Impacts of Sulfur Fertilization on Yield, Grain Quality, and Nitrogen Use Efficiency of Wheat

[1]Hanna Poffenbarger, [1]Dave Van Sanford, and [2]John Grove

[1]Department of Plant & Soil Sciences, University of Kentucky, Lexington, KY 40546; PH: (859-257-5925);
[2]Department of Plant & Soil Sciences, University of Kentucky, Research & Education Center, Princeton, KY 42445 (859-562-1301); Email: hanna.poffenbarger@uky.edu dvs@uky.edu jgrove@uky.edu

REASONS FOR RESEARCH:

An adequate supply of sulfur (S) is critical for plants to grow healthy and complete their life cycle. Historically, S has not been widely applied in crop production because crops were able to obtain enough from the soil and atmospheric deposition. However, the combination of higher yielding crops, cleaner air, and purer fertilizer products has led to increased frequency of S deficiency in many parts of the world. This has led to the question: Is S fertilization needed to optimize wheat yields in Kentucky?

Apart from the potential yield benefits from S fertilization, there may be quality benefits for wheat. Much of the baking quality of wheat derives from attributes of the protein – how much protein, and which specific types of protein are present in the grain. Both nitrogen (N) and S are components of plant protein and needed at a ratio of approximately 15:1 in wheat grain (Zhao et al. 1999). If either nutrient is deficient, then the quality of baked goods could suffer.

Lastly, we hypothesize that there may be sustainability benefits of S fertilization in wheat. Because both N and S are needed to build protein, an inadequate supply of S could lead to reduced plant growth and incomplete use of applied N (Salvagiotti et al. 2009). In contrast, plants that are not limited by S will grow more vigorously and will more thoroughly scavenge available N in the soil profile. A higher N use efficiency will lead to lower nitrate leaching and less environmental damage.

GOALS AND OBJECTIVES:

Our overall goal is to understand the potential benefits of S fertilization of wheat in Kentucky and beyond. Our specific objectives are to:

1) Determine the effects of S fertilization on yield, grain quality, and N use efficiency of several soft winter wheat varieties in Kentucky,
2) Establish the linkage between grain N:S ratio and quality characteristics, and
3) Identify which environmental conditions lead to S deficiency in wheat.

METHODS:

Objective One

In fall of 2020, we established a field study at Lexington and Princeton to evaluate response of wheat yield, quality, and N use efficiency to combinations of N and S fertilization (Table 1). The fertility treatments were applied to five wheat varieties (Table 2). The treatments were laid out in a randomized design with four replicates at each location. The Lexington study was located on a soil classified as a

Bluegrass-Maury silt loam, which is a deep, well-drained soil formed in silty material over residuum weathered from phosphorus-rich limestone. The Princeton study was located on a soil classified as a Crider silt loam, which is a deep, well-drained soil formed in silty material over residuum weathered from limestone. Selected soil properties are presented in Table 3. For Lexington, the average temperature was 1° F above average and rainfall was 7.35 inches above average for the period of October 1, 2020 through July 1, 2021. For Princeton, the average temperature was 1° F below average and rainfall was 3.66 inches above average for the same period.

The study followed corn for silage in Lexington and corn for grain in Princeton. Prior to planting the study, the fields were prepared by disking and cultipacking. At both locations, the wheat was drilled at a seeding rate of 35 seeds ft^2. Weeds, insect pests, and fungal diseases were managed according to the University of Kentucky Wheat Production Guide, with Harmony and Warrior applied during stem elongation and Caramba or Prosaro applied during flowering.

Prior to planting, a six-inch deep soil sample consisting of 12 cores per sample was collected in each replicate at each location. The samples were dried, ground to pass a 2 mm sieve, and analyzed for Mehlich 3-extractable nutrients, pH, and soil organic C concentrations at University of Kentucky Regulatory Services. Soil samples were also taken to two feet deep in early March, before any fertilizer application. Those samples were analyzed for soil inorganic N and sulfate concentrations. When heads became visible early in the spring, we took leaf chlorophyll measurements using a SPAD meter. Three readings were taken on the flag leaf of ten plants per plot. At this time, 40 flag leaves were also removed for tissue N concentration. The flag leaf samples were analyzed at Waters Agricultural Laboratories. Chlorophyll measurements were repeated on all plots during grain filling, when the plants had begun to senesce to determine impacts of the fertility treatments on leaf stay-green.

