MHPEC Sulfur Study Report 2019

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Introduction:

The Field Variability Study (FVS) was conducted from 2015 to the present day with the overall goal of identifying and remediating factors responsible for variable processing potato yield. Fifty-five soil, plant, and environmental factors have been identified in 23 grower fields and each factor has been ranked according to impact on potato yield. Soil sulfur availability has been identified as the second most influential variable responsible for differences in total yield and was the sixth most influential variable responsible for variation in the 6-10 oz yield. Petiole sulfur availability was the third most influential variable on the same 6-10 oz yield. These yield associations were found at the mid-bulking and row closure growing stages of ‘Russet Burbank’ in Manitoba, which roughly approximates to early August and early July, respectively.

The FVS also offered insight into the amount of soil sulfur typically seen in grower fields, which ranged from 0-120 lbs, regardless of sampling date. In a cursory examination of the data set, 40-60 lbs of sulfur appeared to be the beneficial amount of available soil sulfur, where compromised yields were observed outside of this range. The lowest yields appeared to be associated with sampling sites with no soil sulfur. This cursory examination did not have the benefit of any statistical test or association. **The goal of this study was to identify the exact range of lbs of soil sulfur needed by row closure and possible products and rates needed to accomplish the task. Outcomes of this study are set in the context of small, controlled research plots to demonstrate the importance of a unique sulfur fertilizer regime to potato growers in order to justify field-scale validation studies that are necessary for industry adoption.**

Methods:

A factorial randomized complete block design was enacted with four blocks in 2019. The soil at the site was a Halboro series Orthic Black Chernozem with a loamy sand texture. The site has a typical crop rotation of potato-wheat-canola and is irrigated. All of these factors are a reasonable representation of lighter soils that potatoes are grown on in Manitoba, except the black chernozem exhibits greater organic matter content typical of lighter soils. Regardless of the organic content, the crop rotation resulted in low preseason soil sulfur tests with approximately 8-12 lbs of soil sulfur available.

The entire experiment was 2,282.34 m^2 (approximately 0.57 Acre). Each plot was 3.6m wide and 12 m long, or 43.2 m^2 (approximate 0.011 Acres). The experiment was constructed with five fertilizer treatments: Tiger Xp (Tiger-Sul Inc, Irricana, Alberta), Tiger Combo (Tiger-Sul Inc, Irricana, Alberta), no sulfur amendment (negative control), magnesium sulfate ($MgSO_4$, Redfern Farm Services, Brandon, Manitoba), ammonium sulfate ($(NH_4)_2SO_4$) as a soil amendment with ammonium thiosulfate ($(NH_4)_2S_2O_3$ ATS) through fertigation (Redfern Farm Services, Brandon, Manitoba). Each fertilizer treatment, except the negative control, was applied at the equivalent of 20, 60, and 100 lbs of sulfur expected in the soil by row closure (approximately early July). The total amount of each fertilizer needed to achieve the goal by row closure varied based on sulfur content, with exact application rates displayed in Table 1 below:

Formulation (NPKS)	Fertilizer	Goal lbs by row closure	Lbs/A of product required to achieve goal	Lbs product applied preplant per replicate (4 plots)	Fertigation Fertilizer and Formulation	Sulfur Fertigation rate (lbs)
0-0-0-85	Tiger XP	20	24	1.2	None	None
0-0-0-85	Tiger XP	60	71	4	None	None
0-0-0-85	Tiger XP	100	118	6	None	None
12-0-0-50	Tiger Combo	20	40	2	None	None
12-0-0-50	Tiger Combo	60	120	6	None	None
12-0-0-50	Tiger Combo	100	200	10	None	None
0-0-0-16	Magnesium Sulfate	20	125	7	None	None
0-0-0-16	Magnesium Sulfate	60	375	19	None	None
0-0-0-16	Magnesium Sulfate	100	625	32	None	None
21-0-0-24	Ammonium Sulfate	20	68	4	Ammonium Thiosulfate 12-0-0-26	3
21-0-0-24	Ammonium Sulfate	60	188	10	Ammonium Thiosulfate 12-0-0-26	3
21-0-0-24	Ammonium Sulfate	100	313	16	Ammonium Thiosulfate 12-0-0-26	3
Negative Control (no additional sulfur)			0	0	None	None

Table 1. Sulfur fertilizer products employed in the study are listed by sulfur content to display the amount of each product necessary to achieve the goal lbs of sulfur available at row closure, as determined at a soil test conducted by Agvise, Inc. (Northwood, North Dakota). The fertigation rate assumes 3 lbs sulfur is approximately 1 gallon of ammonium thiosulfate per fertigation event. One fertigation event was required in 2019, as determined by petiole testing from Agvise Inc. All plots received 115 lbs/A of mono-ammonium phosphate (MAP, 11-52-0-0), 42.24 lbs/A of Kmag blend (0-0-60-0), and 466.6 lbs/A of ESN (polymer coated urea named Environmentally Smart Nitrogen, 44-0-0) from Redfern Farm Services, Brandon, Manitoba.

