STARTER FERTILIZER PLACEMENT AND RATES FOR NO-TILLAGE WINTER WHEAT PRODUCTION

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INTRODUCTION

Producers who seek to take advantage of the labor and machinery savings possible with no-tillage (NT) small grain production have largely overcome seeding problems by using seeders capable of producing uniform crop stands, even planting into large amounts of residue, i.e. high-yield corn stover. However experiences and research from Virginia and the Piedmont and Coastal Plain regions of North Carolina have shown that winter growth and tillering was lower with NT production (Weisz and Bowman, 1999). This same effect of lower tiller production has been found to exist in NT spring wheat (Chevalier and Chia, 1986). Planting up to one week earlier than the date recommended for conventional wnter wheat is one common method to increase fall growth, however this rarely results in tiller numbers equal to those in conventional plantings. Earlier planting also increases the likelihood of early maturity in spring and the chance for freeze damage. An additional management strategy to enhance no-till small grain yields is to increase preplant nitrogen (N) rates by 10-15 lb/ac and apply 15-30 lb/ac in early winter. However, this increases the cost of production, especially with increased N fertilizer costs, and can also increase the likelihood of spring and winter freeze damage.

Research with no-till corn in Virginia has shown a clear advantage to applying N and P in close proximity to the seed and below the surface residue levels (Alley and Martz, 1997). For no-till winter wheat, supplying fertilizer nutrients in close proximity to the seed at planting, and below the surface residue may increase fall tiller and root system development and lead to higher yields. While not directly measuring grain forming tillers, Boman et al. (1992) found increased total season wheat forage yield due to seed-banded phosphorus (P) fertilizer on acid soils with high soil test P levels. Wheat forage yields were increased due to banding P in Texas, especially in dry years (Miller, 1998). Goos and Johnson (2001) found increased tillering, early growth, and P uptake when P fertilizer was placed in-furrow at planting. Nitrogen placed in furrow has also been shown to increase growth, tiller production, and grain yield in studies conducted in Arizona (Clark and Carpenter, 2002).

Finally, nutrient placement is the only process available with the potential to counter the problem of slow fall growth and limited tiller development in no-till winter wheat. The surface residue needs to remain in place and will absorb heat that would be available in the soil for fall seedling growth and development. Increased nutrient supplies close to the seed may stimulate more efficient utilization of available heat units.

The objectives of this research were to evaluate wheat tiller density, and grain yield response to at-planting fertilizer placement method, and to determine the effect of starter fertilizer rates, nutrients, and combinations placed with the seed at planting on wheat tiller density, grain yield, and yield components.

MATERIALS AND METHODS

A seven row Great Plains no-till drill was equipped with a liquid fertilizer delivery system that enabled placement of fertilizer solutions in the following positions: (1) behind the no-till coulter and in front of the double-disk opener(IC); (2) between the double-disk opener with a Keaton brand seed firmer (DD); and (3) over the row behind the press wheel (BP). The system was pressurized with carbon dioxide and utilized three manifolds (one for each placement treatment) equipped with quick-couplers to enable changes to be made between plots. Fertilizer solutions for each treatment were mixed and placed in 3 three liter plastic bottles that were connected to the system by a screw top and stainless steel "straw". The bottles were pressurized from the top and the fertilizer solutions flow from the bottom of the bottle through the straw to the manifold. Fertilizer application rates were regulated by stainless steel metering orifices within each tube leaving the manifold. This arrangement provided uniform flow to all rows.

Rate and placement experiments were established at the Eastern Virginia Research Center near Warsaw, VA in the 2006, 2008 and 2009 harvest seasons, the L. C. Davis and Sons Farm in New Kent County in 2006 and the Jason Benton Farm in Middlesex County in 2008 and 2009. The fertilizer placement methods trials were planted on Oct. 12, 2005, Oct 16, 2007, and Oct 14, 2008 at Warsaw, VA, on Oct. 13 at New Kent County and on Oct 16, 2007 and Oct 15, 2008 at Middlesex County. All sites are in the Virginia Coastal Plain on soils utilized for grain crop production. 'McCormick' wheat was seeded at 27 seeds per foot of row in all experiments. Plants established per ft^2 at GS 15, tillers per ft^2 at GS 25, tillers per ft^2 at GS 30, heads ft^2 at GS 75, grain yield, and test weight as influenced by the various placement methods and the fertilizer materials were measured in all studies.