Once the wheat had reached maturity, a biomass sample was taken in each plot. Plants were cut just above the soil surface from two feet of a central row. The number of stems and heads were counted, and dry weights were taken of stems, kernels, and chaff. The kernels were analyzed for protein concentration using near-infrared spectroscopy. The biomass samples are currently being ground in preparation for tissue N and S analysis. Lastly, the wheat was harvested using a small plot combine and the combine-harvested grain samples were used to measure sedimentation volume. Sedimentation volume provides an indication of gluten quality (higher sedimentation volume = better quality). Additional measurements of baking quality are in progress.

Objectives 2 and 3

In addition to the fieldwork, we have also been compiling data from the literature to address Objectives 2 and 3. We have identified over 20 studies that include data on grain yield, grain N and S concentrations, dough mixing characteristics, and baking characteristics in response to S fertilization. Our team is working on the analysis this fall.

RESULTS:

Wheat yield

There was a significant effect of fertility treatment and variety on wheat yield in 2021. The effect of fertility treatment was similar across all varieties, so we present the effects of fertility treatments averaged across varieties (Figure 1). In Lexington, wheat yielded 60% more with N than without N (62 bu/acre vs 39 bu/acre). Sulfur fertilization further increased wheat yield by 37% (86 bu/acre vs 62 bu/acre), but only in the presence of N fertilizer. In Princeton, N fertilization doubled wheat yield (87 bu/acre vs 43 bu/acre) but there was no effect of S fertilization. The extra N applied at heading did not increase yield at either location.

The relative productivity of varieties varied between the two locations (Figure 2). However, Agrimax 454 was a top-yielding variety at both locations, averaging 72 bu/acre across fertility treatments and locations, while Pembroke 14 was relatively low-yielding at both locations, averaging 63 bu/acre.

Grain quality

Fertilization practices influenced wheat protein concentrations. Both at Lexington and Princeton, the plots that received no N fertilizer had the lowest protein levels, while those that received an extra dose of N at heading had the highest protein levels (Figure 3). The addition of S fertilizer tended to decrease the protein levels slightly. Pembroke 14 stood out as the variety with the highest protein at both locations (Figure 4).

In addition to grain protein, we also measured sedimentation volume as a measure of gluten quality. These measurements have only been completed for a subset of treatments so far (Check, N-only, N-extra, N-extra+S). Among those treatments, the plots that received an extra dose of N along with S produced the grain with the highest sedimentation volume in Lexington. In Princeton, the highest sedimentation volumes were observed in the N-extra and N-extra+S treatments (Figure 5). Pembroke 14 and Vision 45 had the highest sedimentation volumes among the varieties at both locations (Figure 6).

Nitrogen use efficiency

We found support for the idea that S fertilization can increase N use efficiency as measured by partial factor productivity - the quotient of yield to N fertilizer rate. Because S addition increased yield at Lexington, the crop was able to make more yield per unit of N fertilizer when S was also applied (Figure 7). Because the extra N added at heading did not boost yield, there was a lower N fertilizer use efficiency in that treatment at both locations. With adequate but not excessive N and S, the wheat crop produced nearly 1 bushel per 1 pound of N fertilizer. The partial factor productivity varied among varieties, but the effects were not consistent between sites (Figure 8).

CONCLUSIONS:

This study demonstrated that S fertilization can lead to increased yield, quality (as measured by sedimentation volume), and N use efficiency of wheat, provided that N is adequately supplied. We also found that an additional dose of N at heading can increase grain protein and sedimentation volume but not yield. Agrimax 454 and Princeton 21 were high-yielding but low in quality, whereas Pembroke 14 was relatively low-yielding but high in quality. Overall, our results show that S fertilization is a practice to consider for wheat production in Kentucky. However, because the response was not consistent across sites, additional research is needed to understand where response to S fertilization is most likely occur. In the coming weeks, we hope to get a better understanding of this through our literature review.