Only the cultivar Russet Burbank was used for the study. Experimental plots were prepared by cultivating on April 29th and individually fertilized on May 2nd, 2019. Fertilizers were applied with a custom-modified R-tech Terra Mater fertilizer applicator that was set up to apply up to three different fertilizers in a single pass. Two sets of three Gandy Boxes were arranged in rows, and a single box of amazon cups was set up at the front in order to accommodate the three different types of fertilizer at possible rates of 6 lbs/A to 584 lbs/A (depending on fertilizer pellet size, vehicle speed, and gear combinations selected). The machine was set to broadcast all fertilizers over four potato rows at 36 inches between the rows. Each row of fertilizer applicators was calibrated for each pelleted formulation of fertilizer employed in the experiment and for every fertilizer rate in the treatment structure. Pre-plant fertilizer was immediately mixed into soil post-application with a Lely Rotterra 350-33 (Lely, Maassluis, Netherlands) to a depth of up to 10 inches. Burbank seed (2-3 oz, average 2.5 oz (data not shown)) was planted on May 6th, 2019 with no gaps between plots, 36 inches between rows, 13 inches between seed pieces within row, and 6-7 inches deep (from top of hill). Seed was treated with Titan Emesto (Bayer, Leverkusen, Germany) at a rate of 20.8 mL per 100 kg of seed. Pesticide applications and irrigation schedule were typical for the potato growing region in Carberry, Manitoba (data not shown). Hills were created as plants emerged on June 7th, 2019 using a power hiller attached to a tractor. Row closure was observed on July 15th, 2019, and five 0-6 in. soil and 30 petiole samples per plot were collected on the same day. Thirty petioles were collected weekly on every Friday in July from four ammonium sulfate treatments to determine if a fertigation event was required the following week. Finally, five 0-6 in. soil samples were taken from every plot for late bulking soil sulfur assessment on the 20th of August. The lbs of sulfur available in soils and the percentage of sulfur in petioles were determined by Agvise Inc (Northwood, North Dakota). Fertigation events were to be conducted in July as determined by low petiole percentage sulfur in the ammonium sulfate treatment only, regardless ammonium sulfate of rate. Low petiole percentage sulfur was only observed once on July 15th, 2019. Fertigation was conducted through a Hardi (Davenport, IA, USA) NL 80-26' SB PT sprayer with three inline filters, triple nozzle bodies, and three boom controls using a minidrift 03-blue nozzle at approximately 41 PSI at 2-4 miles per hour. Applications were done in the early morning and diluted as quickly as possible to limit fertilizer burn. One gallon of ammonium thiosulfate was mixed with 10 imperial gallons of water and applied only to the ammonium sulfate treatment. This application was immediately diluted with ¼ inch of water from a linear irrigator (see Fig. 1 below).

Fig 1. An example fertigation event demonstrating concentrate is applied directly to foliage and then immediately diluted to the correct ratio by a linear irrigator on a cloudy morning to prevent fertilizer burn.

Harvest occurred on September 17th, 2019 and was completed using 1-row digger on a 10m section of a designated harvest row that was unsampled and untrampled during the season. This harvest row was the innermost part of each plot to buffer it as much as possible from edge effects. The total yield of each plot was recorded as lbs harvested, as well as the lbs of each tuber size category (less than 3 oz, 3-5.9 oz, 6-9.9 oz, 10-11.9 oz, 12 oz and greater) and quality metrics were recorded (weight of rotted tubers, green tubers, hollow heart tubers in grams, as well as specific gravity). This information was used to calculate an approximate Canadian dollar value using these metrics to determine bonuses and deductions for a mid-season shipment of Burbank potatoes from a demonstration processor contract (data not shown).

Statistical tests were conducted with SAS v9.4 (SAS, Cary, NC). More specifically, proc mixed was employed to construct a linear regression model to compare the combined variables of fertilizer treatment and desired rate by row closure to a yield parameter (e.g. fertilizer treatment effect determined for the 6-10 oz yield category). This analysis was completed for each yield parameter separately. In each case a Satterthwaite approximation is used to delineate limits for all variables that had a lower boundary constraint of zero. The blocking factor was used as a random effect as a vector for the mixed model. Because assumptions for the normal distribution of errors and homogeneity of variances were not met (data not shown), the repeated statement was used to model the variance of the combined fertilizer/rate. Finally, the lsmeans statement was used to determine significance of pairwise comparisons of a yield parameter between two fertilizer treatments (provided the type III test of fixed effects from the mixed model was significant with $P \leq 0.05$). Familywise type I error was controlled for the multiple comparisons in the lsmeans statement using a Tukey adjustment, with all subsequent reported *P*-values between specific treatments referring to this Tukey-adjusted *P*-value.

