Nitrogen Fertilization Considerations for High-Yielding Winter Wheat In the South Central Piedmont of North Carolina

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ABSTRACT

Nitrogen management in the production of winter wheat are important for both yield and quality. Application timing and rate are critical for winter wheat production fields with high yield potential. An on-farm, randomized trial, was conducted in Unionville, North Carolina, to investigate the correlation between N fertilization rates, yield, and plant lodging. Winter wheat was evaluated at rates of 100, 125, 150, and 175 lbs N/ac during the second (early Spring, GS-25) and topdress (GS-30) application for each treatment. Tissue samples were collected at GS-30 and analyzed for NO_3-N concentration. Plant height, head length, and spikelet count were measured at GS-85 (soft dough) and no significant differences were found. Means were 40.6 inches, 4.7 inches, and 25.2 spikelets, respectively. However, significant differences in yield were observed between the 100 lbs/ac and 150 lbs/ac application rates. Means were 90.8 bu/ac and 67.7 bu/ac, respectively. Significant differences were also observed in percent lodging between all treatments except for 100 lbs/ac, 150 lbs/ac, and 175 lbs/ac. Means were 25%, 30%, and 95% for percent lodging, respectively. Results indicated a moderately positive correlation between increasing N fertilization rates and percent lodging. These findings reinforce the relationship between N fertilization and winter wheat lodging.

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Rah Virginia Mil! Go Hokies, and Go Pack!

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Introduction

Globally, *Triticum aestivum* L. (wheat), is the 3rd most-produced cereal and the 2nd most-produced for human consumption after *Orya sativa* (rice), and *Zea mays* (maize) (Sowell, 2023). The United States (US) produced 1.2 billion tons between 2000 and 2022 or 8.4% of global wheat (Rastogi and Ang, 2022). Soft red winter (SRW) wheat accounts for about 15% of total production in the US and is mostly grown along the Mississippi River and in Eastern states (Sowell, 2023). The war in Ukraine serves as a reminder of how the global market can impact crop production domestically in the US. Growers experienced an increase in the price of nitrogen (N) from approximately $400/ton to $900/ton between the months of September and November 2021 with prices not decreasing until March 2023 (Kee et al., 2023). Grain prices also increased 50% during the 2021-2022 growing season (Lin, et al., 2023).

Nitrogen is an important macronutrient in forming tillers, plant photosynthesis, and building protein in grains (White, 2021). Application rates and yield are directly correlated and well understood (Weisz et al., 2001, Flowers et al., 2004, Heiniger et al., 2019). In North Carolina, 1.6 pounds of N is known to produce one 60-pound bushel of wheat at 13.5% moisture (Post, 2021). The economic and agronomic link between N and wheat yield cannot be understated.

Farmers in Union County North Carolina planted 45,800 acres of winter wheat in 2022 with a county average of 75 bushels per acre (bu/ac) and a total yield of 3.4 million bushels (USDA, 2023). The second-highest producing county in North Carolina, Robeson, produced 1.27 million total bushels with an average yield of 57 bu/ac. (USDA, 2023). Wheat yield

contest submissions from 2008-2022 in Union County averaged 107 bu/ac with an emphasis on producing high test weight, average test weight 58.5, (n = 88), and high quality; the falling number averaged 333.8 (n = 45) and protein averaged, 9.2% (n = 39) for milling and baking purposes. It is well known that untimely and misapplied N can cause wheat to lodge, (Wu et al., 2019), increase disease pressure from foliar pathogens (Simón et al. 2020), and increase the potential to pollute waterways via runoff and leaching (Singh et al. 2021). Union County growers also frequently indicated that if they over-apply N the wheat will “lay down” or lodge (M.S. Menaker, personal communication, 2023).

Nitrogen is typically applied directly via varying grades (32-0-0, 30-0-0, 28-0-0) and rates (Gallons per Acre, GPA) of urea ammonium nitrate (UAN). Residual nitrogen carryover from litter (manure) applied before the previous corn crop is also loosely considered, during the season of SRW production. Residual soil N varies depending on the type (broiler, turkey, layer, etc.) of litter with estimates ranging from between 20 lbs N/ton to 57 lbs N/ton. Environmental conditions (heat, moisture, incorporation vs. surface applied) also play a role in N mineralization (Eghball et al. 2002). Approximately half the total amount becomes plant available during the targeted crop and the remaining half becomes available for the following crop (Kulesza & Sharara 2020).

