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Temperature Effects on Yield of Ideal Wheat Cultivars

Jeffrey Jiang
University of South Carolina - Columbia

Temperature Effects on Yield of Ideal Wheat Cultivars

By: Jeffrey Jiang

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Approved:

Dr. Johannes Stratmann

Director of Thesis

Dr. Zhengqing Fu

Second Reader

Steve Lynn, Dean

For South Carolina Honors College

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Thesis Summary:

Wheat in South Carolina is a necessity for farmers, mainly as a cover crop for optimal cycles of growth. It occupies the fourth highest acreage on average for a yearly cycle, but only the seventh highest value of production (U.S. wheat). Since it's a necessity, it becomes valuable to increase the yield of these plants, as getting rid of them is impractical due to their role as an important cover crop. The Uniform Soft Red Winter Wheat Nursery was a project that tried to establish and test elite cultivars, or varieties, of wheat. In my thesis, I attempt to explore the relationship found from the raw data in this study between various temperature factors and yield of these elite wheat cultivars.

Abstract:

North American wheat growing areas show variation in many different factors, one of the most varied and important being temperature. Temperature is well established to correlate with yield. Given data from the Uniform Soft Red Winter Wheat Nursery and independently gathered data from government-owned weather stations, I explored possible correlations between temperature and wheat yield that can be extrapolated to areas that are not covered by the Uniform Soft Red Winter Wheat Nursery database. My analysis did not reveal strong correlations between temperature and growth, and in some cases, the sample size was too small. From this study, it was found that average temperature is slightly correlated to average yield, with an R^2 value of 0.1987. Average low temperature is slightly correlated as well, with an R^2 value of 0.1917. Average high temperature was found not to be correlated at all, with an R^2 value of 0.0023. While there are tangible values from these findings, more research is needed to expand on this correlation.

Introduction:

Wheat in South Carolina has fallen out of favor as one of our main staple crops in the past few decades. The effects of global warming everywhere have decreased the viability of wheat (You et. Al, 2008), but South Carolina in particular has seen increased variability of temperature. In addition to temperature, fungal diseases inhibit the growth and proliferation of the most common wheat variety grown in South Carolina (Boyles et. Al, 2019). Given data from over 120 exemplary wheat strands and 40 different growing locations, as shown in Figure 1, it should be possible to determine the best-performing cultivar of wheat, and it will also be possible to compare climates across the different growth sites to find the one that would best suit South Carolina's changing climate.

Figure 1: Map of 41 locations present in this study.

Previous research relating to this generated the Uniform Soft Red Winter Wheat Nursery database. A nursery in this study refers to an independently supervised plot that housed a single cultivar of wheat. The supervisors would then document yield data from these plots as well as other information that pertained to yield. The Uniform Soft Red Winter Wheat Nursery is a category of small grains and potato germplasm research that the USDA sponsors. One thing that this nursery doesn't have is growth data for South Carolina. While it would be impractical to conduct this experiment in South Carolina due to time and money constraints for a college student, this information could be used for the benefit of South Carolina. Therefore, I analyzed wheat yield data alongside climate data for the areas detailed in the study and will be compared to the climate of South Carolina.

Temperature has many ways of affecting the growth of plants. Since it would be impractical to test all of the various types of temperature factors in this study, three important ones were selected. The average temperature, the low temperatures per month, and the high temperatures per month will be correlated with yield. Next, the low temperatures in months will be correlated with yield as well. Finally, the high temperatures per month will be correlated with yield. These factors may have a relationship with yield. Given decent correlation numbers, it will be possible to answer the question of which of these exemplary wheat Cultivars are best suited to the temperature of South Carolina by a few comparisons. The first comparison is between average temperature readings for the years of the study in South Carolina and average temperatures for each of the locations in the study. After this is pinpointed, the lows and the highs can also be compared in the same way. All of these comparisons can then be related to the master spreadsheet for the most similar numbers.

Data:

Over the last four years of the Uniform Southern Soft Red Winter Wheat Nursery, there have been over 41 unique locations and 124 different cultivars of soft winter wheat that have been studied as a focus of the nursery. Throughout the study, there were many overlapping cultivars that were studied many times, as well as many locations that held the trial for multiple years. Each location had a different starting and ending month as well, due to various climate reasons, such as early frost setting in or temperature not matching ideal growth conditions.

	Month Planted	Month Harvested	2012-2013	2013-2014	2014-2015	2015-2016
Griffin, GA	November	June				
Lexington, KY	October	July				
Knoxville, TN	October	June				
Blacksburg, VA	September	July (Rain Delay)				
Warsaw, VA	October	June				
Brownstown, IL	October	July				
Lafayette, IN	October	July				
Clarksville, MD	October	July				
Columbia, MO	October	July				
Mead, NE	NA	NA				
Nairn, ON	October	August				
Arlington, WI	September	July				
Battle Ground, IN	October	July				
Champaign, IL	October	July				
Harrisburg, IL	October	June				
West Lafayette, IN	October	July				
Winsfield, KS	October	June				
Custar, OH	NA	NA				
Urbana, IL	October	July				
Plymouth, NC	November	June				
Napoleon, OH	October	July				
Marianna, AR	October	June				

