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Accomplishments Report
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Investigating Nitrogen Use Efficiency for Winter Wheat Quality in Organic Rotations in Nebraska
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Termination Report: 01/01/2012 to 12/31/2015

Summary
NW07505 excelled for the trait of "nitrogen use efficiency for bread quality." NW07505 ranked with Lyman as the highest yielding cultivar, had a large gain in soil total N, was moderately low in soil mineral N depletion per bushel, and excelled for bread baking quality at the lowest protein content level. This distinction comes with a tradeoff: The high bread quality of NW07505 appeared to result from high Short Yield and a consequently low Flour Yield, which were consistent traits for NW07505 across years. This report should stimulate interest among farmers and bakers for the anticipated release of NW07505 on the market, while raising some concerns among millers about the low milling yield. NE06607 emerged as a star performer in this 3 year study, and must be resurrected as a potential cultivar for organic production. This is a welcome development, as NE06607 showed promise for its low DON vomitoxin content in trials in Vermont. On the other hand, NE07444, which had appeared to be a top performing line with excellent quality at low protein content, performed near the bottom of this set, next to our confirmed marginal bread quality cultivar, Overland.

Compost application in the spring and planting wheat after a previous crop of alfalfa were investigated as methods to increase wheat grain protein content to capture a higher value market. A minimal compost application (20 lbs total N per acre) at planting time revealed a significant increase in protein content only after soybeans (without an impact on yield) and only in the third year of this study in which the planting date was a month later after soybeans than after alfalfa. In the second year of this study, in which the date of winter wheat planting was the same for both systems, wheat grain yield after alfalfa was double that of wheat after soybeans without an impact on protein content. Wheat grain yield was higher after alfalfa than after soybeans both years, indicating that date of planting was not entirely responsible for the yield disparity between the two systems.

There were no significance differences among cultivars, previous crops or compost treatments for mineral N depletion. Economic calculations (not completed) would be based on the balance between N that was removed from the system in the grain (ie the protein yield) and the gain or loss in total N. Since variation could not be detected for total N between production systems, an economic analysis would be meaningless. However, there was a significant gain in Total N (1000 lbs./acre) in the soybean system where grain yields were quite low, indicating that nitrogen that was not used by the wheat crop was added to the Total N rather than being lost.

Selection for bread quality would be simplified greatly if reduction flour (RF) mixographs could be used to predict bread quality for stoneground flour (SGF) and reconstituted whole flour (WF) as well as RF, or to predict sourdough baking performance. Wheat flour and dough characteristics were examined in each system to

find parameters that could be used for early generation selection for RF and WF bread quality among experimental wheat lines. Milling and dough characteristics were discovered that could predict RF and WF straight dough bread baking performance. The most significant predictors of excellent RF Bread Quality, along with single kernel weight (SKWT), were long dough mix time (DMT) and short dough proof time (DPT) explaining 51% of the variation in RF bread quality. A long DMT strongly contributed to improved RF bread score despite its negative correlation with specific loaf volume and exterior score. A long DPT was even more detrimental (negatively correlated) to WF bread performance than to RF bread performance.

Mixograph tests were performed on wheat cultivars from each environment (wheat after soybeans and wheat after alfalfa for two years (see table below). The search for quality characteristics that vary minimally with the environment singled out RFMRV (midline right value) as the only variable that was significantly different among cultivars without interactions with the environment. Comparisons of mixograph data with dough mixing and baking performance showed RFMTI, RFMTW and RFMRV to be highly correlated with protein content. It appears that these traits contribute to the variation in bread baking well beyond their association with protein content. Because of interactions with the environment, RFMTI, RFMTW can only be used to predict RF bread performance when tested over contrasting environments and require statistical analysis using protein as a covariate. Breeders can use RFMRV as a predictor for RF bread quality if protein content is controlled as a covariate regardless of the sample environment.

Reflecting on artisan baking tests using stone ground flour in 2012, RFMPT (midline peak time), RFMTI (midline tail integral), RFMTW (midline tail width) and RFDPT were significantly correlated with sourdough bread score. These variables fluctuated depending on the previous crop, but were still significantly correlated with sourdough score after controlling for ALFPCT (the percent of wheat grain from the alfalfa field), as a partial correlate. Despite variability in stoneground flour sourdough bread scores among artisan baker participants, two properties, stoneground flour ash (positive correlation) and RFDPT (negative correlation) explained 22% of the overall sourdough bread score independently of protein content. Bakers may consider sourcing stoneground flour with higher ash content to obtain better sourdough bread performance. Breeders may consider selecting for lower RFDPT as well as higher whole milled flour ash content when selecting lines for sourdough baking.

Objectives

By providing farmers and bakers with knowledge of a protein content threshold for specific wheat cultivars and the means to reach this threshold for improved cultivars, the broad goal was to insure the successful release of improved wheat cultivars to seed growers and farmers and to increase the appeal of having wheat in the organic rotation.

Wheat nitrogen use field experiments were conducted: 1) to determine whether the combination of change in cropping systems and cultivar choice would deplete N for the subsequent crop and; 2) to demonstrate and provide information for agronomic practices that will enable organic producers to optimize their systems for selected wheat cultivars to meet a protein content threshold.

Quality analyses of grain harvested from the different cropping system and cultivar combinations were performed: 1) to determine the protein threshold for good baking quality for selected wheat cultivars; and 2) to identify quality test output that can be used to identify cultivars that meet baker requirements for whole-wheat bread.

Overview of Activities

Organic farmers who advise the University of Nebraska-Lincoln (UNL) Organic Working Group emphasize low protein content as a perennial problem in organic wheat production in Nebraska and have asked researchers to address this issue. Building on five years of winter wheat cultivar trials and N fertility experiments conducted on certified organic UNL experiment station land, we proposed a novel solution to the protein content problem. We investigated bread quality in relation to nitrogen use of 12 of our most promising experimental lines and released cultivars previously identified as having good end-use quality at lower protein content. Previously, we identified two high-yielding low-protein winter wheat experimental lines with excellent bread-making quality that perform well in organic systems in Nebraska: NE07444 and NW07505 and two high protein experimental lines, NW03681 and NE08457, which appear to require the higher protein content to produce acceptable bread. This is in contrast 'Karl 92', widely grown in organic systems because it normally has the highest protein content in organic cultivar trials and excellent bread quality. McGill was chosen for its apparent requirement for higher nitrogen content to bake well. Quality tests enabled us to discover the "protein content threshold" for each wheat line to make acceptable bread. To address farming systems that are not adequate to produce sufficient protein for the chosen cultivar, we investigated three methods for improving the protein content: 1) change from a rotation that grows wheat after soybeans to growing wheat after alfalfa, 2) inter-seed tillage radish with the wheat to scavenge N and supply it to wheat in late spring, and 3) use a compost treatment immediately before planting wheat and tillage radish. We studied the N depletion in the new rotation (wheat after alfalfa) and compared it to the traditional rotation (wheat after soybeans) as a preliminary task for determining whether the proposed changes in cropping system may affect subsequent crops, with the intention of providing organic farmers with viable cultivar and cropping system options.

Wheat Nitrogen Use Field Experiments

Activities for N-Use Field Experiments

N Experiments-Year 1 (2011 planting- 2012 harvest- 2013 processing)

In 2011 twelve experimental lines which had shown positive protein responses to manure or top-dressing treatments in organic farming systems in Nebraska, were sown on 2400 sq. ft. strips under conditions that would produce a wide range of protein contents, including environments after either soybeans (October 26) or alfalfa (September 23), and treatments with and without Chilean nitrate (applied at jointing stage in April 2012 to 100 feet of every 400-foot plot after alfalfa only) and/or sheep manure (two years previous). The recently released hard red winter wheat cultivar, 'McGill,' was planted after alfalfa with the same fertility treatments as for the above experiment on two acres with a Great Plains no-till drill with additional treatments of radish in front of or behind the press wheel in four reps of randomized complete blocks. Radish vegetation cover index was measured on Nov. 11 using Greenseeker® spectral reflectance technology. Because of low (60%) emergence, due to poor quality McGill seed from our supplier and the subsequent infestation and growth of pennycress where the wheat stand was thin, the larger plots were abandoned and only small subplots (5 ft x 20 ft) were harvested in late June. The adjacent wheat increases fared well, resulting in high yields of quality seed.

N Experiments-Year 2 (2012 planting- 2013 harvest- 2014 processing)

Data from the first year, including the level of common bunt contamination, was used to select eight of the experimental lines to be accompanied by four cultivars chosen for the range in inherent protein content and known baking ability to optimize our understanding of nitrogen-use efficiency for these cultivar types. Two of the bunt-susceptible lines, NE05425 (high protein content) and NE03490 (low protein content), were essential for this study. Since the radish experiment was abandoned in the previous year, both radish and non-radish treatments were included in the field that followed alfalfa (strip 2). No radish plots were planted in the field that followed soybeans (strip 6) because radishes needed to be planted in August and could not be delayed until after soybean harvest. The nitrogen use experiment was thus conducted with three main treatments (wheat after alfalfa with or without a catch crop of tillage radishes and wheat after soybeans) and two soil fertility treatments (with or without compost at the rate of approximately 20 lbs. N per acre). Wheat plots in the alfalfa and soybean fields were planted on October 3 and October 4, respectively. Two types of compost (a high-N turkey manure compost and a stable humified compost), from Bio-Ag Solutions of Hershey NE, were prepared for spreading with a Barber screw-type spreader by mixing together, sifting and drying to 12 % moisture. On the alfalfa strip, Nitro® Tillage radishes were planted with a Barber screw-type spreader at 4.65 pounds per acre on 8-31-12 shortly after a final disk incorporation of alfalfa. Soil samples were collected at 2 or 3 cores per treatment*rep at 0-8 inches and 8-24 inches immediately before applying compost on 10-3-12 with the Barber spreader at 1700 lbs./acre, followed by planting of wheat with a no-till drill. Similarly, a day later, compost was applied on the soybean strip (strip 2) at 1500 lbs./acre within hours after disking and culti-packing soybean residue, and before wheat was planted. Compost analysis revealed a 9.7:1 C:N ratio and that we had applied 18.7 lbs.

total N/acre on the alfalfa strip and 16.3 lbs. N/acre on the soybean strip. Wheat was harvested July 8 and 9 from both strips. Soil cores were collected at 0-8 inches and 8-24 inches by treatment*rep and by wheat entry. Two cores were taken in each treatment*rep (for 2 reps of the soybean strip and 4 reps of the alfalfa strip) on July 25, and by wheat entry for each treatment on July 9 (the day after harvest) for the soybean strip (1 core/plot, 3 reps composite) and July 25 for the alfalfa strip (1 core/plot, 2 reps composite). Ward Labs (Kearney NE) tested the soil for total N, nitrate-N and ammonium-N. Grain protein content was measured on a Perten diode-array NIR.

N Experiments-Year 3 (2013 planting- 2014 harvest- 2015 processing)
A second year of experiments with 12 experimental wheat lines and cultivars was planted after alfalfa and after soybeans, with 3 compost-amended reps compost and 3 reps without compost. Radishes were not planted because of the minimal radish treatment effect in the first year. Bunt spore balls were removed by hand from wheat before planting. A stable humified compost with 7 lbs. total N per ton was obtained from Bio-Ag Solutions of Hershey, NE. On 9-25-13, a Toro 3200 gravel spreader was used to spread 21.9 lbs. total N per acre of the unmodified compost on fallow soil following alfalfa. One pass with the spreader was made also on the non-compost strip so that all plots had a similar pattern of wheel tracks before wheat was planted later that day. Five weeks later soybeans were harvested after a hard frost desiccated weeds. Compost was then applied onto fallowed, loose soil at 23.0 lbs. Total N per acre and incorporated. Two passes with the Toro spreader were also made on the non-compost strip so that both treatments had wheel tracks. Wheat was planted on the soybean strip on the same day. Soil samples on the alfalfa field were taken as planned on eight grid areas at two cores per grid area at 0-8 and 8-24 inches, the day before spreading compost and planting wheat. The regime for sampling soil was later modified; yet, grid sampling data was retained to complement a small fraction of samples collected after harvest. Because of the lack of homogeneity of soil N among blocs in the previous year of soil sampling, it was decided to sample by plot rather than by treatment both before wheat was actively growing in the spring, and again after wheat harvest at one depth. Soil samples were collected from each plot (one core per plot) at 0-24 inches on March 28, 2014 and again immediately after wheat harvest. (Harvest was completed 7-18-14 where alfalfa was the previous crop and 7-22-14 where soybeans was the previous crop). In each range after harvest, one random sample was taken at 0-8 inch and 8-24 inch depths to complement grid samples taken before planting wheat.

Results for N-Use Field Experiments

N Experiments-Year 1 (2011 planting- 2012 harvest- 2013 processing)
In the wheat/radish experiment at UNL's South Central Ag Lab near Clay Center, emergence of radish evaluated on November 11 after two months of growth was very poor for both methods of seeding; direct seeding was a little better (statistically significant differences for Greenseeker vegetation index: broadcast = .231, direct seeding = .248, no radish = .228; there was no interaction between seeding and manure treatments). We cannot explain the poor emergence, since it rained soon after planting and germination tests on blotter in contact with soil from the field plots revealed nearly 100% germination. Radishes only grew to about 3 inches of leaves and had very little root growth, which, according to other studies, is not enough to scavenge N. Radishes froze in mid-December. The radish portion of this experiment was thus abandoned.

However, grain was harvested from small subplots for an unrelated anti-oxidant experiment. Chilean nitrate had been spread in plots that had manure two years previously. NIR grain protein analyses for the 18 subplots revealed higher protein for higher nitrogen inputs: 13.4 % untreated, 13.9% previous manure, 14.6 % previous manure plus Chilean nitrate. Wheat growth for increase strips was much better on field 7 (after alfalfa, planted mid-September) than on field 3 (after soybeans, planted late October). The wheat stand in strip 7 was adequate to suppress winter annuals and growth was about 3 weeks ahead of normal development in the spring. In strip 3, wheat started to germinate on November 11. Good soil moisture and a mild winter enabled the wheat in strip 3 to survive and green up in the spring with an adequate stand. Heavy bunt infestations for some harvested wheat lines led us to re-evaluate the list of promising lines for organic production. We compared bunt counts from 1 kg subsamples of increase plots with bunt counts from 55-gram subsamples from an organic variety trial conducted at the same location. Bunt ratings for four of our most promising lines, NE05496, NE06469, NE05425 and NW03681 were so high that we decided to remove them from the list of promising lines. NE05425, which had a moderately high bunt count also had a high percentage of black tip kernels. Bunt also occurred in our back-up seed increases at Mead, making it difficult to put up seed for the 2013 experiment.

N Experiments-Year 2 (2012 planting- 2013 harvest- 2014 processing)

Protein Content and Protein Yield

Analysis of variance (Proc Mixed-SAS, Table 1.1) revealed highly significant differences for protein content among treatments (with or without compost), among strips (alfalfa, alfalfa/radish or soybeans as previous crops), and among cultivars. Protein content was greatest for the alfalfa strip, averaging 0.50 more than for the soybean strip. Wheat in the radish treatment did not gain any protein over the treatment without radish, and was actually 0.13 less than without radishes. Apparent differences in this pattern for two genotypes (NE03490, and NW07505) were not significant. Protein content was slightly higher for the compost treatment. No rank changes or changes in magnitude of differences among cultivars for protein content were detected among strips or among treatments. There was no date of planting effect, as there would be in a normal year, since the plots after soybeans and after wheat were planted only a day apart.

Table 1.1. Grain Protein Content ANOVA and Least Square Means, 2013

Effect	Num DF	Den DF	F Value				Pr > F	Significance
ibloc(bloc)	7	75	4.11				0.0007	***
cultivar	11	75	7.5				<0.0001	***
trt	1	33	8.44				0.0065	**
strip	2	101	30.51				<0.0001	***
cultivar*strip	22	101	0.78				0.7437	NS
cultivar*trt	11	33	0.53				0.8663	NS
strip*trt	2	33	1.66				0.2051	NS
cultivar*strip*trt	22	33	0.56				0.9225	NS
treatment				compost	none			
grain protein L. S. mean				13.76	13.60		0.0065	**
strip			alfalfa	alfradish	soybean			
grain protein L. S. mean			13.89	13.76	13.39		<0.0001	***
treatment	compost	none	compost	none	compost	none		
strip	alfalfa		alfalfaraidsh		soybean			
grain protein L.S. mean	13.90	13.88	13.89	13.62	13.48	13.30	0.2051	NS

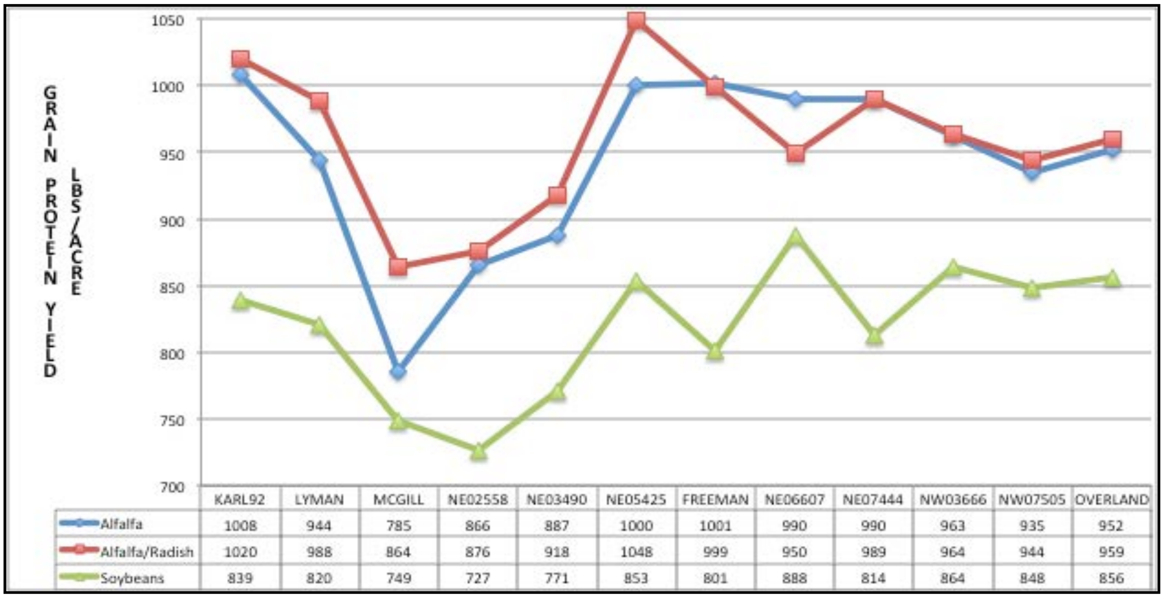
When a similar analysis was conducted for protein yield (product of protein content and grain yield in pounds per acre), interactions were revealed between strip and treatment (P < 0.01) and between cultivar and strip (P < 0.10) (Table 1.2). No cultivar*treatment or cultivar*strip*treatment interactions were detected (data not shown). The non-composted treatments resulted in higher protein yield than in the composted treatments of the alfalfa and alfalfa/radish strips, but had the opposite response in the soybean strip.