One way to mitigate crop lodging, disease, and reduce fertilizer runoff or leaching is to use adaptive management strategies. Adaptive management is a systematic approach that fits management practices to current and projected environmental conditions (Heiniger et al. 2019). Components of adaptive management include variety selection, seeding rate, planting date, plant growth regulator use, pesticide use, long-range weather forecasting, and for the potentially high-yielding wheat field; amount and timing of N fertilizer.

Purpose Statement

The fertilization of winter wheat has been well studied and documented. However, North Carolinian growers frequently question the relevance of research conducted in geographically different parts of the state (coastal plain vs. piedmont vs. mountains). The south-central Piedmont of North Carolina has unique climatic, topographic, and soil type variations. This study examines the following question: What effects does nitrogen fertilization have on the yield and lodging potential of winter wheat grown in the south-central Piedmont of North Carolina?

Materials and Methods

Site Description and Experimental Design

The effects of N fertilization of winter wheat in the south-central Piedmont of North Carolina were evaluated in an on-farm research, no-till field, in the vicinity of Unionville, NC during the 2022-2023 winter wheat growing season under rainfed conditions. The soil type for the field is a Tarrus gravelly silty clay loam; (Table 1). Weather data from the field site can be viewed in Figure 1. The site was prepared with herbicides Gramoxone (paraquat) at 1.03lbs a.i./ac, Roundup (glyphosate) at 1.35 lbs a.i./ac, and Anthem Flex (pyroxasulfone + carfentrazone-ethyl) at 0.13 lbs a.i./ac and 0.009 lbs a.i./ac, respectively.

The SRW wheat variety AgriMAXX 503 (AgriMAXX, Mascoutah, IL), was planted using a 7-foot, 10-row no-till seed drill (model 706NT, Great Plains Ag, Salina, Kansas, United States). The seeding rate was 1.5 million seeds/acre and the rows were spaced 7.5 inches apart. AgriMAXX 503 is a medium-early maturing, high-yielding ($\bar{x}$ = 103.5 bu/ac) variety that has been evaluated for twelve site-years (2020-2023, Union, Rowan and

Granville counties) in North Carolina's Official Variety Testing (NC OVT) program (Medius Ag, 2023). AgriMAXX 503 has a high test weight averaging 57.4 lbs/bu over 22 site years and an average lodging percentage of 18% over 4 site years (Medius Ag, 2023).

Eight N treatments consisting of two factors were evaluated (Table 2). The first factor was the total N tested at four levels (100, 125, 150, and 175 lbs N/ac). The second factor was the rate of the split application at GS-25 and GS-30 tested at two levels (low and high) Treatments were arrangedreplicated in a randomized complete block design with four replicates. Each treatment plot measured 35 feet in length and 7.5 feet in width. All N treatments were applied in the grade of 28-0-0-5.2 (N-P-K-S) and the form of liquid urea ammonium nitrate (UAN). Each treatment plot received 30 lbs N/ac at planting (November 2nd, 2022). The second application was at GS-25 (February 8th, 2023) with rates ranging from 30 to 85 lbs N/ac. The third and final application was at GS-30 (March 10th, 2023) with rates ranging from 30 to 85 lbs N/ac. Nitrogen was applied using a backpack sprayer (Model AS3 T, Bellspray, INC. R&D Sprayers) and a four-nozzle boom with TEEJET XR 11002 VS nozzles on 20-inch spacing.

Data Collection

Whole plant samples were collected at GS-30 and analyzed for macro and micronutrient concentrations by the North Carolina Department of Agriculture & Consumer Services (NCDA&CS). Tissue samples were collected from Treatments 1, 3, 5, and 7 (Table 2). Samples were randomly collected from each plot from treatments 1, 3, 5, and 7 and aggregated into one sample per treatment. Nitrate-N (NO_3-N) was requested and included in the plant tissue reports.