	Month Planted	Month Harvested	2012-2013	2013-2014	2014-2015	2015-2016
Stuttgart, AR	November	June				
Lafayette, IN 2	October	July				
Webberville, MI	October	July				
Oconto, WI	September	August				
Mason, MI	September	July				
New Haven, IN	September	July				
Logan County, KY	October	June				
Ingham County, MI	September	July				
Bella Mina, AL	November	June				
Quincy, FL	NA	NA				
Plains, GA	November	May				
Calhoun, KY	October	June				
Schochoh, KY	October	June				
Hopkinsville, KY	NA	NA				
Baton Rouge, LA	December	May				
Winnsboro, LA	November	May				
Queenstown, MD	October	June				
Brooksville, MS	November	June				
Portageville, MO	October	June				
Milan, TN	November	June				

Figure 2: Table showing all different locations, with month planted and harvested data, when applicable. Cells shaded in red indicate planting or harvesting for that year. Data taken directly from the USRWWN database

Amongst the 124 cultivars of wheat selected for this nursery, there was also overlap between the years that these cultivars were featured; however, there was significantly less overlap here than in the locations where they were planted.

3 Repeats	2 Repeats
Branson	OH08-180-48
Bess	NC08-140
Shirley	NC09-20768
MO080104	OH07-264-35
	IL07-19334
	GA04121-11E26
	MD04W249-11-7
	PP0762A1-2-8

Figure 3: Table detailing which wheat cultivars were repeated over the four analyzed years of the study. Note that there is very little overlap here compared to the overlap of locations.

The coming figures and tables will be color-coded based on the instances of repeats from the information provided in Figure 1 and Figure 2. Below is a legend showing these colors. If no color is present, the location or cultivar only appeared once in this four-year period of the study.

Legend:	4 repeats
	3 repeats
	2 repeats

In the next figures, yield for each cultivar at each planted location is detailed. The yield values are all in bushels per acre of farmed land.

All Values in Bushels/Acre	Stuttgart, AR	Griffin, GA	Harrisburg, IL	Brownstown, IL	Lafayette, IN 1	Lafayette, IN 2	West Lafayette, IN
	2012-2013	2012-2013	2012-2013	2012-2013	2012-2013	2012-2013	2012-2013
Branson	58.9	80.2	99.2	49.7	62.1	77.8	115.7
Bess	73.2	81.4	90.1	46.4	70.2		99.5
Shirley	76.4	71.6	101.5	67.2	60.1	80.3	111.7
MO080104	69.4	106.2	98.1	56.5	77.3	64.8	102.8
NC08-23324	50.4	100	62.6	59.6	50.7	56.5	75.3
KY03C-1237-32	66.5	110.4	102.7	58.9	65.4		98.8
KY03C-1002-02	72.8	105.7	98.4	51.8	77.9	80.7	87.7
VA08MAS-369	67.4	101.1	74.5	57.9	57.6	73.5	71.8
VA09W-73	72.4	117.7	78.2	55.4	50	49.2	64.2
VA10W-21	65.1	74.4	92.9	62.9	67.8	78.4	111.7
DANW1003	72.8	59.4	93.5	41.4	69.8	47.3	74
OH08-180-48	77.9	90.4	86.4	66.5	58.3	73	116.3
ARS07-0525	63.1	95.3	73.6	58.2	70.7	64.3	40.8
NC08-140	77.7	73.6	70.5	58.5	78.6	83	106.3
NC09-20768	56.8	91.8	81.8	60.6	63.5	73.9	81.4
OH08-172-42	66.8	53.9	99.8	61.7	68.9	65.8	87.2
OH07-264-35	66.9	105.8	106.1	64.1	67.3	64	84.6

Figure 4: Segment of table for yield at locations and cultivars grown in the 2012-2013 harvesting period. Black cells indicate compromised harvesting or planting of the cultivar. Data taken directly from the USRWWN database. Complete version found in Supplmentary Table 3.

There were a few problems this year regarding growth and harvesting. Data from Urbana, Illinois was said to be "not reliable due to a randomization error" (Bockelman 2013). In Lexington, "excessive moisture during grain fill and ripening caused test weights to plummet" (Bockelman 2013). Knoxville had a problem with fungal infection during their harvest as well (Bockelman 2013).

All Values in Bushels/Acre	Griffin, GA	Brownstown, IL	Champaign, IL	Harrisburg, IL	Urbana, IL	Battle Ground, IN	Lafayette, IN
	2013-2014	2013-2014	2013-2014	2013-2014	2013-2014	2013-2014	2013-2014
Branson	120.5	74.5	76.7	57.8	75.5	125.7	82
Bess	113.5	80.1	67.5	56.7	76.9	118.3	69.8
Shirley	83.4	64.1	44.2	45.1	65.6	124.5	70.8
MO080104	123.7	79.6	75.7	61.7	75.2	126.5	84.8
NC08-140	78	61.9	33.6	40.9	42	108.6	79.3
NC09-20768	103.3	58.4	19.2	38.7	50.9	108.3	72.8
OH07-264-35	99.7	79.5	57.2	53.2	59.5	115.3	72.8
IL07-19334	101.4	86.2	71.8	61.9	77.7	117.3	93.8
GA04121-11E26	100.9	70	34.1	38.3	43.1	109.1	68.6
MD04W249-11-7	113	87.3	39.3	50.2	56.5	109.6	83.4
VA11W-108	127.8	84.4	64.1	57.8	73.2	130.2	78.1
VA11W-230	125	83.4	50.4	46.5	56.1	117.6	79.3
VA11W-301	87.5	61.3	49.3	36.4	54.1	115.4	67.1
P0722A1-1-7	104.8	93.2	49.5	51	71	107.3	71.9
PP0762A1-2-8	107.3	97.6	68.3	51.1	67.8	134.1	79.3
P04620A1-1-7-4-17	115.9	84.9	63.2	52	76.7	118.5	79.7
LCS229	128.1	73.4	65.6	52.9	84.3	120.4	80.3

Figure 4: Segment of yield data from the 2013-2014 harvesting period. This period had no voided cells, as compared to the previous period, where there were two irreparably damaged harvest locations. Data taken directly from the USRWWN database. Complete version found in Supplmentary Table 4.