Acknowledgements

We thank the Kentucky Small Grain Growers Association for funding this project. We also thank Paula Castellari for her work on the grain quality measurements and literature review, Carrie Knott for helping to manage the Princeton study, and Laura Harris, John Connelly, Sandy Swanson, Connor Raymond, Osei Jordan, Demetria Flowers, William Pearce, and Leticia Pacheco Inoue for their help with study implementation and data collection.

Table 1. Summary of Fertility Treatments Used for the Wheat Fertility Study.

Fertility treatment	Nitrogen rate (lb N/acre)	Sulfur rate (lb S/acre)	Nitrogen timing*	Sulfur timing
Check	0	0	N/A	N/A
S-only	0	30	N/A	Feekes 3
N-only	90	0	Feekes 3 + Feekes 5	N/A
N Extra	120	0	Feekes 3 + Feekes 5 + Feekes 10.5	N/A
N + S	90	30	Feekes 3 + Feekes 5	Feekes 3
N Extra + S	120	30	Feekes 3 + Feekes 5 + Feekes 10.5	Feekes 3

*Super-U and gypsum were hand-applied. 30 lb N/acre applied at Feekes 3, 60 lb N/acre applied at Feekes 5, and 30 lb N/acre applied at Feekes 10.5.

Table 2. Selected Characteristics of Wheat Varieties Used for the Wheat Fertility Study.

Variety	Wheat class	Productivity	Baking quality
Agrimax 454	Soft red winter wheat	High yield	Unknown
Pembroke 2021	Soft red winter wheat	High yield	Weak gluten
Pioneer 26R10	Soft red winter wheat	High yield	Unknown
Pembroke 2014	Soft red winter wheat	Intermediate yield	Strong gluten
Vision 45	Hard red winter wheat	Intermediate yield	Strong gluten

Table 3. Selected Soil Properties of Study Fields Used for the Wheat Fertility Study.

Location	Pre-plant soil test, 0-6 inches				Early spring, 0-24 inches	
	Soil organic C (%)	Soil pH	Mehlich 3 P (lb/acre)	Mehlich 3 K (lb/acre)	Soil inorganic N (lb/acre)	Soil sulfate-S (lb/acre)
Lexington	1.46	6.19	468 (medium)	225 (medium)	23.3	11.9
Princeton	1.11	6.40	43 (medium)	210 (medium)	10.0	19.4

Table 4. Timeline of Activities in the Wheat Fertility Study.

Activity	Date	
	Lexington	Princeton
Soil sampling for routine soil testing and soil organic C concentration	10/3/2020	10/3/2020
Planting	10/18/2020	10/27/2020
Soil sampling for sulfate and inorganic nitrogen	3/5/2021	3/6/2021
First fertilizer application	3/8/2021	3/7/2021
Harmony and Warrior application	3/22/2021	3/30/2021
Second fertilizer application	3/30/2021	3/31/2021
Leaf chlorophyll measurements and flag leaf samples during heading	5/7/2021	5/6/2021
Third fertilizer application	5/11/2021	5/6/2021
Fungicide application	5/20/2021	5/17/2021
Leaf chlorophyll measurements during grain fill	6/10/2021	6/1/2021
Biomass collection	6/23/2021	6/16/2021
Harvest	7/14/2021	6/24/2021