Table 1.2. Wheat Protein Yield Least Square Means, 2013

treatment				compost	none		Pr > F	Significance
protein yield				897	918		0.0062	**
strip			alfalfa	alfradish	soybean			
protein yield			943	960	819		<0.0001	***
treatment	compost	none	compost	none	compost	none		
strip	alfalfa		alfalfaradish		soybean			
protein yield	918	969	950	970	824	815	0.0055	**

Grain protein yield patterns for McGill and NE06607 are contrary to the patterns for other cultivars (Table 1.3). Protein yields in the alfalfa-radish strip were higher than the other strips, reflecting higher grain yields despite lower grain protein content.

Table 1.3. Wheat Grain Protein Yield from Alfalfa, Alfalfa-Radish and Soybean Environments, 2013



Nitrogen Use

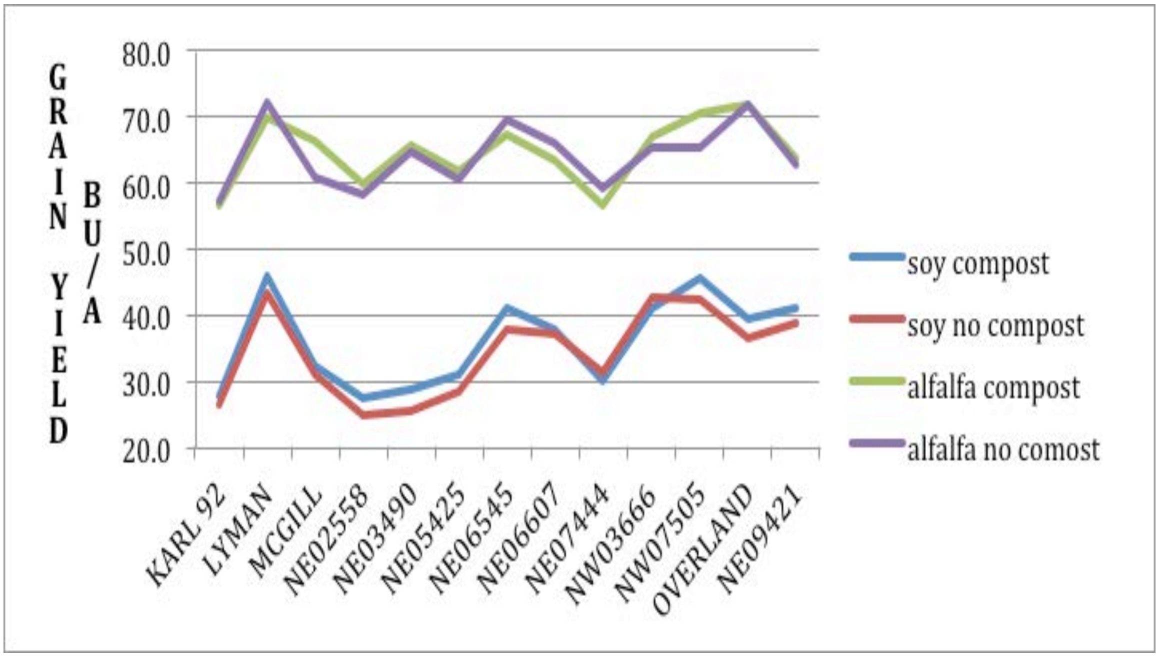
Soil results from the soybean strip could not be analyzed, as the pre-plant soil samples were lost in shipment. For the alfalfa strip, even though post-harvest soil samples were taken for each cultivar, comparisons among cultivars were not possible given the wide range of nitrogen values for the pre-plant treatment plots. Data for 'Total Nitrogen' includes total nitrogen in the top 8 inches of the soil profile plus nitrate nitrogen from 8 to 24 inches. Data for 'Mineral Nitrogen' includes nitrate nitrogen from the top 24 inches plus ammonia nitrogen from the top 8 inches. Soil heterogeneity as indicated by extreme interactions among reps for soil nitrogen precluded meaningful statistical analysis. Total nitrogen ranged from a loss of 300 lbs/acre to a gain of 1000 lbs/acre for the 4 reps of the no compost-radish plots. Mineral nitrogen ranged from a loss of 47 lbs/acre to a gain of 15 lbs/acre for the compost-no radish plots. Median values hint at a single trend: Total nitrogen for the compost-no radish plots appears to have declined to a greater extent than the other treatments. Overall, there appears to be either a net loss or maintenance of the total nitrogen and mineral nitrogen for all treatments. To deal with soil heterogeneity soil sampling was intensified in the following year.

Year 3 (2013 planting- 2014 harvest- 2015 processing)

Grain Yield and Protein Content

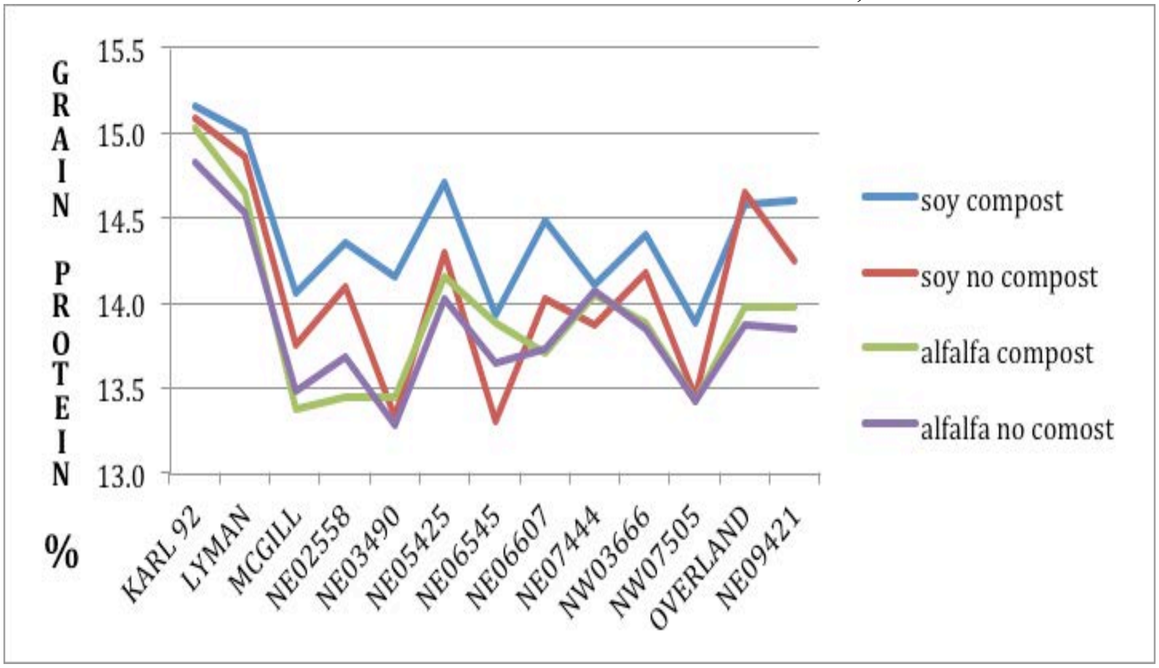
Wheat grain yield (Table 2.1) was much higher across the board after alfalfa than after soybeans, a reflection of the month earlier planting date. Compost did not affect grain yield.

Table 2.1. Grain Yield for Four Treatment Environments, 2014



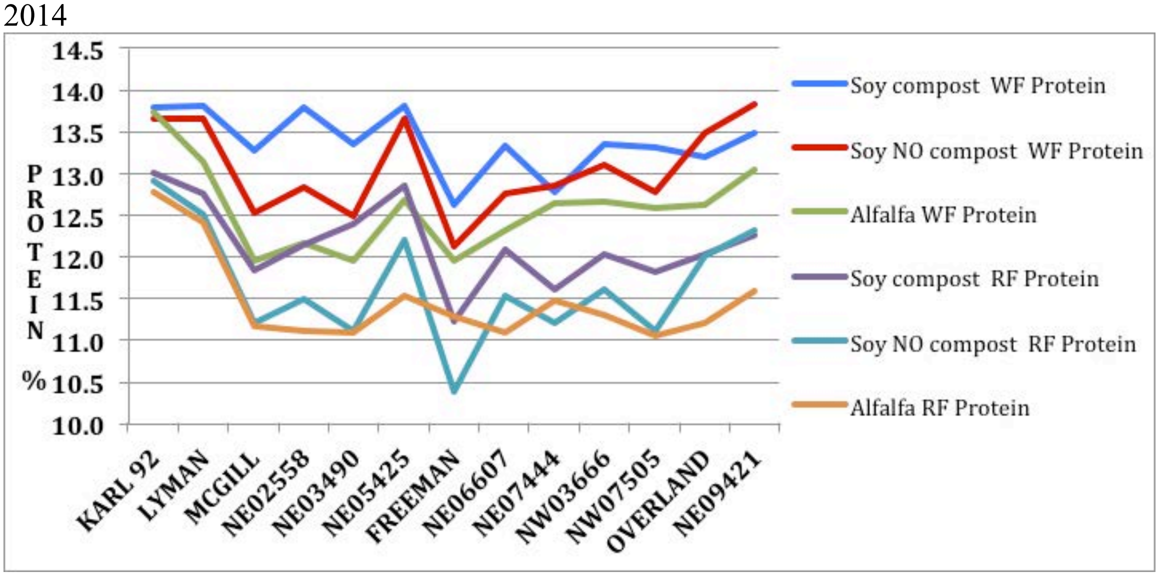
Grain protein content (Table 2.2) after alfalfa was not affected by compost treatment and was similar to grain protein content after soybeans without compost. Compost significantly increased protein content after soybeans for most cultivars except Overland and those with the highest protein content, Karl 92 and Lyman. Karl 92 and Lyman grain protein content did not vary much with compost or previous crop. NE07444 and FREEMAN (NE06545) protein contents were not affected by previous crop. At the lower end of the protein content spectrum were McGill, NE03490, Freeman and NW07505.

Table 2.2 Grain Protein Content for Four Treatment Environments, 2014



Since grain protein content was not affected by compost treatment, alfalfa samples were combined for quality tests. Protein content for WF and RF samples are shown in Table 2.3.

Table 2.3. Protein Content by Flour Type as affected by Previous Crop and Treatment, 2014



Cultivars with lower protein content without compost treatment typically responded with the highest increase in protein content with the compost treatment. The phenomena of "protein dilution" in which lower protein content is anticipated when yields are high and vice versa could explain why protein levels were higher after soybeans than after alfalfa in 2014. A pattern of protein dilution fits the data for Karl 92 (low yield/high protein), Freeman (high yield/low protein) and NW07505 (high yield/low protein). Tables 2.4 and

2.5 reveal diversions from the protein dilution effect, notably for Lyman and Overland. McGill was relatively low in protein regardless of its yield relative to other cultivars.

Table 2.4. Grain Yield and Protein Content after Soybeans, 2014

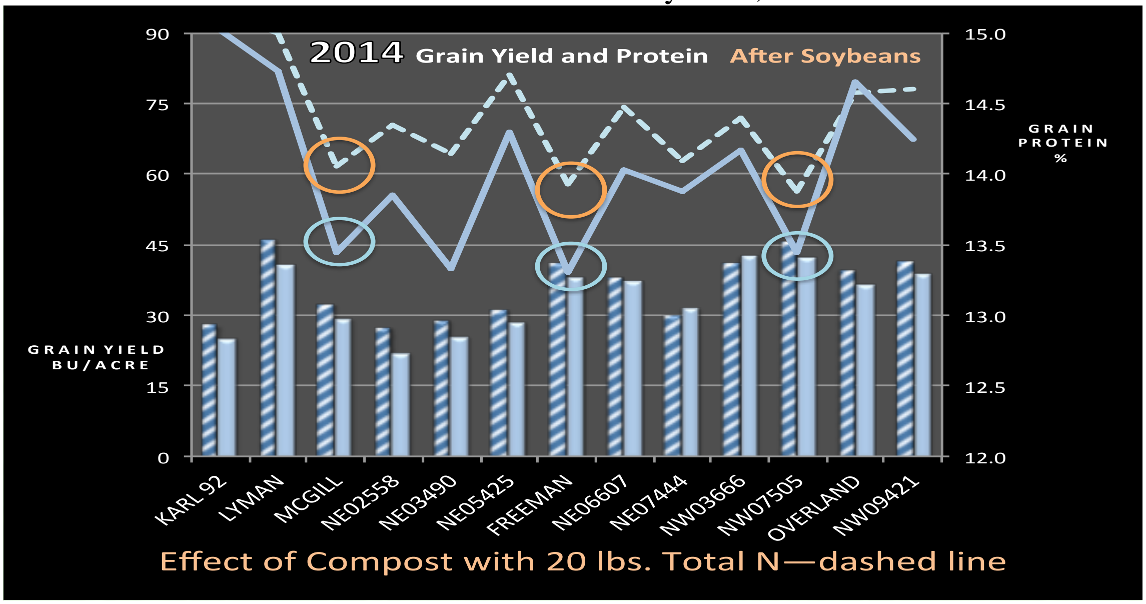
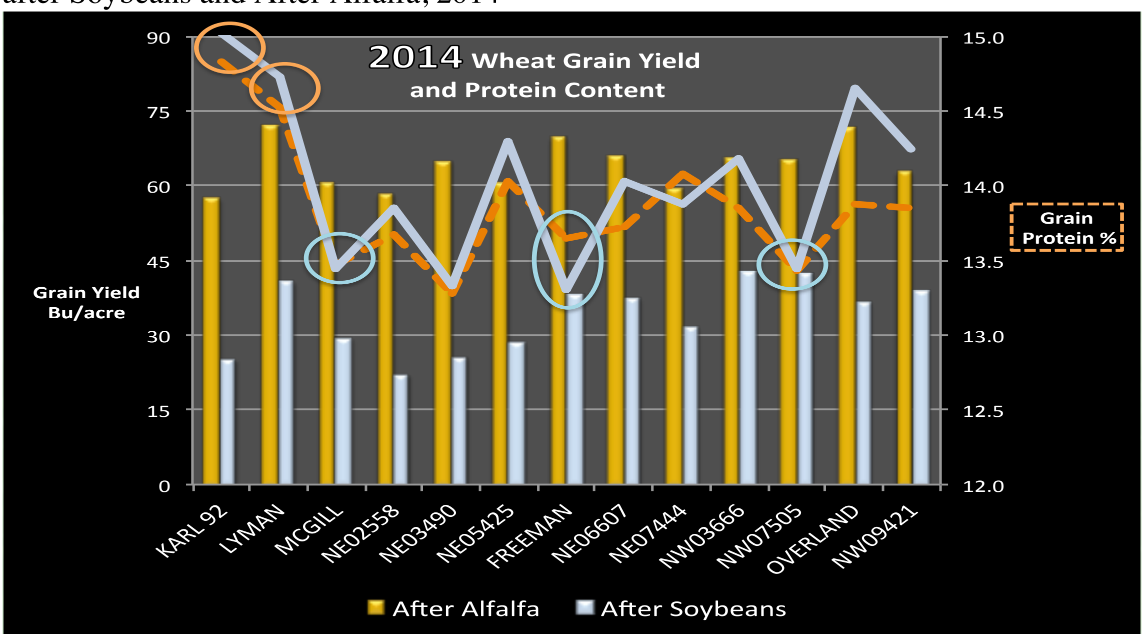


Table 2.5. Wheat Grain Yield and Protein Content for Combined Compost Treatments after Soybeans and After Alfalfa, 2014



Nitrogen Use

Mineral N is the sum of nitrate-N and ammonium-N in the soil layer accessed by wheat roots. The depletion of mineral N during the period of planting to harvest of wheat averaged 120 lbs. N per acre across all treatments. As revealed in Table 2.6, there were no significant differences for soil mineral N depletion during the period from planting to harvest of wheat, except for a marginal difference among cultivars. However, since there were highly significant differences for grain N among cultivars and previous crops, there were also significant differences for "Mineral N Loss" (soil mineral N depletion minus grain N) and for "Soil Mineral N Depletion per bushel." Grain production used more than half of the mineral N (73 lbs.) that was available at planting time. The remainder of mineral N was either was either lost from the soil or incorporated into more stable chemical forms.

