Partners in Progress
WHEAT

Wheat Research at OSU 2007

Supported by the

Oklahoma Wheat Commission

and the

Oklahoma Wheat Research Foundation

Oklahoma State University
Division of Agricultural Sciences and Natural Resources
Oklahoma Agricultural Experiment Station
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Partnerships Enhance Wheat Research

Partners in Progress – Our long-standing partnership with the Oklahoma Wheat Commission and the Oklahoma Wheat Research Foundation is a valuable asset for Oklahoma State University's wheat research and Extension programs. The partnership not only provides partial funding for our research programs, but it also provides valuable input from producers that helps to keep our research programs focused and relevant. It is truly one of the best examples of the Division of Agricultural Sciences and Natural Resources working in a cooperative relationship with commodity groups to achieve common goals. Partial funding for our research and Extension programs comes from wheat producers through the check-off program. We have been and continue to be accountable for the use of these funds.

The *Partners in Progress Wheat Research Report* is one of a series of annual reports from DASNR highlighting research results and impacts of funded projects. This information is utilized throughout the year in educational wheat programs and is distributed to Oklahoma wheat producers to keep them up-to-date on the latest research findings. The research contained in this report has been directed as closely as possible to meet the needs of Oklahoma wheat producers.

At the beginning of each section is a summary of accomplishments for fiscal year 2006-2007. The narrative that follows explains in more detail the progress made during the year.

The long-term continuous support of our wheat research programs from the OWC and the OWRF has allowed our faculty to make significant progress toward the common goal of keeping Oklahoma wheat farmers competitive in regional, national, and international markets. This support makes us truly *Partners in Progress*.

Clarence Watson,
Associate Director
Oklahoma Agricultural Experiment Station
Division of Agricultural Sciences and Natural Resources
Oklahoma State University

Oklahoma State University Division of Agricultural Sciences and Natural Resources Mission Statement

The Mission of the Oklahoma State University Division of Agricultural Sciences and Natural Resources is to discover, develop, disseminate, and preserve knowledge needed to enhance the productivity, profitability, and sustainability of agriculture; conserve and improve natural resources; improve the health and well-being of all segments of our society; and to instill in its students the intellectual curiosity, discernment, knowledge, and skills needed for their individual development and contribution to society.

Challenges of Our Industry

Partners in Progress WHEAT

"There can be no progress if people have no faith in tomorrow." *John F. Kennedy*

Surely President Kennedy had wheat producers and the wheat industry in mind when he made that statement. It is only by faith Oklahoma wheat producers (and the industry) have survived and planted a 2008 wheat crop considering the last two years in the body of the state and the previous several if they were farming in the Panhandle. I know of no other industry that has had to deal with such opposite extremes in such a short period of time.

This is what makes the investment of wheat producer dollars into research so important. If we could rely on consistent weather conditions year in and year out our tribulations would be easily addressed. Since we can not, our survival hinges on our ability to stay at the cutting edge of technology that allows us to be a reliable and consistent supplier of wheat to our customers. Our customers face many of the same risks as wheat producers, including escalating input cost. We must continue to provide our customers with the value they have come to rely on from Oklahoma wheat producers. This can only be done if we continue to develop technology as we have in the past.

This brings me to how producer check-off dollars are invested in research and the methods used to develop new varieties. You will notice the research outlined in this publication takes a comprehensive approach to variety development that includes not just the wheat breeder, but also includes a coordinated effort from germplasm development, to physiologist, to pathologist, to entomologist, to cereal chemist, to geneticist, and wheat management. There is also cooperation from outside the university utilizing a collaborative relationship with other Land Grant institutions and the United States Department of Agriculture. Finally, the potential releases are not only tested for grain yield, but are developed under grazing pressure, a system somewhat unique to Oklahoma. This type of approach under Brett Carver's leadership has made Oklahoma's breeding program one of the premier in the nation.

As Oklahoma wheat producers cost of inputs continue to be at record levels, their ability to be competitive in a world market becomes even more challenging. Those challenges can only be met if we work together through all segments of the industry to continue to provide the safest, most inexpensive, and abundant food supply in the world. Technology has, and will continue, to allow us to do just that. Because we have faith in tomorrow the challenges of our industry will be met through our ability to be *Partners in Progress*.

Mark Hodges, Executive Director
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Genetic Improvement and Varietal Release of Hard Winter Wheat

Wheat Improvement Team

2006-2007 progress made possible through OWRF/OWC support

- Published 17 issues of the *Wheat Production Newsletter* during the 2006-2007 crop year.
- Continued offering timely, high-quality Extension materials to Oklahoma wheat producers.
- Expanded our applied research program to include no-till versus conventional-till direct comparisons among wheat varieties.
- Determined the reaction of greater than 500 Oklahoma State University experimental lines developed by the Wheat Improvement Team to leaf rust (seedling reaction in the greenhouse) and to the wheat soilborne mosaic virus/wheat spindle streak mosaic virus complex in the field. A subset of approximately 160 advanced lines also was tested in the lab using ELISA (enzyme-linked immunosorbent assay), which tests specifically for virus presence and provides an indication if resistance is to wheat soilborne mosaic virus, wheat spindle streak mosaic virus, or both.
- Screened all OSU advanced experimental lines in the greenhouse for seedling reaction to powdery mildew, tan spot, and septoria.
- Initiated a disease nursery in the field to test for the reaction of wheat to tan spot, a foliar fungal disease that can significantly affect wheat production in no- or low-till wheat, when residue is left on the soil surface.
- Provided to breeders throughout the Great Plains the reaction of approximately 500 wheat genotypes to leaf rust (seedling reaction in the greenhouse) and to the wheat soilborne mosaic virus/wheat spindle streak mosaic virus complex in the field.
- Generated another series of 100-plus breeding populations derived from synthetic wheat accessions introduced from CIMMYT.
- Developed germplasms featuring durable forms of leaf and stripe rust reistance that are currently undergoing further agronomic testing.
- Confirmed the absence of Karnal bunt in 72 wheat samples from 18 Oklahoma counties. Receiving this certification allows wheat from Oklahoma to move freely into the export market.

- **Identified advanced experimental lines that appear to have a good combination of dough strength, dough extensibility, and viscoelastic behavior, as well as acceptable baking properties.**
- **Identified OK05905C, an advanced Clearfield® experimental line, with the highest dough strength and extensibility values, and identified the hard white experimental line, OK02522W, with an overall good balance of quality factors, along with a reselection of OK Bullet and OK00611W, a hard white sister of OK Bullet.**
- **Established the combination of functional quality factors that explains the greatest proportion of sample variation and can potentially be used to detect quality samples with similar and exceptional properties.**
- **Completely rebuilt a state-of-the-art wheat molecular genetics laboratory in the Plant and Soil Sciences department to expand our genomic capability in research and variety development.**
- **Discovered a single major genomic region – with modification by other genes or QTL, quantitative trait loci, – that is tightly associated with the degree of elongation of hollow stem (indicative of first hollow stem stage) in a population of recombinant inbred lines produced from a cross between Jagger (typical of early first hollow stem) and 2174 (typical of later FHS).**
- **Documented the presence of several biotypes of Hessian flies in the major wheat growing regions of Oklahoma, and demonstrated resistance of OSU advanced experimental lines and available cultivars to natural fly populations.**
- **Continued foundation-seed multiplication (year 2) of a new hard white (HW) wheat candidate cultivar, OK00611W, that matches or exceeds OK Bullet in agronomic performance, with preharvest sprouting tolerance exceeding most current hard white varieties.**
- **Placed three additional candidate cultivars under preliminary foundation seed increase: OK02522W, a HW reselection from OK00611W; OK02405, a beardless *GrazenGrain®* hard red winter (HRW) wheat with the pedigree GK50/Tonkawa; and OK03522, a *GrazenGrain®* bearded HRW wheat with the pedigree N40/OK94P455.**

OSU's Wheat Improvement Team (WIT) continues its quest for improved genetic solutions to the unpredictable environment endured by Oklahoma wheat producers. Now in their ninth year of coordinated research and Extension programming are 10 OSU faculty working toward the common goal of building a stronger Oklahoma wheat industry: **Brett Carver**, wheat breeding and genetics; **Liuling Yan**, wheat molecular genetics; **Jeff Edwards**, information exchange; **Bob Hunger** and **Art Klatt**, wheat pathology and development of disease-resistant germplasm; **David Porter**, aphid resistance; **Kris Giles** and **Tom Royer**, Hessian fly control; **Bjorn Martin**, stress physiology; and **Patricia Rayas-Duarte**, cereal chemistry. Yan, Giles, and Royer add new strengths to the team, enabling us to capitalize on genomic technology and to better confront a relatively new insect to wheat production in Oklahoma.