For the 2013-2014 harvesting period, the contributor states that they had a "very cold winter … 60+ inches of snow … but an 80+ degree warm but very dry period the last week of April and the first week of May" (Bockelman 2014). One of the underperforming trials, the Harrisburg trial, was described as follows: "Despite the severe winter, the nursery survived OK and trial precision was not as bad expected" (Bockelman 2014). The other trial mentioned in contributor notes was the Mead trial, which had "lots of rain before harvest" (Bockelman 2014).

All Values in Bushels/Acre	Marianna, AR	Griffin, GA	Brownstown, IL	Urbana, IL	Champaign, IL	Battle Ground,	Lafayette, IN
	2014-2015	2014-2015	2014-2015	2014-2015	2014-2015	2014-2015	2014-2015
Branson	72.1	66.2	73	107.4	102	77.5	87.2
Bess	46.2	65.8	77	107.4	96.4	70.9	84.8
Shirley	22.6	58	69.6	103.6	87.5	58.3	85.5
MO080104	67.1	66.5	79.7	105.2	101.7	70.5	91.3
P0762A1-2-8	71.1	77.5	81.4	107.6	100	62.4	94.2
NC10-23663	57	51.2	61.4	106.1	85.4	52.6	84
OH07-263-3	16.9	59.5	74.4	96.2	87.3	55.2	97.3
TN1505	47.5	74.3	76.2	99.7	98.4	54.5	86.1
VA11W-106	75.2	85.9	83.5	112.3	99.7	75.9	100.9
VA11W-182	48.5	74.8	75.8	99.2	97.6	52.4	90
VA12W-248	45.3	65.8	69.6	99	100.3	69.2	88.2
OH07-206-69	40.8	51.7	69.6	94.5	88.4	52.7	90.9
OH08-180-48	40	58	73.7	106.6	100.1	53.3	90.2
053A1-2-5-3-5-3	48.1	65.2	73.7	100.1	99.4	63	86.2
11405A1-4	45.9	74.2	68.7	101	92.3	60.6	85.1
MD09W272-8-4-13-3	29.1	59.1	62.5	84.7	76.7	61.9	73.4
MDC07026-F2-19-13-1	67.6	82.5	75.1	108.4	101	80.5	106.2

Figure 5: Segment of yield data from the 2014-2015 harvesting period. There are three voided plots here, all from Lexington. Data taken directly from the USRWWN database Complete version found in Supplmentary Table 5.

Contributor reports from the 2014-2015 period on the Mead location detailed the severe presence of stripe rust during their harvest. Reports from the Nairn location detail high winter kill as well as low temperatures present throughout the entire trial (Bockelman 2015), which contributed to low yield count compared to the overall numbers.

All Values in Bushels/Acre	Bella Mina, AL	Marianna, AR	Quincy, FL	Griffin, GA	Plains, GA	Champaign, IL	Battle Ground, IN
	2015-2016	2015-2016	2015-2016	2015-2016	2015-2016	2015-2016	2015-2016
AGS 2000	84.9	19	68.7	73.7	30.1	83.8	30.2
Jamestown	69.3	65.6	62.8	72	70.1	117.2	75.7
Hilliard	81.6	96.2	53.9	78	75.8	130.9	109.9
Pioneer Brand 26R41	82.2	85	60.3	62.1	65.2	144.3	107.3
VA12W-72	70.5	79.4	79.1	79	80.9	132.3	109.3
NC11-22289	62.5	58.9	58.8	59.7	55.8	107.2	82
NC10034-11	66.9	60.8	64.7	67.9	40.1	102.8	75.4
TX12D4768	68.2	60.2	75.6	60.7	64.7	109.3	53.2
TX-EL2	80.1	88.1	61.9	83.7	83.2	127.5	92.1
GA071012-14E6	78.3	72	73	69.3	80.8	107.7	40
GA051207-14E53	84	73.4	71.9	85.6	70.8	113.2	47.1
GA07353-14E19	79.3	74.3	87.9	91.7	89.5	112.5	42.8
GAJT141-14E45	85.3	69	69	83.5	79.7	121.4	84.1
TN1601	74.6	8.5	59.5	61.6	19.8	48.9	16.9
TN1602	79.8	21.8	64.4	68.6	16.6	65.5	30.7
TN1604	84.1	82.3	54.7	77.4	72.3	128.2	94
VA12W-68	77.1	80.6	71.2	77.9	85.1	129.8	96.3

Figure 6: Segment of yield data from 2015-2016, the final year analyzed in this study. This year, a new batch of seeds were introduced, with no overlap with the previous cultivars. Little initial problems were detected with this batch. Data taken directly from the USRWWN database. Complete version found in Supplmentary Table 6.