Plots were harvested using a plot combine (Quantum Plus, Wintersteiger) Moisture, grain weight of eahc plot, yield and test weight were all obtained from the combine. Harvest data (percent moisture and grain weight) was used to calculate adjusted grain yield using the formula:

$$Adjusted\ Yield_{Bu/ac} = Yield_{Bu/ac} \times (100 - Harvest\ Moisture\ \%) / 86.5\%$$

This formula is used to calculate yields for the North Carolina Wheat Yield Contest based on the standard bushel per the USDA and adjusts moisture to 13.5% (Post, 2022). Plant height, head length, and spikelet count were collected at GS-85 (soft dough).

Plant height was measured by placing a yardstick in the center of each plot at the base of the wheat and visually observing where the wheat head fell on the yardstick when straightened vertically. The head length was measured by randomly collecting five heads from the centers of each plot as the collector walked through them. Heads were placed against a ruler, manually straightened, and then measured from the bottom to the top spikelet. Care was taken not to collect heads from the edges of the plots. Heads were clipped where the stem and head joined. The number of spikelets per head was determined by placing the head next to a ruler, manually straightening the head and then counting each spikelet, regardless of size.

Percent lodging was captured as a visual estimate of the plots. An adaptation of the methods from Caldicott and Nuttall (1979) was used to determine the percent lodging with a lodging severity scale ranging from 1 - 5. (Figure 3). Percent lodging was determined on the day of harvest and ratings were taken by the same person for each plot.

Statistical Procedure

A one-way ANOVA procedure was used in RStudio (RStudio Team, Boston, MA) to determine if there were differences among the treatments in plant height, head length, and spikelet count. A two-way ANOVA using factors total N and timing was used to evaluate if there was an effect on yield. A *p*-value of 0.05 was used to determine significant differences. When differences were found, a Tukey HSD was used to identify the specific differences among treatment averages.

A correlation coefficient and linear regression model were generated using RStudio (RStudio Team, Boston, MA) to examine the relationship between total N applied and percent lodging. R-squared values were used to evaluate the relationship between yield and percent lodging. All R code was written with the assistance of OpenAI (2023).

Results and Discussion

Adjusted Yield

No significant differences (F-value = 2.4, *p*-value > 0.05) in grain yield were observed (Table 4). The mean trial average was 77.8 bu/ac with the treatment of 45 lbs N at GS-25 plus 50 lbs N at GS-30 total N 125 lbs yielding the highest at 90.8 bu/ac and the treatment of 65 lbs N at GS-25 plus 55 lbs N at GS-30 total N 150 lbs yiledng the lowest at 67.4 bu/ac

Not observing significant differences between treatments is unexpected as split Spring N applications occurring at GS-25 and GS-30 increase yields (Weisz et al., 2001). In Flowers et al., (2004) in-season optimization of nitrogen showed a yield advantage over site-specific optimization. The findings of this study do not match the 74 wheat yield contest entries that were submitted from 2008 to 2022. Figure 2.

Lodging

Significant differences in the percent lodging were observed (Table 4). Significant differences (F value = 7.64) were observed between treatments of 60 lbs N at GS-25 plus 85 lbs N at GS-30 total N 175 and 40 lbs N at GS-25 plus 30 lbs N at GS-30 total N 100, 65 lbs N at GS-25 plus 55 lbs N at GS-30 total N 150 and 45 lbs N at GS-25 plus 50 lbs N total N 125, and 60 lbs N at GS-25 plus 85 lbs N at GS-30 total N 175 and 45 lbs N at GS-25 plus 50 lbs N total N 125 at an HSD $p < 0.05$ (Table 4). The 100 lbs total N treatment with a Spring split of 40 lbs N at GS-25 plus 30 lbs N at GS-30 had the lowest amount of lodging at 25% while the 175 lbs total N with a Spring split of 60 lbs N at GS-25 plus 85 lbs N at GS-30 had the highest lodging at 95%. It has been well understood that high rates of N fertilization can lead to increased lodging (Wu et al., 2019).

Freeze damage was discovered on the first node of plants (browning under the first node, curved stems, most severe damage was split nodes) after the final freeze event of the season (Figure 1). Symptoms of freeze damage included browning under the first node, curved stems, and in the most severe cases, split nodes. Damage was randomly distributed among the plots. This damage, done between GS 18-37 (jointing) may have weakened stems at their base. Combined with late-season storms, this created an environment that would increase the likelihood of lodging to occur.

