in the relative freezing tolerance in the turfgrass samples tested. (Table 3.)

Under artificially controlled temperature LT50 testing, lethal temperatures ranged between -6.0o to -8.5oC, for the Poa reptans, thereby reaching its maximum low temperature tolerance. Relatively low in comparison to regional varieties, we might consider the variety having been acquired from the Oregon region and never exposed to cold prairie winters, had reached its physiological limits.

However, when turfgrass is adequately insulated under the cover of snow, the turf surface temperature remains consistently just below 0'C. Therefore this would protect the plant should ambient air temperatures drop below -6^{o}C. (which they did)

Comparative Cold Tolerance:

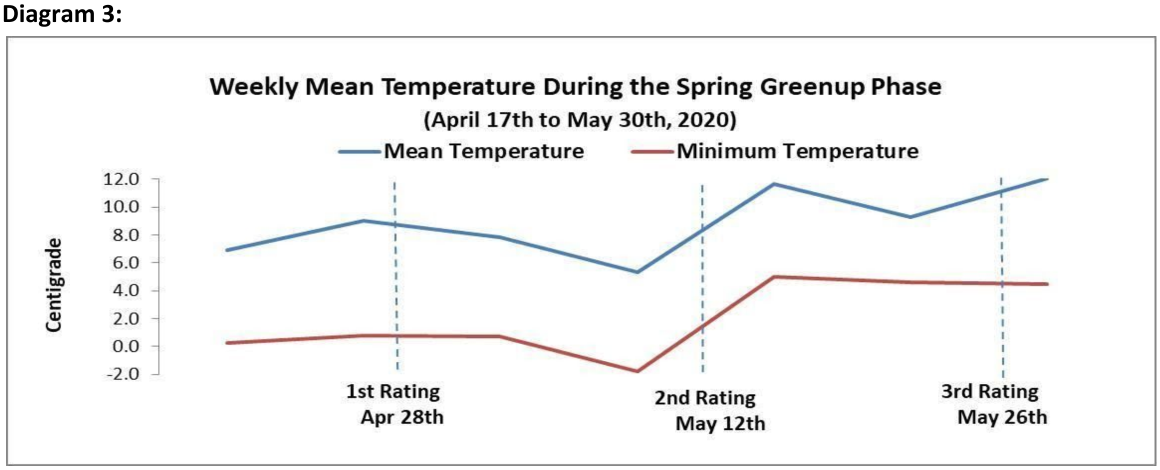
In comparison to 1st year and 2nd year results in cold temperature tolerance, maximum cold tolerance was recorded in year 1 at -13C, and similarly in year 2, at -13'C with average tolerance of approximately -10'C. (fig 1 Year one) which was consistent in both years of the study. Scatterplot matrix results in year one illustrated a weak correlation between N&K tissue content, suggesting that uptake of nutrients are dependent upon each other. The foliar treatments expressed less cold hardiness than their granularly applied counterparts, although the ratio of N/K illustrated consistent maximum hardiness where ratios N/K were 1:1 and 2:1 were applied.

Comparative results: Cold hardiness Relationship between granular and foliar

The percent K content in the leaf tissue from granular applications proven consistently higher in those recorded in the foliar K% data set, suggesting the plant can absorb more soil applied K in the fall than foliar applied K. We might assume this is due to dropping ambient temperatures, and the reduced translocation ability of the plant. However, tissue testing illustrated N% content was consistently higher in the granular study than foliar studies. We might suspect that this is the result of the plant being less efficient at processing foliarly applied K.

Evaluation of the Spring Green-up Phase

Diagram 3:



Weather conditions

Spring green-up is the initial seasonal appearance of green leaves originating from dormant axillary buds as spring temperatures and moisture conditions become favorable for growth. This year, at the PTRC, the spring was primarily overcast and cold. The daily mean ambient day temperature was in the high single degrees values to the low teens. The night temperatures hovered in the low single digits and would drop on occasion into the minus zero temperature range. (Diagram 3)

The evaluation of the plots for signs of initial sign color was initiated on April 28th, one week after the last of the snow cover had melted. The spring evaluation focused on an unforced or natural spring response of the turf plots. There no cultural practices, such as irrigating, verticutting or the application of green tarps were applied to the plots during the evaluation period.