2015-2016 was a departure from the cultivars present in previous nurseries, with an entirely new set of seeds produced and grown. A few locations from previous years return, like Lexington and Knoxville. The most major problem with the year was the early onset of stripe rust. Even the best producing area, Champaign, Illinois, had problems with early winterkill as well as early onset of stripe rust (Bockelman 2016).

The next focus of this thesis is the temperature at each growth location per year. In the below figure, there is an average temperature per location over the months that the study stretches for. The data for the temperature values are taken from the National Centers for Environmental Information's climate data online search. In Supplementary Table 1, exact breakdowns can be found for each month that the observation period spanned, but, in Figure 7, the average temperature is displayed for brevity. Temperature values are all expressed in degrees Fahrenheit.

	Average Temperature at Location		
Griffin, GA	60.53541667	Marianna, AR	60.17142857
Lexington, KY	54.98043478	Stuttgart, AR	55.8875
Knoxville, TN	58.13333333	Lafayette, IN (2)	47.31
Blacksburg, VA	51.57659574	Webberville, MI	44.93
Warsaw, VA	60.20888889	Oconto, WI	43.26666667
Brownstown, IL	50.89375	Mason, MI	43.09090909
Lafayette, IN	48.26470588	New Haven, IN	46.27272727
Clarksville, MD	54.87058824	Logan County, KY	51.21111111
Columbia, MO	53.06764706	Ingham County, MI	42.92727273
Mead, NE	48.99722222	Bella Mina, AL	56.2875
Nairn, ON	44.43142857	Quincy, FL	66.5125
Arlington, WI	41.57714286	Plains, GA	58.34285714
Battleground, IN	49.13823529	Calhoun, KY	53.83333333
Champaign, IL	50.27941176	Schochoh, KY	56.82857143
Harrisburg, IL	51.14285714	Hopkinsville, KY	55.62857143
West Lafayette, IN	46.26	Baton Rogue, LA	63.01666667
Winsfield, KS	52.85	Winnsboro, LA	60.07142857
Custar, OH	44.79166667	Queenstown, MD	52.44444444
Urbana, IL	47.95909091	Brooksville, MS	57.12
Plymouth, NC	54	Milan, TN	55.925
Napoleon, OH	44.95909091		

Figure 7: Average temperature for the selected months and years of the study. When weather stations had insufficient data for the month, the value was omitted from the average. In Supplementary Table 1, these data points can be seen. This data is from the NWS historical weather database.

Results:

The main purpose of this nursery study was to tabulate the yield for each elite cultivar of wheat. This paper covers the final four years of the study, 2012-2015. In Figure 3, the 2012-2013 growth cycle, strong growth outliers are present at the West Lafayette location, Ithaca location, and Warsaw location. Particularly weak growth areas are found at the Brownstown, IL location, Columbia, MO location, and Knoxville. TN location.

As shown in Figure 4, the 2013-2014 growth cycle, yield data from this location was, on average, higher than the yield from the year before. While there are a multitude of factors that could have caused this, during this year, the contributors had comparatively fewer problems with climate than the year before. The highest-performing trial of this year was in Battle Ground, Indiana, and other extremely high yield locations were Griffin, GA, Ithaca, NY, and Blacksburg, VA.

From the data presented in Figure 5, the 2014-2015 growth cycle, it is observed that data on yield from this period was similar to the yield in 2012-2013 (Figure 3). Notable negative outliers from 2014 to 2015 were the Mead location, the Columbia location, and the Nairn location. Positive outliers from this growth season were Arlington, WI, Champaign, IL, and Logan County, KY.

The information provided for 2015-2016 (Figure 6) shows that, when looking at the entire sample on a year-by-year scale, this year had the lowest average yield by a fairly large margin. These locations had no overlap in terms of cultivars studied, so this likely has something to do with the yearly yield decrease. When looking at all four growth periods present, the 2013-2014 growth period had the highest yields, while the 2015-2016 period had the lowest yields. The 2012-2013 and 2014-2015 growth periods had similar average yields.

Figure 8 is derived from Figures 3, 4, 5 and 6, and shows the average yield of all cultivars planted at a singular location over the entire 4-year scope of the study.

	Average Yield Per Location
Griffin, GA	84.02746479
Lexington, KY	72.92517986
Knoxville, TN	72.15492958
Blacksburg, VA	80.26338028
Warsaw, VA	79.59014085
Brownstown, IL	68.49507042
Lafayette, IN	76.67522936
Clarksville, MD	76.07798165
Columbia, MO	53.7559633
Mead, NE	45.89082569
Nairn, ON	62.29266055
Arlington, WI	88.18440367
Battleground, IN	87.42135922
Champaign, IL	86.42815534
Harrisburg, IL	69.24230769
West Lafayette, IN	81.98857143
Winsfield, KS	64.89861111
Custar, OH	63.02285714
Urbana, IL	82.76857143
Plymouth, NC	52.59305556
Napoleon, OH	79.33

Marianna, AR	57.7859375
Stuttgart, AR	69.00512821
Lafayette, IN (2)	68.36756757
Webberville, MI	64.34102564
Oconto, WI	73.35897436
Mason, MI	70.40512821
New Haven, IN	79.65483871
Logan County, KY	91.03225806
Ingham County, MI	72.52258065
Bella Mina, AL	77.14545455
Quincy, FL	64.06666667
Plains, GA	61.57878788
Calhoun, KY	75.46363636
Schochoh, KY	70.35757576
Hopkinsville, KY	69.46363636
Baton Rogue, LA	34.66969697
Winnsboro, LA	44.54848485
Queenstown, MD	62.30909091
Brooksville, MS	53.46666667
Milan, TN	56.54242424

Figure 8: Calculated average yield numbers per viable location found in the study. The left section shows all locations that participated in more than one year of the study while the right section shows only the locations that participated in one year of the study.