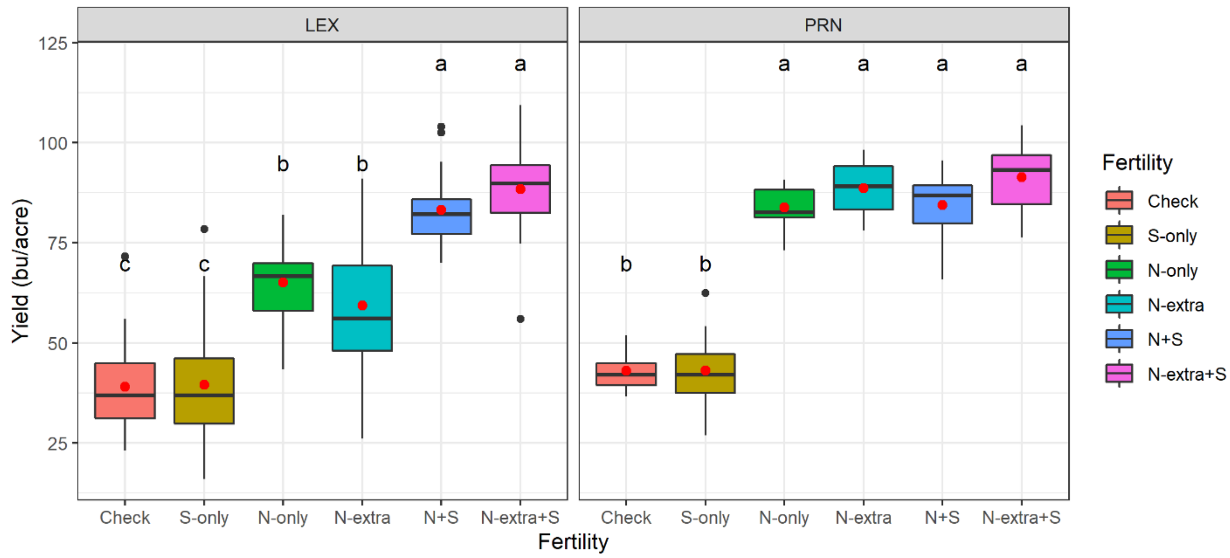

Figure 1. Wheat yield in response to fertilization treatments, averaged across five varieties at Lexington and Princeton in 2021. The boxplots illustrate the variation while the red points show the mean of each treatment. Different letters indicate significant differences between treatments within a location.

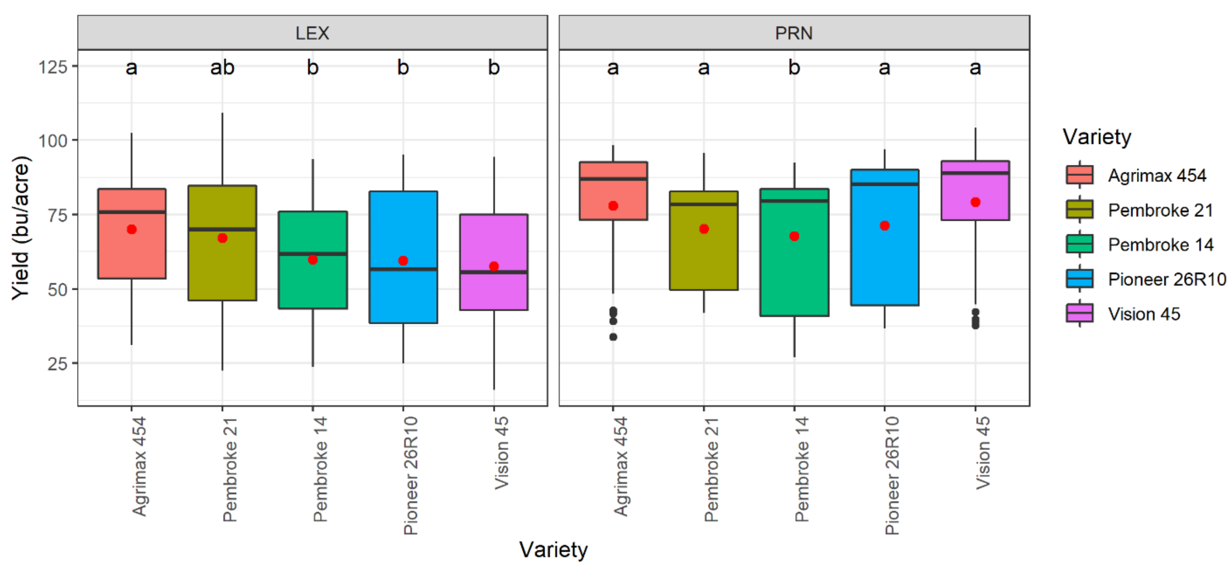

Figure 2. Wheat yield in response to variety, averaged across fertility treatments at Lexington and Princeton in 2021. The boxplots illustrate the variation while the red points show the mean of each treatment. Different letters indicate significant differences between treatments within a location.