Table 4: Spring Greenup Color Ratings and NDVI Index Values

Nitrogen/Potassium Treatments	Color Rating			NDVI Index Value		
	April 28th	May 12th	May 26th	April 28th	May 12th	May 26th
1.5lbs N + 0.5lbs K/ 1000 sq ft.	4.0a	4.5a	5.5a	0.418a	0.463a	0.774a
1.5lbs N + 1.0lbs K/ 1000 sq ft.	4.2a	4.2a	5.5a	0.487a	0.526a	0.772a
1.0lbs N + 0.5lbs K/ 1000 sq ft.	3.7a	4.0a	5.7a	0.440a	0.541a	0.769a
0.5lbs N + 0.5lbs K/ 1000 sq ft.	3.5a	3.7a	5.7a	0.402a	0.488a	0.763a
1.5lbs N + 1.5lbs K/ 1000 sq ft.	4.0a	3.7a	5.2a	0.400a	0.469a	0.763a
1.0lbs N/ 1000 sq ft.	3.7a	4.0a	5.2a	0.464a	0.532a	0.762a
1.0lbs N + 1.0lbs K/ 1000 sq ft.	3.7a	4.2a	5.5a	0.447a	0.532a	0.759a
0.5lbs N + 1.5lbs K/ 1000 sq ft.	3.5a	3.5a	4.7a	0.389a	0.492a	0.759a
1.5lbs N/ 1000 sq ft.	4.0a	3.7a	5.2a	0.433a	0.533a	0.753ab
1.0lbs N + 1.5lbs K/ 1000 sq ft.	3.5a	3.7a	5.2a	0.402a	0.490a	0.753ab
0.5lbs N + 1.0lbs K/ 1000 sq ft.	3.7a	3.5a	5.2a	0.415a	0.430a	0.749ab
0.5lbs N/ 1000 sq ft.	3.0a	3.2a	5.2a	0.370a	0.456a	0.739ab
1.0lbs K/ 1000 sq ft.	3.2a	3.5a	5.5a	0.392a	0.496a	0.737ab
1.5lbs K/ 1000 sq ft.	3.0a	3.2a	5.5a	0.353a	0.469a	0.730abc
0.5lbs K/ 1000 sq ft.	3.2a	3.2a	4.7a	0.381a	0.469a	0.710bc
Untreated Control	3.2a	4.5a	5.0a	0.420a	0.563a	0.687c
$LSD_{0.05}$ =	n/s	n/s	n/s	n/s	n/s	0.045

*Values with the same letter suffix are not statistically different from each other.

Spring Green-up Color Rating

The color score was based on a subjective visual 1 to 9 scale with 1 being straw brown and 9 being dark green. Although there was no significant difference observed between the treatments on each evaluation date, there is a trend of significant spring color change from April 28th to May 12th and through to May 26th respectively. Table 4.)

NDVI

While there was no significant difference between the treatments until the May 26th evaluation. Although there was no significant difference observed between the treatments on April 28th to May 12th, there is a trend of significant change in the NDVI Index Value. Table 4.)

Conclusion:

Fall foliar treatments in 2017 & 2019 illustrated a clear relationship of Nitrogen to Potassium is necessary to maximize winter hardiness and enhance spring green up. Applications of foliarly applied Nitrogen proved effective in tissue accumulation to tissues, as ambient temperatures drop in the fall.
Interestingly however, potassium applications would not accumulate with statistical difference with increasing application rates. Potassium recorded in tissues would not accumulate beyond 2% K through foliar treatments, which has played a role in recording lower cold temperature tolerances within the foliar study.
Previously recorded by similar granular study "Fall Applications of Nitrogen and Potassium and their effect on Winter Hardiness on Annual Bluegrass", (J,B.Ross et al.) *Poa annua var. reptans* would express consistently greater cold temperature tolerance using granular applications.