In Paulsen & Heyne 1984, researchers indicated that the most frequent symptom of a freeze at jointing was damage to the lower stem. This was the case for the field in Unionville. The author speculates that yield was unaffected as NC Official Variety Testing commercial test plots (n = 66) averaged 103.3 bu/ac in the same field (Heiniger, 2023).

Total Nitrogen and Lodging Percentage Correlation

A moderately positive correlation exists between N rates and lodging percentages with an R^2 value of 0.634 (Figure 4). As total N rates increased, lodging increased. This is similar to the findings from Wu et al. (2019). Who found that the difference in visual lodging estimates from a 0 lbs N/ac treatment to a 178 lbs N/ac treatment was seven times greater. A moderate split application of 44 lbs N/acre at pre planting + 44 lbs N/acre at jointing showed lodging similar to the 0 N treatment and increased grain protein (%) ($\bar{x}$ = 12.4% - 14.9%). These findings reinforce the benefits of split N applications. Given that the amount of residual N is unknown in the soil from litter applications, this finding could serve as the baseline for growers trying to increase yields and decrease lodging.

Effects on Plant Anatomy

Head length, spikelet count, and plant height were not significantly different (Table 3). Kayan *et al*. (2018), found that the differences in N rates (0 lbs N/ac, 44 lbs N/ac, 89 lbs N/ac, 133 lbs N/ac) were significant for plant height ($\bar{x}$ = 41 in., 38 in., 40 in., and 41 in., respectively) and head length ($\bar{x}$ = 3.46 in., 3.56 in., 3.62 in., and 3.68 in., respectively) in reduced tillage systems.

Conversely, Shah et al. (2015) using N treatments of 0 lbs N/ac, 53 lbs N/ac, 80 lbs N/ac, and 107 lbs N/ac found no significant difference in plant height ($\bar{x}$ = 37.7 in., 38.9 in., 40.5 in., and 41.7 in, respectively) or head length ($\bar{x}$ = 2.7 in., 2.8 in., 2.9 in., and 2.9 in., respectively).

Further research using modern wheat varieties is needed to determine if a correlation exists between increasing N rates, and plant height, head length, or spikelet number.

Tissue Sampling

The tissue samples indicated no significant differences in N percentages, but there were differences in nitrate N (NO_3-N). All samples tested low in N percentage (Table 5). This is expected given that tissue samples were taken twelve days prior to GS-30. The 100 lbs N/acre and 175 lbs N/acre treatments contained the highest levels of NO_3-N with 239 ppm and 258 ppm, respectively. The 125 lbs N/acre and 150 lbs N/acre treatments contained lower levels of NO_3-N with 91.8 ppm and 58.9 ppm, respectively. This did not correlate with N rates or lodging (R^2 = 0.066).

Summary and Conclusion

The results of this study do not support that there is a positive correlation between increasing nitrogen rates and increased yield. This study did find that increasing nitrogen rates moderately correlated with increased lodging. Treatments did not affect plant height, head length, or spikelet count. An untreated control or “check plot” could also have been used to further examine the effects the treatments had. In this experiment, AgriMAXX 503 showed a yield ranging from 67 bu/ac (treatment 6) to 90 bu/ac (treatment 2). In total, these treatments delivered 150 and 100 lbs N/acre. Meaning, these treatments should have, at minimum, produced 93 bu/ac and 62 bu/ac, respectively. Yield contest data from Union County, NC indicate a wide response to N rates across multiple varieties (Figure 2). In conclusion, further research into modern wheat varieties should be conducted for farmers in Union County, NC to ensure efficient N recommendations are being properly utilized.

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Table 1. Soil information from the field trial in Unionville, NC including in-season total rainfall (in.), planting, and harvest dates. Phosphorous, manganese, zinc, and copper values are likely in excess from a history of site-specific poultry litter applications

Soil Type:	Tarrus gravelly silty clay loam	**Ca %:**	69
HM %:	0.71	**Mg %:**	16
W-V:	0.85	**Mn-I:**	257
CEC:	11.5	**Zn-I:**	665
BS %:	89	**Cu-I:**	1435
Ac:	1.3	**Total Rainfall (in.):**	22.8
pH:	6.1	**Planting Date:**	11/2/2022
P-I:	444	**Harvest Date:**	6/14/2023
K-I:	97		

Table 2. Summary of all nitrogen applications in both pounds per acre and gallons per acre for 28% UAN.