Results:

The first year of study in 2019 indicated that sulfur treatments had a significant effect on the amount of available soil sulfur, in lbs, at row closure ($P = 0.0277$) and late bulking ($P = 0.0079$).

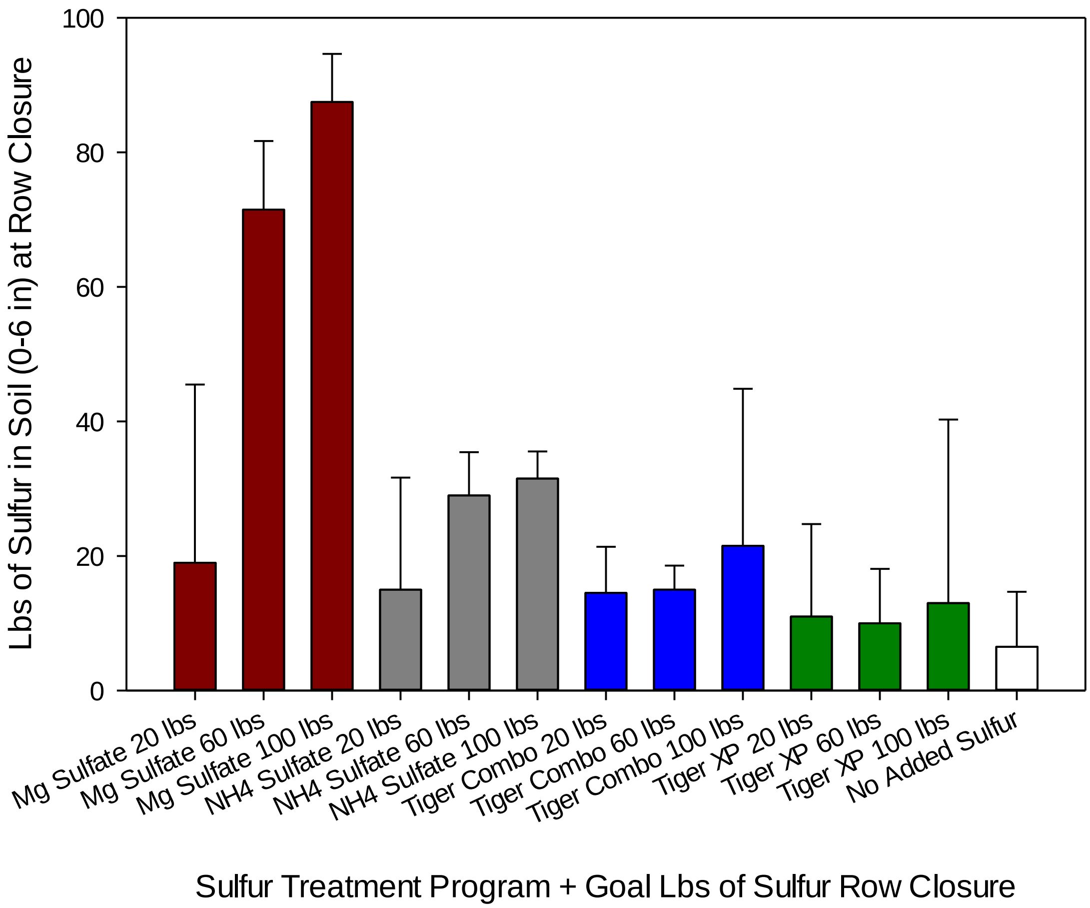

Fig 2. The effect of sulfur treatment program (x-axis) on the availability of soil sulfur (y-axis) at row closure. Bars indicate mean lbs of sulfur and the standard error is above each bar. Mg sulfate signifies magnesium sulfate, while NH4 sulfate stand for ammonium sulfate. All fertilizer rates for each treatment can be found in Table 1.

The goal of each treatment, whether 20, 60, or 100 lbs, was to have a standardized amount of sulfur available by row closure in order to evaluate the impact on final yield parameters and compare between fertilizer products. Treatments where 20 lbs of sulfur was intended to be available in the soil were generally very close to the target because the means in Fig 2 are generally close to 20 lbs. However, 60 and 100 lbs of soil sulfur were harder to achieve with the same precision. The 60 and 100 lbs targets for ammonium (NH4) sulfate, Tiger combo, and Tiger XP were less than expected by approximately 20-60 lbs of sulfur at row closure. The exception was observed with the magnesium (Mg) sulfate treatment, where the amount of available sulfur was within 10 lbs of the target by row closure (Fig 2).

Specific pairwise comparisons of sulfur treatments on available soil sulfur at row closure is as follows in Table 2. The greater column refers to the treatment with the largest amount of soil sulfur, whereas the lesser has the smaller amount of soil sulfur. Combinations of fertilizers that are not present were not significant ($P \leq 0.05$). This list does not include comparisons that trended towards significance ($P \leq 0.1$).