The leaf rust epidemic of 2007 forced us to take a long look at where we are heading in the direction of leaf rust resistance. While we have a smaller lineup in several phases of our program, we nevertheless have the core genetic base to stay ahead of this ever-adapting disease. While the Oklahoma wheat producer was applying fungicide at historic levels in 2007 to protect against both powdery mildew and leaf rust, we were active in the field and greenhouse checking where our weaknesses and strengths may lie. With no doubt, the Jagger lineage that permeated our program in 2007 has less presence as we move into the next crop year, as we used near-ruthless selection to keep only the materials with effective resistance to both diseases.

In this report, you can read more about these and other significant breakthroughs: 1) molecular dissection of the first hollow stem (FHS) stage trait never before achieved in winter wheat, 2) unique comparisons between conventional and no-till systems for forage production and first hollow stem stage date, 3) introgression of synthetic wheats throughout the wheat improvement program, from early generation populations to advanced lines, and 4) an almost-surprising discovery of effective levels of resistance to native field populations of Hessian fly in current WIT materials.

Information Exchange and Systems Research

Jeff Edwards
Plant and Soil Sciences

Information exchange takes on high priority in the WIT's goal to deliver timely and relevant information to the Oklahoma wheat farmer. We accomplished this goal in 2007 through a variety of delivery methods and information outlets. A total of 17 issues of the *Wheat Production Newsletter* were published during the 2006-2007 wheat production season, and the e-mail distribution list for this publication continues to grow. Despite the record rainfall during harvest, wheat variety trial results were again published in a timely fashion, which allowed farmers and seed producers to make well-informed decisions regarding seed purchases.

Our effort to make OSU Extension wheat publications among the best in the nation continued in 2007. Color brochures for the newest OSU wheat varieties, Duster and Centerfield, were developed and distributed. We also published a no-till fact sheet entitled, *PSS-2132 No-till Wheat Production in Oklahoma*, which received an award of excellence by the American Society of Agronomy.

Research efforts in 2006-2007 revealed new answers to some old questions. First, we examined the relationship between first hollow stem and heading a little more closely and found that these two events are more closely related than first thought. Second, we looked at forage production in no-till and conventional-till systems and found that forage production in no-till systems might not quite measure up to that of conventional-till systems; however, we also discovered that first hollow stem in no-till production systems was later than in conventional till systems. This research will continue for at least the next two years to see if those trends hold. Finally, we continued to provide coleoptile length, post-harvest dormancy, and FHS data on the newest wheat varieties released in the southern Great Plains. Our goal with continuing these investigations is to help farmers avoid problems before they start.

Wheat Pathology Research and Development of Disease Resistant Germplasm

Bob Hunger
Entomology and Plant Pathology

Testing for reaction to leaf rust and the wheat soilborne mosaic virus (WSBMV)/wheat spindle streak mosaic virus (WSSMV) complex is conducted annually on wheat breeder lines from the Central Plains. However, Oklahoma Wheat Research Foundation funds also support testing of advanced OSU breeder lines for the presence of a virus (either WSBMV or WSSMV) in the plants. This is done in the lab using the serological test ELISA (enzyme-linked immunosorbent assay) and provides information critical to determining if a line is resistant to one or both viruses.

OWRF funds also support testing OSU breeder lines in the greenhouse for reaction to tan spot, septoria, and powdery mildew, as well as for testing lines in the field for reaction to stripe rust in southern Texas. This was expanded in fall 2007 to include a field nursery to help determine adult-plant reaction to tan spot on wheat. This is part of the doctoral research project of Kazi Kader, who is jointly funded by the OWRF and the Oklahoma Agricultural Experiment Station. Results from his research should contribute to an understanding of the effects of these two diseases on wheat production and incorporating resistance to these diseases into the base germplasm pool. Such research is important because of the increased emphasis on no-till and low-till wheat production, which leaves significantly greater amounts of wheat residue on the soil surface. The fungus that causes tan spot survives on this residue, so tan spot incidence and severity can increase dramatically in no- and low-till wheat production systems.

Complementary to this research is the master's research project of Jana Morris, also jointly funded by OWRF and the OAES. Her project will allow us to use a convenient greenhouse assay for tan spot reaction, with immediate attention given to finding resistance among the many synthetic wheat lines introduced from CIMMYT. The combination of Kader's and Morris' projects will help us develop and implement protocols to more accurately evaluate reaction to tan spot and perhaps septoria leaf blotch in the near future.

Funds provided by the OWRF supported the testing of the 2007 Oklahoma wheat crop for the presence of Karnal bunt. Results from this testing were used to certify that Oklahoma wheat was produced in areas not known to be infested with Karnal bunt, which allowed Oklahoma wheat to move freely into the export market.

Art Klatt
Plant and Soil Sciences

The Germplasm Development Program of the WIT has two primary objectives: 1) improve the stability and durability of leaf and stripe rust resistance in adapted winter wheat materials for Oklahoma, and 2) transfer useful genes from the synthetic wheats into adapted winter wheat materials. Breeding efforts are in progress to transfer the multiple minor gene resistance (MGR) for leaf rust and stripe rust found in many spring wheats from CIMMYT into our adapted winter wheat cultivars. Many of the selections from the initial MGR crosses are in advanced generations and numerous lines will be tested in preliminary yield trials during the 2007-2008 season. We are convinced that adapted cultivars with durable rust resistance will be highly beneficial to the Oklahoma producer.

More than 120 new crosses were made to synthetic wheats introduced in 2007. We believe this relatively novel genetic resource will provide new genes for rust resistance, enhance drought tolerance, improve leaf characteristics, and provide better resistance to other foliar diseases such as tan spot. Advanced materials from some of the earliest crosses to synthetics are being evaluated in preliminary yield trials during the 2007-2008 crop cycle. These trials should give us a better idea of the overall potential for these unique materials. One advanced line derived from our first crosses with synthetic wheats will make a first-ever appearance in the 2007-2008 OSU Wheat Variety Trials.

A regional cooperative nursery near San Antonio, Texas, continues to serve as a hotspot selection site for leaf rust and stripe rust resistance. All introduced materials are screened in south Texas before being used as parents, and early generation populations (F_2) are initially evaluated under severe rust pressure at this site. All advanced materials entering into the preliminary yield testing stage will also be grown in this nursery to confirm their rust resistance.

Our cooperative research program with CIMMYT has shown that spectral reflectance at selected wavelengths can be used as an indirect selection tool for grain yield and total biomass in spring and winter wheat. Utilization of this technology is limited due to the lack of a relatively inexpensive, light-weight sensor to record measurements in the field. However, efforts are underway in cooperation with the OSU Biosystems and Agricultural Engineering department to develop such a sensor that might be used by breeders. We are convinced the sensor will help increase the effectiveness of early generation selection for grain yield and biomass.