Where we can conclude that the N/K relationship exists, and applied 2:1 ratio, or 1:.5 will produce the best fall color, hardiness, and spring green up results, the foliar study did uncover the plants affinity to absorb these respective nutrients when applied foliarly vs granular.

When comparing this foliar trial to the previous granular study, foliar absorption of Potassium did not accumulate above 2%. Granularly applied however, the plant accumulated K in tissues consistently above 2%, and as high as 3.9% K, implying granularly applied K is more effectively translocated via root uptake in fall treatments.

Based upon the results of the foliar study and comparison to the previous granular study, the PTRC recommends turf managers apply Nitrogen by foliar OR granular, with granular Potassium at ratios 1:1 to 2:1, in order to accumulate K tissue content above 2%, thereby increasing cold tolerance, fall color, and spring green up of poa annua - reptans var.

References:

Carroll, J.C. and F.A. Welton. 1939. Effects of heavy and late applications of nitrogenous fertilizer on the cold resistance of Kentucky bluegrass. Plant Physiol. 18:19-36.

Ebdon, J.S., M. DaCosta, J. Spargo, and W.M. Dest. 2013. Long-term Effects of Nitrogen and Potassium Fertilizaton on Perennial Ryegrass Turf. Crop Sci. 53:1750-1761.

Hurto, K.A. and J. Troll. 1980. The influence of nitrogen:potassium ratios on nutrient content and low temperature hardiness of perennial ryegrass, p 114. In: Agronomy abstracts. Amer. Soc. Agron., Madison, WI.

Markland, F.E. and E.C. Roberts. 1967. Influence of varying nitrogen and potassium levels on growth and mineral composition of *Agrostis palustris.* Huds, p.53. In: Agronomy abstracts. Amer. Soc. Agron., Madison, WI.

Munshaw, G.C., E.H. Ervina, C. Shang, S.D. Askew, X. Zhang, and R.W. Lemus. 2005. Influence of Late-Season Iron, Nitrogen and seaweed extract on Fall Color Retention and Cold tolerance of Four Bermudagrass Cultivars. Crop Sci. 46:273-283.

National Turfgrass Evaluation Program. 2016. A Guide to NTEP ratings. [Online] available at: http://www.ntep.org/reports/ratings.htm#quality verified: November 4, 2016

Stiegler, J.C, M.D. Richardson, D.E. Karcher, T.L. Roberts, and R.J. Norman. 2013. Foliar Absorption of Various Inorganic and Organic Nitrogen Sources by Creeping Bentgrasss. Crop Sci. 53:1148 – 1152.

Stiegler, J.C., M.D. Richardson, D.E. Karcher, and A.J. Patton. 2010. Foliar Nutrient Uptake by Cool-Season and Warm-Season Turfgrasses. Green Record. Jan-Feb.: 7-9

Taulavuori, K., E. Taulavuori, and L.J. Sheppard. 2014. Truths or myths, fact or fiction, setting the record straight concerning nitrogen effects on levels of frost hardiness. Env. And Exp. Botany. 106:132-137.

Tompkins D.K., J.B. Ross, and D.L. Moroz. 2000. Dehardening of annual bluegrass and creeping bentgrass during late winter and early spring. Agron. J. 92:5-9.

Webster D.E. and J.S. Ebdon. 2005. Effects of Nitrogen and Potassium Fertilization on Perennial Ryegrass Cold Tolerance During Deacclimation in Late Winter and Early Spring.

Wehner, D.J., J.E. Haley, and D.L. Martin. 1988. Late Fall Fertilization of Kentucky bluegrass. Agron. J. 80:466-471.

Reference Data sets:
2019/20 https://drive.google.com/file/d/1NGXYSlXuIcrSgmk_EtQk4U7gfsObnr9M/view?usp=sharing
Tissue analysis:
https://docs.google.com/spreadsheets/d/1e7oSwG5JsaYdWZxAK9E7zIIKtLkpBMXR--crDV_MWS8/edit?usp=sharing