Table 2.6. ANOVA for Soil Mineral N Depletion and Soil Total N Gain, 2014

Source†	Soil Mineral N Depletion (A)	N in Grain (B)	Mineral N Loss (A minus B)	Soil Mineral N Depletion per Bushel	Soil Total N Gain
mp	NS	***	**	***	*
sp	NS	*	NS	NS	NS
mp*sp	NS	NS	NS	NS	*
ssp	Marginal ~	***	*	***	NS
mp*ssp	NS	NS	NS	NS	*
sp*ssp	NS	NS	NS	NS	NS
mp*sp*ssp	NS	NS	NS	NS	NS
model Pr > F	0.1334	< 0.0001	0.0001	< 0.0001	0.0924
C.V.	39	9	101	39.4	164
Mean	120	73	47	2.8	867

NS = not significant at P < 0.05; * is significance at P < 0.05; ** is P < 0.01; *** is P < 0.001.
† Explained in Tables 12.7 and 12.8.
~ P = 0.0966

Mineral N use and loss during the period between wheat planting and harvest is shown by previous crop and fertility treatment in Table 2.7. Soil after soybeans/wheat lost more than twice as much mineral N after accounting for the amount of N in harvested grain as for alfalfa/wheat (70 vs. 24 lbs. N/acre, L.S.D. = 13). On the other hand, soil after soybeans/wheat *gained* more than 3 times as much total N by harvest time as for soil after alfalfa/wheat (1401 vs. 333 lbs. N/acre, L.S.D. = 390). This difference in total soil N was very significant despite a high degree of variability among replications (C.V. = 164 compared to a mean of 867).

Table 2.7. Previous Crop and Fertility Treatment Least Square Means and Significance of Differences for Mineral N Use and Loss, 2014

PREVIOUS CROP (main plot = mp)								
Cultivar	Grain Yield	Grain Protein	Protein Yield	Soil Mineral N Depletion (A)	N in Grain (B)	Mineral N Loss (A minus B)	Soil Mineral N Depletion per Bushel	Soil Total N Gain
	bu/acre	%	lbs/acre	lbs/acre	lbs/acre	lbs/acre	lbs/bu	lbs/acre
SOYBEANS	35	14.2	298	122	52	70	3.7	1401
ALFALFA	64	13.9	536	118	94	24	1.9	333
LSD (.05)	1	0.1	10	13	2	13	0.3	390
Significance of Differences	***	NS	***	NS	***	**	***	*
FERTILITY TREATMENT (subplot = sp)								
NONE	49	13.9	408	121	65	56	2.8	754
COMPOST	50	14.2	426	119	68	51	2.7	980
LSD (.05)	1	0.1	10	13	2	13	0.3	390
Significance of Differences	NS	**	*	NS	*	NS	NS	NS
PREVIOUS CROP * FERTILITY TREATMENT (mp * sp)								
SOY NONE	34	14.0	283	117	45	72	3.7	1101
SOY COMPOST	36	14.4	313	127	50	77	3.6	1701
ALFALFA NONE	64	13.9	533	124	85	39	2.0	408
ALFALFA COMPOST	65	13.9	539	112	86	26	1.7	258
Significance of Interaction	NS	*	NS	NS	NS	NS	NS	*

NS = not significant at P < 0.05, * is P < 0.05, ** is P < 0.01, *** is P < 0.001

Since soil mineral N depletion was only marginally different among cultivars, the highest yielding cultivars had the lowest amount of soil mineral N per bushel of grain. When averaged across environments (Table 2.8), Lyman, with the highest grain yield (along with Overland), had the top protein yield per acre and also the least loss of soil mineral N (along with NW09421) after accounting for grain N. Lyman also had the least gain in total soil N. In contrast, Karl 92, with its very low grain yield, resulted in the highest gain in total soil N. The check cultivar, NW09421, was on par with Lyman for loss of mineral N. NW07505, which ranked with Lyman for the highest grain yield, had a large gain in soil total N and a moderately low soil mineral N depletion per bushel.

Table 2.8. Least Square Means and Significance of Differences of Mineral N Use and Loss for Wheat Cultivars, 2014

CULTIVAR (split split plot = ssp)								
Cultivar	Grain Yield	Grain Protein	Protein Yield	Soil Mineral N Depletion (A)	N in Grain (B)	Mineral N Loss (A minus B)	Soil Mineral N Depletion per Bushel	Soil Total N Gain
	bu/acre	%	lbs/acre	lbs/acre	lbs/acre	lbs/acre	lbs/bu	lbs/acre
KARL 92	42	15.0	374	117	66	52	3.3	1540
LYMAN	57	14.7	503	107	88	19	2.1	480
MCGILL	47	13.6	382	115	67	48	2.8	790
NE02558	42	13.8	345	135	61	75	3.6	757
NE03490	46	13.6	374	115	66	49	3.2	1014
NE05425	45	14.3	388	146	68	79	3.6	889
FREEMAN	54	13.7	444	124	78	46	2.5	567
NE06607	51	14.0	426	125	75	51	2.7	534
NE07444	44	14.0	373	100	65	35	2.7	968
NW03666	54	14.1	454	120	80	40	2.3	859
NW07505	56	13.5	453	125	79	46	2.4	1188
OVERLAND	55	14.3	466	136	82	55	2.7	732
NW09421	51	14.2	436	93	76	16	2.0	953
LSD (.05)	3	0.2	25	33	4	33	0.8	994
Significance of Differences	***	***	***	Marginal~	***	*	***	NS

NS = not significant at $P < 0.05$, * is $P < 0.05$, ** is $P < 0.01$, *** is $P < 0.001$
~ $P = 0.0966$

Tables 2.9 and 2.10 depict higher losses in soil mineral N for wheat after soybeans, which is more than made up with significant increases in total N ($P < 0.05$). Despite the lack of significance between cultivars for total N when averaged across previous crops, a significant interaction exists between cultivars and previous crop ($P < 0.05$), which is evident when comparing the patterns for NE07444, Overland, Lyman, Freeman and McGill (large differences in total N between the two cropping systems and net losses in total N after alfalfa) with Karl 92, NE06607, NE03490 and NE02558 (small differences and healthy gains in total N after alfalfa).

Table 2.9. Nitrogen Gains, Losses and Accumulation in Wheat Grain after Soybeans as a Previous Crop, 2014

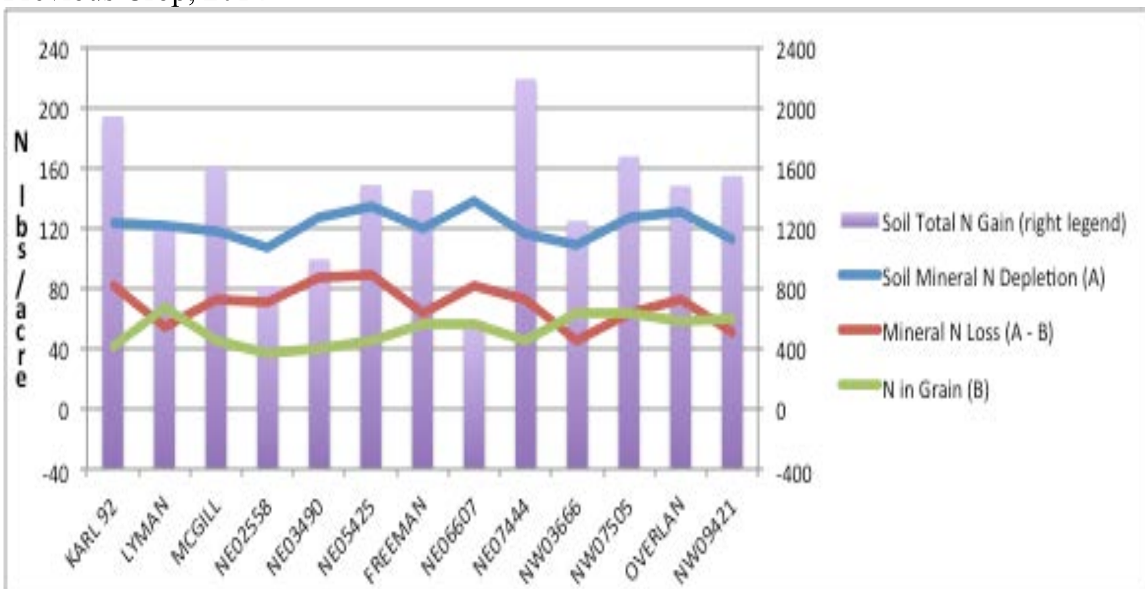
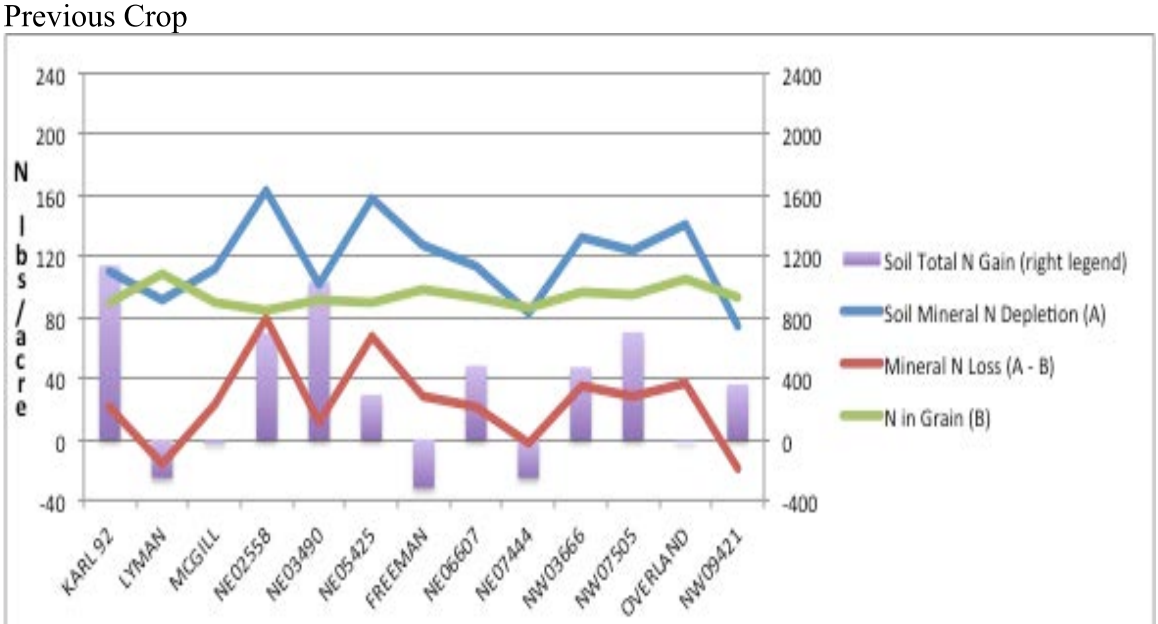


Table 2.10. Nitrogen Gains, Losses and Accumulation in Wheat Grain after Alfalfa as a Previous Crop



Wheat Quality Tests

Activities for Wheat Quality Tests

Blended Samples

Baking tests were performed on samples blended to achieve a broad range of protein content for each cultivar using sourdough baking methods for stoneground flour (SGF), and using standard yeasted dough and baking methods for white reduction flour (RF) and reconstituted whole flour (WF). SGF sourdough baking tests and RF farinograph tests were conducted only in the first year, as a larger amount of wheat was required than could be obtained from the small plots used in the second and third-year nitrogen use field experiments. RF baking tests were conducted all three years. RF baking tests were supplemented with data from micro-quality tests that measured bread, milling, single kernel and dough properties (Table 3.1). Protein content (PRO), ash content (ASH) and dough water absorption (DABS) were corrected to 14 % moisture basis. WF baking tests were conducted in the third year in addition to RF baking. WF mixograph tests were conducted in the first and third year on blended samples.

Unblended Samples

Additional RF mixograph tests were conducted on samples that retained the average protein content level of cultivars within treatments during the second and third years. These are referred to as “unblended samples.” WF mixographs were conducted on unblended samples in the third year.

Table 3.1 Terminology of Quality Test Parameters

Bread Properties		
	Code	Unit
loaf volume	LV	cc
specific loaf volume	SPV	cc/gram
firmness	FIRM	Pascals
slice area	SLICEA	mm squared
slice brightness	SLICEB	
number of cells	CELLNO	
cell diameter	CELLD	mm
cell non-uniformity	NONUNIF	
cell elongation	ELONG	
exterior score	EXTSC	scale of 1 - 6
crumb score	CRUMBSC	scale of 1 - 6
texture score	TEXTSC	scale of 1 - 6
bread score	BREADSC	scale of 1 - 6

Milling Properties		
	Code	Unit
Ash	ASH	%
Flour Yield	FYIELD	%
Bran Yield	BRANY	%
Short Yield	SHORTY	%
Bran Score	BRANSC	scale of 1 - 6
Short Score	SHORTSC	scale of 1 - 6
Milling Score	MILLSC	scale of 1 - 6
Protein	PRO	%

Dough Properties		
dough water absorption	DABS	%
dough mix time	DMT	minutes
dough score	DSC	scale of 1 - 6
dough proof time	DPT	minutes

Mixograph Parameters		
mixo water absorption	MABS	%
midline peak time	MPT	minutes
midline peak value	MPV	% Torque at peak
midline right value	MRV	% Torque 2 minutes after peak
midline right slope	MRS	% Torque/min. 2 minutes after peak
midline right width	MRW	% Torque
midline tail width	MTW	% Torque at end of run (8 min.)
midlline tail integral	MTI	% Torque/min. at end of run (8 min.)
mixing tolerance score	MTOLSC	scale of 0-7

Single Kernel Properties	
SKH	hardness score
SKD	diameter, mm
SKW	weight, mg
SKSF	% soft
SKSSF	% semisoft
SKSHD	% semihard
SKHD	% hard
SKCLASS	Classification

Wheat Quality Protocols

RF and WF Mixographs. Ten-gram mixographs (National Manufacturing, Lincoln, NE, USA) were run on all flours in triplicate after approved method 50.40.02 (AACC International 2012). Water added to the flour was determined following approved method 54-40A (AACC International) using the regression equation based on the protein content provided in the method with a +1.8% adjustment for WF (Bruinsma et al 1978), and is recorded as MABS. The mixograph machine records the torque on an arm that swings in response to the viscosity of dough being stirred between mixing pins connected to the arm and pins in the mixing bowl for a user-defined duration (an eight-minute period in the case for hard winter wheat). Mixograph software establishes a midline, a topline and a bottom line across the peaks and valleys of the resulting graph, and identifies inflection points, band widths (ranges between top and bottom lines), and areas under the lines at user-defined points in time from the start of mixing. Of the forty four parameters from mixograph computer output, nine are sufficient to describe the full range of mixing qualities (Elangovan, 2008), while only six of these nine are regularly reported for use by the UNL wheat-breeding program and were recorded for all three years: MPT, MPV, MRV, MRW, MTW and MTI. Two individuals visually assessed angles and band width across the entire mixograph chart and assigned a mixing tolerance score (MTOLSC) on a scale of 0 to 6. In 2013 and 2014, MRS was also retrieved.

RF Farinographs. Great Plains Analytical Lab conducted farinograph tests in accordance with AACC method 54-21.02. Farinograph analysis provides the following measures of dough visco-elasticity in the arbitrary Brabender Unit (BU): "water absorption"—the amount of water absorbed by flour to reach 500 BU at a specified mixing time (determined prior to conducting the farinograph test); "arrival time" to reach 500 BU (a measure of the rate of water absorption by flour of the predetermined water amount); "peak time" to reach the peak BU; "MTI" (mixing tolerance index)—BU difference between peak time and 5 minutes after peak; "departure time" to fall back to 500 BU; and "stability"—the difference between arrival and departure time.

RF Milling. RF was milled on a Buehler mill in accordance with AACC approved method 26-21.02 from grain tempered to 15.0 % moisture content.

RF Bread Production. Baking quality of samples was determined using the Optimized Straight-Dough Bread-Baking Method (AACC approved method 10-10.03). Loaf volume (LV) was determined according to AACC approved method 10-05.01 using rapeseed displacement following cooling for an hour. Loaves were sliced 12.5 mm thick per slice using an electric knife and bread slicing guide (Black & Decker Corporation, Towson, MD USA), bread firmness (FIRM) was measured according to AACC approved method 74-10.02 in the center of three 12.5 mm thick bread slices, and images were analyzed using a C-Cell imaging system (Calibre Control International Ltd., UK) following the manufacturer's instructions.

WF Milling. Whole grain flour of unblended samples for mixographs was milled from untempered grain on a Quadramat Junior Mill (Doblado-Maldonado et al, 2013). Bran was ground to 2 mm on a UDY grinder and was re-mixed with the flour to produce WF. WF for blended samples was milled as for RF on a Buehler mill. Bran was ground with a burr mill and was mixed with all other mill streams to reconstitute WF.

WF Bread Production. Baking quality of WF samples was determined using the straight dough method for 100% whole wheat in AACC approved method 10-13.02, except dough water absorption (DABS) and dough mixing time (DMT) were estimated from mixograph data and by making test doughs. The dough formula includes several additives: unemulsified shortening, sucrose, malt syrup, whey, ammonium phosphate and ascorbic acid, in addition to water, salt and flour.