Data from placement studies were subjected to analysis of variance. Due to interaction effects of treatments across sites and years, each experimental location was analyzed and presented separately. Mean comparisons using a protected LSD test were made to separate tillage treatments and cultivars where F-tests indicated that significant differences existed ($P<0.05$).

Single degree of freedom contrasts were developed to test for trends in response to increasing N or P rates as well as the impact of potassium thiosulfate (KTS) application. Treatment means and analyses are presented by site.

RESULTS AND DISCUSSION

EXPERIMENT 1—FERTILIZER PLACEMENT METHODS

2005-06

Fertilizer placement at rates of 25 and 33 lbs of N per acre along with phosphorus (25 or 17 lbs P_2O_5) and potassium (8 lbs K_2O) did not influence stand establishment. However, N rates up to 60 lbs N/acre tended to decrease plants established (Tables 1 and 2) Phosphorus and potassium thiosulfate applications did not influence stand establishment. Visual observations in January showed improved growth for fertilizer placed with the seed compared to broadcast treatments, but no large differences were observed for tiller numbers at growth stage (GS) 25 or GS 65 (Tables 1 and 2).

No significant differences were seen between treatments for plants ft^2 at GS 15 at the New Kent site. The variation in the data reflects the difficult planting environment caused by heavy residue at this site. Heads per ft^2 at GS 65 were significantly lower in the check treatment than for all plots receiving the fall fertilizer treatments, but the fertilized treatments did not differ significantly (Table 1). Grain test weight was not influenced by fertilizer source or placement method. Grain yield was highest, 93 bu/ac for a broadcast application of 33-17-8-5.5. Treatments yielding significantly less than this were the check, 33-17-8-5.5 applied between the double disc openers, and those treatments applied behind the press wheels, regardless of rate (Table 1).

Plants per ft^2 at the Warsaw site did not show as much variation as at the New Kent location, but the broadcast treatment of 25-25-8-5.5 showed significantly lower plants established than two of the other treatments (Table 2). Examination of the data revealed that one replication had a much lower value (13 plants ft^2) than the other 3 replications. However, we have no reason to discard this plot and thus we have a significant difference that does not have biological explanation. The broadcast treatment should have the least effect on plant establishment of any of the fertilizer treatments because the fertilizer is least concentrated with respect to the seed. This appears to be a random occurrence. Tiller counts made at the Warsaw site at GS 25 showed the check plot treatment having significantly lower tillers per ft^2 than the other treatments, although there is variation in these numbers. Heads per ft^2 at GS 75 showed the check plot having lower head numbers as did the injection coulter (IC) and the behind the press wheel (BP) treatments (Table 2). Grain test weight did not differ due to source or fertilizer placement. Likewise, no differences in grain yield were found.

2007-08

Plants ft^{-2} and tillers per unit area were highest for the Grower Standard at Middlesex (Table 3). This relationship did not continue late-season, as the number of heads ft^{-2} at harvest were less than for most other treatments. The number of kernels per head was proportionally high and was similar to the effect of applying 33-17-8-5.5 behind the press wheels which also produced relatively lower head numbers at harvest. At Warsaw, there was no effect of treatment on early season plant stand, but the Grower Standard, 25-25-8-5.5 applied broadcast, 33-17-8-5.5 applied between the disc openers using seed firmers, and the check all had GS 30 tiller numbers higher than the other treatments (Table 4). Injecting 25-25-8-5.5 behind the cutting coulter produced the highest grain yield of 80.6 bu ac^{-1} at Middlesex in 2008 (Table 4). Application of 25-25-8-5.5 or 33-17-8-5.5 DD or 33-17-8-5.5 BP resulted in grain yields that were significantly higher than the check (Table 3). At Warsaw, grain yield of the two broadcast treatments were significantly lower than the other treatments (Table 4). Grain test weight at Warsaw was highest for 33-17-8-5.5 applied either DD or IC (Table 4) while grain test weight was not significantly affected by treatment at the Middlesex site.