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*-value
Ammonium sulfate 100 lbs	Tiger combo 20 lbs	$P = 0.0478$
Ammonium sulfate 100 lbs	None	$P = 0.0189$
Ammonium sulfate 100 lbs	Tiger combo 60 lbs	$P = 0.0269$
Magnesium sulfate 100 lbs	Ammonium sulfate 20 lbs	$P = 0.0381$
Magnesium sulfate 100 lbs	Tiger combo 100 lbs	$P = 0.0418$
Magnesium sulfate 100 lbs	Tiger combo 20 lbs	$P = 0.0376$
Magnesium sulfate 100 lbs	Tiger combo 60 lbs	$P = 0.0287$
Magnesium sulfate 100 lbs	Magnesium sulfate 20 lbs	$P = 0.0417$
Magnesium sulfate 100 lbs	None	$P = 0.0293$
Magnesium sulfate 100 lbs	Tiger Xp 100 lbs	$P = 0.0363$
Magnesium sulfate 100 lbs	Tiger Xp 20 lbs	$P = 0.0338$
Magnesium sulfate 100 lbs	Tiger Xp 60 lbs	$P = 0.0326$
Magnesium sulfate 60 lbs	Ammonium sulfate 20 lbs	$P = 0.0410$
Magnesium sulfate 60 lbs	Tiger combo 100 lbs	$P = 0.0493$
Magnesium sulfate 60 lbs	Tiger combo 20 lbs	$P = 0.0403$
Magnesium sulfate 60 lbs	Tiger combo 60 lbs	$P = 0.0385$
Magnesium sulfate 60 lbs	None	$P = 0.0295$
Magnesium sulfate 60 lbs	Tiger Xp 100 lbs	$P = 0.0387$
Magnesium sulfate 60 lbs	Tiger Xp 20 lbs	$P = 0.0353$
Magnesium sulfate 60 lbs	Tiger Xp 60 lbs	$P = 0.0338$
Tiger combo 20 lbs	None	$P = 0.0287$

In general, all magnesium sulfate and the 100-lb treatment of ammonium sulfate increased soil sulfur at row closure compared to the negative control; no sulfur was supplied in any negative control plot. Ammonium sulfate and magnesium sulfate generally provided more soil sulfur than comparable rates of Tiger Xp. Magnesium sulfate was the only sulfur fertilizer where the comparison between 100 and 20 lbs treatments actually produced statistically distinguishable soil sulfur tests.