Sourdough Bread Production. Thom Leonard, consultant to Heartland Mills and veteran artisan baker, developed a sourdough protocol for baking and evaluating whole grain loaves, and coordinated artisan bake trials. Through a two-week period in February and early March, bakers communicated as a group by email, offering suggestions and obtaining clarification from Leonard. Leonard collected and summarized score sheets from each baker. To address shortcomings in the artisan baking tests, Richard Little modified the sourdough protocol to test six samples per week at the UNL Food Industry Pilot Plant with four loaves from 640 grams of dough for each sample (two for each proofing time allotment). Sourdough was built at 100% hydration in two stages on day 1, retarded at 38° overnight, combined with an autolysed dough, adjusted to an optimal hydration rate for each sample, fermented at 75° for four hours, retarded overnight, divided, shaped and proofed for 2.5 and 3.0 hours. One sample of each experimental wheat line was tested and scored using this procedure to supplement artisan baker data.

Single Kernel Characterization. "The single-kernel characterization system (SKCS) crushes individual kernels and uses algorithms based on the force-deformation profile data to classify wheat samples into soft, hard, or mixed market classes." (Gaines, et al, 1996.) Single kernel diameter and weight are also measured.

Quality Tests-Year 1 (2011 planting- 2012 harvest- 2013 processing)

Wheat was harvested June 23 on the alfalfa strip a day after a rain and June 25 on the soybean strip. Wheat grain samples were kept in burlap and dried on racks at 90 F. for 20 days. Cleaned samples of the experimental lines were blended among environments and treatments to obtain a bushel at each of 3 protein content levels for most of the wheat lines. The grain protein range varied for each wheat line, making it necessary to assign different grain protein categories for each line.

Wheat Quality Tests with SGF Blended Samples

Large blended samples (40 to 50 pounds) were cleaned on a gravity seed cleaner to remove bunt balls and were stone-milled at Heartland Mill (western Kansas) in January. Stoneground flour was packaged in 2.5 kg plastic bags and shipped to seven artisan bakers around the United States in January and to four other bakers through May 2013. Samples were grouped by stoneground flour protein content: A 11.9-12.3 %; B 12.4-12.8 %; C 12.9-13.2 %; D 13.3-13.7 %; E 13.8-14.0 %; and F > 14.0 %. SGF samples were analyzed by mixograph at the UNL Crop Quality Lab. Samples were paired to obtain as many with both B and D categories, and to overlap so that two bakers would analyze each sample. Six lines could be tested in only two protein categories, since the final protein content of the third category was not different than the other two categories. (See Table 5.0 for a cultivar list showing WGF, SGF and RF protein content). Four samples (26, 28, 29 and 32) that were duplicates of the SGF protein category of other samples for that cultivar were not distributed to artisan bakers.

Wheat Quality Tests with RF Blended Samples

After bunt spore balls were removed by hand, 35 four-pound samples were milled in the UNL Crop Quality Lab on a Buehler mill to produce RF. RF samples were tested in January 2013 using AACC farinograph method 54-21.02 at a laboratory chosen by Baystate Milling Co. (Great Plains Analytical Laboratory) and were baked in the UNL Crop Quality Lab. RF and WF from Buehler mill streams (including finely ground bran) were analyzed by mixograph in the UNL lab.

Quality Tests-Year 2 (2012 planting- 2013 harvest- 2014 processing)

Wheat Quality Tests with RF Blended Samples

Seed was mixed among reps to obtain three or four protein NIR grain protein levels of 13.0, 13.5, 14.0 and 14.5. Protein categories were re-assigned to each sample based on WF instead of RF protein content, which had unexplained high values (Table 3.2). Forty-one composite samples from the 2013 crop representing 3 relative WF protein groups for each cultivar (that corresponded to 3 or 4 absolute protein levels) were baked in the UNL Crop Quality Lab.

Table 3.2 Protein Content Ranges for Grain measured by NIR, and for WF and RF measured by LECO Analyzer, 2013

	Protein Content Ranges		
Category	NIR Grain	LECO WF	LECO RF
A	13.0	11.9 - 12.4	10.5 – 11.4
B	13.5	12.5 - 13.0	12.5 – 13.0
C	14.0	13.1 - 13.6	13.1 – 13.6
D	14.5	13.6 - 14.3	13.5 – 14.4

Wheat Quality Tests with RF Unblended Samples

RF Mixograph tests were performed on 72 samples from the 2013 crop that were composites of all four reps for each cultivar*treatment entry.

Year 3 (2013 planting- 2014 harvest- 2015 processing)

Grain samples for baking tests were assembled from 3 to 6 plots at two grain protein content levels for five cultivars (Karl 92, NE05425, NE06607, NE07444, NW03666) and at three predicted grain protein levels for the other cultivars. An equal amount of seed was used from each plot to obtain 2700 grams for each of 34 samples. For lack of enough seed, there was no attempt to equalize the amount from each treatment (soy or alfalfa, with or without compost). Nor was it possible to obtain the same predicted protein categories for each cultivar. The higher protein composite samples were usually dominated by grain from soybean treatments. Wheat samples from the soybean treatment of the desired protein level were sometimes avoided when they contained very high levels of bunt spore balls.

Wheat Quality Tests with RF and WF Blended Samples

Mixograph tests were performed in conjunction with baking tests on WF and RF from blended grain samples.

Wheat Quality Tests with RF and WF Unblended Samples

To increase our ability to discriminate environmental effects on mixograph parameters, we conducted standard AACC mixographs on RF and WF on unblended samples from alfalfa, soybean and soybean with compost environments. RF and WF for mixographs were milled from 100 grams of un-tempered grain on a Quadramat Junior Mill (Doblado-Maldonado et al, 2013). Bran was ground to 2 mm on a UDY grinder and was mixed with the flour to reconstitute WF.

Results for Wheat Quality Tests

Quality Tests-Year 1 (2011 planting- 2012 harvest- 2013 processing)

Wheat Quality Tests with SGF Blended Samples

Of the eleven artisan bakers who received stoneground wheat samples from UNL, only seven followed through, resulting in only one bake test per sample for many of the samples. For several reasons, comparisons among bakers' results were thought to be unreliable (Table 4.1). Differences among bakers in skill for using 100% SGF in sourdough bread and in using the scoring method became evident. Little's results showed very few differences among cultivars for overall bread score or components (with only NE08457 receiving an overall score different than 7), indicating that the variability in results between bakers was likely due to the baker rather than to the sample. Despite the error from variability among bakers, a few apparent trends may make it worthwhile to pursue correlation analysis. Within each baker's sample set there was a trend showing that the higher protein category had the best baking score. Two bakers agreed on low ratings for NE05425, which corresponded to poor RF bread scores for this cultivar.

Table 4.1. SGF Sourdough Baking Properties Compared to Key RF Mixing and Bread Properties, for Comparisons based on WFPRO Category.

	WFPRO					SGFPRO		Sourdough Properties											RFPRO		previous crop = alfalfa	Milling	RF Mixing Properties			RF Baking
CULTIVAR	Category	%	Sample	REP	Sourdough Baker	Category	%	Mixing	Floor Time	Make up	Proof	Proof Condition	Proofing Tolerance	Loaf	Crumb	Loaf Volume Index	Overall Score	Hydration	Category	%	percent of sample	FYIELD	Best Farino-graph	MPT	DPT	BREADSC
NW07505	B	13.4	1	1	RL	B	12.4	6	6	8	8	8	5	8	8	8	7		C	11.5	55	70		11	43	4.3
NW07505	B	13.1	2	1	RL	C	12.9	8	7	6	7	7	7	7	7	7	7	83.0	B	11.1	33	71		14	43	3.9
NW07505	B	13.1	2	2	MK	C	12.9	5	6	5	7	6	6	6	6	8	6		B	11.1	33	71		14	43	3.9
NW07505	C	13.9	3	1	MK	C	13.1	5	6	5	6	6	6	7	6	8	6		D	12.1	100	69		8	44	3.3
NW03681	C	13.9	4	1	RL	B	12.4	7	7	8	5	7	5	6	8	8	7	84.0	D	11.9	2	72	*	6	52	3.3
NW03681	C	13.9	4	2	JH	B	12.4	5	5	6	8	8	8	7	7	8	7		D	11.9	2	72	*	6	52	3.3
NW03681	C	14.2	5																E	12.8	63	71	*	6	44	4.1
NW03681	D	15.3	6	1	JH	D	13.8	8	8	8	8	7	8	8	8	9	8		F	13.3	72	73	*	5	45	3.9
NW03666	A	12.3	7	1	RL	A	12.0	6	7	7	8	8	6	7	7	7	7	85.3	B	10.3	31	72		12	43	3.4
NW03666	A	12.3	7	2	RG	A	12.0	3	4	2	5	3	2	5	5	7	4		B	10.3	31	72		12	43	3.4
NW03666	B	12.8	8	1	RG	B	12.4	4	5	6	8	5	5	6	5	9	6		B	11.0	63	73		10	43	4.0
NW03666	C	14.0	9	1	RG	D	13.4	4	5	4	7	6	6	2	5	5	5		C	11.5	100	73		8	43	4.1
NE08457	A	12.5	10	1	RL	B	12.4	7	8	8	8	7	7	8	7	6	8	86.4	B	10.7	19	72		7	44	4.3
NE08457	A	12.5	10	2	SM	B	12.4	5	5	6	5	4	3	5	7	8	6		B	10.7	19	72		7	44	4.3
NE08457	C	13.9	11	1	SM	B	12.4	6	6	6	5	6	6	5	6	8	6		C	11.8	48	71		6	45	4.3
NE08457	D	14.9	12	1	SM	C	12.9	7	7	7	7	7	7	7	8	9	7		E	12.8	100	71		5	44	4.6
NE07444	A	12.5	13	1	TL	A	11.9	6	5	6	7	6	7	7	7	8	7		B	10.4	8	73		12	44	3.8
NE07444	A	12.5	14	1	RL	B	12.3	7	6	6	7	8	6	6	7	6	7	84.6	B	10.6	33	73		10	42	3.8
NE07444	B	13.3	15	1	TL	C	12.9	7	6	6	8	6	6	7	7	9	7		C	11.6	92	72		6	43	3.0
NE06607	A	12.1	16	1	JH	A	11.7	6	7	7	8	7	7	7	7	9	7		A	10.3	18	74		11	45	3.8
NE06607	B	13.2	17	1	JH	B	12.4	7	8	8	8	7	7	7	7	9	7		C	11.3	42	74	*	8	46	2.8
NE06607	C	14.1	18	1	MK	C	12.9	6	7	5	7	6	7	7	6	9	7		D	12.2	70	74	*	5	45	2.5
NE06469	B	13.0	19	1	RL	B	12.2	7	7	8	8	8	8	7	6	6	7	80.8	B	11.0	4	72		8	50	4.7
NE06469	B	13.0	19	2	RG	B	12.2	2	3	2	5	4	4	4	6	8	4		B	11.0	4	72		8	50	4.7
NE06469	C	13.8	20	1	RL	C	13.0	7	8	6	7	6	7	6	6	7	7	83.7	C	11.8	42	72	*	6	43	4.0
NE06469	C	13.8	20	2	RG	C	13.0	3	4	4	8	7	6	3	6	7	5		C	11.8	42	72	*	6	43	4.0
NE06469	D	15.1	21	1	RG	D	13.7	5	5	4	8	6	6	3	5	6	5		F	14.3	88	71	**	5	44	4.5
NE05496	C	13.9	22	1	MK	C	13.2	3	4	5	6	5	6	7	6	7	5		D	12.1	69	72		8	50	4.3
NE05496	D	14.7	23	1	MK	D	13.4	5	6	5	7	6	5	7	6	8	6		F	13.3	100	71	*	7	41	4.9
NE05425	A	12.2	24	1	AP	A	11.8	5	6	3	5	4	4	4	5	9	5		A	10.3	0	73		11	56	2.8
NE05425	A	12.2	24	2	SM	A	11.8	1	5	6	7	7	6	6	5	8	6		A	10.3	0	73		11	56	2.8
NE05425	C	13.8	25	1	RL	B	12.6	7	8	7	8	8	8	7	7	7	7	83.1	C	11.7	43	71	*	7	49	1.9
NE05425	C	13.8	25	2	AP	B	12.6	6	6	5	6	6	7	6	7	9	6		C	11.7	43	71	*	7	49	1.9
NE05425	C	13.8	25	3	SM	B	12.6	2	5	5	5	5	3	4	4	7	4		C	11.7	43	71	*	7	49	1.9
NE05425	D	14.9	26																F	14.5	100	71	**	6	45	2.6
NE02558	A	12.3	27	1	RG	A	11.9	2	2	3	4	4	3	5	4	7	4		A	10.1	12	71		9	46	4.0
NE02558	B	12.8	28																B	11.0	31	70		8	44	4.3
NE02558	C	13.8	29	1	RL	C	12.9	7	8	6	7	7	6	7	7	8	7	84.9	C	11.8	100	71	*	5	40	4.6
NE02558	C	13.8	29	2	RG	C	12.9	7	5	6	6	5	5	4	5	8	6		C	11.8	100	71	*	5	40	4.6
NI08708	B	13.1	30	1	MK	B	12.4	5	6	6	6	5	6	6	6	7	6		B	11.0	25	73		8	42	4.8
NI08708	C	13.9	31	1	MK	C	13.1	5	6	5	5	6	6	6	6	8	6		C	11.8	57	72	*	6	40	4.7
NI08708	C	13.9	32																C	12.0	60	71		6	44	4.8
MCGILL	A	12.4	33	1	RL	A	11.7	7	7	6	7	7	6	8	7	6	7	82.5	B	10.7	36	72		9	40	4.3
MCGILL	A	12.4	33	2	JW	A	11.7	5	7	6	6	6	6	7	7	9	7		B	10.7	36	72		9	40	4.3
MCGILL	A	12.4	33	3	JW	A	11.7	7	5	8	9	9	7	9	8	9	8		B	10.7	36	72		9	40	4.3
MCGILL	B	12.9	34	1	JW	A	11.7	8	7	8	8	9	8	8	8	9	8		B	10.9	23	72		8	37	5.0
MCGILL	B	12.9	34	2	JW	A	11.7	8	9	8	9	9	8	8	8	9	9		B	10.9	23	72		8	37	5.0
MCGILL	C	13.9	35	1	JW	C	12.8	7	5	7	8	9	9	8	7	9	8		D	12.0	100	71	*	6	37	5.1

Correlation Analysis
Several RF farinograph and SGF, WF and RF mixograph parameters were compared with sourdough baking parameters using SAS Proc Corr and Proc Reg statements. The correlation matrices show the Pearson Correlation Coefficient above the probability level for the significance of the correlation (Probability > |r| under the hypothesis that r =0).

Partial Correlates. Surprisingly, no significant correlations were revealed between components of sourdough baking performance and protein content or ALFPCT (data not shown). Therefore, partial correlations were avoided initially in correlation analysis with sourdough baking parameters.

SGF Sourdough Bread and RF Bread. Very few RF baking properties correlated with SGF sourdough baking properties (data not shown). Only one RF bread property, FIRM, a measure of the resistance to compression, had a significant (negative) correlation ($P < 0.05$) with overall sourdough performance ($R = - 0.315$) that was reflected in correlations with mixing, loaf and crumb components of the sourdough process.

SGF Sourdough Bread and RF Farinograph. RF protein content and percentage of sample from the alfalfa strip (ALFPCT) were significantly correlated with farinograph output and were thus used as partial correlates, using SAS Proc Corr, in comparing sourdough and farinograph properties. Farinograph output lacked significant partial correlations with either sourdough or white dough baking performance. Thus, for this set of cultivars, farinograph analysis appears to lack the potential for detecting or predicting dough and baking properties that are not influenced by protein content.

Farinograph data revealed a possible milling error. Contrary to what was expected based on other micro-quality and baking data, NW07505 samples alone were markedly lower than 30 minutes for stability (at 9.9, 1.7, and 2.8 minutes) and 32 minutes for departure time (at 10.0, 2.8, and 4.1 minutes); had exceedingly high MTI (35, 60 and 90 BU compared to a maximum of 33 BU for other samples); were quite low for peak time (4.0, 1.7, and 2.0 minutes, compared to a minimum of 6 minutes for other samples). Since NW07505 samples were the first to be tested on the farinograph, and there was not enough flour for more than one re-run, it is possible that the farinograph test was problematic. An alternative explanation is that a milling error resulted in an abnormally high short yield for NW07505 (an average of 9.4% short yield for the three NW07505 samples compared to a maximum of 7.0% for all other samples). However, short yield lacked correlation with sourdough baking score or components, either with or without NW07505 data. NW07505 data was removed from data sets for correlation and regression analysis with farinograph data.

SGF Sourdough Bread and SGF ASH and SGF Mixograph. SGF quality tests revealed significant correlations between a few milling and mixograph parameters and SGF sourdough baking (Table 4.2). SGFASH ($R = 0.413$, $P < 0.01$) in particular and SGFMRW ($R = -0.263$, $P < 0.10$) and MTI ($R = -0.281$, $P < 0.10$) appear to be useful correlates with overall sourdough baking performance. The correlation between SGFASH and overall sourdough baking score reflects strong correlations between ash content and crumb score ($R = 0.452$, $P < 0.01$). Mixing and makeup appear to have contributed to the correlation of sourdough baking score with SGFASH (R = 0.334 and 0.356 respectively, P < 0.05), and with MRW (R = 0.253, 0.261, respectively, P < 0.10).