EXPERIMENT 2 – STARTER FERTILIZER RATES

2005-06

This experiment was planted at the same time and with the same planter as Experiment 1. At the New Kent location, plants per ft^2 decreased with increasing N rate, with the major reduction in plants occurring at the 45 and 60 lbs N/acre rates (Table 5). Phosphorus rate increase resulted in greater plants per ft^2, greater tiller numbers at both GS 25 and GS 30 and more heads. This did not result in a grain yield increase, however (Table 5). Grain yield was ultimately not affected by rates of N, K, or S.

Plants ft^2 at GS 15 at Warsaw showed little influence of fertilizer treatment (Table 6). Tillers per ft^2 at GS 25 increased from 29 in the check plot to 56 with increasing N rate. The treatment that did not receive the potassium thiosulfate application had lower tiller numbers per ft^2 at GS 25 indicating a potential benefit to this application in the starter fertilizer (Table 6). Fifteen to 30 lb per acre of phosphorus resulted in greater tiller numbers at GS 30 compared to those plots receiving no phosphorus. Heads per ft^2 at GS 75 were similar across fertilizer rates. Grain yield increased in a linear fashion with P rate, from 76 to 84 bushels per acre (Table 6). Grain test weight was unaffected by treatment.

2007-08

At the Middlesex site, there was a significant linear increase in plants ft^{-2}, GS 30 tillers, and grain yield in response to increasing N rate (Table 7). There was also a concurrent linear decrease in individual kernel weight with increasing N rate. Application of KTS resulted in significantly lower grain yield at this site when compared only to plots also receiving 30 lb ac^{-1} of N and P_2O_5 (Table 7). However grain yield for a number of other treatments also receiving KTS were not different from the highest yield. Yield components for plots receiving 30 lb ac^{-1} of N and P_2O_5 with and without KTS were not different. At Warsaw, there was a significant linear response to N for heads per unit area at harvest and grain yield. Grain yield increased at a rate of 0.1 bu ac^{-1} per additional lb of N applied, up to 60 lb ac^{-1} (Table 8). There was also a linear decrease in grain protein with increasing P application (Table 8). This effect is likely of little consequence, since values ranged only from 11.1 to 11.7 which is in an acceptable range for soft red winter wheat. The addition of KTS resulted in greater heads at harvest but lower number of kernels per head, which is the generally expected relationship among these yield components.

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Table 1. Wheat vegetative, grain yield, yield component, and grain protein response to starter fertilizer placement in no-till wheat, New Kent County, 2005-06. Nutrient sources are ammonium polyphosphate, urea-ammonium nitrate solution (30%N), and potassium thiosulfate solution (0-0-25-17S).