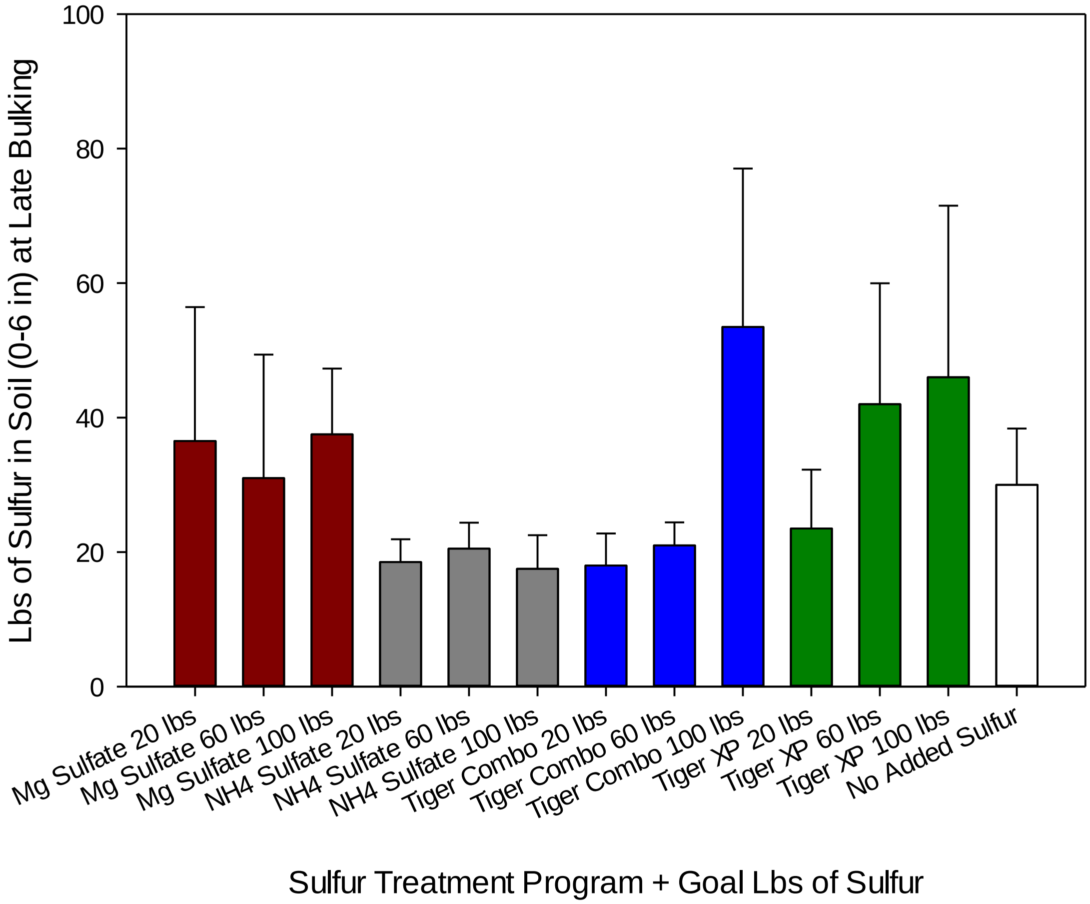

Fig 3. The effect of sulfur treatment program (x-axis) on the availability of soil sulfur (y-axis) at late bulking. Bars indicate mean lbs of sulfur and the standard error is above each bar. Mg sulfate signifies magnesium sulfate, while NH4 Sulfate stand for ammonium sulfate. All fertilizer rates for each treatment can be found in Table 1.

Specific pairwise comparisons of sulfur treatments on available soil sulfur at late bulking is as follows in Table 3. The greater column refers to the treatment with the largest amount of soil sulfur, whereas the lesser has the smaller amount of soil sulfur. Combinations of fertilizers that are not present were not significant ($P \leq 0.05$). This list does not include comparisons that trended towards significance ($P \leq 0.1$).

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*-value
None	Ammonium sulfate 60 lbs	$P = 0.0293$
Tiger Xp 20 lbs	Ammonium sulfate 60 lbs	$P = 0.0261$
Tiger Xp 60 lbs	None	$P = 0.0279$
Tiger Xp 60 lbs	Tiger Xp 20 lbs	$P = 0.0145$
Tiger Xp 100 lbs	Ammonium sulfate 60 lbs	$P = 0.0453$

Fewer comparisons between rates within or between treatment programs were statistically significant at late bulking (Table 3) than at row closure (Table 2). A likely explanation for these observations exists in two general observations when contrasting Figs 2 and 3: first, the standard errors generally appear to be larger at late bulking than at row closure (indicating greater variability of soil sulfur in the late season). Second, the general availability of soil sulfur was less in the later season than the early season for treatments with magnesium sulfate, but the opposite was true for Tiger Xp. An additional noteworthy observation was that lower rates of Tiger Xp had more available soil sulfur than the ammonium sulfate treatment. Finally, Tiger Xp was the only treatment again to have statistically significant differences between the lowest rate (20 lbs) and the moderate rate (60 lbs).

The availability of petiole sulfur at row closure, expressed in the percentage of dry plant matter composed of sulfur, was also significantly impacted by sulfur treatment ($P = 0.0002$).