Treatments	Total N (lbs/acre)	At planting (lbs/acre)	Gallons/acre	1st Split (lbs/acre) GS-25	Gallons/acre	2nd Split (lbs/acre) GS-30	Gallons/acre
1	100	30	10	30	10	40	13
2	100	30	10	40	13	30	10
3	125	30	10	45	15	50	16
4	125	30	10	50	16	45	15
5	150	30	10	55	18	65	21
6	150	30	10	65	21	55	18
7	175	30	10	60	20	85	28
8	175	30	10	85	28	60	20

Table 3. Average plant height, head length, and spikelet count for each treatment. Measured in inches. All treatments received 30 lbs. N/acre at planting, GS-0. NS = not significant.

Spring Split Nitrogen Applications	Plant Height (in)	Head Length (in)	Spikelet Count
30 lbs/acre at GS-25 + 40 lbs/acre at GS-30, 100 lbs total, NS	39.5	4.7	24.9
40 lbs/acre at GS-25 + 30 lbs/acre at GS-30, 100 lbs total, NS	41.3	4.77	25.35
45 lbs/acre at GS-25 + 50 lbs/acre at GS-30, 125 lbs total, NS	41	4.81	25.4
50 lbs/acre at GS-25 + 45 lbs/acre at GS-30, 125 lbs total, NS	39	4.53	24.45
55 lbs/acre at GS-25 + 65 lbs/acre at GS-30, 150 lbs total, NS	40.5	4.85	25.65
65 lbs/acre at GS-25 + 55 lbs/acre at GS-30, 150 lbs total, NS	39.87	4.87	25.5
60 lbs/acre at GS-25 + 85 lbs/acre at GS-30, 175 lbs total, NS	40.12	4.8	25.5
85 lbs/acre at GS-25 + 60 lbs/acre at GS-30, 175 lbs total, NS	41.43	4.71	25.35

Table 4. Treatments, adjusted yield averages (bu/ac), and percent lodging. Treatments with asterisks indicate significant differences (* = $p < 0.05$, ** = $p < 0.01$). All treatments received 30 lbs N at planting or GS-0.

Treatment	Adjusted Yield Means (bu/ac)	Percent Lodging
30 lbs N (GS-25) + 40 lbs N (GS-30), Total N 100 lbs	76	50
40 lbs N (GS-25) + 30 lbs N (GS-30), Total N 100 lbs	90	25*
45 lbs N (GS-25) + 50 lbs N (GS-30), Total N 125 lbs	80	30**
50 lbs N (GS-25) + 45 lbs N (GS-30), Total N 125 lbs	84	30*
55 lbs N (GS-25) + 65 lbs N (GS-30), Total N 150 lbs	79	60
65 lbs N (GS-25) + 55 lbs N (GS-30), Total N 150 lbs	67	80
60 lbs N (GS-25) + 85 lbs N (GS-30), Total N 175 lbs	74	95**
85 lbs N (GS-25) + 60 lbs N (GS-30), Total N 175 lbs	76	65

Table 5. Predictive plant tissue report results for each treatment. Nitrate nitrogen was not significantly different (p>0.05) between treatments.

	Nutrient Measurements are given in units of parts per million (ppm)												
Total N (lbs/acre)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe	Mn	Zn	Cu	B	Mo	NO_3-N
100	3.15	0.59	4.42	0.30	0.13	0.20	55.0	36.8	20.9	6.62	3.26	-	239
125	3.34	0.72	4.8	0.33	0.15	0.23	59.4	45.1	25.1	7.01	3.7	-	91.8
150	3.22	0.69	4.52	0.32	0.14	0.22	65.9	48.6	27.8	6.94	3.44	-	58.9
175	3.28	0.67	4.61	0.29	0.14	0.22	56.2	40.2	26.3	7.35	3.35	-	258
	Interpretation Indexes												
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo	
100	39-L	79-H	68-S	53-S	43-L	53-S	54-S	53-S	51-S	55-S	51-S	-	
125	41-L	86-H	72-S	54-S	50-S	54-S	54-S	55-S	53-S	56-S	51-S	-	
150	40-L	84-H	69-S	54-S	48-L	54-S	55-S	55-S	55-S	56-S	51-S	-	
175	40-L	83-H	70-S	53-S	45-L	54-S	56-S	54-S	54-S	57-S	51-S	-	
	Other Results					**Nutrient Ratios**							
	Na (%)	Cl (%)	C (%)	DW(g)	Al	N:S	N: K	Fe: Mn					
100	0.01	-	-	23.6	15.4	16.0:1	0.71:1	1.50:1					
125	0.01	-	-	22.0	8.19	14.3:1	0.70:1	1.32:1					
150	0.01	-	-	24.7	25.7	14.6:1	0.71:1	1.36:1					
175	0.01	-	-	31.8	10.5	14.9:1	0.71:1	1.40:1					