Figure 9 is also derived from Figures 3, 4, 5 and 6, and shows average yield, calculated firstly for each cultivar, then average yield was also calculated for each location in the study.

All Values in Bushels/Acre	Average Yield Across All Locations and Periods
Branson	79.85
Bess	74.37692308
Shirley	75.45757576
MO080104	81.66363636
NC08-23324	66.82380952
KY03C-1237-32	77.285
KY03C-1002-02	78.55238095
VA08MAS-369	72.41428571
VA09W-73	69.31904762
VA10W-21	78.7047619
DANW1003	68.99047619
OH08-180-48	72.18863636
ARS07-0525	65.9952381
NC08-140	69.87857143
NC09-20768	69.30714286
OH08-172-42	67.78571429
OH07-264-35	73
IL07-4415	69.35714286
IL07-19334	79.43333333
VA11W-108	86.90952381
VA11W-230	81.65714286
VA11W-301	76.48571429
P0722A1-1-7	78.29047619
PP0762A1-2-8	80.38888889
P04620A1-1-7-4-17	82.49047619
LCS229	82.74761905
LCS321	83.69047619
MO120187	79.59047619
MO110799	84.35238095
KWS023	85.05238095
KWS024	83.83809524
KWS025	81.06190476
OK109143CF	72.68095238
OK11311F	72.7
OK11754WF	72.55238095
IL09-3264	82.59047619
IL07-18533-3	81.1952381
KY03C-1237-12	76.12380952
KY03C-1237-05	80.73333333
MD05W10208-12-16	76.4047619
NC10-23663	68.98222222
OH07-263-3	79.35333333
OH08-235-33	76.27619048
AR00179-2-2	78.44285714
AR04015-5	75.95714286
MSU Line F0013R	71.92857143
MSU Line F0036R	76.13333333
MSU Line F1026R	76.5952381
TN1505	73.92083333
VA11W-106	78.9375
VA11W-182	70.59166667
VA12W-248	71.58333333
OH07-206-69	61.58695652
053A1-2-5-3-5-3	70.8875
11405A1-4	67.9625
MD09W272-8-4-13-3	59.7
MDC07026-F2-19-13-1	81.27916667
MDC07026-F2-19-13-4	77.12083333
F2024R	70.9375
F2029R	70.72916667
MO 110201	75.65416667

IL07-20728	67.06666667
KWS008	75.08571429
KWS009	74.9
KWS010	73.59047619
AR00255-16-1	65.07142857
AR01209-2-1	69.00952381
KY03C-1237-39	75.72380952
LCS10516	71.35238095
LCS19228	77.70952381
LCS19229	77.9952381
GA04121-11E26	69.00238095
GA04434-11E44	68.65238095
P04606RA1-1-7-1-6-3	67.68095238
P05247A1-7-3-121	76.0047619
P05222A1-1-2-7	71.2047619
DANW1006	68.57142857
DANW1008	74.47142857
MD04W249-11-7	76.73333333
MD04W249-11-12	74.73809524
MD04W249-11-16	70.04285714
MO 121058	80.30833333
ES12-1049	76.9125
ES12-1307	76.50833333
AR05094-4-1	77.3125
AR05079-2-1	75.52083333
KY05C-1369-14-6-3	65.62916667
KY05C-1051-37-18-5	69.67916667
IL02-19463-7	65.5
IL10-19464	70.49166667
IL10-21934	76.40833333
AGS 2000	54.26086957
Jamestown	65.64782609
Hilliard	76.54782609
Pioneer Brand 26R41	71.6826087
VA12W-72	74.7
NC11-22289	57.29130435
NC10034-11	63.33043478
TX12D4768	60.74782609
TX-EL2	74.22608696
GA071012-14E6	62.71304348
GA051207-14E53	68.17391304
GA07353-14E19	71.43043478
GAJT141-14E45	69.85652174
TN1601	44.52173913
TN1602	54.20869565
TN1604	73.10869565
VA12W-68	76.49130435
VA13W-38	64.80434783
VA13W-124	72.29565217
KWS 060	54.05217391
KWS 081	51.54347826
KWS 083	51.37391304
LA08090C-9-2	61.88695652
LA08115C-30	59.92173913
LA09011UB-2	63.54782609
DH11SRW8-48	66.96086957
ES14-0618	47.81304348
AR06473-9-4-4	68.12608696
AR06024-7-2	55.77391304
MD09W272-8-4-13-3-15	73.32173913
MD09W272-8-4-14-6	72.56521739
MD09W272-8-4-14-8	72.8173913
MD07W478-14-5	67.6173913

Figure 9: Calculated average yield values over the entire four-year period for each individual cultivar. There was a slight number of cultivars that persisted over the years, which is indicated by the color the cell was coded.