Characterization of Insect Populations and Resistance in Wheat

Kris Giles and Tom Royer
Entomology and Plant Pathology

Debut report

We initiated two Hessian fly field experiments during the 2006-2007 growing season that focused on a survey of current Hessian fly populations in Oklahoma and the evaluation of reaction of advanced breeder lines to Hessian fly. The overall objective of this work is to identify and incorporate Hessian fly resistance and make those sources available to the WIT. During the 2006-2007 growing season, we collected Hessian fly pupae from all of the major wheat growing areas in Oklahoma. In most locations, populations were low and sporadic; however, in a few fields near Blackwell and near Clinton, extremely high densities were observed. As expected, higher densities were most common in or near continuous no-till wheat fields. Pupae were sent to Kansas State University and USDA-ARS in Indiana for biotyping. Reports for 2006-2007 data indicate that reactions were highly variable, but several biotypes are present in Oklahoma. According to Sue Cambron (USDA-ARS, Indiana) the most common are traditionally classified as biotypes B, C, and GP.

This data indicates that multiple Hessian fly resistance genes need to be considered in the breeding program. The WIT has already incorporated several resistance genes, shown to be effective toward Oklahoma Hessian flies, into the OSU wheat breeding program. One specific gene originating in *Triticum dicoccoides* is being enriched in several breeding populations with the aid of molecular markers. Others are being combined with resistance genes already present in WIT materials to broaden our genetic base of resistance. Not to stop there, the WIT is creating breeding populations that, with the continued emergence of molecular markers, will enable us to combine resistance to multiple pests, such as Hessian fly, curl mite (the vector for wheat streak mosaic virus), Russian wheat aphid, and/or greenbug.

The 2006-2007-crop season allowed us to thoroughly evaluate the reaction of advanced lines in the OSU breeding program to heavy infestations of natural fly populations in Blackwell. Though heavy rains prevented harvest and yield comparisons, we were able to show that the number of Hessian fly pupae that developed in spring 2007 varied widely among entries. Several experimental lines (Table 1) had low

Table 1. Pupae per tiller for wheat entries in the 2006-2007 Oklahoma Elite Trial at Blackwell.

Entry	Pupae	Entry	Pupae	Entry	Pupae
OK04726W	0.022	OK05905C	1.666	OK03305	2.193
OK04111	0.134	OK03522	1.722	OK02125	2.295
OK03311	0.152	OK01420	1.776	OK01307	2.425
Centerfield	0.229	OK00611W	1.807	OK05737W	2.460
OK04904C	0.438	OK Bullet ERU	1.877	OK04507	2.466
OK05903C	0.564	OK05830	1.937	OK04505	2.499
Chisholm	0.596	Endurance	1.979	OK02405	2.501
Duster	0.904	OK00514-05804	1.997	Overley	2.571
OK04315	1.114	OK04108	2.014	OK04733W	2.950
OK00514-05806	1.346	Deliver	2.026	Danby	3.278
OK Bullet	1.358	OK02522W	2.082	OK05741W	3.628
Guymon	1.548	OK04525	2.157		

LSD 1.454

numbers of flies that survived to the pupal stage, which indicates relative resistance to flies in Oklahoma, and many of these lines will continue in the breeding program. As expected, resistant cultivars such as Centerfield, Chisholm, and Duster had fewer pupae than highly susceptible cultivars such as Overley. Currently, Oklahoma wheat producers do have resistance options for Hessian fly and future breeding efforts look promising.

Dave Porter
USDA-ARS and
Plant and Soil Sciences

Testing and selecting for Russian wheat aphid (RWA) and greenbug resistance in WIT breeding lines continued this year. Several excellent lines with high levels of resistance were advanced through the variety development process. A small nursery was screened for resistance to Russian wheat aphid biotypes 1 and 2. Two sister lines that both showed a high level of resistance to RWA1 had differing responses to RWA2 – one was susceptible to RWA2 and one showed a moderate level of resistance. Three populations derived from single-plant selections from STARS-0601W (our last RWA-resistant germplasm release) were highly resistant to both biotypes. Three selections from a sister line of STARS-0601W were also tested. STARS-0601W is available for use in the U.S. and worldwide. This germplasm line, and other RWA-resistant lines with improved agronomic traits, continues to proceed through the various phases of the variety development process.

Widespread integration of greenbug biotype E (GBE, which is the predominant biotype in Oklahoma) resistance genes into WIT breeding lines remains a high priority. During 2006-2007, three nurseries, which totalled 90 wheat entries, were tested for feeding damage reaction in response to GBE. Resistant entries were retested for confirmation of uniform resistance. While the percentage of all lines with greenbug resistance genes remains low, good progress has been made to move very effective greenbug resistance into lines that are now stable and uniform for resistance.

A collection of 412 spring synthetic wheats was tested for resistance to GBE and RWA1. More than 80 of these synthetic lines were found to have some level of resistance to GBE, although most were segregating. Resistant plants were rescued from the screening test and grown to maturity for seed increase; all plants were individually harvested. These lines may prove to be a source of new greenbug resistance genes. None of the synthetics were resistant to RWA1.

Stress Physiology

Bjorn Martin
Plant and Soil Sciences

Drought is the leading cause of crop failure in the U.S. and worldwide. Wheat is oftentimes grown entirely under rainfed conditions, and frequently, like in the southern Great Plains, in places with severe moisture limitations. Considering expectations of globally changing weather conditions, this situation will likely get worse rather than better in years to come. In Oklahoma, lack of moisture at the soil surface is many times a severe problem during planting. This leads to poor germination and poor stand establishment. This is particularly problematic because of the frequent planting of wheat for the dual purpose of grazing and grain harvest. Poor early growth means a lost opportunity for grazing.

We initiated a project in 2007 to screen wheat cultivars and breeding materials for coleoptile elongation with and without water-deficit stress. At the center would be those materials that are of interest to the wheat improvement program at OSU. We will rely on this program for materials to be evaluated. The rationale for screening for coleoptile length is that deeper placement of the seed during planting would increase the likelihood of sufficient soil moisture for germination. This is because the soil is usually the driest at the surface.

In the past year we have attempted several methods to precisely determine coleoptile length. We are now leaning toward a method previously used at Colorado State University. Here 20 seeds are evenly spaced and sandwiched between moistened germination papers. The papers are formed into loose rolls that are placed vertically in a plastic tray with a little water (or a PEG solution, to mimic water-deficit stress) at the bottom. Each tray contains multiple rolls in a typical seed-germination test. After covering the trays, they are placed at 39°F for four days to assure uniform germination. Following the cold treatment, the trays are placed in a growth chamber at 72°F for 16 days to allow the seed to germinate. Coleoptile length is then measured. If of interest, also longest-root length can be measured the same way. Results of an elite series of OSU breeder lines are forthcoming.

Cereal Chemistry

Patricia Rayas-Duarte

Biochemistry and Molecular Biology

The long-term objective of this OWRF/OWC-sponsored research is to compare key functionality parameters among elite lines in the WIT breeding program. Our priority is to study the combination of dough strength, extensibility, and viscoelastic properties in varieties and elite lines presently available, and build a database that will identify the combinations that improve baking performance

During this funding period, we analyzed the range of dough extensibility, gluten viscoelastic properties, and gluten content in a selected group of 42 hard winter wheats that included varieties and elite lines grown in Stillwater during 2006. We also compared the separation of quality properties based on methods used traditionally in the wheat breeding program to estimate wheat protein quality versus three new methods: creep-recovery (viscoeleastic properties), micro-extensibility, and glutomatic (CREG) analyses.

The samples included both red (79%) and white (21%) winter wheats. The analysis included extensibility and mixing properties, wet gluten content, gluten index, SDS sedimentation, baking tests, and high-molecular-weight glutenin allelic composition. Among the micro-extensibility properties, means for all samples (with range of values) were 0.15 N for Rmax or dough strength (range 0.09 to 0.23 N), 75 mm for dough extensibility at maximum dough strength (54 to 89 mm), and 8.5 N mm area under the curve to dough strength (4.3 to 14.2 N mm). Partial correlation coefficients adjusted for protein variation showed a positive relationship between dough strength and extensibility (r = 0.83, P<0.01) in this set of samples. A positive correlation of gluten index (P<0.01) and negative correlation of wet gluten content (P<0.01) with all extensibility parameters were obtained.