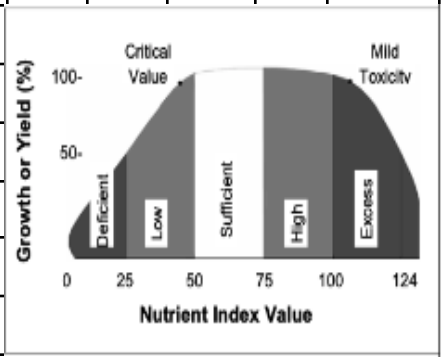

Figure 1. Weather data was collected from the in-field weather station. Growing Degree Units (GDUs) started accumulating from 1/1/2023. Included are rainfall in inches, last freeze date, and dates precipitation occurred. Accumulated rainfall in 1986 (historic low, Monroe, NC) was 8 inches between Jan. 1 and June 14. The historic high in 1922 was 34.6 inches between Jan. 1 and June 14. Accumulated rainfall in 2023 was 22.8 inches between Jan. 1 and June 14.

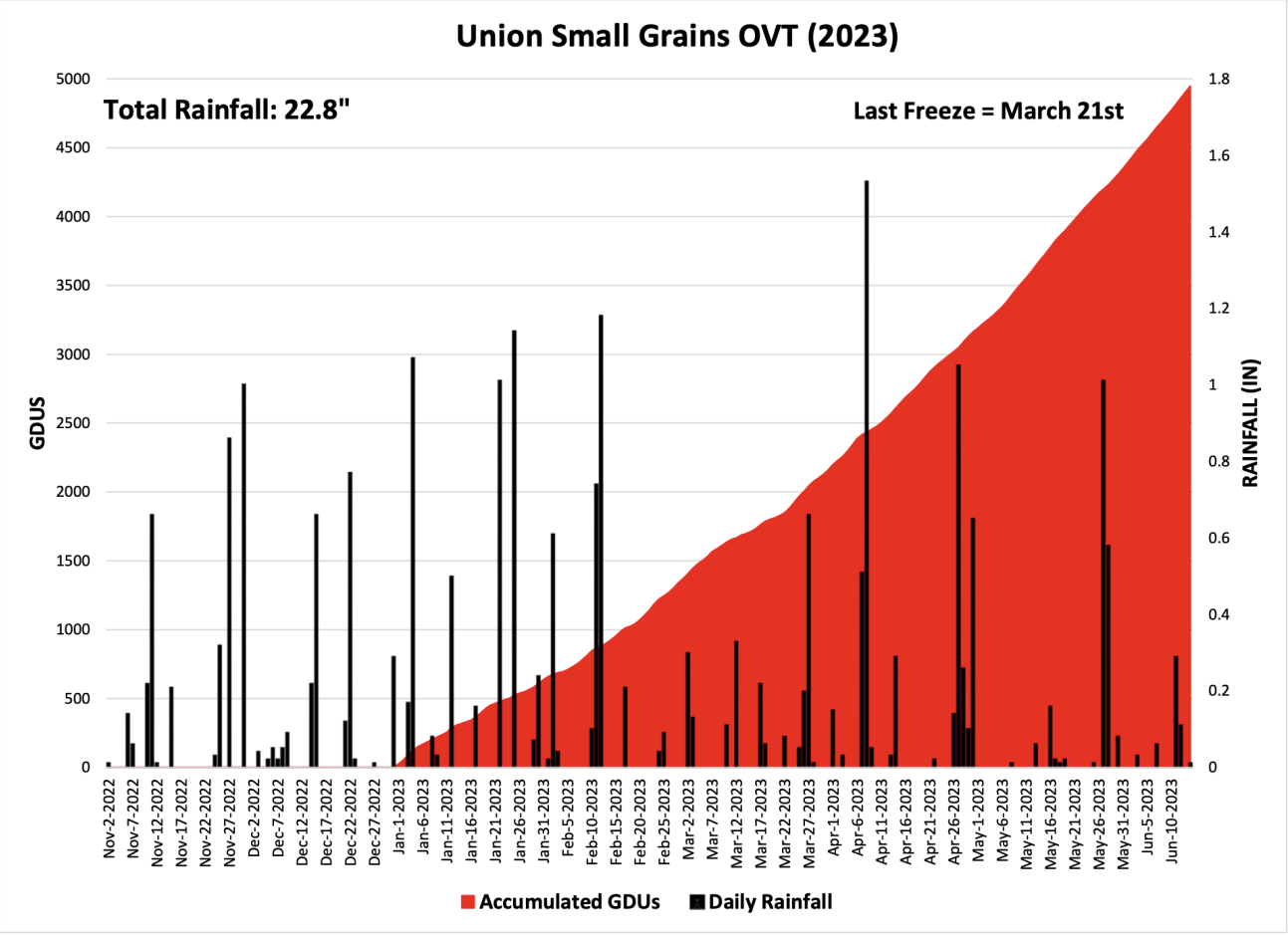

Figure 2. Seventy-four (n = 74) wheat yield contest entries from Union County North Carolina. Adjusted yield (bu/ac) response versus total nitrogen (lbs/ac) applications between the years of 2008 and 2022. R-squared = 0.142, ($p < 0.05$).