Table 4.2. Pearson Correlations and Significance between SGF Sourdough Baking Properties and SGF Ash and Mixograph Properties, 2012

		Sourdough Baking Properties of Whole Stoneground Flour									
Parameter		Mixing	Floor Time	Make up	Proof	Proof Condition	Proofing Tolerance	Loaf	Crumb	Loaf Volume Index	Overall Score
Number of Observations		45	45	45	45	45	45	45	45	45	45
Stoneground Whole Flour Properties	PRO	0.039	-0.003	-0.158	0.041	-0.104	0.121	-0.235	-0.137	-0.175	-0.149
		0.797	0.986	0.300	0.789	0.497	0.430	0.121	0.368	0.250	0.329
	ASH	0.334	0.150	0.356	0.050	0.276	0.238	0.295	0.452	0.063	0.413
		0.025	0.324	0.016	0.744	0.067	0.116	0.049	0.002	0.683	0.005
	MABS	0.003	0.007	-0.120	-0.117	-0.112	0.043	-0.204	-0.126	-0.139	-0.130
		0.985	0.963	0.431	0.443	0.462	0.780	0.178	0.408	0.362	0.394
	MPT	-0.259	-0.109	-0.193	-0.120	-0.061	-0.125	-0.026	-0.137	0.006	-0.215
		0.086	0.475	0.205	0.431	0.692	0.412	0.867	0.369	0.968	0.156
	MPV	0.087	0.038	-0.127	0.242	0.031	0.175	0.061	-0.095	0.027	-0.014
		0.568	0.804	0.407	0.109	0.838	0.251	0.689	0.535	0.860	0.926
	MRV	0.031	0.041	-0.111	0.196	0.053	0.168	0.085	-0.104	0.077	-0.023
		0.838	0.788	0.469	0.197	0.730	0.270	0.580	0.495	0.613	0.882
	MRW	-0.253	-0.125	-0.261	-0.138	-0.175	-0.280	-0.119	-0.259	-0.101	-0.263
		0.094	0.414	0.084	0.367	0.250	0.063	0.436	0.086	0.510	0.081
	MTI	-0.245	-0.147	-0.276	-0.035	-0.230	-0.208	-0.154	-0.315	-0.093	-0.281
		0.105	0.336	0.067	0.817	0.129	0.170	0.314	0.035	0.542	0.062
	MTOLSC	-0.083	0.038	-0.212	0.109	-0.137	-0.015	-0.055	-0.182	0.059	-0.170
		0.587	0.803	0.162	0.478	0.370	0.924	0.719	0.230	0.698	0.264

SGF Sourdough Bread and RF Milling. The few correlations (P < 0.1) between reduction milling characteristics and sourdough baking performance may be important for understanding but not for predicting baking performance. Higher bran yield (R = -0.269) may have negatively impacted overall sourdough score (R = -.290).

SGF Sourdough Bread and RF Dough Properties. The impact of the RF fraction on the mixing properties of SGF sourdough bread is evident in the significant correlations shown in Table 4.3. RFDPT was negatively correlated with sourdough score (R = -0.400, P<0.01). RFMPT and RFMPV were correlated with overall sourdough score to a lesser extent (P < 0.05, R = - 0.345 and R = 0.334). Correlation between several components of the sourdough process and each of these parameters was evident with the strongest correlation between sourdough mixing and RFDPT (P < 0.01, R = - 0.438). Thus, these three RF mixograph and dough parameters may substitute for SGF mixograph parameters in attempts to predict SGF sourdough baking performance.

Table 4.3. Pearson Correlations and Significance between SGF Sourdough Baking Properties and Mixograph and Dough Properties of Reduction Flour, 2012

		Sourdough Baking Properties of Whole Stoneground Flour									
Parameter		Mixing	Floor Time	Make up	Proof	Proof Condition	Proofing Tolerance	Loaf	Crumb	Loaf Volume Index	Overall Score
Number of Observations		45	45	45	45	45	45	45	45	45	45
Reduction Flour Mixograph and Dough Properties	MABS	0.106	0.075	-0.020	0.047	0.039	0.154	-0.123	0.013	-0.051	-0.061
		0.489	0.626	0.897	0.761	0.801	0.312	0.422	0.930	0.741	0.691
	MTOLSC	-0.025	0.026	0.101	-0.035	0.146	0.091	0.136	0.075	0.176	0.019
		0.868	0.867	0.507	0.820	0.338	0.551	0.373	0.622	0.246	0.903
	MPT	-0.371	-0.196	-0.256	-0.198	-0.224	-0.293	-0.123	-0.243	-0.214	-0.345
		0.012	0.197	0.089	0.192	0.139	0.051	0.422	0.108	0.159	0.020
	MPV	0.339	0.109	0.273	0.211	0.304	0.261	0.307	0.327	0.206	0.334
		0.023	0.476	0.070	0.164	0.043	0.083	0.040	0.028	0.176	0.025
	MTI	-0.262	-0.106	-0.133	-0.099	-0.005	-0.108	-0.008	-0.146	0.051	-0.211
		0.082	0.490	0.384	0.518	0.976	0.482	0.959	0.339	0.737	0.165
	DABS	0.229	0.150	0.107	0.020	0.159	0.170	0.075	0.184	0.112	0.100
		0.130	0.326	0.484	0.898	0.297	0.265	0.623	0.225	0.464	0.512
	DMT	-0.148	-0.144	-0.122	0.040	-0.014	-0.126	0.139	-0.041	-0.075	-0.061
		0.333	0.346	0.425	0.795	0.928	0.411	0.362	0.790	0.626	0.693
	DSC	0.102	0.005	-0.031	-0.064	-0.073	0.044	-0.273	-0.103	0.022	-0.092
		0.506	0.975	0.838	0.674	0.633	0.773	0.070	0.500	0.885	0.550
	DPT	-0.438	-0.202	-0.225	-0.317	-0.291	-0.211	-0.281	-0.303	-0.061	-0.400
		0.003	0.183	0.136	0.034	0.052	0.164	0.061	0.043	0.691	0.007

SGF Sourdough Bread and WF Mixograph. WF mixograph analysis revealed very few correlations with SGF sourdough baking (data not shown). Small negative correlations ($P < 1.0$) of sourdough baking overall score with WFMPT ($R = -0.306$) and WFMTI ($R = -0.284$), reflected small negative correlations of these mixograph parameters with sourdough mixing ($P< 0.05$, $R = -0.374$ and $P < 0.10$, $R = -0.298$, respectively). Otherwise, WF mixograph analysis appears useless for predicting sourdough baking performance of SGF samples after controlling for the protein effect.

Partial Correlates. Of note, two key SGF parameters that lacked correlation with protein (SGFASH and SGFMTI) also lacked correlation with ALFPCT (Table 4.4). Of the RF parameters that were identified as being potentially useful for predicting sourdough baking performance, it is noteworthy that RFMPT, RFMTI, and RFDPT, lack correlation with RF protein content ($P = 0.105$, 0.461 and 0.725). However, these parameters were also correlated with ALFPCT. By using ALFPCT as a partial correlate, these parameters were still highly correlated with sourdough baking performance and components of the sourdough process (Table 4.5).

Table 4.4. Protein Correlations with SGF Mixograph Properties, RF Mixograph and Dough Properties and WF Mixograph Properties (Pearson Correlations/Pr > r), 2012

Stoneground Flour Mixograph Preperies			Reduction Flour Mixograph Properties			Reduction Flour Dough Properties			Reconstituted Whole Flour Mixograph Properites		
	SGFPRO	ALFPCT		RFPRO	ALFPCT		RFPRO	ALFPCT		WFPRO	ALFPCT
N	44	44		44	44		44	44		44	44
SGFASH	0.024	0.122									
	0.876	0.429									
SGFMABS	0.758	0.613	RFMABS	0.961	0.579				WFMABS	0.957	0.546
	0.000	0.000		0.000	0.000					0.000	0.000
SGFMPT	-0.427	-0.562	RFMPT	-0.247	-0.428	RFDMT	-0.744	-0.550	WFMPT	-0.365	-0.519
	0.004	0.000		0.105	0.004		0.000	0.000		0.015	0.000
SGFMPV	0.642	0.697	RFMPV	0.450	0.513				WFMPV	0.645	0.605
	0.000	0.000		0.002	0.000					0.000	0.000
SGFMRV	0.604	0.567							WFMRV	0.633	0.494
	0.000	0.000								0.000	0.001
SGFMRW	-0.282	-0.228							WFMRW	-0.112	-0.316
	0.064	0.136								0.469	0.037
SGFMTI	-0.181	-0.154	RFMTI	-0.114	-0.288				WFMTI	-0.252	-0.157
	0.240	0.319		0.461	0.058					0.099	0.310
SGFMTOLSC	0.081	0.056	RFMTOLSC	0.262	0.011	RFDSC	0.272	0.199	WFMTOLSC	0.114	0.303
	0.602	0.717		0.086	0.943		0.074	0.196		0.463	0.046
						RFDPT	-0.054	-0.439			
							0.725	0.003			

Table 4.5. Sourdough Baking Correlations with Key RF Mixograph and Dough Parameters without NW07505 data using ALFPCT as a Partial Correlate, 2012

partial ALFPCT, Exccluding NW07505 data										
Parameter	Mixing	Floor Time	Make up	Proof	Proof Condition	Proofing Tolerance	Loaf	Crumb	Loaf Volume Index	Overall Score
Number of Observations	40	40	40	40	40	40	40	40	40	40
RFMPT	-0.454	-0.229	-0.335	-0.210	-0.374	-0.397	-0.341	-0.425	-0.254	-0.484
	0.004	0.161	0.037	0.199	0.019	0.012	0.034	0.007	0.118	0.002
RFMPV	0.346	0.100	0.284	0.152	0.363	0.346	0.417	0.403	0.208	0.405
	0.031	0.543	0.080	0.355	0.023	0.031	0.008	0.011	0.203	0.011
RFMTI	-0.284	-0.104	-0.227	-0.110	-0.087	-0.072	-0.165	-0.305	0.075	-0.284
	0.080	0.530	0.165	0.506	0.598	0.662	0.315	0.059	0.651	0.079
RFDPT	-0.402	-0.200	-0.278	-0.263	-0.314	-0.172	-0.342	-0.363	-0.044	-0.437
	0.011	0.223	0.087	0.106	0.052	0.296	0.033	0.023	0.791	0.005

Only one RF bread property, FIRM, a measure of the resistance to compression, had a significant, but negative correlation ($P < 0.05$) with overall sourdough performance ($R = -0.317$) that was reflected in several correlations with components of the sourdough process: mixing, proof, proof condition, loaf and crumb. FIRM, as well as the other baking properties do not appear to be correlated with ALFPCT. Hence, no insight regarding baking properties will be gained by doing a separate correlation analyses for samples from each environment.

Regression Analysis for SGF Sourdough Bread

SGF and RF Variables identified through correlation analysis were standardized to a mean of 5 and standard deviation of 1. Using the MAXR selection procedure in SAS, only SGFASH and SGFMABS contributed to the regression model ($P<0.05$ for each variable) and together accounted for **28.2%** (R^2) of the overall sourdough bake score when NW07505 data was not included in the analysis. If only the key variables identified previously are used in the regression analysis (excluding SGFMABS), then DPT and MPT become part of the regression model. Without NW07505 in the data set, DPT and SGFASH accounted for 22.4% (adjusted R^2) of the sourdough bake score. When NW07505 was added to the data set, MPT replaced DPT in the regression equation, also with an adjusted R^2 of 22.4% of the overall sourdough bake score.

Wheat Quality Tests with RF Blended Samples

The high correlations of mixograph and dough properties with the percent of sample from the alfalfa strip (ALFPCT) indicate that it will be useful to compare mixographs for samples entirely from the alfalfa strip with samples entirely from the soybean strip. As shown in Table 4.6, RFPRO was very highly correlated with RFMABS for both previous crop sources ($P < 0.0001$, $R = 0.857$ and 0.853) but was correlated with RFMPV and RFMTI only for the alfalfa source ($P < 0.0001$, $R = 0.624$ and 0.630, respectively), suggesting that the previous crop had an effect on mixing properties independently of protein content. Thus, the effect of environment is too great to make use of RFMPV or RFMTI data for SGF selection or sourcing decisions for use in sourdough baking. This leaves RFMPT as the sole RF variable for this purpose. However, the independence of the mixograph x environment interaction from protein content suggests that the change in cropping systems may affect bread quality in unsuspected ways. Unfortunately, testing bread quality vs. cropping system was outside of the scope and resources of this project.

Table 4.6. Pearson Correlations of Reduction Flour Protein Content with Ash Content and Mixograph Parameters for Samples Sourced from Strips with Previous Crops of Alfalfa and Soybeans, 2012

	RFPRO		
PREVIOUS CROP	ALFALFA	SOYBEANS	COMBINED
N	36	24	60
RFASH	0.009	0.127	0.005
	0.961	0.554	0.973
RFMABS	0.857	0.853	0.943
	0.000	0.000	0.000
RFMTOLSC	0.167	0.173	0.257
	0.329	0.418	0.048
RFMPT	0.015	-0.213	-0.581
	0.931	0.317	0.000
RFMPV	0.624	0.298	0.762
	0.000	0.158	0.000
RFMAREA	0.630	0.191	0.546
	0.000	0.371	0.000

Quality Tests-Year 2 (2012 planting- 2013 harvest- 2014 processing)

Wheat Quality Tests For RF Unblended Samples
As a lead to discovering protein thresholds for each cultivar for good baking quality, the 2013 experiment with unblended samples was designed to elucidate the effect of environments on protein correlations with mixograph parameters.

RFPRO and Mixograph Correlations. Since there were no correlations between MTW and RFPRO, MTW may be a more useful variable than MRW, which was correlated with RFPRO in two environments (Table 9.1). The usefulness of MPT was confirmed for lack of protein correlations across environments. An additional mixograph parameter, right slope (MRS), had variable correlations with RFPRO by environment, and will not be considered further.

Table 5.1. Correlations between RF Protein and Mixograph Properties for Split Treatment Plots of Previous Crop, Cover Crop, and Compost, 2013

		Reduction Flour (RF) Mixograph Properties										
Treatment	N	FY	BRANSC	MABS	MPT	MPV	MRV	MRS	MRW	MTW	MTI	MTOLSC
RFPRO	48	0.131	0.195	0.909	0.076	0.448	0.471	0.288	0.115	0.019	-0.069	-0.008
Alfalfa Previous Crop		0.376	0.185	0.000	0.607	0.001	0.001	0.048	0.435	0.898	0.640	0.960
RFPRO	24	-0.139	-0.066	0.883	0.268	0.586	0.499	0.115	0.453	0.285	0.354	0.283
Soybeans Previous Crop		0.518	0.759	0.000	0.206	0.003	0.013	0.592	0.026	0.177	0.090	0.181
RFPRO	48	0.177	-0.011	0.927	0.141	0.641	0.550	0.424	0.282	0.095	0.186	0.111
No Cover Crop		0.229	0.940	0.000	0.338	0.000	0.000	0.003	0.052	0.520	0.207	0.454
RFPRO	24	-0.187	0.411	0.906	0.165	0.328	0.415	0.034	0.032	0.118	-0.133	0.026
Radish Cover Crop		0.382	0.046	0.000	0.441	0.118	0.044	0.876	0.880	0.584	0.537	0.906
RFPRO	36	0.114	0.173	0.917	0.059	0.560	0.568	0.335	0.225	0.006	0.016	0.003
Compost		0.508	0.314	0.000	0.734	0.000	0.000	0.046	0.187	0.974	0.927	0.986
RFPRO	36	0.081	0.004	0.920	0.235	0.537	0.441	0.285	0.166	0.177	0.153	0.139
No Fertilizer		0.638	0.980	0.000	0.168	0.001	0.007	0.092	0.333	0.302	0.372	0.420

ANOVA and Cultivar Means and Interactions for Quality Traits. Mean separation among cultivars was clearly defined for key flour and mixograph properties (Table 5.4) with little interaction among environments for MPT and MTW (Tables 5.2 and 5.3) except for NW07505 with much lower MPT values in the soybean environments than in the alfalfa environments. The model lacked replications within environments, and hence lacked degrees of freedom to detect significance of differences and interactions between cultivars within each environment.