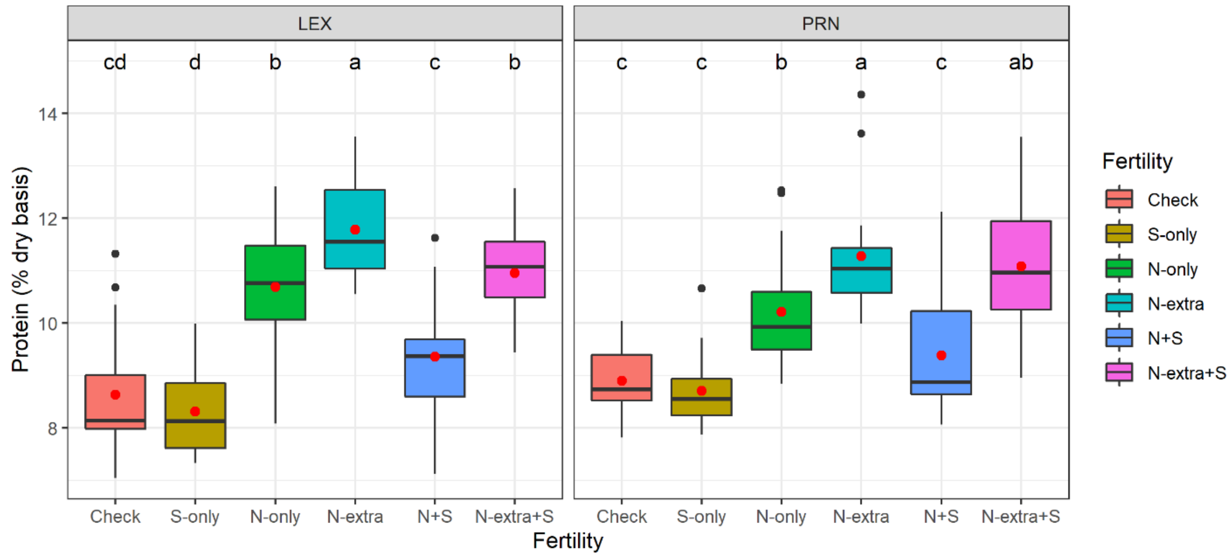

Figure 3. Wheat protein in response to fertilization treatments, averaged across five varieties at Lexington and Princeton in 2021. The boxplots illustrate the variation while the red points show the mean of each treatment. Different letters indicate significant differences between treatments within a location.