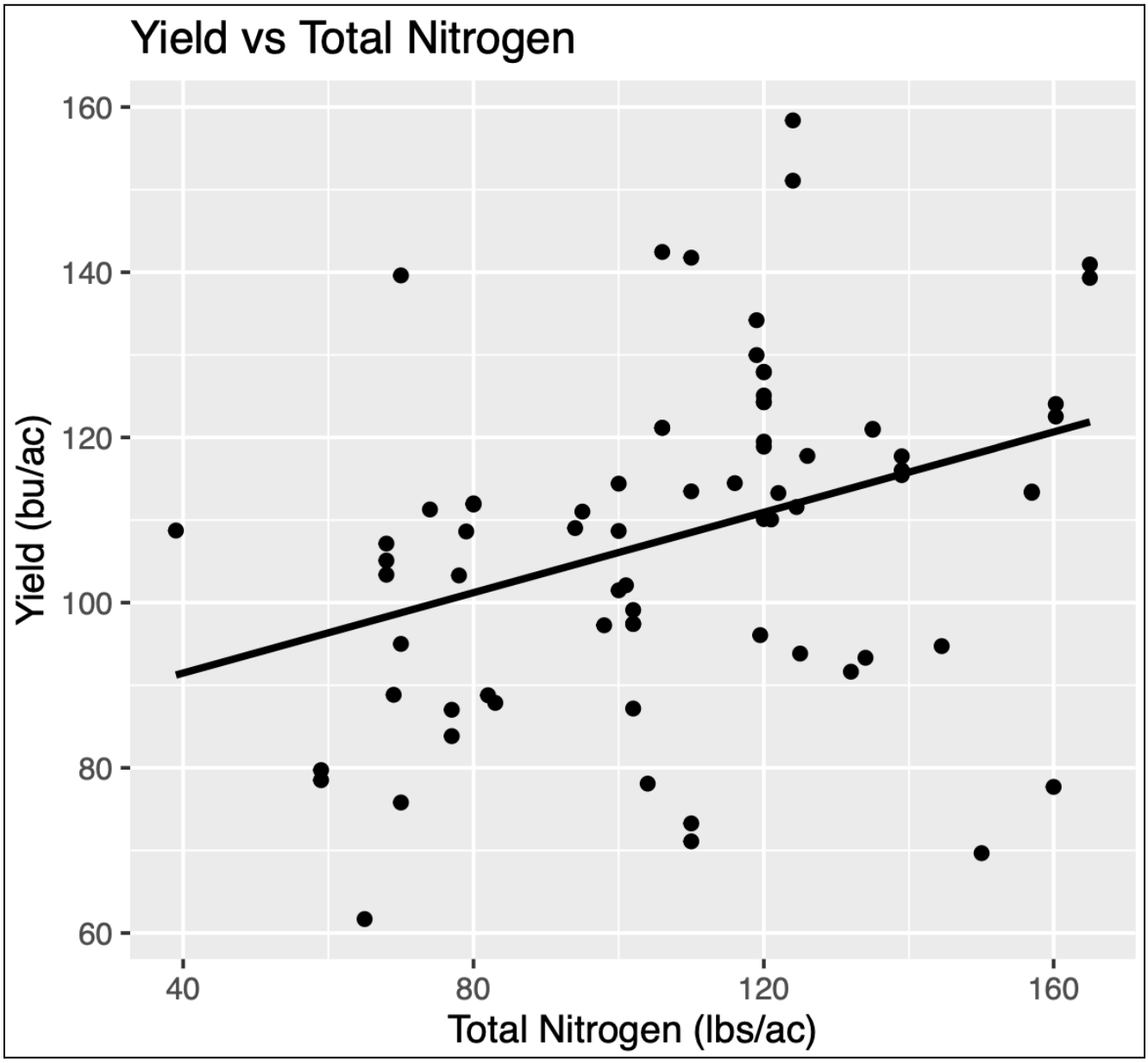

Figure 3. The angle of lodging is determined using the following scale:

1 = no lodging = 100% upright

5 = completely lodged = 100% flat

Ratings made in between the scale are expressed as percentages according to the angle of lodging.