Table 5.2. MPT for Wheat Cultivars in Six Split-Plot Environments, 2013

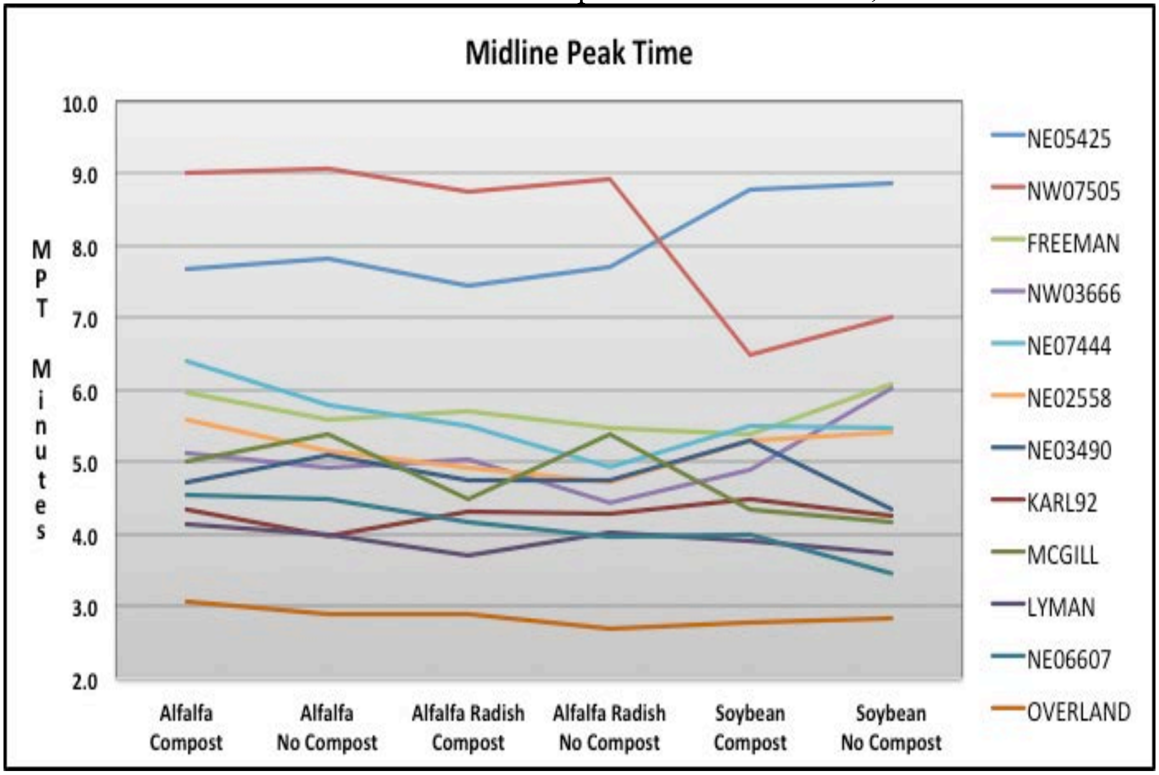


Table 5.3. MTW for Wheat Cultivars in Six Split-Plot Environments, 2013

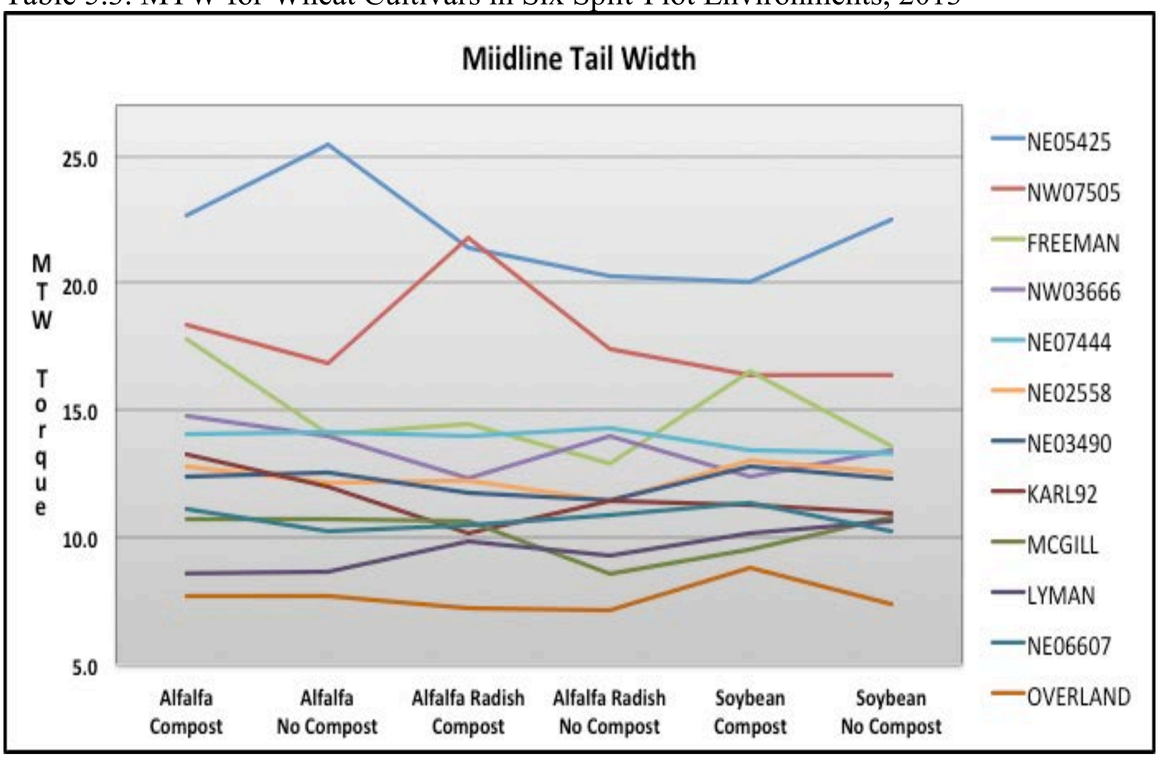


Table 5.4. Key Flour and Mixograph Properties for Wheat Cultivars Across Treatments and Previous Crops, 2013.

		FLOUR PROPERTIES		MIXOGRAPH PROPERTIES		
Cultivar	N	RF PROTEIN (14% M.B.)	FLOUR YIELD (%)	MPT	MTW	MXING TOLERANCE SCORE
KARL92	6	13.2	72.7	4.8	11.5	4.3
LYMAN	6	13.0	69.1	3.9	9.6	3.4
MCGILL	6	12.1	69.0	4.1	10.1	4.2
NE02558	6	12.0	67.6	5.1	12.4	4.4
NE03490	6	11.9	70.3	4.8	12.2	4.4
NE05425	6	12.4	68.3	8.1	22.0	5.6
NE06545	6	11.8	69.7	5.6	14.9	4.5
NE06607	6	12.3	70.5	4.3	10.7	3.6
NE07444	6	12.3	69.1	5.2	13.9	4.8
NW03666	6	11.9	69.0	5.7	13.5	4.6
NW07505	6	12.5	64.5	8.2	17.9	4.3
OVERLAND	6	11.8	70.7	2.9	7.6	2.0
Pr > F		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

Wheat Quality Tests For RF Blended Samples

The purpose of baking in the second year of the study was to confirm the value of parameters without significant correlations with protein content for predicting bread quality. RF Mixograph tests were performed in May 2014 on 72 samples from the 2013 crop that were composites of all four reps for each entry.

RF Bread, Milling and Mixing and WF Protein Categories. Significant differences among protein categories were detected only for dough proof time (decreasing with an increase in protein) and for MTW (increasing with an increase in protein from categories A to C, then dropping off). Scores for bread texture and overall bread score trended upward with an increase in protein (Table 5.5).

Table 5.5. Means for WF Protein Categories and Significance of Differences among RF Quality Properties, 2013

	RF Milling		RF Mixograph and Dough Parameters					RF Bread		
WF Protein Category	Flour Yield (%)	Short Yield (%)	MPT (min.)	MTW (%Torque)	MTI (%Torq / Min.)	Mixo Tolerance Score (0-7, 7 is best)	Dough Proof Time (min.)	Specific Bread Volume (cc/g)	Texture Score (1-6, 6 is best)	Bread Score (1-6, 6 is best)
A (11.9 - 12.4)	71.4	3.2	6.3	11.1	99.1	3.5	61.8	6.3	4.0	4.1
B (12.5 - 13.0)	71.1	3.0	5.9	12.2	110.8	3.7	58.8	6.7	4.1	4.4
C (13.1 - 13.6)	70.9	3.1	7.0	13.6	106.4	4.1	53.8	6.6	4.4	4.5
D (13.6 - 14.3)	71.4	3.1	6.2	11.7	106.4	3.7	51.1	6.6	4.6	4.6
LSD .05	0.9	0.3	0.6	1.4	17.9	1.4	5.2	0.3	0.6	0.4
Significance of Differences	NS	NS	NS	***	NS	NS	***	NS	NS	NS
Pr > F	0.4124	0.2200	0.2582	0.0079	0.5815	0.5472	0.0019	0.1341	0.2904	0.1910

RF Protein Correlations. The RF mixograph parameters of most interest based on the previous year results, MPT and MRW, as well as MABS, FYield, BranY and BranSc were correlated with RFPRO (Table 5.6). Therefore, RFPRO was used as a partial correlate for correlation analysis between mixing and baking properties (table 10.3).

Table 5.6. Pearson Correlations between RF Protein Content and RF Quality Parameters, 2013

	Reduction Flour Milling, Mixograph, Mixing and Baking Parameters											
RFPRO	Milling	FY	BRANY	SHORTY	BRANSC	SHORTSC	MILLSC	RFASH				
		0.034	-0.039	-0.008	0.133	0.166	0.356	0.192				
		0.844	0.820	0.964	0.441	0.334	0.033	0.262				
	Mixograph	RFMABS	RFMPT	RFMPQ	RFMRPQ	RFMRS	RFMRW2	RFMRW8	RFMAREA	RFMTOLSC		
		0.919	0.413	0.225	0.409	-0.069	0.480	0.292	-0.014	0.190		
		0.000	0.012	0.187	0.013	0.689	0.003	0.084	0.933	0.266		
	Dough	RFDABS	RFDMT	RFDSC	RFDPT	RFLV	RFSPV					
		0.850	0.248	0.155	-0.475	0.257	0.151					
		0.000	0.144	0.366	0.003	0.131	0.380					
	Baking	RFFIRM	RFSLICEA	RFSLICEB	RFCELLNUM	RFCELLD	RFNONUNIF	RFELONG	RFEXTSC	RFCRUMBSC	RFTEXTSC	RFBREADSC
		-0.348	0.135	-0.154	0.343	-0.309	-0.189	0.014	0.282	0.248	0.360	0.381
		0.037	0.431	0.370	0.041	0.067	0.269	0.935	0.096	0.144	0.031	0.022

RF Bread, Milling and Mixing Correlations. While using RFPRO as a partial correlate (Table 5.7) for the parameters that are very strongly correlated with RF bread score (P < 0.001), shorter RFDPT also correlates with greater RF loaf volume, specific volume, cell density, cell uniformity, texture score, and crumb score, and lesser firmness, thus with a higher RF bread score (P< 0.0001, R = -0.615). Notable exceptions are specific volume and cell elongation. A greater short yield correlates strongly with bread score (with lesser bread firmness, more uniform cells, greater cell elongation, and higher crumb score, texture score and overall bread score (P < 0.001, R = 0.531). MTOLSC correlates positively with bread score, texture score, crumb score, and cell diameter. Parameters less significantly correlated (P < 0.10) with baking properties include flour yield (R = -0.330), MTW (R = 0.294), MTI (R = 0.333) and DMT (R = 0.327).

Table 5.7. Significant RFPRO Partial Correlations of RF Milling and Mixing with RF Baking Properties, 2013

	SHORTY	RFMPT	RFMRW	RFMTW	RFMTI	RFMTOLSC	RFDMT	RFDSC	RFDPT
RF Specific Bread Volume	-0.035	-0.437	-0.056	-0.165	0.141	-0.105	-0.400	0.237	-0.444
	0.843	0.009	0.750	0.343	0.418	0.549	0.017	0.170	0.008
RF Bread Score	0.012	-0.447	-0.078	-0.199	0.186	-0.073	-0.384	0.313	-0.444
	0.945	0.007	0.658	0.252	0.286	0.679	0.023	0.067	0.008
RF Exterior Score	0.501	0.382	0.241	0.373	0.250	0.427	0.482	0.495	-0.430
	0.002	0.024	0.164	0.027	0.147	0.011	0.003	0.003	0.010
RF Crumb Score	0.594	0.321	0.307	0.367	0.322	0.464	0.406	0.513	-0.542
	0.000	0.060	0.073	0.030	0.059	0.005	0.016	0.002	0.001
RF Texture Score	0.531	0.207	0.242	0.294	0.333	0.414	0.327	0.565	-0.615
	0.001	0.232	0.161	0.086	0.050	0.014	0.055	0.000	0.000

Regression for RF Bread Score. Stepwise regression of unique parameters with strong partial correlations with RF bread score resulted in a 4-parameter model that explained 57.5 % of the bake score. The equation is RF Bread Score = 4.12137 -0.03761*RFDPT+ 0.09171*RFMPT + 0.00951*RFMTI+ 0.26146*SHORTY.

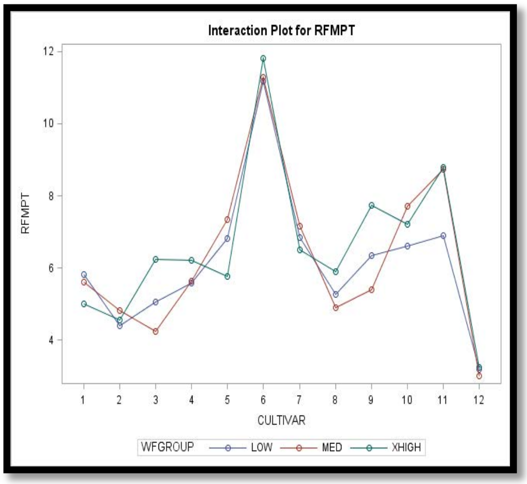
ANOVA for WF Protein Group and Interactions with Cultivars. Analysis of variance (Table 5.8) that modeled cultivar and WF protein group with key quality parameters detected differences among WF protein groups for Bread Score ($P < 0.10$), DPT ($P < 0.001$), MTW ($P < 0.05$), and Specific Loaf Volume (SPV, $P < 0.10$). Cultivars were significantly different for MPT, Short Yield and MTW ($P < 0.0001$) and to a lesser degree for Bread Score ($P < 0.001$), DPT ($P < 0.01$) and SPV ($P < 0.10$), but not for MTI ($P = 0.763$) when tested against the interaction between WF protein group and cultivar. No significant interactions were detected.

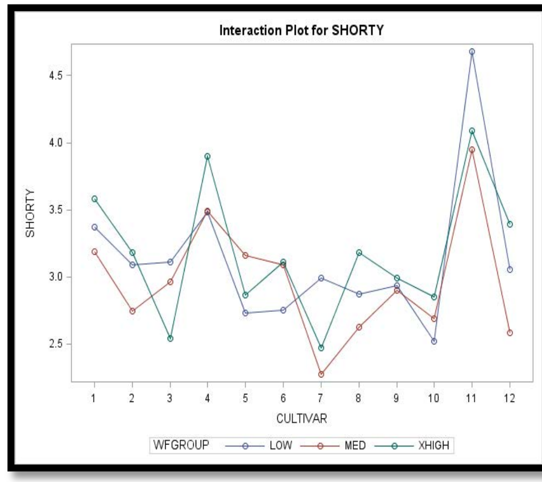
Table 5.8. GLM ANOVA for Cultivar and WF Protein Group (Low, Medium or High for that Cultivar) with Key Quality Parameters, 2013

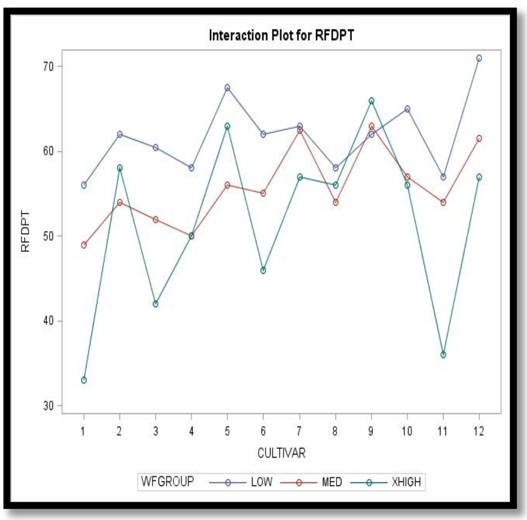
		Pr > F						
	DF	RFBREADSC	RFMPT	RFMTW	RFMTI	RFDPT	RFSPV	RFSHORTY
MODEL	14	0.0009	< 0.0001	< 0.0001	0.7607	0.0003	0.0533	< 0.0001
CULTIVAR	11	0.0007	< 0.0001	< 0.0001	0.7561	0.0024	0.0756	< 0.0001
WF PROTEIN GROUP	3	0.0996	0.3273	0.0126	0.7436	0.0002	0.0767	0.2120
C.V. %		9.1	10.5	12.1	17.1	8.8	4.6	8.6

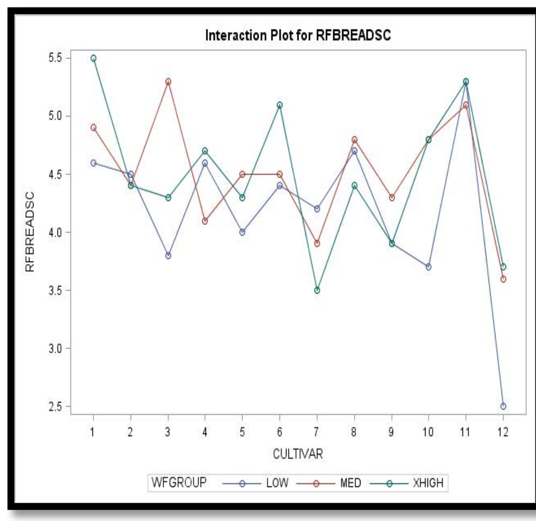
RF Bread Score and Quality Parameters for WF Groups. RFMPT and RF Short yield varied little between protein groups. Visual examination of the interaction plots (Table 5.9) reveals unique features for a few cultivars that might explain some of the correlation or lack thereof between these quality parameters and bread score. Of the cultivars with the best RF bread scores: cultivar #6 (NE05425) is distinguished by high MPT; Cultivar #11 (NW07505) is distinguished by high short yield at all protein levels and low dough proof time at the highest protein level (36 minutes); and cultivar #1 (Karl 92) is also distinguished by low dough proof time at the highest protein level (33 minutes), but also by relatively low MPT between 5 and 6 minutes. Overland stands out as having a very poor baking score, corresponding to long dough proof time (55 to 70 minutes) and very low MPT (2.5 minutes).