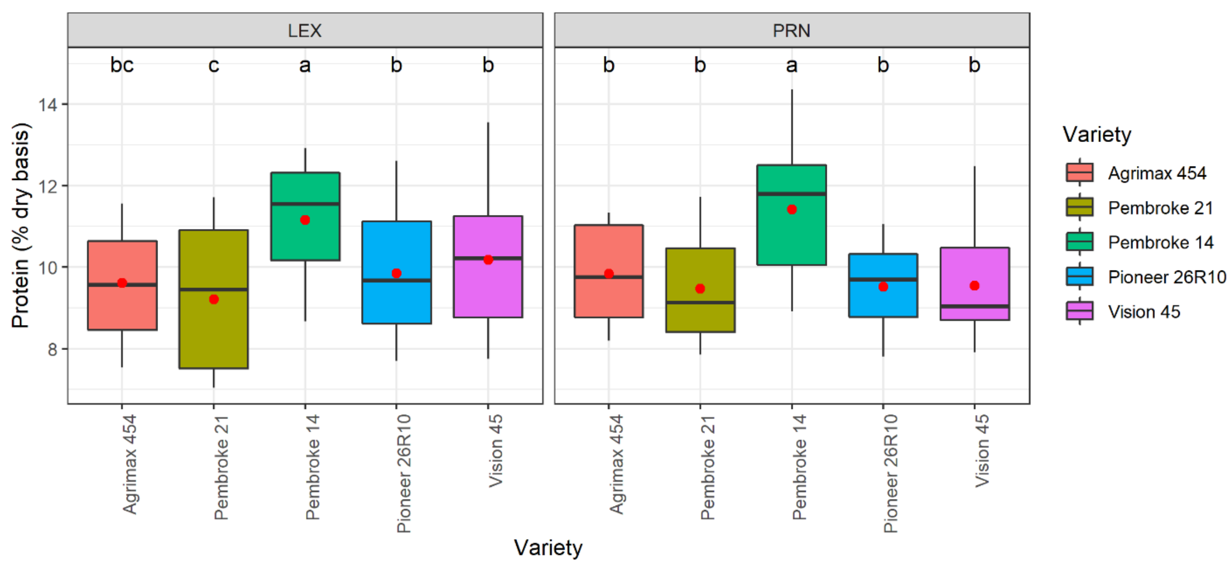

Figure 4. Wheat protein in response to variety, averaged across fertility treatments at Lexington and Princeton in 2021. The boxplots illustrate the variation while the red points show the mean of each treatment. Different letters indicate significant differences between treatments within a location.

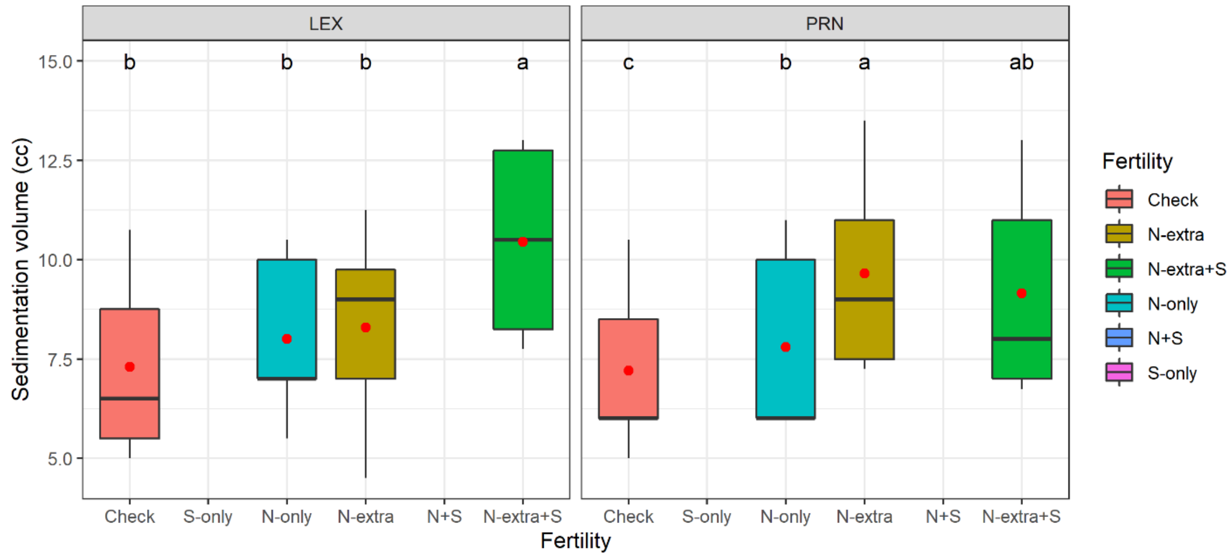

Figure 5. Sedimentation volume in response to selected fertilization treatments, averaged across five varieties at Lexington and Princeton in 2021. The boxplots illustrate the variation while the red points show the mean of each treatment. Different letters indicate significant differences between treatments within a location.