In order to find a novel solution that would increase yield of wheat by changing the cultivar of wheat grown in South Carolina, a few graphs were generated to better understand and interpret the data shown in the previous section. We are mainly interested in the relationship between yield and a few different factors. For example, correlating Figure 8 on average temperatures at growing locations and Figure 7 on average yields in those locations could reveal a relationship between the average temperature and the average harvested yield of the cultivar. These factors will be needed to generate a list of ideal wheat cultivars that can match the temperature profile of South Carolina and allow for a suggestion as to which wheat cultivars will best fit the Richland area.

From Figure 8 and the standard deviation values found in Supplementary Table 2, a graph can be generated that shows the strongest performers from the period of the paper, 2012-2015.

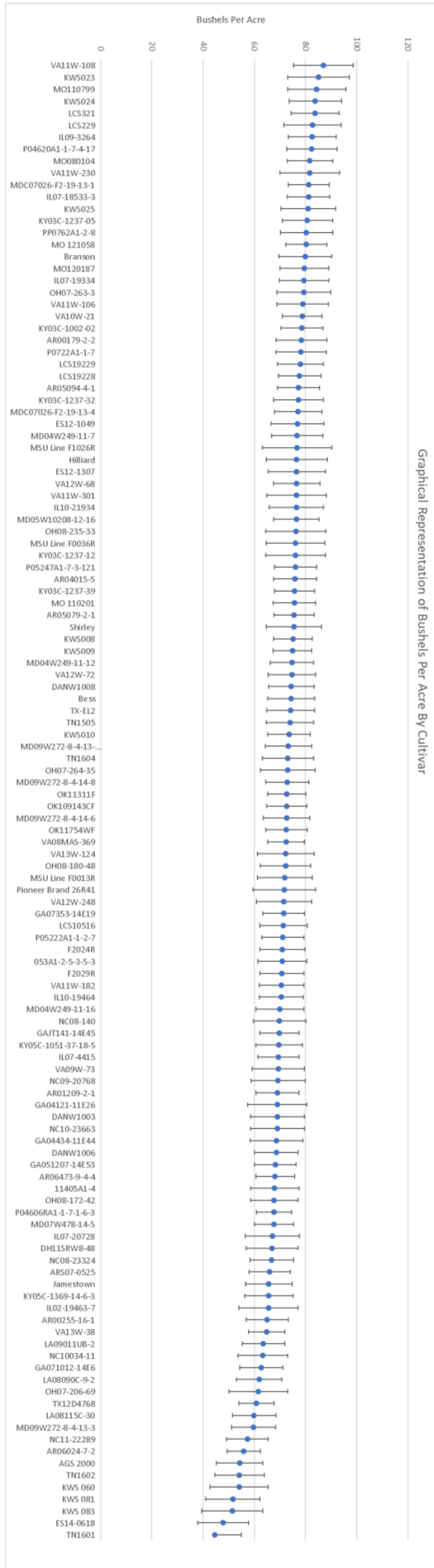

Figure 10: Graphed values of average yield per yield. Error bars are calculated standard deviation values, exact values of which can be found in Supplementary Table 2.

From the above graph, it can be seen that the VA11-W-108 cultivar of wheat was the best performer from the four years encompassed in this study. The TN1601 cultivar of wheat was the worst performer by a large margin. The values are clumped together, so it would be best to take multiple cultivars at the top end of the chain into the next step of the process. The error bars found on the graph are generated based on standard deviation, which can be found in Supplementary Table 2.

After looking at the yield agnostic of any outside factors, it becomes important to figure out which temperature-related factors will have any sort of correlation towards the yield shown in the above graph. From the data section, three different types of temperature factors were generated. The first temperature factor is the average temperature throughout the trial. The second is the lowest temperature present during the months of the trial. The final is the highest temperature present during the trial. These factors were compared to the calculated average yield per location as temperature is a function of location, not a function of the cultivar of wheat planted at that location. The graph generated by the first temperature factor is a scatter plot of the values from Figure 7 and Figure 9 and is shown below:

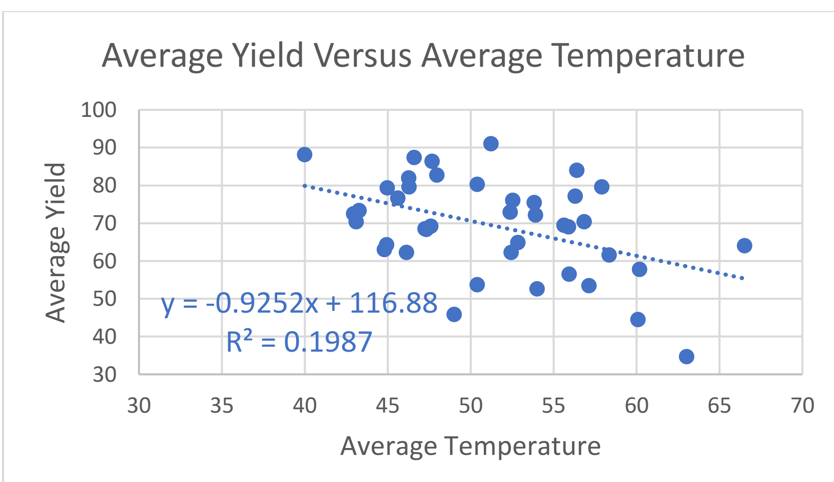

Figure 11: Average Temperature Versus Average Yield graph, where temperature is in Fahrenheit and Yield is in Bushels/Acre. A slight negative correlation is observed.