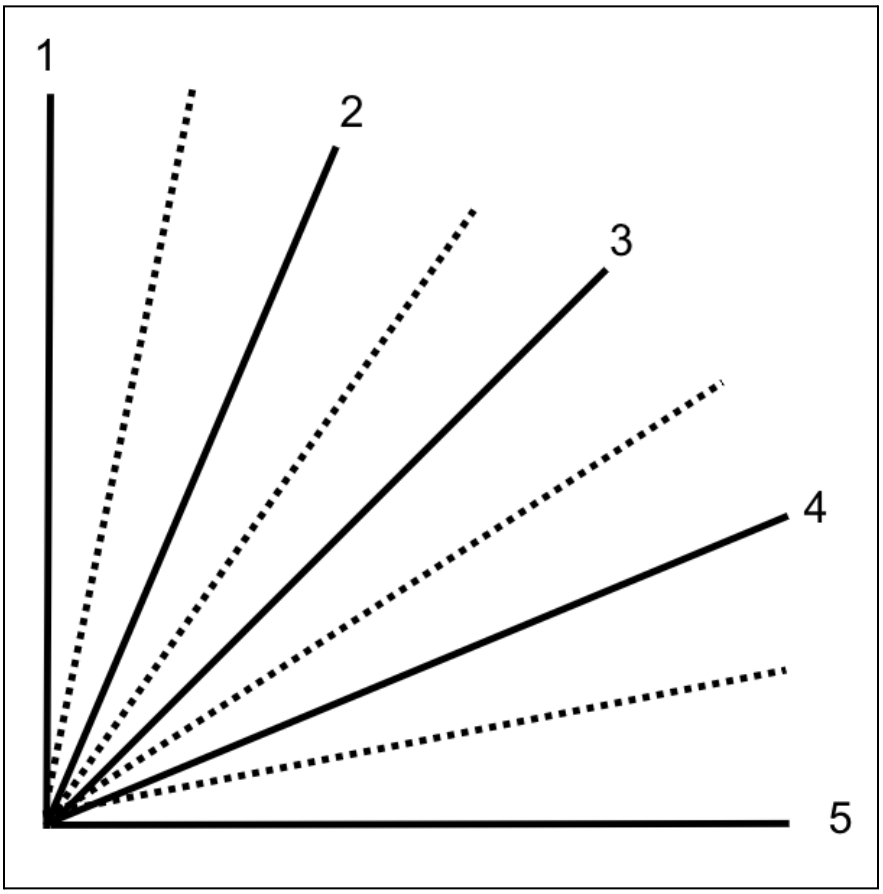

Figure 4. Percent lodging versus total nitrogen applied for the Union County nitrogen rate trial during the 2022 - 2023 growing season. R-squared value of 0.634 ($p < 0.05$). A moderate correlation exists between total nitrogen applied and percent lodging.