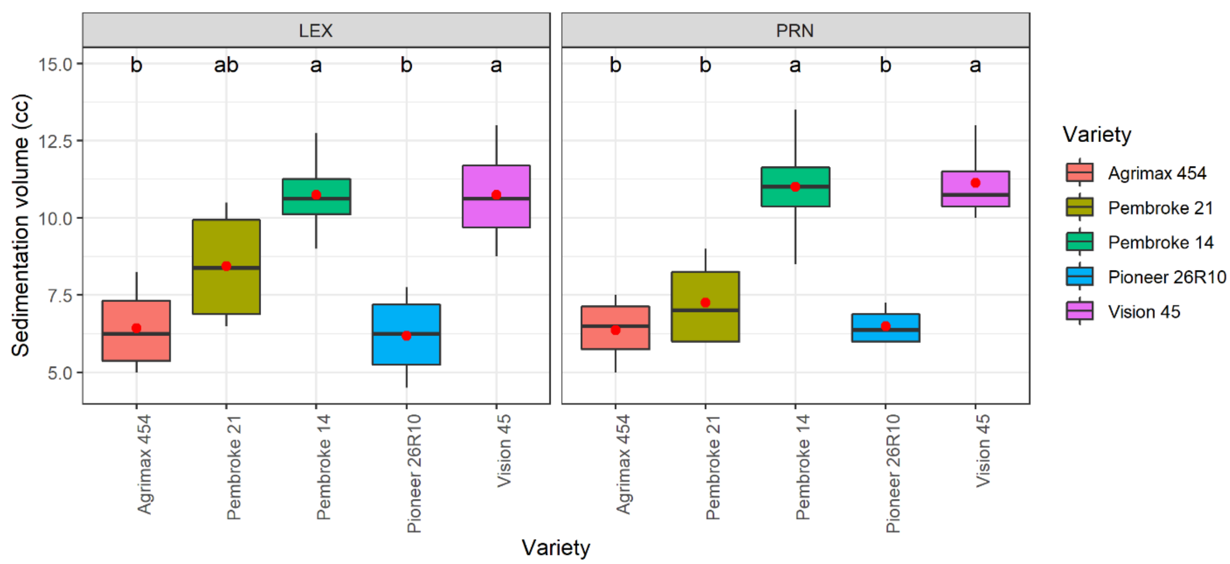

Figure 6. Sedimentation volume in response to variety, averaged across fertility treatments at Lexington and Princeton in 2021. The boxplots illustrate the variation while the red points show the mean of each treatment. Different letters indicate significant differences between treatments within a location.

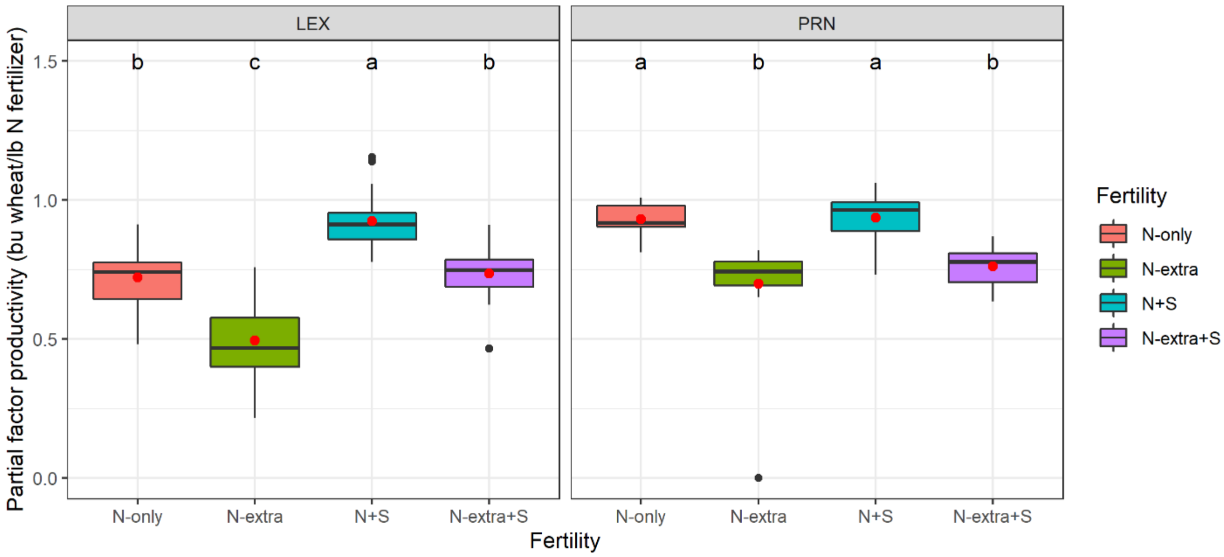

Figure 7. Partial factor productivity in response to fertilization treatments, averaged across five varieties at Lexington and Princeton in 2021. The boxplots illustrate the variation while the red points show the mean of each treatment. Different letters indicate significant differences between treatments within a location.