We used principal component analysis (PCA) to compare the three methods of quality assessment – glutomatic, micro-extensibility, and creep-recovery – with the more traditional methods used in wheat breeding programs. The PCA analysis enables us to see two-dimensional relationships in an otherwise complex, multi-dimensional data set. The glutomatic methods explained the highest percentage of the sample variation (76%), compared with the traditional testing (67%), and the combination of traditional and glutomatic methods (66%). Partial correlations of 19 analyses for the 42 hard winter wheats, when adjusted for differences in protein content, showed that the variables from creep recovery, micro-extensibility, and glutomatic methods were highly intercorrelated. In addition, significant correlations were found among the variables from the three CREG testing methods, farinograph peak time, and mixograph mixing time.

Partial correlation analysis performed for both traditional and the new CREG testing methods improves visualization of the interrelation between distinctive properties (variables) of wheat quality. The most exciting part of this work was the use of PCA to identify patterns in the data. This analysis tells us what variables are closely related and the magnitude of their relationship, and it is particularly useful for assessing a large number of wheat samples and variables – a feature all too common in wheat breeding programs. It graphically depicts the wheat varieties and elite lines that are more closely or distantly related based on certain variables and can assist in predicting the usefulness of introducing new analytical tools to the breeding program.

Wheat Molecular Genetics

Liuling Yan

Plant and Soil Sciences

Debut report

It is an honor to be a member of OSU's Wheat Improvement Team and to file this debut report in *Partners in Progress*. With OWRF/OWC-sponsored funding, a functional wheat molecular genetics laboratory was completely rebuilt, and includes two sets of acrylamide gel systems for molecular marker investigation, other gene-cloning tools, and several other pieces of equipment. Current throughput capability is 400 DNA samples within two to three hours.

Our initial project was to identify genetic loci responsible for arrival time of first hollow stem in winter wheat. Using simple sequence repeats (SSR) markers, we are excited to report that a major locus for FHS date, a critical trait for production of dual-purpose wheat in Oklahoma, was located in a genomic region. This finding is the first of its kind and will enable further research into the interrelationship between arrival time for FHS and heading date.

This growth stage can first be identified immediately below the developing head. It occurs prior to the jointing stage, when enlarged nodes and extended internodal tissues are detectable above the soil surface. When hollow stem first measures 2 cm on nongrazed plants adjacent to and planted at the same time as grazed plants, cattle should be removed from wheat pasture in a dual-purpose production system; otherwise, continued grazing could impair spike production. Precocious arrival at FHS is therefore an undesirable trait for a dual-purpose wheat cultivar.

We mapped approximately 200 SSR markers in a $F_{7:8}$ population consisting of 96 recombinant inbred lines (RILs). Brett Carver generated this population by crossing two winter wheat cultivars, Jagger (typical of early FHS) and 2174 (typical of later FHS). These RILs with their parental lines were grown in the field to determine their phenotype for FHS. Ten individual plants were collected per line, and the length of hollow stem between the crown and base of the developing spike was measured. Based on the 200 SSR markers, genetic linkage groups were first constructed using MapMaker 3.0. Another program, WinQTLCart 2.5, was then used to conduct single-marker analysis and interval analysis. We found clear segregation of hollow-stem length, varying from 1.44 to 8.25 cm, which could be equated with up to two weeks in developmental time. Segregation of FHS in this population was found tightly associated with a major locus but modified by other minor loci, called QTL (quantitative trait loci).

Although the actual gene represented by each QTL is under further investigation, genome-wide molecular markers used in this study can be applied to the OSU wheat improvement program to make direct selection for optimum arrival at FHS a realistic goal in developing dual-purpose wheat cultivars or grain-only cultivars that may be less prone to late-winter freeze events.

Wheat Breeding and Variety Development

Brett Carver
Plant and Soil Sciences

2007 – another year to remember... Nature can leave its mark, whether in once-smooth prairie fields that became gorged with gullies after torrential rains, in orange orchards with not a single fruit after a killing frost, or even on roads buckled by recurring extremes in temperature. So, too, has nature left its mark on the OSU wheat improvement program in the last four years. Unprecedented extremes have reoccurred such that we can no longer call them unprecedented. Simply look at the past four years: 2004, severe spring heat and drought stress; 2005, stripe rust infection of epidemic proportions; 2006, drought stress again, but this time season-long; 2007, severe disease pressure again, but this time from powdery mildew and leaf rust.

What does this mean to a wheat variety development program? First, we operate with fewer numbers (breeding populations, breeding lines, candidate cultivars) because each year removes unfit materials that do not stand up to nature's extremes. Second, what remains are breeding materials that possess multiple forms of stress tolerance. In essence, our program is smaller, but better. What might not be so obvious is that the better materials that remain in the program may not offer any improved yield potential in a year when drought and disease stress are absent. Nonetheless, waiting for such a year in Oklahoma, or the southern Plains, could be a very long wait.

No rest from leaf rust... Just like always, leaf rust has been nibling away at wheat yield and kernel size for the past several years, but it packed a powerful punch in 2007, coming in with full force by the first week of April and finally giving in to hotter conditions in mid May. During that six-week period, we observed a wide array of reactions in Oklahoma.

Varieties with once-effective race-specific resistance genes, *Lr*17 (Jagger) and *Lr*24 (Guymon, Jagalene), quickly succumbed to the disease in April, while others with a different genetic makeup, such as Overley and OK Bullet that may contain *Lr*41 plus other unnamed resistance genes, developed a very late infection with less impact on grain yield and kernel size. The reactions shown by Overley and OK Bullet nearly resembled a slow-rusting pattern with lower rust severity, but still a susceptible reaction type, compared with more susceptible cultivars. Still others, such as Endurance, showed definitive signs that the leaf rust pathogen tried to survive on its leaves, but this variety continued to choke it off by destroying any tissue surrounding the point of attack. This hypersensitive reaction produced considerable leaf chlorosis, but the leaf remained photosynthetically active, assuring survival of the variety.

What does the leaf rust epidemic of 2007 mean to wheat breeding programs in the region? Many programs have had to eliminate materials once believed to be effective on leaf rust, only to learn in 2007 that their genetic makeup was not suited for that level and duration of infection. We were no different. The USDA-ARS Cereal Disease Laboratory in Minnesota conducts annual surveys of pathogen races and their distribution across the U.S., and we understand at this point that as many as five races were active in the southern Great Plains. One of those races overcomes the resistance of *Lr*17, while yet another overcomes the resistance of both *Lr*17 and *Lr*24.

We obviously must rely on nonspecific resistance when developing new varieties (see Bob Hunger's and Art Klatt's reports), and we do have some indirect evidence that the kind of leaf rust resistance that prevails in our program is just that – nonspecific. One piece of evidence comes from assays conducted by Hunger for resistance expressed in the seedling stage, relative to resistance that we both evaluated during the critical adult-plant stages in the spring. It is the adult-plant resistance that we believe is critical to survival of a variety, whereas seedling resistance, while impressive in the field even in the adult stages, appears to be at the mercy of race changes of the pathogen. Combining those two types of resistance can be quite effective, even in the long-term, but that task would be similar to putting pieces of a jigsaw puzzle together without being able to see the pieces. We desperately need the molecular markers for candidate genes to see the pieces.

This is what we know currently about the type of leaf rust resistance in our program. Based on leaf rust reactions in 2007 among 457 intermediate to advanced breeding lines tested in replicated yield trials across the state, we found 170 (37%) to have an effective level of resistance throughout the 6-week infection period. Of those 170 lines, 121 (71%) were rated as moderately to very susceptible in the seedling stage to a bulk collection of rust isolates made in 2006. Hence these lines are postulated to have adult-plant resistance, though some bias could exist due to possibly different races of leaf rust present in 2006 and 2007. Current OSU varieties that repeatedly show adult-plant resistance to leaf rust are Endurance, and to a lesser extent, 2174. Duster showed a resistant adult-plant reaction and a resistant reaction in the seedling stage.

A few words about Endurance... The performance of Endurance in 2007 turned a few heads, as it endured intense infection from both powdery mildew and leaf rust, and in the end, managed to hold its seed dormancy through numerous post-harvest rainfall events. Its yielding ability in 2007 was not surprising, but given the past two years, it may have seemed that way.