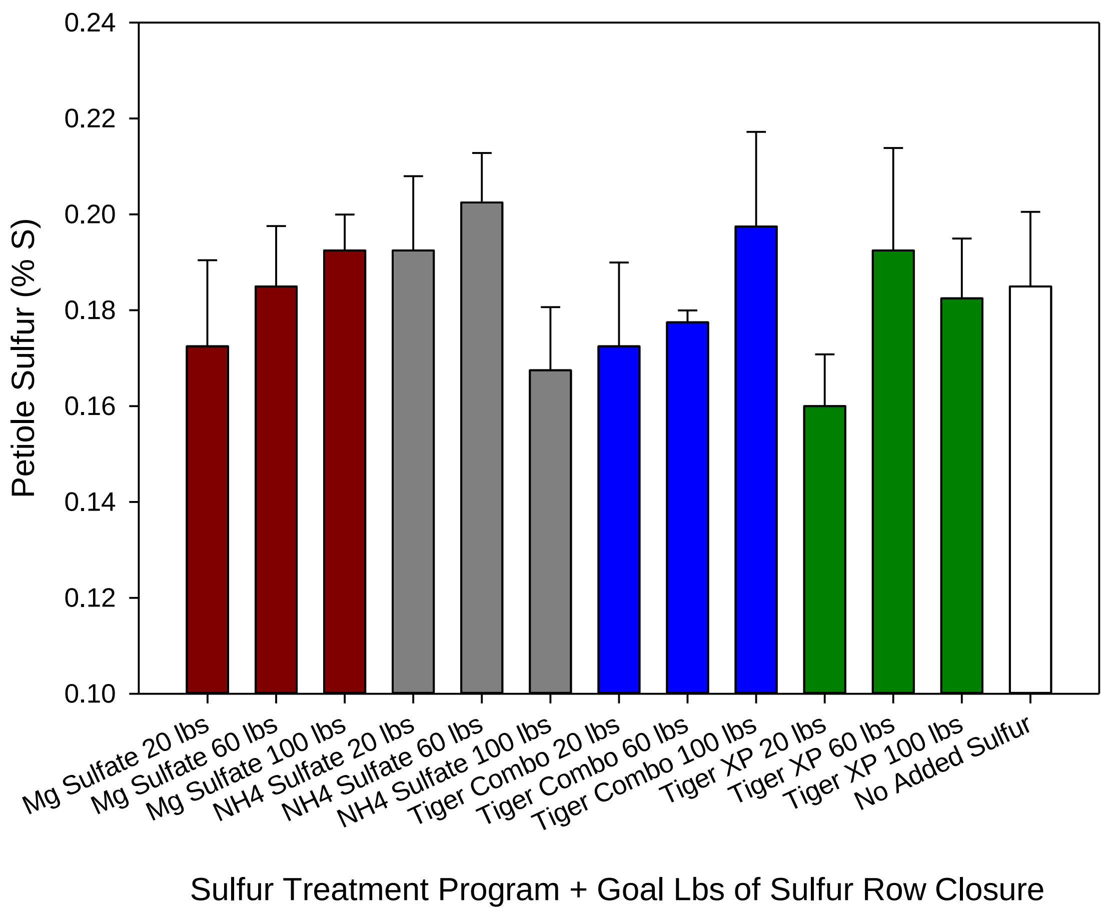

Fig 4. The effect of sulfur treatment program (x-axis) on the availability of petiole sulfur (y-axis) at row closure. Bars indicate mean lbs of sulfur and the standard error is above each bar. Mg sulfate signifies magnesium sulfate, while NH4 Sulfate stand for ammonium sulfate. All fertilizer rates for each treatment can be found in Table 1.

Specific pairwise comparisons of sulfur treatments on available petiole sulfur is as follows in Table 4. The greater column refers to the treatment with the largest amount of petiole sulfur, whereas the lesser has the smaller amount of petiole sulfur. Combinations of fertilizers that are not present were not significant ($P \leq 0.05$). This list does not include comparisons that trended towards significance ($P \leq 0.1$).

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*-value
Ammonium sulfate 100 lbs	None	$P = 0.0035$
Ammonium sulfate 100 lbs	Tiger Xp 20 lbs	$P = 0.0038$
Ammonium sulfate 100 lbs	Tiger Xp 100 lbs	$P = 0.0077$
Ammonium sulfate 60 lbs	Tiger Xp 20 lbs	$P = 0.0012$
Ammonium sulfate 60 lbs	Tiger Xp 100 lbs	$P = 0.0032$
Ammonium sulfate 60 lbs	None	$P = 0.0014$
Magnesium sulfate 100 lbs	Tiger combo 60 lbs	$P = 0.0379$
Magnesium sulfate 100 lbs	Tiger Xp 20 lbs	$P = 0.0263$
Magnesium sulfate 100 lbs	None	$P = 0.0004$
Magnesium sulfate 100 lbs	Tiger Xp 100 lbs	$P = 0.0008$
Magnesium sulfate 100 lbs	Tiger Xp 20 lbs	$P = 0.0002$
Magnesium sulfate 60 lbs	None	$P = 0.0020$
Magnesium sulfate 60 lbs	Tiger Xp 20 lbs	$P = 0.0018$
Tiger combo 60 lbs	None	$P = 0.0121$
Tiger combo 60 lbs	Tiger Xp 100 lbs	$P = 0.0379$
Tiger combo 60 lbs	Tiger Xp 20 lbs	$P = 0.0149$
Tiger Xp 100 lbs	Tiger Xp 60 lbs	$P = 0.0294$
Tiger Xp 100 lbs	Tiger Xp 60 lbs	$P = 0.0037$
Tiger Xp 60 lbs	None	$P = 0.0013$
Tiger Xp 60 lbs	Tiger Xp 20 lbs	$P = 0.0006$

In general, all sulfur amendments increased soil sulfur at row closure compared to the negative control, where no sulfur was supplied. Ammonium sulfate and magnesium sulfate generally provided more soil sulfur than comparable rates of Tiger Xp. Tiger Xp was the only sulfur fertilizer where the 100, 60, and 20 lbs rates actually produced statistically distinguishable soil sulfur tests.

There was no significant sulfur treatment effect on total yield ($P = 0.2184$), value ($P = 0.3564$), or any size profile. More specifically, observed differences in the 3-6 oz yield ($P = 0.4908$), 6-10 oz yield ($P = 0.7179$), 10-12 oz yield ($P = 0.3162$), and greater than 12 oz yield ($P = 0.8958$) were all not significant (Fig 5). The effect of sulfur treatment on specific gravity trended towards significance ($P = 0.1060$, Fig. 6), which is a notable outcome for a single year of study.