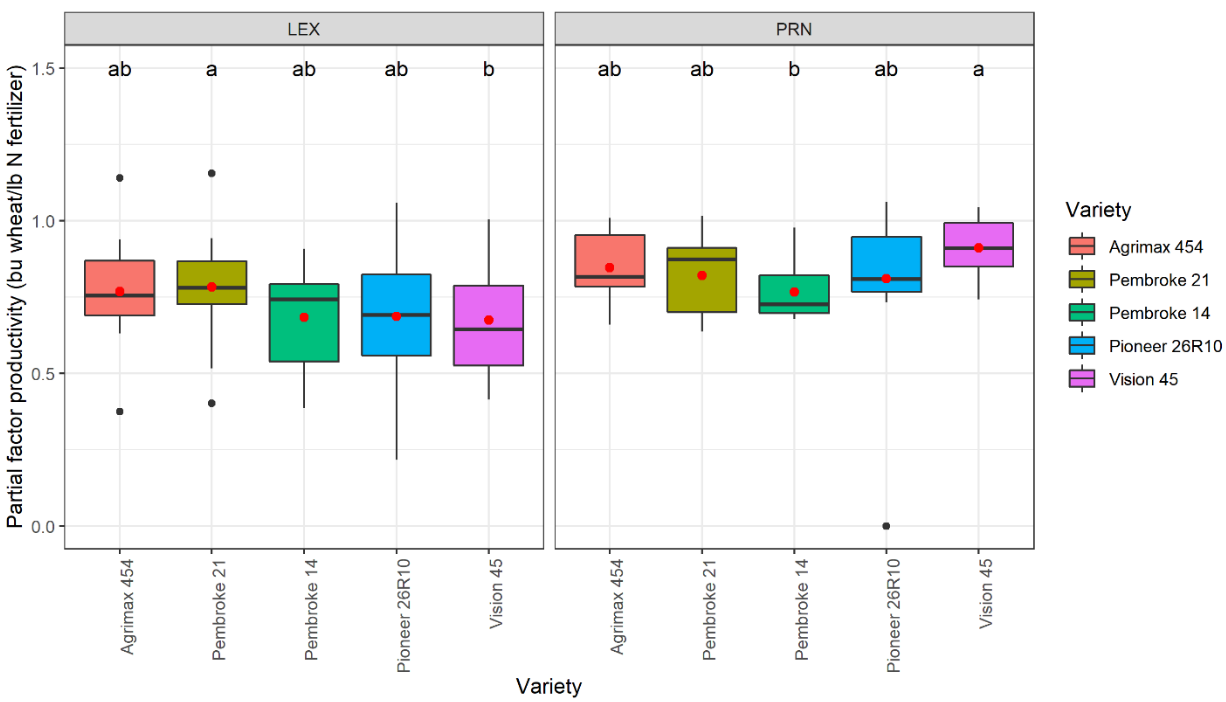

Figure 8. Partial factor productivity in response to variety, averaged across fertility treatments at Lexington and Princeton in 2021. The boxplots illustrate the variation while the red points show the mean of each treatment. Different letters indicate significant differences between treatments within a location.

REFERENCES:

Salvagiotti, F. et al. 2009. Sulfur fertilization improves nitrogen use efficiency in wheat by increasing nitrogen uptake. Field Crops Research 113: 170-177.

Zhao, F. et al. 1999. Responses of breadmaking quality to sulfur in three wheat varieties. Journal of the Science of Food and Agriculture 79: 1865-1874.