Endurance was released in 2004, and in the previous year was evaluated in the Southern Regional Performance Nursery across the Great Plains[1]. There it placed in a virtual first-place tie for grain yield. The only other entry tested in that nursery that currently holds significant acreage in Oklahoma was Overley, which ranked 13th for mean grain yield. We knew then that Endurance had special yield potential and was widely adapted, but it was not truly expressed in 2005 when stripe rust was the primary yield-limiting factor, or in 2006, when severe drought stress suppressed varietal differences.

The wide adaptation potential of Endurance was evident in the 2007 Uniform Bread Wheat Trial that is conducted mostly in southeastern U.S. locations[2]. Among 10 locations ranging from Dallas, Texas, to Georgia to Maryland, Endurance ranked 7th for mean yield and was the highest yielding HRW check variety in the nursery, which included Jagger, Jagalene, Hatcher, Ripper, OK Bullet, Deliver, and Duster.

Wide adaptation and high yield potential aside, Endurance does have a few features – positive and negative – that warrant attention in this report, as it will likely take on significant acreage in the near future. We have learned much more about Endurance since its release in 2004. We were truly not aware of its ability to hold seed dormancy in the head under moist conditions, as Endurance has not been used in our preharvest sprouting tests normally reserved for hard white wheat. This level of dormancy, fortunately, does not appear to carry over into the fall. Endurance typically emerges rapidly with early sowing for fall wheat pasture. It will grow more prostrate than most varieties during the fall, especially as seeding rate decreases. As with most varieties, forage production from Endurance will improve noticeably with higher seeding rates. Grazing tolerance is above average for Endurance, which means it typically recovers well after grazing. Its late arrival to first hollow stem stage only helps in that situation,

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1 See http://www.ars.usda.gov/sp2UserFiles/ad_hoc/54402000HardWinterWheatRegionalNurseryProgram/2003SRPNlinks.pdf

2 See http://www.ars.usda.gov/SP2UserFiles/ad_hoc/66452500Downloads/2006-07%20Uniform%20Bread%20Wheat%20Trial%20Preliminary%20Report.xls

but producers should recognize that its later FHS stage is associated with later heading and slightly later harvest maturity than most Jagger-derived varieties. While Endurance is currently rated as moderately resistant to leaf rust and powdery mildew, it has intermediate tolerance to stripe rust and can show a susceptible reaction to wheat spindle streak mosaic virus. Reaction to Hessian fly is moderately susceptible. We provided direct comparisons among Endurance, OK Bullet, and Duster in the 2006 *Partners in Progress*, and those reappear below with some updating and the addition of Overley, a Kansas State University release (Table 2).

Synthetic wheats make their debut... As we promised in previous *Partners in Progress* reports, the WIT placed the first replicated yield trial of 23 synthetic-derived breeder lines in the field in 2006-2007. We actually chose two locations, Stillwater and Lahoma, because those locations have historically been very kind to us in returning a crop. History aside, we lost both locations and both yield trials immediately prior to harvest. All was not lost because we gained very valuable information on this material – all except for yield, test weight, and quality.

For example, we learned that several synthetic derivatives (SDs) showed unusually high tolerance to leaf rust, with noticeably good green-leaf retention. Head size was also noticeably larger than the checks, and among plots grown and harvested for seed increase, kernel size was impressive though potential test weight was not, due to an exaggerated kernel crease. Potential weaknesses we observed in this first set of SDs were later maturity and threshability (tight glumes and intact spikelets). Many of these lines will be retested in 2008, along with a new generation of SDs entering yield trials for the first time. An SD from the 2007 trials, OK07S110, will appear in

Table 2. Agronomic and quality comparisons for Endurance, OK Bullet, Duster, and Overley.

Character	Endurance	OK Bullet	Duster	Overley
First hollow stem	Late	Early	Mod. late	Very early
Grazing tolerance	Very good	Intermediate	Good	Fair (high stocking rate)
Acid soil tolerance	Very good	Good	Good	Good
Lodging resistance	Good	Very good	Fair	Good
Leaf rust	Mod. resistant	Mod. susceptible	Resistant	Mod. susceptible
Stripe rust	Intermediate	Resistant	Mod. resistant	Resistant
Soilborne mosaic	Mod. resistant	Resistant	Resistant	Resistant
Spindle streak mosaic	Susceptible	Resistant	Resistant	Resistant
Powdery mildew	Mod. resistant	Susceptible	Mod. resistant	Susceptible
Hessian fly	Mod. susceptible	Susceptible	Resistant	Susceptible
Test weight	Intermediate	Very good	Good	Good
Kernel size	Mod. large	Large	Mod. small	Very large
Baking quality	Intermediate	Very good	Very good	Very good

one of the OSU Wheat Variety Trials conducted by Jeff Edwards.

Hard white wheat - same class, new varieties... Surveying the region, hard white wheat has risen to the top of the yield charts in several wheat variety development programs. Those programs include the Texas A&M University breeding program at Bushland, Texas; the Kansas State University breeding program at Hays, Kansas, where just recently a WSMV resistant line was released as a HW variety (RonL); and the USDA-ARS program at Lincoln, Nebraska, could follow right behind with another HW variety with a different and potentially more reliable form of WSMV resistance. Even a Clearfield® variety with a white seedcoat from Colorado State University is on track for possible release. AgriPro and WestBred breeding programs continue to excel in the development of high-performance HW varieties.

What is different now? Part of the difference is in the term preharvest sprouting tolerance, a key agronomic trait that has been lacking in HW wheat, but now often is mentioned in the same sentence. The level of tolerance may not exceed the best HRW varieties, but it is at least on par with many HRW varieties. That situation certainly applies to the WIT program. The experimental advanced line, OK00611W, has shown levels of sprout tolerance well exceeding that of Guymon, the susceptible HW check, and comparable to the recent release from KSU, Danby (Table 3).

OK00611W can go where Danby has difficulty – in central areas of Oklahoma; moreover, it can perform better than many current HRW varieties. OK00611W out-yielded its sister line, OK Bullet, across Oklahoma in 2007 by 4 bu/ac (51 versus 47 bu/ac); and, in none of the eight environments was OK00611W surpassed by OK Bullet. The future looks bright for hard white wheat variety development. As our export markets continue to call for HW wheat, the WIT remains committed to developing new improved varieties, both red and white.

Current status on candidate varieties... Read more in Table 4 about critical decisions made in the past crop year on candidate HRW and HW varieties. The pipeline does not appear to have such a direct connection to Jagger, as we attempt to diversify the gene pool with parentage from alternative sources. That may not be the case with our next potential HW release, but it certainly applies to our HRW base.

Table 3. Preharvest sprouting tolerance based on three independent tests of percentage germination of seed harvested in the field at physiological maturity in 2006.

Putative field sprouting tolerance	Entry	Test 1[1]	Test 2[2]	Test 3[2]	Mean
			%		
Good	**OK00611W**	**17**	**34**	**50**	**34**
Good	Danby (HW)	13	30	17	20
Good	OK Bullet (HRW)	41	60	53	51
Intermediate	Intrada (HW)	64	54	61	60
Poor	Guymon (HW)	87	85	95	89
	Trial Mean	**45**	**54**	**63**	**54**

[1] Percentage germination on day 4.
[2] Percentage germination on day 3.

Table 4. Candidate HRW and HW wheat varieties tested in 2006-2007.