Fertilizer Placement	Source	Nutrients Applied N-P-K-S	GS 15 Plants	GS 25 Tillers	GS 30 Tillers	GS 75 Heads	Kernels head^{-1}	Weight kernel^{-1}	Grain Yield	Test Weight	Grain Protein
		-----lb/ac-----	plants/ft^2	tillers/ft^2	tillers/ft^2	heads/ft^2		oz	bu/ac	lb/bu	---%---
DD	15-15-5-3.3S	25-25-8-5.5	18	38	49	68	21	1.23	88.5	62.0	12.08
IC	15-15-5-3.3S	25-25-8.5.5	17	38	48	63	19	1.26	80.2	62.2	11.83
BP	15-15-5-3.3S	25-25-8.5.5	19	42	52	63	15	1.24	73.4	62.3	11.92
Broadcast	15-15-5-3.3S	25-25-8-5.5	18	42	50	70	18	1.24	80.2	62.0	12.15
DD	20-10-5-3.3S	33-17-8-5.5	20	46	55	63	16	1.24	71.8	62.0	11.91
IC	20-10-5-3.3S	33-17-8-5.5	14	32	38	69	17	1.23	87.8	62.0	12.03
BP	20-10-5-3.3S	33-17-8-5.5	15	33	42	70	16	1.23	71.1	61.9	11.88
Broadcast	20-10-5-3.3S	33-17-8-5.5	16	38	45	63	18	1.24	82.6	62.3	12.26
Check	0-0-0-0	0-0-0-0	21	48	59	71	17	1.24	78.7	61.9	11.61
Grower Standard	15-15-5-3.3S BC at Planting + 25 lbs N BC Dec	25-25-8.5-5.5 + 25	18	40	50	56	17	1.24	89.4	62.0	12.27
LSD 0.05			6	2	3	16	4	0.03	21.3	0.5	0.26

DD = Between double disc openers.
IC = With NT injection coulter in front of the double disc openers.
BP = Behind press-wheel, over the row.

Table 2. Wheat vegetative, grain yield, yield component, and grain protein response to starter fertilizer placement in no-till wheat, EVAREC, Warsaw, VA, 2005-06. Nutrient sources are ammonium polyphosphate, urea-ammonium nitrate solution (30%N), and potassium thiosulfate solution (0-0-25-17S).

Fertilizer Placement	Source	Nutrients Applied N-P-K-S	GS 15 Plants	GS 25 Tillers	GS 30 Tillers	GS 75 Heads	Kernels head^{-1}	Weight kernel^{-1}	Grain Yield	Test Weight	Grain Protein
		-----lb/ac-----	plants/ft^2	tillers/ft^2	tillers/ft^2	heads/ft^2		oz	bu/ac	lb/bu	---%---
DD	15-15-5-3.3S	25-25-8-5.5	25	59	69	64	24	1.20	83.2	61.3	11.89
IC	15-15-5-3.3S	25-25-8.5.5	24	53	64	69	31	1.19	85.0	61.5	12.13
BP	15-15-5-3.3S	25-25-8.5.5	22	50	51	68	21	1.19	85.3	61.6	11.93
Broadcast	15-15-5-3.3S	25-25-8-5.5	28	50	69	64	24	1.19	84.1	61.2	12.14
DD	20-10-5-3.3S	33-17-8-5.5	27	57	66	63	26	1.20	86.4	61.3	11.95
IC	20-10-5-3.3S	33-17-8-5.5	22	50	46	68	29	1.18	75.7	61.2	11.67
BP	20-10-5-3.3S	33-17-8-5.5	24	66	62	65	30	1.15	82.0	61.7	12.14
Broadcast	20-10-5-3.3S	33-17-8-5.5	19	61	66	67	30	1.19	81.6	61.5	12.25
Check	0-0-0-0	0-0-0-0	22	30	58	60	25	1.20	84.0	61.5	12.40
Grower Standard	15-15-5-3.3S BC at Planting + 28 kg N ha^{-1} BC Dec	25-25-8.5-5.5 + 25	25	59	55	68	24	1.21	84.1	61.5	12.21
LSD 0.05			6	2	3	16	7	0.04	8.4	0.4	0.49

DD = Between double disc openers.
IC = With NT injection coulter in front of the double disc openers.
BP = Behind press-wheel, over the row.

Table 3. Wheat vegetative, grain yield, yield component, and grain protein response to starter fertilizer placement in no-till wheat, Middlesex County, VA, 2007-08. Nutrient sources are ammonium polyphosphate, urea-ammonium nitrate solution (30%N), and potassium thiosulfate solution (0-0-25-17S).