Table 5.9. Interactions among Cultivars for Key Mixing Parameters and Bread Score at Three WF Protein Group Levels, 2013









Protein Threshold, Year 2

The following protein threshold analysis (Table 5.10) is based on the cumulative baking score for each of the twelve lines. The threshold for 'very good' bread on a 1 – 6 scale was arbitrarily set at 4.5. Above 5 would be considered 'excellent'. The patterns for protein threshold were quite varied. Three lines (NW07505, NE02558 and NE06607) made very good RF bread in the lower WF protein category of 11.9 – 12.4, which is consistent with expectations. NE05425, known as a strong gluten line, reached the threshold at 13.1 -13.6 % protein, and increased to excellent at the higher protein category. McGill reached the excellent category at 12.5 to 13.0 % protein, then tapered off. Lyman reached the threshold at 12.5 – 13.0 % protein, and maintained about the same score for higher protein levels. Three lines, Freeman, Overland, and NE07444, did not reach the threshold and did not contain enough protein to test at the higher level. NW03666 reached the threshold at 12.5 - 13.0 % and maintained at the higher protein level. Karl 92 reached the threshold at a higher protein level of 13.1-13.6%. However, Karl 92 is a high protein line and could not be tested at lower protein content. NE03490 was close to the threshold at the highest protein level.

Table 5.10. Protein Threshold based on Bread Score and WF Protein, 2013

WF PROTEIN CATEGORY (RANGE OF %)	BREAD SCORE ON A SCALE OF 1 - 6, WHERE 6 IS BEST											
A (11.9 - 12.4)			3.8	4.6		4.4	4.2	4.7	3.9	3.7	5.3	2.5
B (12.5 - 13.0)		4.5	5.3	4.1	4.0		3.9		4.3	4.8	5.1	3.6
C (13.1 - 13.6)	4.6	4.4		4.7		4.5	3.5	4.8	3.9	4.8	5.3	3.7
D (13.6 - 14.3)	5.2	4.4	4.3		4.4	5.1		4.4				
PROTEIN THRESHOLD FOR BREAD SCORE OF 4.5	C OR LOWER	B	B	A		C		A		B	A	
	KARL 92	LYMAN	MCGILL	NE02558	NE03490	NE05425	FREEMAN	NE06607	NE07444	NW03666	NW07505	OVERLAND

Quality Tests-Year 3 (2013 planting- 2014 harvest- 2015 processing)

Wheat Quality Traits for Blended Samples

Protein for WF and RF. Protein content percentages (LECO system, N factor of 5.85, corrected to 14% moisture content basis) for the targeted (predicted from NIR grain protein) protein categories were as follows for Grain (G), Whole Flour (WF), and Reduction Flour (RF). The difference in protein levels between WF and RF for these samples was mostly between 1.3 and 2. Noteworthy anomalies were NE05425 (~0.8), Lyman high and mid-protein samples (~1.0), and the Overland mid-protein sample (~2.5).

Category	G	WF	RF	RF Outliers
A	13.2	12.0 – 12.3	10.6 – 10.9	10.2
B	13.7	12.4 – 12.9	11.1 – 11.2	10.4, 10.6, 12.1
C	14.2	13.2 – 13.6	11.5 – 12.0	11.3, 12.4
D	14.7	13.7 – 14.1	12.5 – 12.9	12.0, 13.4

Three samples (for NW07505, NW09421 and NE06545) were not used for comparing RF and WF baking and mixograph properties because WF protein contents for these cultivars were between the categories and lacked a suitable lower protein category for comparison.

RF Bread and RF Mixographs. The mixograph properties to be compared are those with high correlations with bread score and its components of exterior score, crumb score and texture score, plus the very important property of specific bread volume. RF bread properties were highly correlated with MPT, MTW, TOLSC, DMT and DPT with (Table 5.11).

Table 5.11. Pearson Correlations of RF Mixing Parameters with Key RF Bread Properties, with RF Protein and Single Kernel Hardness Class as Partial Correlates, 2014

		RFMPT	RFMTW	RFTOLSC	RFDMT	RFDPT
RF Specific Bread Volume	Pearson r	-0.375	-0.274	-0.121	-0.442	-0.157
	Pr > |r|	0.035	0.129	0.509	0.011	0.392
RF Bread Score	Pearson r	0.520	0.467	0.373	0.471	-0.481
	Pr > |r|	0.002	0.007	0.035	0.007	0.005
RF Exterior Score	Pearson r	-0.257	-0.103	-0.036	-0.334	-0.234
	Pr > |r|	0.156	0.574	0.843	0.062	0.198
RF Crumb Score	Pearson r	0.556	0.464	0.349	0.518	-0.375
	Pr > |r|	0.001	0.008	0.050	0.002	0.035
RF Texture Score	Pearson r	0.667	0.530	0.446	0.650	-0.494
	Pr > |r|	0.000	0.002	0.011	0.000	0.004

WF Bread and WF Mixographs. WF baking properties were highly correlated with DPT and less correlated with MPT and MTW (Table 5.12). TOLSC and DMT lacked correlation with WF bread properties and are not shown here.

Table 5.12. Pearson Correlations for WF Mixing Parameters vs. Key WF Bread Properties, with WF Protein and Single Kernel Hardness Class as Partial Correlates, 2014

		WFMPT	WFMTW			WFDPT
WF Specific Bread Volume	Pearson r	-0.433	-0.385			-0.857
	Pr > |r|	0.017	0.036			0.000
WF Bread Score	Pearson r	-0.298	-0.367			-0.847
	Pr > |r|	0.110	0.046			0.000
WF Exterior Score	Pearson r	-0.393	-0.418			-0.815
	Pr > |r|	0.032	0.022			0.000
WF Crumb Score	Pearson r	-0.286	-0.332			-0.854
	Pr > |r|	0.126	0.073			0.000
WF Texture Score	Pearson r	-0.195	-0.313			-0.772
	Pr > |r|	0.302	0.093			0.000

WF Bread Score and Single Kernel Properties and Mixographs. Regression was performed between bread score components and subsets of mixograph, dough, milling and single kernel characteristics. Covariation is taken into account at each step of the "Max R" SAS regression procedure, so it is not surprising that regression models often mirrored partial correlation results (Tables 13.2 and 13.3). SKW and SK Hardness components were part of the best regression models explaining WF Bread Score. Along with these SK parameters, WFMRW contributed 35% to bread score fairly equally to each bread component (crumb score, exterior score and texture score), along with MPV for exterior score. WFPRO along with WFDPT contributed 79% to bread score. WFDPT alone contributed 71% to bread score. DPT was a strong contributor to each bread score component.

Along with SKClass, MPT and MRW contributed 53% to WF bread score, which exceeds the contribution of dough properties. DMT and DPT contributed 37%. When the above mixograph and dough properties were used as regressors, DMT dropped out and MPT and MRW were replaced by MTW. Together the parameters explained 59% of RF bread score. When only key regressors were used, MTW and DPT contributed 39% to RF bread score.

Statistical Analysis Across Years, 2013 and 2014

Wheat Quality Tests for Blended Samples, 2013-2014

Protein Categories. Since LECO RF protein content in 2013 was problematic, the LECO WF category designations for each sample are used for grouping the samples into protein categories. WF protein ranges in the four categories were consistent between 2013 and 2014 quality test samples (Table 6.1).

Table 6.1. Ranges for Protein Categories for 2013 and 2014 Wheat Quality Samples

2014 Category	2014 Protein Content				2013 Category	2013 Protein Content		
	NIR Grain	LECO WF	LECO RF	RF Outliers		NIR Grain	LECO WF	LECO RF†
A	13.2	12.0 – 12.3	10.6 – 10.9	10.2	A	13.0	11.9 - 12.4	10.5 – 11.4
B	13.7	12.4 – 12.9	11.1 – 11.2	10.4, 10.6, 12.1	B	13.5	12.5 - 13.0	11.5 – 12.4
C	14.2	13.2 – 13.6	11.5 – 12.0	11.3, 12.4	C	14.0	13.1 - 13.6	12.5 – 13.4
D	14.7	13.7 – 14.1	12.5 – 12.9	12.0, 13.4	D	14.5	13.6 - 14.3	13.5 – 14.4

Combined ANOVA for WF Categories, 2013-2014. Combined data for 2013 and 2014 was analyzed for variance of cultivars and WF category using PROC GLM. The significance of differences among categories and among cultivars is of prime importance in this analysis. This is especially true for bread score, and its components—crumb score, exterior score, and texture score. If bread score or its components are different for each WF protein category, and at the same time there are differences among cultivars, we are closer to finding an optimal level of protein, and it would then be worthwhile to perform regression analysis to determine which milling and mixing properties can predict the bread score or its components. On the other hand, if an interaction exists between year and cultivar for bread score or its components, it would be more difficult to determine the inherent quality of a cultivar. An interaction between cultivar and WF category for these traits would indicate that a particular protein category for a particular cultivar is not always the best for bread quality or its components or predictors.

Cultivars in the data set in which samples were assigned to these four WF categories did not have a full set of 4 samples; several had only 2 samples that matched these categories, and some had duplicate entries in a category.

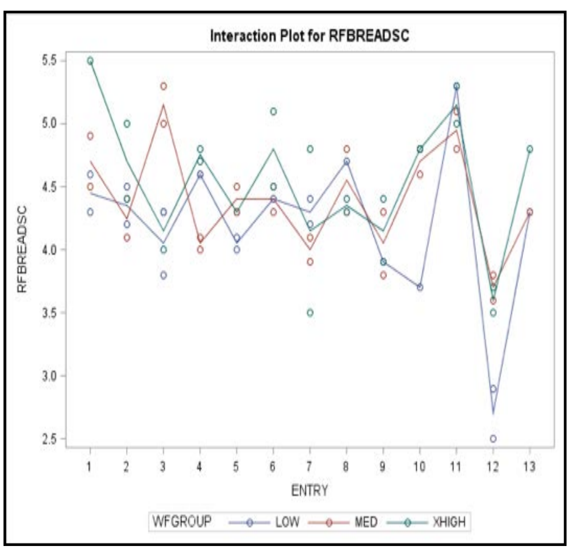
Degrees of freedom were gained by leaving year out of the analysis and treating each year*experiment as a separate environment. Thus, six environments were described: previous crop of alfalfa with mixed samples for both years, and soybeans as a previous crop with or without a compost treatment for both years. This allowed the use of 'cultivar*WF category' as an error term to properly correct the mean of each cultivar or WF category.

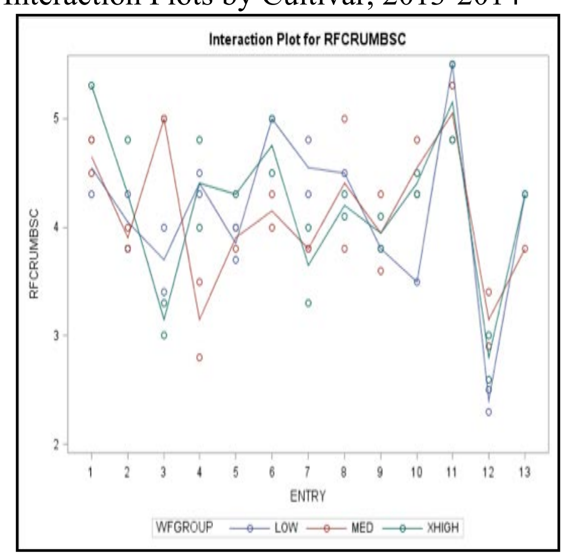
Because of the lack of interaction for cultivar*WF category for most properties, enough degrees of freedom were gained by running the analysis without the 'cultivar*WF category' term in order to use year as a dependent variable in addition to cultivar and WF category, along with all possible interaction terms.

To obtain a more balanced data set, samples were re-assigned into low, medium and high protein content groups relative to each cultivar. Using cultivar, 'WF group' and cultivar*WF group and leaving year out of the model, the ANOVA results were similar to the model with WF category, thus giving some assurance that both models were appropriate. Use of WF group compared to WF category lowered the coefficient of variation slightly for most variables, and did not appreciably change the levels of significance or R-squared values. The use of WF group revealed an interaction between group and cultivar for DPT and RFEXTSC (both $P < 0.10$) that was not evident when using WF category. The ANOVA results for WF group will be reported.

RF Bake Test ANOVA Without the Year Term, 2013-2014. RF Bread Score across years showed significant differences among cultivars ("entries" in Table 6.2, $P < 0.001$) and WF groups ($P < 0.001$) and low coefficient of variation (7.5) and high R-squared value (0.88). An interaction for RF Bread Score was detected between cultivar and WF group ($P < 0.05$), which is most evident in the high bread score for the medium protein group for entry 3 (McGill) and for the low protein group for entry 8 (NE06607) and entry 11 (NW07505). RF Crumb score, a component of Bread Score, drives this interaction.

Table 6.2. RF Bread Score and Crumb Score Interaction Plots by Cultivar, 2013-2014





RF Bake Test ANOVA With the Year Term, 2013-2014. A general linear model that included year and appropriate interactions terms among years, cultivars and WF categories showed significance only for RFMTW ($P < 0.01$) and RFDMT ($P < 0.10$). Year and cultivar terms for RFMTW were both highly significant ($P < 0.001$), and WF category was significant ($P < 0.01$). For DMT, cultivar was the only dependent variable that was significant (P < 0.05). A strong interaction between cultivar and environment indicates that RFMTW would require testing in multiple environments before it is used for evaluating cultivars. DMT may be a stable property with further value in this quest. There were significant interactions of cultivar*WF group for DPT, CRUMBSC and BREADSC, indicating that not all cultivars responded in the same manner to an increase in protein level. The ANOVA model was not significant for flour yield or short yield, but was marginally significant for bran yield, RFASH and RFSPV (P< 0.1), was significant (P < 0.01) for MTOLSC and MTW, and was highly significant (P < 0.001) for MPT, DPT, DMT, TEXTSC, CRUMBSC and BREADSC. In the significant regression models, cultivars showed significant differences for each of these parameters. DPT was highly significantly different among WF groups, SPV and BREADSC were significantly different, and MTW and TEXTSC were marginally significantly different. R-squared values for the significant models ranged from 0.70 for RFSPV to 0.95 for RFDMT. The significance levels of these parameters will be used to interpret and confirm the following regression analyses.

RF Bake Test Correlation Summary, 2013-2014. A summary of correlation analyses using protein content in 2013 and protein content and SKClass in 2014 as partial correlates will first be presented. Three correlation analyses (Tables 6.3 and 6.4) converged on MPT, DPT and MTW as key mixing properties for further analysis. Two analyses converged on DMT, which also had a high R-squared value for differences among WF groups in 2014 bake tests. BREADSC and two of its three components, TEXTSC and CRUMBSC showed significant differences among cultivars.

Table 6.3. Summary of Milling and Mixing Parameters Significantly Correlated with Bread Scores for 2013

Correlations with Partial RFPRO			FY	SHORTY	RFMPT	RFMRW	RFMTW	RFMTI	RFMTOLSC	RFDMT	RFDPT
2013 Baking Scores	RF Specific Bread Volume	Pearson r	-0.213	-0.035	-0.437	-0.056	-0.165	0.141	-0.105	-0.400	-0.444
		Prob.	0.219	0.843	0.009	0.750	0.343	0.418	0.549	0.017	0.008
	RF Bread Score	Pearson r	-0.233	0.012	-0.447	-0.078	-0.199	0.186	-0.073	-0.384	-0.444
		Pr > |H|	0.179	0.945	0.007	0.658	0.252	0.286	0.679	0.023	0.008
	RF Exterior Score	Pearson r	-0.238	0.501	0.382	0.241	0.373	0.250	0.427	0.482	-0.430
		Pr > |H|	0.170	0.002	0.024	0.164	0.027	0.147	0.011	0.003	0.010
	RF Crumb Score	Pearson r	-0.264	0.594	0.321	0.307	0.367	0.322	0.464	0.406	-0.542
		Prob.	0.126	0.000	0.060	0.073	0.030	0.059	0.005	0.016	0.001
	RF Texture Score	Pearson r	-0.330	0.531	0.207	0.242	0.294	0.333	0.414	0.327	-0.615
		Pr > |H|	0.053	0.001	0.232	0.161	0.086	0.050	0.014	0.055	0.000

Table 6.4. Summary of Milling and Mixing Parameters Significantly Correlated with RF Bread Scores with Partial RFPRO (top) and Partial RFPRO and SKClass, 2014

Correlations with Partial RFPRO, SKCLASS			FY	SHORTY	RFMPT	RFMRW	RFMTW	RFMTI	RFMTOLSC	RFDMT	RFDPT
2014 Baking Scores	RF Specific Bread Volume	Pearson r			-0.375		-0.274		-0.121	-0.442	-0.157
		Prob.			0.035		0.129		0.509	0.011	0.392
	RF Bread Score	Pearson r			0.520		0.467		0.373	0.471	-0.481
		Pr > |H|			0.002		0.007		0.035	0.007	0.005
	RF Exterior Score	Pearson r			-0.257		-0.103		-0.036	-0.334	-0.234
		Pr > |H|			0.156		0.574		0.843	0.062	0.198
	RF Crumb Score	Pearson r			0.556		0.464		0.349	0.518	-0.375
		Prob.			0.001		0.008		0.050	0.002	0.035
	RF Texture Score	Pearson r			0.667		0.530		0.446	0.650	-0.494
		Pr > |H|			0.000		0.002		0.011	0.000	0.004
Correlations with Partial WFPRO, SKCLASS					WFMPT		WFMTW				WFDPT
2014 Baking Scores	RF Specific Bread Volume	Pearson r			-0.433		-0.385				-0.857
		Prob.			0.017		0.036				0.000
	RF Bread Score	Pearson r			-0.298		-0.367				-0.847
		Pr > |H|			0.110		0.046				0.000
	RF Exterior Score	Pearson r			-0.393		-0.418				-0.815
		Pr > |H|			0.032		0.022				0.000
	RF Crumb Score	Pearson r			-0.286		-0.332				-0.854
		Prob.			0.126		0.073				0.000
	RF Texture Score	Pearson r			-0.195		-0.313				-0.772
		Pr > |H|			0.302		0.093				0.000

RF Bake Test Regression Analysis. Regression analysis was performed using MAXR selection criteria of SAS to determine key milling and mixing properties that had promise for predicting bread quality. Significant regressors were determined from mixograph, dough and milling variables analysed separately and in combination (Table 6.5). MTOLSC helps explains 34 % of variation in breadscore in tandem with protein content and Single Kernel Hardness score.