Selection	Action	Pedigree	Comments
OK00611W	FS increase	KS96WGRC39/ Jagger	HW for central OK with good sprout tolerance and high test weight. Resistant to WSBMV, stripe rust, and low pH. Must plant late, but it can catch up. Cast from the same mold as OK Bullet. **HW**
OK02522W	FS increase	KS96WGRC39/ Jagger	A more pure reselection from OK00611W, still with white bran. Slightly more consistent for yield than OK00611W and better shatter tolerance and similar sprout tolerance. **HW**
OK00514W	Terminated	KS96WGRC39/ Jagger	An OK Bullet reselection with white bran. Used a electronic seed sorter to remove the 2% white seed out of OK Bullet. Did not yield as well as OK00611W and OK02522W, and more variable for height. **HW**
OK02405	FS increase	Tonkawa/GK50	Stripe rust and leaf rust resistant beardless wheat with a Hungarian connection. A legitimate tri-purpose beardless replacement for Deliver, but test weight is not as high as Deliver. OK02405 may eventually give way to OK03305, pending results in 2008. **HRW**
OK03305	Advanced	N40/OK94P455	What OK02405 lacks in test weight, this beardless wheat makes up and more. With Ukranian influence from N40, it opens up this part of our program to a unique gene pool. Good drought tolerance, good baking quality at a lower protein content, and threshes very clean. We need to learn more about its leaf rust reaction, as it appeared to change in late 2007. **HRW**

Table 4 is continued on the next page.

OK03522	FS increase	N566/OK94P597	Cross looks similar to OK03305, but still quite different – Eastern European influence on both sides of parentage (Ukraine, Romania). A bearded, high-quality grain-only type wheat that has perhaps the highest yield potential among elite lines in the program. The Achilles heel could be susceptibility to drought and moderate lodging. Very large berry, with unparalleled kernel weight exceeding 40 mg in 2007. **HRW**
OK04505	Advanced	OK91742/ 2*Jagger	Did a reverse in 2007 after stellar yield performance in two previous years. Indisputable drought tolerance, with very attractive foliar disease package, except for powdery mildew susceptibility. The OK91742 parent is also one of Deliver's parents. Highly prostrate growth habit will likely keep this candidate on target for grain-only systems. Will look for come-back in 2008 or could be terminated. **HRW**

Partners in Progress
WHEAT

Wheat Variety Trials

Jeff Edwards
Plant and Soil Sciences

2006-2007 progress made possible through OWRF/OWC support

- **Dry conditions delayed wheat emergence until late December or early January in many areas of the state.**
- **An early-April freeze combined with record precipitation during grain fill and harvest devastated what looked to be a bumper crop of wheat.**
- **In contrast to the rest of the state, the Oklahoma Panhandle had near record wheat production and was a bright spot in an extremely difficult wheat production year.**
- **The full wheat variety trial report is available at www.wheat.okstate.edu (*PT-2007-6 Oklahoma Small Grains Variety Performance Tests 2006-2007*).**

2007 Wheat Crop Overview

The weather pendulum swung from one extreme to another during the 2006-2007 wheat production season. Most of the state was very dry during wheat sowing in fall 2006. In contrast, the 2007 harvest will go down as one of the wettest in history.

Wheat sowing generally went according to schedule in north central Oklahoma. Crop emergence, however, did not. The majority of fields in this area of the state did not receive enough rainfall to induce wheat germination until January 2007. As a result, grazing was not an option for most north-central Oklahoma wheat farmers.

Southwest Oklahoma wheat farmers were also hampered by dry conditions early in fall 2006. A few timely rainfalls in November and plenty of carryover soil nitrogen helped salvage wheat forage production in this region of the state. In fact, wheat forage production at our El Reno test site was well over 1 ton per acre.

Eastern Oklahoma farmers had adequate moisture last fall and generally obtained a satisfactory stand of wheat. Fields in this region and most of northern Oklahoma were snow and/or ice covered during late December and early January. The moisture from these ice and snow events outweighed any tissue damage resulting from the cold temperatures. In fact, the snow and ice probably reduced the amount of tissue damage to wheat by insulating the crop from cold, blowing winds.

Ice and snow gave way to warmer-than-average temperatures during late winter and early spring. For example, average temperature for the month of March in Alfalfa and Kay counties was 9°F above the 35-year average. This, along with adequate moisture, allowed the late-emerging wheat in north central Oklahoma to tiller much better than expected. This breathed new life into some fields that had been written off as nonsalvageable.

Warm temperatures also advanced phenological development of the 2006-2007 wheat crop. By the time April 1 rolled around all but the latest-emerging fields in southwest and northeast Oklahoma were nearing or past the boot stage and many fields were partially headed. Freeze could not have hit at a worse time.

Temperatures the weekend of April 5 dipped well below freezing across much of the state. Hardest hit was northeastern Oklahoma where temperatures dropped well into the teens and stayed there for several hours. The vast majority of wheat in this part of the state was a total loss.

Initial evaluation of wheat in central and northern Oklahoma indicated that these areas had largely escaped freeze injury. Some fields of early varieties such as Overley displayed significant injury, but wheat heads and flag leaves in most fields remained green and showed little evidence of freeze injury.

The only symptomology observed in many of these fields was swollen or bent nodes a few centimeters above the soil surface. This stem injury appeared benign at first but later proved to be the downfall for much of the Oklahoma wheat belt. Fields that displayed this type of injury in mid April were severely lodged by late May. Many were never harvested. Those that were harvested produced low test weights and poor kernel size.

Wet conditions prevailed during the entire harvest season of 2007. Many fields that showed great promise earlier in the year were never harvested due to wet soil conditions and poor test weight. In spite of the challenging year, we were able to harvest most of the OSU wheat variety performance tests in 2007 (Table 1).

The one bright spot in 2006-2007 was the Oklahoma Panhandle. With the exception of a few weeks in May, this region had adequate moisture during the entire growing season. The leaf rust that devastated much of the Oklahoma crop did not appear in the Panhandle until late in the growing season and did not affect yield much. Nitrogen limited production in some fields, as yields were almost double what they have been the past couple of years and most farmers have become accustomed to fertilizing for lower yield potential.

Hessian fly was a major issue for many wheat producers again in 2006-2007. The common thread among several of the Hessian fly-infested fields was proximity to no-till continuous wheat. Other insect problems in 2006-2007 included fall armyworm, aphids, and true armyworm. Wheat farmers in the Panhandle also had to contend with Russian wheat aphids in a few fields.

Barley yellow dwarf virus was commonly observed in many wheat fields in spring 2007. There were also many look-alike symptoms in fields that laboratory analysis proved not to be barley yellow dwarf related. Some of these symptoms were probably caused by wet, cool conditions – others perhaps by heavy foliar disease pressure. The exact cause for yellowing in many of these fields, however, was never positively identified.

Foliar disease was present during much of the production season. Powdery mildew was present in susceptible varieties such as Jagger and Jagalene (Table 2). Leaf rust was observed in many wheat fields as early as November 2006. Leaf rust remained a major foliar disease problem throughout the production season and many fields were treated with a fungicide after flag leaf emergence. The variety Jagger, which was resistant to leaf rust when originally released, was hit hard by the disease in 2007. Newer varieties such as Overley and OK Bullet resisted the disease for much of the season but were showing some active rust pustules by mid May.

Black chaff was present in some Oklahoma wheat fields in 2007, which is a rare occurrence in Oklahoma. Likewise, black (sooty) head mold was observed in Oklahoma wheat fields. Subsequent infection of maturing and mature grains resulted in black point in the grain harvested from many of these fields.

Table 1. 2007 Oklahoma wheat variety trial summary.