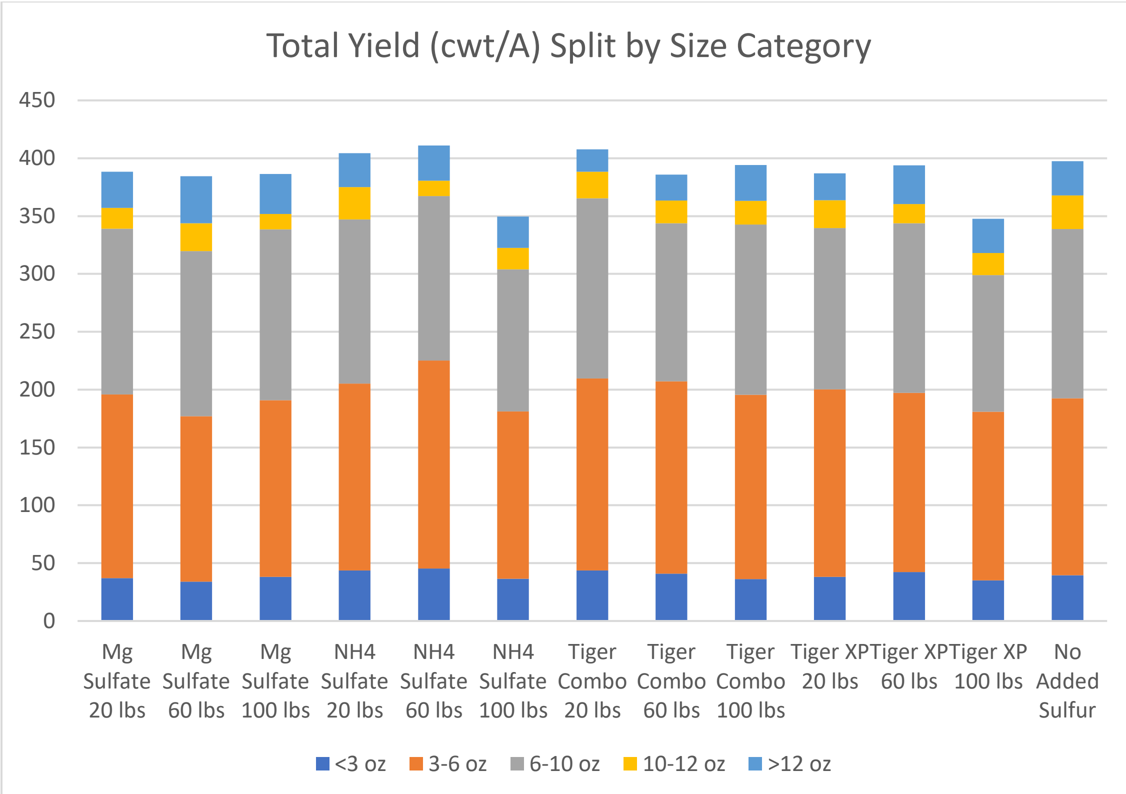

Fig 5. The total yield consisting of the average of the four replicates of each fertilizer treatment with each column separated by the tuber size profile. The tuber size profile also consists of the average of the four replicates within a given treatment. There was no significant sulfur treatment effect on total yield or any size category.