The above graph generated a trendline that suggests a slight negative correlation between the average temperature and the average yield of the location. This slight negative correlation is partially supported by the R^2 value of 0.1987, suggesting a chance at a correlation. This implies that the trend is that, generally, the colder the location is, the better winter wheat grows. However, the small value of the slope and general distribution of the data points may also suggest that there is no strong correlation between the average temperature and average yield, at least in a sample of this size. The next graph generated is based on the second temperature factor, the absolute lowest temperature during the trial.

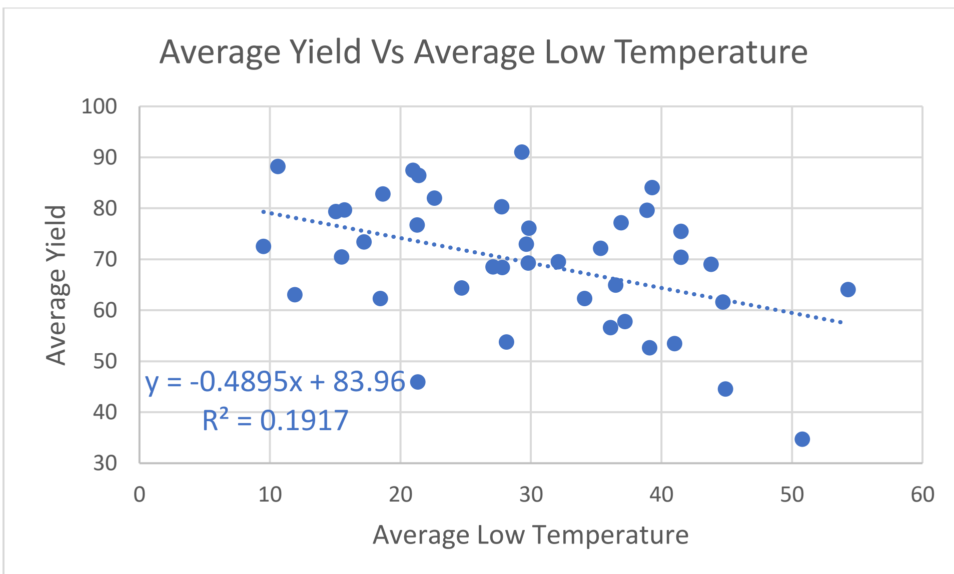

Figure 12: A graph of Average Yield vs Average Low Temperature. A slight negative correlation is observed.

Low-temperature readings give a good approximation of extended exposure to freezing temperatures as well as different levels of winter kill. These levels of winter kill were mostly detailed in the contributor notes, but the notes were not all-encompassing. The trendline in this graph also tends to favor the lower temperatures, with a negative correlation as the temperature gets higher. The R-squared value is fairly low, at 0.1917. This is either due to no apparent correlation or a lack of sample size in the study. The final results graph, shown below, created in this study is the correlation between the average yield and the absolute high temperature in each of the locations of the study.

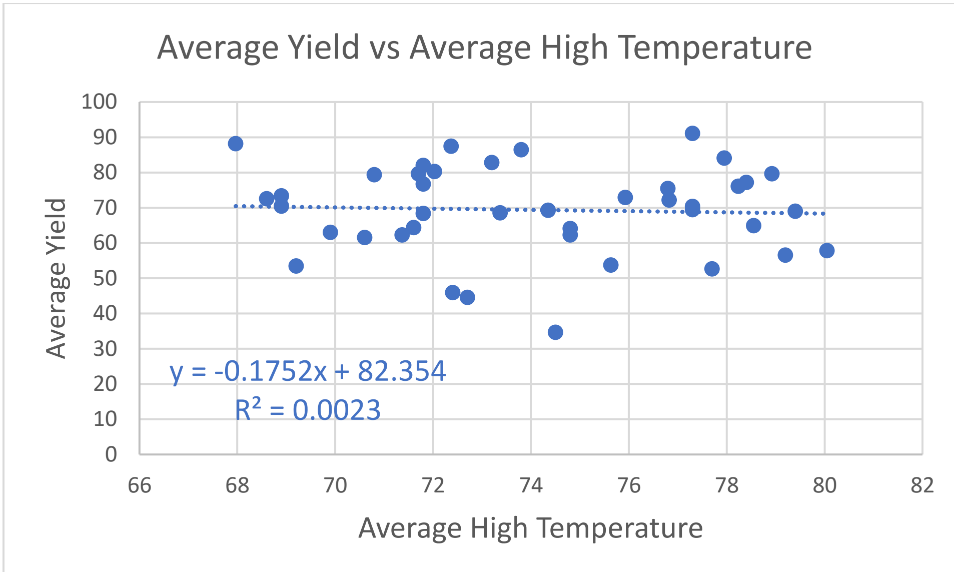

Figure 13: A graph of Average Yield versus Average High Temperature. No correlation is observed here.

The above graph shows the relationship between the average yield and the average high temperature of each location that participated in this study. An R-squared value close to 0, suggests the presence of zero correlation in the absolute high temperatures of a location, at least in the range of this study. Since the R^2 value is so small, it is not worth looking into the slope of the generated trendline.