	Alva	Balko	Buffalo	Cherokee	Cimarron County	Elk City	El Reno Conv. Till DP	El Reno Conv. Till GO	El Reno No-till DP	El Reno No-till GO	Frederick	Gage	Goodwell Irrigated	Goodwell Non-irr.	Hooker	Kingfisher	Marshall DP	Marshall GO	Olustee
										bu/a									
2174	30	82	55	36	-	45	11	16	14	15	35	38	61	70	-	39	11	23	47
Avalanche (W)	-	81	-	-	70	-	-	-	-	-	-	-	64	67	59	-	-	-	-
Centerfield	36	83	56	34	-	46	15	12	12	13	44	40	66	58	-	33	9	25	47
Cutter	23	86	48	19	-	36	12	21	14	23	41	37	64	76	-	42	14	21	48
Danby (W)	29	98	57	26	81	48	20	23	17	20	41	53	73	73	62	47	15	23	46
Deliver	36	84	64	34	-	63	19	22	17	20	44	49	66	72	-	40	20	32	48
Doans	34	84	62	28	-	58	23	21	30	28	53	42	66	64	-	40	20	36	51
Duster	35	93	65	28	78	44	19	27	18	26	47	50	69	84	72	52	22	32	48
Endurance	34	94	65	40	75	53	19	25	20	25	45	52	68	77	70	45	20	29	50
Fannin	31	85	57	30	-	54	7	19	8	21	49	37	66	75	-	42	14	32	51
Fuller	32	88	65	35	-	61	17	26	20	30	54	55	76	78	-	52	19	40	60
Guymon (W)	-	89	-	-	-	-	-	-	-	-	-	-	67	68	-	-	-	-	-
Ike	-	78	-	-	-	-	-	-	-	-	-	-	60	71	-	-	-	-	-
Intrada (W)	-	91	-	-	65	-	-	-	-	-	-	-	65	73	60	-	-	-	-
Jagalene	19	87	49	18	73	35	8	18	12	20	34	40	69	75	58	42	11	21	50
Jagger	21	84	51	20	67	40	8	19	11	22	39	38	68	67	61	40	9	22	54
JEI 110	29	87	57	27	-	50	12	22	12	15	51	44	64	73	-	47	12	31	55
Lakin (W)	-	94	-	-	-	-	-	-	-	-	-	-	66	68	-	-	-	-	-
Neosho	-	-	-	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OK Bullet	33	92	63	29	77	59	17	22	19	28	45	49	73	78	67	50	21	37	59
Okfield	25	83	54	32	-	38	16	16	13	15	40	43	62	65	-	43	12	24	44
Overley	35	92	62	31	-	55	15	32	19	32	53	43	72	77	-	50	16	28	64
ProtectionCL	19	80	50	22	-	37	7	19	9	20	42	36	68	71	-	44	13	26	56
Santa Fe	33	92	64	33	-	56	14	22	14	28	47	43	77	71	-	49	20	32	59
Shocker	34	80	58	34	-	56	15	22	13	24	45	38	64	67	-	46	21	29	54
Stanton	-	83	-	-	-	-	-	-	-	-	-	-	62	78	-	-	-	-	-
TAM 110	-	89	-	-	72	-	-	-	-	-	-	-	60	68	58	-	-	-	-
TAM 111	28	98	60	-	72	43	13	24	14	18	40	49	74	75	65	48	18	28	45
TAM 112	-	97	-	-	76	-	-	-	-	-	-	-	73	72	75	-	-	-	-
Trego (W)	-	91	-	-	76	-	-	-	-	-	-	-	61	70	60	-	-	-	-
OK Bullet 06ERU	30	89	61	29	-	55	13	-	-	-	45	49	67	71	-	51	20	37	56
OK00611W	32	-	-	-	-	-	-	-	-	-	-	-	64	76	-	-	-	-	-
OK02125	28	-	-	29	-	-	16	-	-	-	48	-	65	-	-	44	17	31	-
OK02522W	31	91	62	30	-	63	18	-	-	-	51	47	66	75	-	51	19	37	58
OK03305	-	-	-	-	-	56	-	-	-	-	-	-	-	-	-	-	-	-	61
OK03522	-	-	60	-	-	-	-	-	-	-	-	-	-	-	-	51	-	-	-
OK04505	29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OK05737W	-	92	63	32	-	61	15	-	-	-	44	-	71	70	-	53	20	33	-
OK05905C	26	-	-	-	-	-	-	-	-	-	33	41	-	-	-	-	-	-	-
Mean	30	88	59	29	74	51	15	21	15	22	44	44	67	72	64	46	16	30	53
LSD (0.05)	3	9	9	5	5	4	4	3	3	3	7	6	10	14	6	6	4	4	3

Table 2. Wheat variety comparison chart adapted from the OSU publication Production Technology Vol. 18, No. 6 rev. 1.

Source	Entry	Lodging	First Hollow Stem	Maturity	High-temp Germ. Sensitivity	Coleoptile Length	Acid Soil Tolerance	Hessian Fly	Wheat Stream Mosaic[1]	Septoria	Soil-borne Mosaic	Leaf Rust	Stripe Rust	Powdery Mildew	Tan Spot	Variety Protection
HARD RED WINTER WHEAT VARIETIES																
AgriPro	AP502 CL	3	VE	VE	2	1	4	S	-	3	3	4	4	1	2	P-94
AgriPro	Cutter	4	VE	M	4	3	1	S	3	3	1	4	1	4	4	P-94
AgriPro	Doans	2	M	M	-	-	2	S	-	2	2	1	1	2	-	P-94
AgriPro	Dumas	1	E	E	2	4	4	S	-	3	4	3	-	3	2	P-94
AgriPro	Fannin	2	VE	VE	3	1	1	-	-	-	1	1	1	2	-	P-94
AgriPro	Jagalene	2	E	E	3	2	2	S	3	2	1	4	1	4	3	P-94
AGSECO	7853	3	VE	M	3	4	2	-	-	2	1	3	-	2	-	N
CSU	Above	2	VE	VE	2	2	4	-	3	3	4	4	4	1	2	P-94
CSU	Hatcher	3	-	M	-	2	3	-	-	-	-	3	2	-	-	P-94
CSU	Ripper	1	-	VE	-	2	4	S	-	-	-	4	4	-	-	P-94
KSU	Karl 92	3	E	E	2	4	3	-	-	2	1	4	-	1	2	P
KSU	2137	1	L	L	3	4	1	S	3	3	2	3	4	2	3	P-94
KSU	2145	2	E	E	2	2	3	PR	4	2	1	1	2	3	4	P-94
KSU	Fuller	2	VE	E	-	-	3	-	3	3	1	1	1	3	3	A-94
KSU	Ike	3	VL	L	2	2	4	PR	-	1	4	4	-	2	-	P-94
KSU	Jagger	3	VE	VE	1	2	1	S	3	1	1	4	1	4	2	P-94
KSU	Overley	1	VE	VE	4	3	2	S	3	2	1	3	1	4	2	A-94
NE	Scout 66	4	-	L	-	1	4	-	-	3	4	4	-	3	-	N
OSU	Triumph 64	4	L	M	4	1	4	-	-	4	4	4	-	3	1	N
OSU	2174	1	VL	L	4	3	3	PR	4	2	1[2]	2	2	1	4	P-94
OSU	Chisholm	2	L	E	3	3	3	PR	-	3	4	4	1	3	4	N
OSU	Centerfield	2	L	M	4	3	3	PR	-	-	2	2	2	1	4	A-94
OSU	Custer	2	E	E	1	3	4	-	-	3	4	3	4	1	3	N
OSU	Deliver	3	L	M	2	4	4	-	-	2	1	1	1	1	3	A-94
OSU	Duster	3	M	M	1	3	1	R	-	3	1	1	2	2	4	A-94
OSU	Endurance	2	VL	M	1	2	1	S	4	3	2[2]	2	2	2	3	A-94
OSU	OK Bullet	1	E	E	1	2	2	S	3	2	2	3	1	3	3	A-94
OSU	Ok101	2	E	VE	1	4	1	S	-	3	2	3	3	4	4	N
OSU	Ok102	1	VL	L	4	1	3	PR	-	3	1	2	4	2	4	N
OSU	Okfield	2	M	L	4	1	3	PR	-	3	4	3	3	1	3	A-94
TX	Lockett	4	E	VL	1	-	2	S	-	-	4	2	3	-	-	P-94
TX	TAM 107	3	E	M	3	2	4	-	-	3	4	4	-	1	-	P
TX	TAM 110	2	VE	VE	2	1	4	S	3	3	4	4	4	1	4	P-94
TX	TAM 111	3	M	M	3	1	3	S	3	2	3	3	1	3	3	P-94
TX	TAM 112	4	-	E	-	1	1	S	3	-	-	3	4	1	-	P-94
TX	TAM 303	2	-	E	-	1	-	S	-	-	-	1	3	1	-	A-94
WestBred	Shocker	2	VE	E	4	3	2	S	4	2	1	1	2	2	2	P-94
WestBred	Santa Fe	2	VE	E	1	2	2	S	3	1	1	1	2	3	2	P-94
HARD WHITE WHEAT VARIETIES																
KSU	Danby	3	VL	M	4	3	3	-	3	4	4	4	1	4	4	A-94
KSU	Heyne	3	VE	M	1	-	1	-	-	2	1	1	-	2	-	P-94
KSU	Lakin	2	VL	M	1	4	3	-	-	4	2	3	4	4	3	P-94
KSU	RonL	3	L	M	-	3	4	S	1	4	1	3	1	2	4	P-94
KSU	Trego	4	L	M	2	3	4	S	3	3	2	4	4	3	4	P-94
OSU	Guymon	3	VE	L	1	4	3	S	-	2	1	3	4	3	3	A-94
OSU	Intrada	4	E	E	1	3	3	S	-	3	2	3	3	4	2	N