Table 6.5. Regression of RF Baking Scores with Milling, SKCS and RF Mixing Properties, 2013-2014

Dependent Variable	Common Regressor Covariates	Independent Variable Set	R^2	Significant Regressor Variables at P < 0.05
RF Bread Score	RF Protein and Single Kernel Characteristics	Mixograph	0.34	RFPRO SKSHD MTOLSC
		Mixograph and Dough	0.51	SKWT DMT DPT
		Dough	0.51	SKWT DMT DPT
		Milling, Mixograph and Dough	0.59	SKWT SHORTY MTI DMT DPT
RF Crumb Score		Mixograph	0.44	SKWT SKSHD MPT MPV
		Mixograph and Dough	0.45	SKWT MPV DMT
		Dough	0.48	SKWT DMT DPT
		Milling, Mixograph and Dough	0.48	SKWT DMT DPT
RF Texture Score		Mixograph	0.40	MPT MPV
		Mixograph and Dough	0.64	SKCLASS MTOLSC DMT DPT
		Dough	0.55	SHORTY DMT DPT
		Milling, Mixograph and Dough	0.62	SHORTY MTOLSC DMT DPT
RF Exterior Score		Mixograph	0.40	SKDIA SKWT MPV MRV MTW MTOLSC
		Mixograph and Dough	0.45	SKDIA SKWT MRW MTW DMT DPT
		Dough	0.33	DMT DPT
		Milling, Mixograph and Dough	0.49	SHORTY BRANSC MILLSC MPV MRV DPT

Wheat Quality Tests for Unblended Samples, 2013-2014

Combined ANOVA for Milling and Mixograph Properties. ANOVA across years revealed very few significant differences among cultivars, previous crops or years for quality parameters. Each variable had at least one significant interaction term, except for RFMRV, which also had highly significant differences among cultivars. Flour yield and MTW were the only variables affected by previous crop. Because of the highly significant cultivar differences and minimal interaction terms or environmental effect (year or cultivar effect), RFMRV and RFMPV may be the most promising candidates for use in selection programs, if they can be used to predict baking performance.

Table 6.6. Significance of Differences for Milling and Mixograph Properties of Unblended Samples, 2013 - 2014

	RFPRO	FLOURY	BRANSC	RFMABS	RFMPT	RFMPV	RFMRV	RFMRW	RFMTW	RFMTI	RFMTOLSC
Model	**	NS	**	NS	NS	*	*	NS	NS	NS	NS
YEAR	***	NS	**	***	NS	NS	NS	NS	NS	NS	NS
MP "Previous Crop"	NS	***	NS	NS	NS	NS	NS	NS	*	NS	NS
Entry "Cultivar"	***	NS	**	NS	NS	***	***	NS	NS	NS	NS
YEAR*Entry	NS	NS	**	NS	*	NS	NS	NS	*	**	**
YEAR*MP	***	*	NS	***	*	*	NS	*	*	*	NS
MP*Entry	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
YEAR*MP*Entry	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Coefficient of Variation (%)	3.9	1.5	11.6	2.1	6.9	3.5	3.3	12.4	10.6	6.9	6.8
R-Squared	0.83	0.98	0.85	0.78	0.98	0.83	0.81	0.91	0.96	0.92	0.95

Statistical Analyses Across Years for RF Blended Samples, 2012-2014

Combined data for 2012 through 2014 had seven common cultivars (Table 7.1). Data that was lacking from 2012 (single kernel characterization and some mixograph variables - MRS, MRW, MRV AND MTW) was not included in the analysis. Only two WF protein groups (relative for each cultivar) were in common among years for all cultivars, designated as “low” and “medium” protein. Dough variables dominated, but mixograph variables contributed as much to bread score in a model with Bran Yield and RFASH.

Table 7.1. Regression of RF Bread Scores with Milling and Mixing Properties, 2012-2014 from Seven Cultivars

Dependent Variable	Common Regressor	Independent Variable Set	R^2	Significant Regressor Variables at P < 0.05
RF Bread Score	RF Protein	Mixograph and Milling	0.65	RFPRO BRANY RFASH RFMPV
		Dough and Milling	0.70	RFPRO FLOURY RFDABS RFDSC
		Mixograph, Dough and Milling	0.70	RFPRO FLOURY RFDABS RFDSC
		Mixograph and Dough	0.68	RFPRO RFMABS RFMPT RFMPV RFMTOLSC RFDABS RFDSC

WF Protein Threshold Across Years, 2013-2014

A bread score of 4.5 is considered 'good,' and 5.0 is 'excellent.' Depicted in Table 16.1 and listed in order of declining bread quality in relation to protein content, the WF protein threshold level (Table 8.1) for good bread baking performance of 4.5:

- was reached at its lowest WF protein level of 12.1 % for NW07505 and NE06607 and was exceeded (above 5.0) at all protein levels for NW07575;
- for KARL 92 was reached at its lowest protein level of 13.5 % and was exceeded at its highest protein level of 14.3;
- for NE02558 was reached at its lowest (12.1) and highest (13.5) protein levels, but not at its medium protein level;
- for NW03666 was reached at its medium protein level of 12.9;
- for MCGILL was reached and exceeded 5.0 only at medium protein level (12.6);
- for LYMAN was reached at its highest protein level between 13.4 and 13.9;
- for NE05425 was reached at its highest protein level above 13.5 and 14.2;
- for NW09421 was reached at its highest level above 13.7;
- for NE03490 was not reached but was close at its medium protein level of 13.3;
- for FREEMAN was not reached at its highest protein level of 13.5;
- for NE07444 was not reached at its highest protein level of 13.3;
- for OVERLAND was not reached at its highest protein level of 13.8, with bread scores below 4.0 at all protein levels;

Table 8.1. RF Bread Score and Baking Component Means by Cultivar and WF Protein Group, 2013-2014

Cultivar	WF Protein Group	WF Protein Content	Bread Score	Exterior Score	Texture Score	Crumb Score	RF Protein Content
NW07505	LOW	12.1	5.3	4.5	5.8	5.5	11.1
NW07505	MED	12.8	5.0	4.7	5.2	5.1	11.4
NW07505	XHIGH	13.6	5.2	5.4	5.0	5.2	12.5
NE06607	LOW	12.0	4.7	5.3	4.3	4.5	11.3
NE06607	MED	13.1	4.6	5.1	4.3	4.4	11.9
NE06607	XHIGH	13.8	4.4	4.5	4.3	4.2	12.7
KARL 92	LOW	13.5	4.5	4.4	4.5	4.6	12.4
KARL 92	MED	13.9	4.7	4.8	4.8	4.7	12.7
KARL 92	XHIGH	14.3	5.5	5.3	6.0	5.3	12.3
NE02558	LOW	12.1	4.6	4.8	4.7	4.4	10.7
NE02558	MED	12.8	4.1	4.7	4.4	3.2	11.6
NE02558	XHIGH	13.5	4.8	4.9	5.0	4.4	12.4
NW03666	LOW	12.2	3.7	4.0	3.5	3.5	11.0
NW03666	MED	12.9	4.7	5.1	4.6	4.6	11.8
NW03666	XHIGH	13.6	4.8	5.3	4.8	4.4	12.2
MCGILL	LOW	12.2	4.1	4.7	3.7	3.7	11.0
MCGILL	MED	12.6	5.2	5.6	5.1	5.0	11.7
MCGILL	XHIGH	13.8	4.2	5.7	3.7	3.2	12.6
LYMAN	LOW	12.7	4.4	5.4	3.7	4.1	12.1
LYMAN	MED	13.4	4.3	5.4	3.6	3.9	12.8
LYMAN	XHIGH	13.9	4.7	5.5	4.4	4.3	12.8
NE05425	LOW	12.1	4.4	3.8	4.5	5.0	12.5
NE05425	MED	13.5	4.4	4.7	4.6	4.2	12.5
NE05425	XHIGH	14.2	4.8	4.3	5.4	4.8	13.6
NW09421	LOW	13.0	4.3	4.5	4.3	4.3	11.1
NW09421	MED	13.7	4.3	4.8	4.3	3.8	11.9
NW09421	XHIGH	14.1	4.8	5.0	5.0	4.3	12.8
NE03490	LOW	12.4	4.1	4.7	3.7	3.9	11.7
NE03490	MED	13.3	4.4	5.1	4.3	3.9	12.3
NE03490	XHIGH	14.2	4.3	4.3	4.3	4.3	12.9
FREEMAN	LOW	12.2	4.3	4.3	4.2	4.6	10.4
FREEMAN	MED	13.0	4.0	4.7	3.7	3.8	11.5
FREEMAN	XHIGH	13.5	4.2	5.0	3.8	3.7	11.8
NE07444	LOW	12.3	3.9	4.3	3.8	3.8	11.1
NE07444	MED	12.9	4.1	4.4	3.9	4.0	11.4
NE07444	XHIGH	13.3	4.2	4.6	4.0	4.0	12.3
OVERLAND	LOW	12.4	2.7	4.3	2.1	2.4	10.6
OVERLAND	MED	13.2	3.7	4.9	3.0	3.2	11.2
OVERLAND	XHIGH	13.8	3.6	5.0	3.1	2.8	12.2

Organic Farmer Involvement

Year 1 (2011 planting- 2012 harvest- 2013 processing)

Three organic farmers in Nebraska considered using fall-established tillage radishes sown together with wheat to retain soil nitrogen until the wheat needs it in the spring. Nitro tillage radish was sown in early October with the wheat seed on two organic farms. The radish stand was acceptable, but lacked much growth, as it froze on Nov. 11. The alternative would be to sow radishes separately in August, and no-till drill the wheat into the radish mulch. Because of the drought, earlier planting of radishes on the western-most organic farm was considered a bad idea, as the radishes would compete for sparse moisture. The other two farms lacked no-till equipment for planting wheat into the radish mulch and preferred to let the university do this type of experiment.

Year 2 (2012 planting- 2013 harvest- 2014 processing)

The star performing line for organic production that baked well despite low protein content, 'NW07505', was increased on organic land at UNL's South Central Ag Lab (SCAL). Organic farmer members of OPINS Co-op (Organic Producers in Iowa, Nebraska and South Dakota) planted three other high performing lines in this category for test marketing (NE07444, NW03666, NE02558). Dry conditions in western Nebraska combined with late planting resulted in poor plant stands for NW03666 and NE02558 that were ultimately abandoned and replanted to spring crops. NE07444 produced enough seed to plant 33 acres the following year.

Of the increases planted by farmer cooperators and presented to two millers, NE02558 and NW03666 were rejected for an odor of common bunt, leaving only NE07444 as favorable to millers.

Year 3 (2013 planting- 2014 harvest- 2015 processing)

The increased seed of NE07444 was planted on 33 acres in September 2013. NW07505 that had been increased at SCAL was color sorted to obtain 30 pounds of 99% white seed. OPINS Co-op planted the 30 pounds on a half-acre after alfalfa. OPINS had also intended to plant 1500 pounds of low purity NW07505 (only 93% white kernels) for test marketing, but put it off to the following year pending purification of the seed. This seed was later sorted at the Iowa State Seed Lab, increasing the purity to 97.8 % white kernels, which is still far above the maximum of 0.05% allowed for Nebraska certified seed. Sorting also removed many seeds with black-point disease.

Dry conditions combined with late planting of NE07444 on 33 acres in western Nebraska resulted in poor plant stands that were ultimately abandoned and replanted to spring crops.

Year 4 (2014 planting- 2015 harvest- 2015 planting)

A thousand pounds of 97.8% pure NW07505 was planted in mid-September 2014 in western Nebraska by an OPINS coop farm for test marketing purposes. Additional color sorting from 40 pounds on a lab-scale sorter produced 15 pounds of 99.5% pure NW07505, which was hand-sorted to produce three pounds of 99.94% pure seed. This seed was planted on October 29, 2014 in Arizona. The seed increase of 1500 pounds of 99.94 % pure hard white NW07505 arrived from Arizona in July 2015.

The 1000 pounds of 97.84 % pure hard white NW07505 seed planted by the west Nebraska farmer for OPINS Co-op was decimated by hail and yielded only 5 bu/acre. In a normal year, this variety would have above average test weight, but this year was below 57 lbs./bu. The farmer decided not to continue growing this variety. The seed increase of 1500 pounds of 99.94 % pure hard white NW07505 arrived from Arizona in July 2015. A different OPINS farmer in Wyoming planted this seed on October 14, 2015.

Outreach and Target Audiences:

The Third Organic Wheat Conference, organized by Richard Little and Liz Sarno, featured a presentation on the goals of the NUEQ project. Over 40 people from Iowa, Nebraska and Kansas attended the 6-hour conference and field tour held at UNL-ARDC, Mead, Nebraska, on June 11, 2012. At the Bread Baker's Guild event, WheatStalk 2012, June 25-27 in Chicago, Rich Little displayed a poster that explained the NUEQ project to the 150 attendees, mostly artisan bakers, and solicited involvement. A UNL Nebguide and related data was published to the web in July 2013, featuring wheat lines included in the NUEQ study. This web address was promoted in an email to over 200 organic farmers, researchers and enthusiasts. See http://cropwatch.unl.edu/web/wheat/organic . Richard Little presented an eOrganic seminar in May 2013 on "Breeding for Winter Wheat Quality," http://www.youtube.com/watch?v=wM_n8CROGNM, and delivered a similar presentation on December 7, 2013 at the Western Sustainable Ag Conference in Ogallala, Nebraska with an update on the NUEQ project. The presentation included preliminary artisan baking results. Little presented at the March 2015 Wheat Quality Council Annual Meeting in Kansas City on the topic of breeding wheat for organic environments. This conference brings together a national representation of wheat breeders, millers, and other wheat industry personnel. Key slides comparing yield and protein for two organic rotations in contrast with conventional environments were gleaned from the CERES Trust NUEQ research. Little presented at the December 8, 2015 Fall Organic Wheat Conference of the Kansas Organic Producers in Oakley, KS on the topic of "Selecting vs. Breeding Wheat for Organic Environments," with over 30 Kansas and Nebraska farmers attending. Half of the presentation focused on NUEQ research.

Financial Summary

A total of $148,611.71 was spent, leaving a balance of $2,224.29, which was returned to CERES Trust via check on 2/12/16. A final financial report was submitted on 2/5/16 and is copied below.

Nebraska University of Lincoln

STATEMENT OF EXPENDITURES

TO:
Julie Bessent
Organic Research Initiative
6907 University Avenue, Suite 228
Middleton, WI 53562

OFFICE OF RESEARCH MANAGEMENT
Post-Award Administration
2200 Vine St., 151 Whittier Research Center
Lincoln, NE 68583-0861
FED ID # 47-0491233

AGREEMENT TITLE/CONTRACT NUMBER:
Investigating Nitrogen Use Efficiency for Winter Wheat Quality in Organic Rotations in Nebraska

Directed by P. Stephen Baenziger

REPORT: 26-6222-0482-001 FINAL

REPORT PERIOD: 1/1/2012 to 12/31/15

REFERENCE NUMBER: 26-6222-0482-001

ANALYSIS OF CLAIMED CURRENT AND CUMULATIVE COSTS

MAJOR COST ELEMENTS	BUDGET	AMOUNT FOR CURRENT PERIOD	CUM. AMOUNT FROM INCEPTION TO DATE
Salaries and Wages	$45,100.00	$0.00	$46,027.16
Employee Benefits	$21,718.00	$0.00	$22,059.65
Operating Expenses	$36,350.00	$2,680.00	$39,728.80
Travel-Domestic	$8,500.00	$358.48	$6,939.56
Consumable Supplies	$9,000.00	$2,289.48	$4,134.16
Equipment	$0.00	$0.00	$0.00
F & A Costs - 25% DC (20% TFFA)	$30,168.00	$1,332.00	$29,722.38
Total Amount	$150,836.00	$6,659.96	$148,611.71

Total Awarded to Date	**150,836.00**
Total Expenditures to Date	**148,611.71**
Remaining Balance	**$2,224.29**

PLEASE REMIT A COPY OF THE INVOICE ALONG WITH THE PAYMENT.

"I certify that all expenditures reported (or payment requested) are for appropriate purposes and in accordance with the agreements noted above."

Trudy Nienaber

Trudy Nienaber - Project Specialist

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(402) 472-4370

Date: **FINAL**
February 5, 2016

UNFORM2 10-01