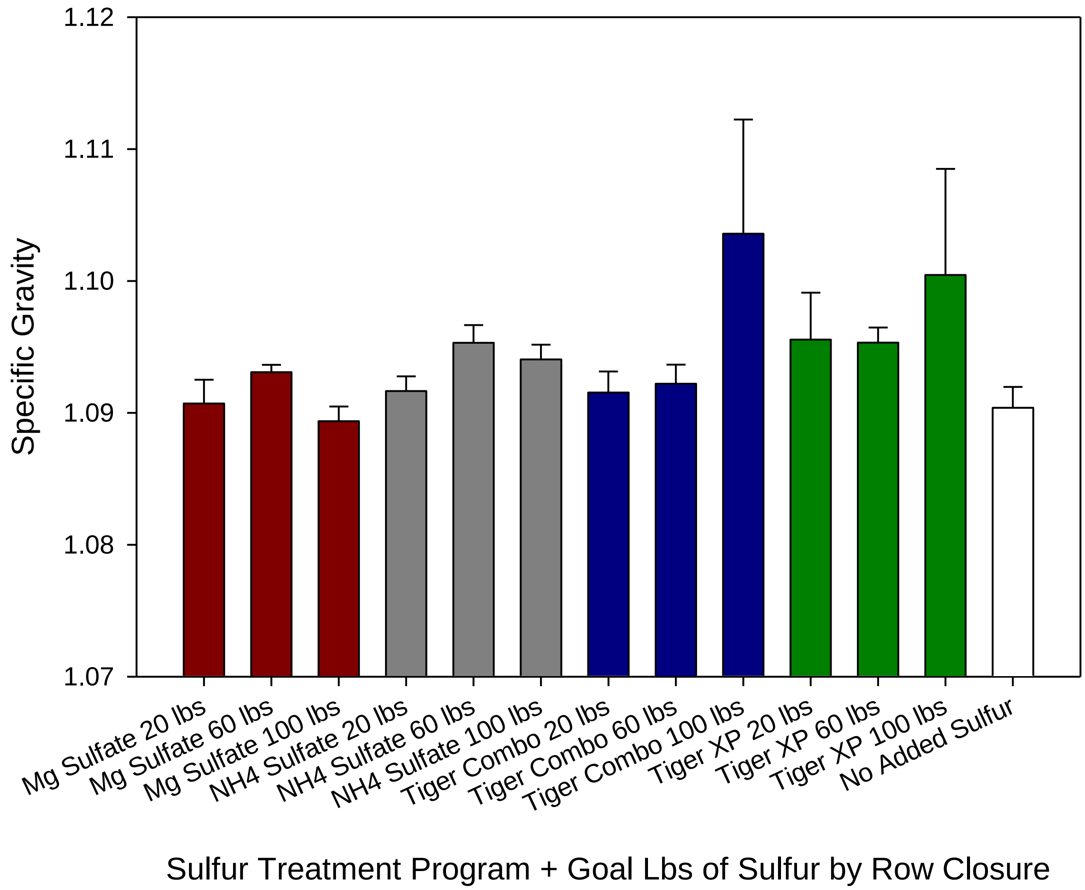

Fig. 6. The effect of sulfur treatment program on potato specific gravity. There was a nearly significant effect ($P = 0.1060$) of sulfur treatment program on specific gravity.

Discussion:

The present study was based upon statistical associations created from the larger field variability study that encompassed observations from 23 grower fields over five years. The goal of this study was to identify the exact range of lbs of soil sulfur needed by row closure and possible products and rates needed to accomplish the task to improve yield and quality of processing potatoes.

The results contained in this report are from a single year of study, indicating all results and trends are preliminary at best. At least two years of study are required for conclusive results. In addition, these results are from small plot studies. Field scale studies with grower partners are required to identify if trends carry over into larger scales and are economically feasible for processing growers to enact on their farms.

The observation of no significant treatment effects on yield, value, and quality metrics was not wholly unexpected for a study with only a single year of study. Observations from the field variability study indicated the effect of a single nutrient on total yield was generally small, suggesting many data points are necessary to observe statistically significant differences. Several years of study will likely be needed to observe these differences given the limitation of only so many plots can be planted and maintained in a single field season.

Statistically significant treatment effects on the availability of sulfur in the soil and petioles at row closure is an important, critical observation as a quality control check, even with only one year of study. This check ensures that the sulfur product employed have the impact that was intended. Results from Figs 2-6 and Tables 2-4 characterize the specific differences that were observed in 2019, and they collectively demonstrated the differences between the rates of the same product and highlighted the differences between the same rates of different products. The quality control check also evaluates the accuracy of fertilizer calculations relative to the goal of available sulfur at row closure (i.e. did 32 lbs of magnesium sulfate per plot generally have 100 lbs of soil sulfur available by row closure when the soils were tested). In the case of magnesium sulfate, all three rates of products tested with 10 lbs of the desired target rate (Fig. 1). The target amount of available soil sulfur was also met in the case of the 20-lb rates of ammonium sulfate, Tiger Combo, and Tiger XP. Conversely, the amount of these three products applied preplant did not provide 60 and 100 lbs of available sulfur by row closure. Generally, no more than 40 lbs of available sulfur was observed in the 60 and 100-lb treatments of ammonium sulfate, Tiger Combo, and Tiger XP.

The inability to observe the desired rates of available soil sulfur despite correctly applying the theoretical amount of ammonium sulfate, Tiger Combo, and Tiger Xp needed to have 60 and 100 lbs of available soil sulfur by row closure presents a challenge for study. This challenge is a possible explanation why growers also theoretically apply enough sulfur fertilizer, but the data from the field variability study indicates that not enough sulfur is present at row closure; the absence of sulfur then becomes a contributor to variability in the total yield and size profile. **The study will still need to maintain treatments with the same amount of ammonium sulfate, Tiger Combo, and Tiger Xp as originally applied in 2019 to provide concrete conclusions with two years of data. Based on the challenge from this year's results, it is necessary to also introduce new treatments where increasing amounts of ammonium sulfate, Tiger Combo, and Tiger Xp are applied in the attempt to create 60 and 100 lbs of available sulfur in soil by row closure.**

Tiger Combo and Tiger Xp are also designed as slow-release products over several growing seasons. The challenge from the 2019 year of study could be attributed to this intended design. In 2020, it is imperative to sample the same sites from 2019 to determine that these products are indeed releasing sulfur slowly as intended. Likewise, it is imperative to increase the rates of these products in the attempt to successfully achieve the 60 and 100-lb rates to meet the goal of the present study.

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