Fertilizer Placement	Source	Nutrients Applied N-P-K-S	GS 15 Plants	GS 30 Tillers	GS 75 Heads	Kernels head^{-1}	Weight kernel^{-1}	Grain Yield	Test Weight	Grain Protein
		-----lb/ac-----	plants/ft^2	tillers/ft^2	heads/ft^2		oz	bu/ac	lb/bu	---%---
DD	15-15-5-3.3S	25-25-8-5.5	17	43	49	29	1.19	77.8	61.3	10.30
IC	15-15-5-3.3S	25-25-8.5.5	18	43	49	30	1.20	80.6	61.2	10.01
BP	15-15-5-3.3S	25-25-8.5.5	18	46	49	29	1.18	77.5	61.1	10.63
Broadcast	15-15-5-3.3S	25-25-8-5.5	16	44	50	28	1.17	74.0	61.2	10.59
DD	20-10-5-3.3S	33-17-8-5.5	16	47	50	29	1.20	78.7	61.3	10.40
IC	20-10-5-3.3S	33-17-8-5.5	18	40	49	29	1.20	77.2	61.3	10.55
BP	20-10-5-3.3S	33-17-8-5.5	20	43	48	31	1.16	78.6	61.3	9.88
Broadcast	20-10-5-3.3S	33-17-8-5.5	17	42	50	28	1.18	74.0	61.2	10.40
Check	0-0-0-0	0-0-0-0	17	49	49	29	1.18	77.6	61.2	10.76
Grower Standard	15-15-5-3.3S BC at Planting + 25 lbs N BC Dec	25-25-8.5-5.5 + 25	22	54	47	31	1.18	76.9	61.1	10.55
LSD 0.05			3	6	1	1	0.10	1.0	0.6	0.27

DD = Between double disc openers.
IC = With NT injection coulter in front of the double disc openers.
BP = Behind press-wheel, over the row.

Table 4. Wheat vegetative, grain yield, yield component, and grain protein response to starter fertilizer placement in no-till wheat, EVAREC, Warsaw, VA 2007-08. Nutrient sources are ammonium polyphosphate, urea-ammonium nitrate solution (30%N), and potassium thiosulfate solution (0-0-25-17S).

Fertilizer Placement	Source	Nutrients Applied N-P-K-S	GS 15 Plants	GS 30 Tillers	GS 75 Heads	Kernels head^{-1}	Weight kernel^{-1}	Grain Yield	Test Weight	Grain Protein	
		-----lb/ac-----	plants/ft^2	tillers/ft^2	heads/ft^2		oz	bu/ac	lb/bu	---%---	
DD	15-15-5-3.3S	25-25-8-5.5	27	54	41	33	1.17	71.7	57.3	10.69	
IC	15-15-5-3.3S	25-25-8.5.5	26	52	42	33	1.17	73.3	58.4	11.30	
BP	15-15-5-3.3S	25-25-8.5.5	26	54	44	31	1.18	71.9	57.7	11.13	
Broadcast	15-15-5-3.3S	25-25-8-5.5	27	55	45	29	1.16	68.9	55.7	11.40	
DD	20-10-5-3.3S	33-17-8-5.5	27	58	47	30	1.17	72.7	59.0	11.07	
IC	20-10-5-3.3S	33-17-8-5.5	27	49	48	28	1.17	70.6	59.4	10.91	
BP	20-10-5-3.3S	33-17-8-5.5	28	51	45	31	1.17	72.6	58.2	11.52	
Broadcast	20-10-5-3.3S	33-17-8-5.5	28	54	42	28	1.19	64.8	58.7	11.52	
Check	0-0-0-0	0-0-0-0	27	59	49	27	1.18	70.6	58.7	10.97	
Grower Standard	15-15-5-3.3S BC at Planting + 28 kg N ha^{-1} BC Dec	25-25-8.5-5.5 + 25	26	58	44	33	1.14	72.0	58.1	11.55	
LSD 0.05			4		4	7	1	0.21	3.3	0.5	0.18

DD = Between double disc openers.