From Figures 11 - 13, the two factors with any kind of correlation to average yield seem to be average temperature and average low temperature. The two generated equations from the trendlines are as follows:

Average Temperature: $y = -0.9252x + 116.88$

Average Low Temperature: $y = -0.4895x + 83.96$

In order to propose a solution to which elite wheat cultivar would best perform in South Carolina, the temperature values for the state are needed. These values are shown in Figure 13.

Columbia, SC													
Year	January	February	March	April	May	June	July	August	September	October	November	December	Average
2012	49.4	52.2	65.4	67	75.4	77.5	85	80.4	75.5	65	52	52.5	66.4
2013	52.5	47.7	51	65	70.4	79.1	80.5	79.3	76.2	66.3	52.7	51.5	64.4
2014	40.3	48.9	52.2	65.6	74.3	82	83	82	76.7	66.8	50.5	50	64.4
2015	44.7	43.1	58.6	67	73.5	82.6	85.3	82.6	76.7	64.6	59	60.1	66.5
2016	44.3	49	62.4	65.9	72.7	83	87.2	84.3	79.4	68.3	56.2	49.7	66.9

Figure 13: Temperature Values by Month for the weather station nearest Columbia, SC, the capital of South Carolina and where this study is being written from.

More values that are needed for the approximation are shown as follows:

Average Temperature: 62.57 ± 13.47 Degrees Fahrenheit

Average Low Temperature: 43.85 ± 3.07 Degrees Fahrenheit

Average temperature was calculated by taking the average of the cells shaded in green, while the average low temperature was calculated by referring to Supplementary Table 2 and taking the average of the lowest average temperature shown in the table. Values that follow the average temperature are calculated standard deviation values. Plugging these numbers into the equations provided on page 18 gives us an average yield of 58.99 ± 12.46 bushels per acre predicted from the average temperature calculation and a yield of 62.49 ± 1.50 bushels per acre. The location that matches the given temperature numbers most closely, as well as include a large sample size, is Warsaw, VA. Since Columbia, S.C. matches Warsaw, VA closely in temperature, the best performing cultivars of wheat there should produce similarly strong results in the Columbia area.

	Warsaw, VA	
GA04434-11E44	117.2	
Shirley	99.3	9.1994565
Branson	91	16.168797

Figure 14: Top three performers from Warsaw, VA over all 3 years of the study. Column 2 is average yield, whereas column 3 is standard deviation. GA04434-11E44 has no standard deviation, as it only appears once in the study.

Given the data from Figures 14, 6, 5, 4, and 3 on the best-performing cultivars of wheat in Warsaw, the best-performing strand for Columbia, SC's temperature climate should be the GA04434-11E44 cultivar, given its extremely high output of 117.2 bushels per acre. When accounting for sample size constraints, it may be worthwhile to test both the Shirley and Branson strands, due to their three standard deviation mean being a range that could be larger than the GA04434-11E44 yield.

Limitations:

Given the circumstances of this study, there are many limitations. This study only covers the final four years of the nursery. Increasing the sample size to the entire sample, at around 16 years total, would allow for significantly more data. More locations could be included, which gives more temperature and yield readings. Cultivars could be reintroduced into the pool to provide data on which of them has the highest yield as well. More data would lead to a result that would be more based on fact. Temperature readings at the government weather stations were not entirely accurate to the exact area the wheat plants were grown, with a few miles of distance between them. While this is a reasonable solution, exact temperature readings from contributors could be crucial in finding a correlation. Temperature values vary throughout the areas selected for the nursery, so the weather readings are likely not entirely accurate. Ideally, in conjunction with the increased sample size, data with factors affecting yields like severe stripe rust fungus or weather-related problems can be eliminated, in order to have the purest set of results.

Conclusion:

In this study, I showed that average high temperatures had little to no bearing on the average yield of elite winter wheat cultivars. I also found that there was a slight negative correlation between yield and average temperature/average low temperature. To specify, the lower the average temperature, the higher the yield and the lower the average low temperature, the higher the average yield of these winter wheat cultivars. This information is supported by other contemporary studies such as the work done by Huang et. al. Their work explores the idea that temperature increases due to global warming negatively effects yield of winter wheat in the largest winter wheat producer in the world, China. My thesis tends to be supported by this as well, since, as a rule of thumb, the lower the temperatures were tended to be correlated with higher yield.

Even though the R^2 number was low, it indicated a weak correlation. This correlation allowed for a suggestion into what the best cultivars would be, in terms of temperature, for Columbia, SC. The cultivar selected was the GA04434-11E44 strand.

Given this information, and if this information is accurate, all suitable wheat cultivars in the greater Columbia area could be replaced by this strand of wheat. The average wheat crop in the United States during the period of this study, 2013-2016, produced approximately 40.2 bushels per acre (U.S. Wheat n.d.). Although the sample size is small, the GA04434-11E44 strand of wheat produced 117.2 bushels per acre, an approximately 190% increase in the yield of this cultivar over average wheat cultivars. While this is very optimistic, it is evident that there is ample room for higher-producing cultivars. Increasing the yield of the cultivars opens many different possibilities for what can be done. Some of the existing wheat cultivars could be replaced by other cultivars, increasing the yield of wheat per acre. Another option is to keep the amount of land used to plant the same. This would still lead to an increase in the amount of wheat produced total and a higher economic boon for the state of South Carolina.

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