IC = With NT injection coulter in front of the double disc openers.

BP = Behind press-wheel, over the row.

Table 5. Plant and grain response to starter fertilizer rate in no-till wheat, New Kent County, 2005-06. All applications were placed between the double-disk openers at planting using seed firmers. Nutrient sources were ammonium polyphosphate solution, urea-ammonium nitrate solution (30% N), and potassium thiosulfate.

				GS 15	GS25	GS30	GS 75	Grain	Test
N Rate	P Rate	K Rate	S rate	Plants	Tillers	Tillers	Heads	Yield	Weight
---------------------lb/ac---------------------				plants/ft^2	tillers/ft^2	tillers/ft^2	heads/ft^2	bu/ac	lb/bu
0	0	0	0	13	38	49	68	89	62.0
15	30	8	5.5	22	38	48	63	80	62.2
30	30	8	5.5	24	42	51	63	73	62.3
45	30	8	5.5	18	42	50	70	80	62.0
60	30	8	5.5	15	46	55	63	72	62.0
30	0	8	5.5	14	32	38	69	88	62.0
30	15	8	5.5	15	33	42	70	71	61.9
30	30	0	0	16	37	45	63	93	62.3
30	45	8	5.5	21	48	58	71	79	61.9
30	60	8	5.5	18	40	50	56	89	62.0
Contrasts									
N Rate Linear				ns	ns	ns	ns	ns	ns
N Rate Quadratic				**	ns	ns	ns	ns	ns
P Rate Linear				*	*	*	**	ns	ns
P Rate Quadratic				ns	ns	ns	ns	ns	ns
KTS				ns	ns	ns	ns	ns	ns
*,** - Significant at the 0.01 and 0.05 levels, respectively									

Table 6. Plant, tiller, head count, grain yield, and test weight response to starter fertilizer rate in no-till wheat, EVAREC, Warsaw, VA, 2005-06. All applications were placed between the double-disk openers at planting using seed firmers. Nutrient sources were ammonium polyphosphate solution, urea-ammonium nitrate solution (30% N), and potassium thiosulfate.

				GS 15	GS25	GS30	GS 75	Grain	Test
N Rate	P Rate	K Rate	S rate	Plants	Tillers	Tillers	Heads	Yield	Weight
----------------------lb/ac----------------------				plants/ft2	tillers/ft2	tillers/ft2	heads/ft2	bu/ac	lb/bu
0	0	0	0	25	59	69	64	83	61.3
15	30	8	5.5	24	53	64	69	85	61.5
30	30	8	5.5	22	50	51	68	85	61.6
45	30	8	5.5	28	50	69	64	84	61.2
60	30	8	5.5	27	57	66	63	86	61.3
30	0	8	5.5	22	50	46	68	76	61.2
30	15	8	5.5	24	66	62	64	82	61.7
30	30	0	0	19	61	66	67	82	61.5
30	45	8	5.5	22	30	58	60	84	61.5
30	60	8	5.5	25	59	55	68	84	61.5
Contrasts									
N Rate Linear				ns	ns	ns	ns	ns	ns
N Rate Quadratic				ns	**	ns	ns	ns	ns
P Rate Linear				ns	ns	ns	ns	**	ns
P Rate Quadratic				ns	ns	*	ns	ns	ns
KTS				ns	**	ns	ns	ns	ns
*,** - Significant at the 0.10 and 0.05 levels, respectively									

Table 7 Plant, tiller, head count, grain yield, and test weight response to starter fertilizer rate in no-till wheat, Middlesex County, VA, 2007-08. All applications were placed between the double-disk openers at planting using seed firmers. Nutrient sources were ammonium polyphosphate solution, urea-ammonium nitrate solution (30% N), and potassium thiosulfate.

N Rate	P Rate	K Rate	S rate	GS 15 Plants	GS 30 Tillers	GS 75 Heads	Kernels head^{-1}	Weight kernel^{-1}	Grain Yield	Test Weight	Grain Protein
----------------------kg ha^{-1}----------------------				plants/ft^2	tillers/ft^2	heads/ft^2		oz	bu/ac	lb/bu	---%---
0	0	0	0	17	50	43	34	1.16	77.2	61.4	10.35
15	30	8	5	18	53	41	36	1.16	77.3	61.4	9.85
30	30	8	5	19	53	48	30	1.15	75.1	61.3	10.07
45	30	8	5	20	52	45	35	1.16	81.2	61.3	10.84
60	30	8	5	20	51	45	37	1.11	83.2	61.4	10.19
30	0	8	5	19	56	47	32	1.16	78.1	60.9	10.60
30	15	8	5	17	53	43	34	1.15	76.7	61.6	10.76
30	30	0	0	18	57	45	35	1.13	80.5	61.4	10.27
30	45	8	5	20	51	44	33	1.21	78.9	61.4	10.84
30	60	8	5	19	51	44	35	1.14	79.4	61.3	10.96
Contrasts											
N Rate Linear				0.001**	0.001**	0.282	0.4423	0.0512*	0.0072**	0.4291	0.8069
N Rate Quadratic				0.3365	0.3365	0.4768	0.1037	0.2909	0.0747*	0.6423	0.8865
P Rate Linear				0.2998	0.2998	0.5876	0.4177	0.7763	0.3849	0.1342	0.4145
P Rate Quadratic				0.2969	0.2969	0.5754	0.7443	0.7925	0.825	0.0209**	0.3939
KTS				0.4376	0.4376	0.3483	0.0767	0.4294	0.0381**	0.7845	0.6279
*,** - Significant at the 0.10 and 0.05 levels, respectively											

Table 8. Plant, tiller, head count, grain yield, and test weight response to starter fertilizer rate in no-till wheat, EVAREC, Warsaw, VA, 2007-08. All applications were placed between the double-disk openers at planting using seed firmers. Nutrient sources were ammonium polyphosphate solution, urea-ammonium nitrate solution (30% N), and potassium thiosulfate.

N Rate	P Rate	K Rate	S rate	GS 15 Plants	GS 30 Tillers	GS 75 Heads	Kernels $head^{-1}$	Weight $kernel^{-1}$	Grain Yield	Test Weight	Grain Protein
-----------------------kg ha^{-1}-----------------------				plants/ft^2	tillers/ft^2	heads/ft^2		oz	bu/ac	lb/bu	---%---
0	0	0	0	25	58	42	31	1.19	68.6	56.1	11.14
15	30	8	5	26	60	44	30	1.17	71.4	57.2	10.74
30	30	8	5	25	59	42	31	1.19	68.6	58.9	11.57
45	30	8	5	22	54	48	28	1.19	71.3	56.1	11.74
60	30	8	5	25	56	48	31	1.17	77.7	59.4	11.20
30	0	8	5	24	61	42	31	1.20	69.6	57.9	11.70
30	15	8	5	24	60	44	30	1.19	70.4	59.0	11.28
30	30	0	0	24	63	48	26	1.20	66.9	56.4	11.64
30	45	8	5	25	57	42	32	1.20	71.8	56.4	11.14
30	60	8	5	24	56	46	29	1.18	71.9	58.6	11.07
Contrasts											
N Rate Linear				0.1862	0.1862	0.0213**	0.5753	0.5306	0.0157**	0.194	0.1813
N Rate Quadratic				0.472	0.472	0.6971	0.5757	0.5476	0.1445	0.98	0.3344
P Rate Linear				0.3847	0.3847	0.36	0.8782	0.4904	0.3872	0.7993	0.098*
P Rate Quadratic				0.9314	0.9314	0.4382	0.2496	0.6819	0.4141	0.3485	0.8752
KTS				0.1793	0.1793	0.0796*	0.0373**	0.4836	0.5822	0.1972	0.8487
*,** - Significant at the 0.10 and 0.05 levels, respectively											