General: 1 = Excellent, 4 = Poor

Maturity & First Hollow Stem: VE = Very Early, E = Early, M = Medium, L = Late, VL = Latest

Coleoptile: 1 = Longest, 4 = Shortest

Hessian Fly: S = Susceptible, PR = Partially resistant, R = Resistant

Variety Protection: N = Not protected, P = Protected PVPA - 1970 , P - 94 = Protected PVPA - 1994, A-94 = PVPA - 1994 applied for

1 Ratings for wheat streak mosaic virus adapted from K-STATE publication MF-991, Erick De Wolf author.

2 Reaction presented is to soilborne mosaic; reaction to spindle streak is a '3'.

Jointed Goatgrass Management with the New OSU Clearfield® Wheat Variety Centerfield

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2006-2007 progress made possible through OWRF/OWC support

- **Problems with jointed goatgrass are expected to rapidly get worse as growers adopt no-till wheat.**
- **A new OSU Clearfield® wheat variety is being tested in a system to manage jointed goatgrass in wheat.**

As Oklahoma wheat growers have attempted to minimize tillage for economic reasons, jointed goatgrass, a winter annual grass, has become a serious weed pest in northwest Oklahoma wheat fields. Jointed goatgrass has been thick along roadsides for many years, but it does not invade fields where conventional tillage is used. As we have reduced summer tillage for economic reasons, jointed goatgrass has quickly invaded these fields.

Like most of the grassy weeds in wheat, jointed goatgrass was introduced from Europe many years ago. It is a very close relative of wheat, so close that natural hybrids are often found in fields. The hybrid spikelets look just like jointed goatgrass or wheat, depending on which one was the female parent. When the hybrid seeds are planted back with wheat and head out in the spring, the head looks strange and wheat growers sometimes wonder what they are. These hybrids eventually fail to set good seed. In Woods County Oklahoma, the frequency of wheat x jointed goatgrass hybrids in wheat delivered to elevators averages 0.076%. So, these hybrids are not a real concern, unless they hybridize in a natural backcross to other jointed goatgrass plants, thereby providing a bridge for movement of genes from wheat into this weedy relative.

The close genetic relationship between wheat and jointed goatgrass has made it hard to find a herbicide to kill jointed goatgrass in wheat. To overcome this problem, varieties of wheat have been developed with genetic tolerance to the herbicide imazamox, sold as Beyond® and Clearmax®. We refer to these varieties by the trademark name for the herbicide resistance genetics, i.e. Clearfield® varieties. Oklahoma State University recently released a new Clearfield® hard red winter wheat variety, named Centerfield, which we consider a much better variety than earlier Clearfield® varieties, and much better adapted to central and western Oklahoma. Centerfield carries substantial tolerance to soil-borne mosaic virus, has good tolerance to acid soils, and exhibits good canopy coverage in the fall to provide additional competition against weed infestations. It is also resistant to the Great Plains biotype of Hessian fly, which is becoming more important every year.

When the Clearfield® system was introduced a few years ago, variety selection was not very good for Oklahoma and several Oklahoma farmers who applied the herbicide for feral rye control were disappointed with the results. Our research has demonstrated wide variation in tolerance of Oklahoma feral rye populations to Clearmax®. That experience has made it somewhat difficult to develop enthusiasm for the concept of seeding a much superior Clearfield® wheat variety and applying Clearmax® herbicide for jointed goatgrass control. However, of the various winter annual grass weeds that infest Oklahoma wheat fields, jointed goatgrass is the most susceptible to Clearmax®. With this background, we decided that we needed to take a serious look at the use of Clearmax® on Centerfield wheat for controlling jointed goatgrass. To put it to the real test, we decided that this had to be done on typical farms with local applicators doing the spraying and have treated areas large enough to evaluate using farm scale drills and combines.

Since Centerfield is a new variety, there was not enough seed available to do this in the 2006-2007-crop year. Instead, we took what seed we had and planted it for seed increase. The goal was to get enough seed for 40 acres on five or six wheat fields. We planted enough Centerfield in fall 2006 to do this. However, due to repeated heavy rains, harvest on two of the three plots was delayed until late July. Duals were finally rigged on a small combine and the wheat was mudded out. The field was rutted up pretty bad and still all the wheat was not harvested, so our plans for fall 2007 were changed to 20 acres for the five growers. These growers are scattered across north central and northwest Oklahoma. Each of these growers will be applying Clearmax® this winter and we will see the results in spring 2008, compared to the wheat in the rest of the field.

Plans are to collect data on yield, dockage, and grade of the Clearfield® and the traditional wheat, market value of each, relative frequency of insect pests and disease in each system, and economic analysis of the cost/benefit of the Clearfield® system. Information will be coming from your local OSU Extension office regarding field tours to be held at each site in spring 2008.

If we have a decent year for wheat this year, the supply of Centerfield wheat seed should be much better for fall 2008.

Development of a Weather-based Model for Predicting First Hollow Stem in Winter Wheat

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2006-2007 progress made possible through OWRF/OWC support

- **The soil-temperature models developed earlier for predicting first hollow stem (FHS) in three FHS wheat categories were refined using several additional years of FHS observations from Stillwater.**
- **These models were tested against two calendar-based methods, one using the average observed FHS date for each wheat category and the other using March 15.**
- **The soil-based models showed themselves superior to the two calendar-based methods, outperforming them in each of the three wheat categories. Depending on wheat category, ranges in model error are reduced from 24 to 29 days (calendar methods) to 16 to 21 days. Mean absolute errors (average number of days by which FHS is over or under predicted) are reduced from 6 to 16 days (calendar methods) to only 4 to 5 days.**
- **With the exception of the late FHS varieties, March 15 is clearly seen as being much too late in predicting FHS and even in this category, the soil-based model does better.**
- **Model recommendations for predicting FHS date in dryland wheat are presented, along with probability distributions based on the normal distribution, with a view toward creating an operational product utilizing the Oklahoma Mesonet, the state's automated weather station network.**

The purpose of this multi-year project was to develop optimal weather-based models to predict the occurrence of first hollow stem (FHS) in winter wheat, with a goal of implementing such a model on the Oklahoma Mesonet, the state's automated weather monitoring network nearing 120 stations. Such a product could be used as a management tool for producers who use winter wheat as a dual-purpose crop, as it would provide guidance as to when to remove cattle from grazed fields – not only to avoid wheat yield loss after FHS date (as observed in ungrazed wheat), but also to be able to keep cattle on the fields as long as possible (up to FHS date).

The FHS database (dates of first occurrence) originally used in this project for model development consisted of 10 years of observations from wheat variety trials at Marshall (1994-1997 plantings) and Stillwater (1998-2003 plantings). For purposes of this study, wheat varieties were grouped into three categories with respect to appearance of FHS (early, middle, and late). Early (E) varieties are represented by Jagger; middle (M) by Custer and Ok101; and late (L) by Ike, 2174, and Ok102. The goal was to develop an optimal weather-based model for estimating FHS date for each category of wheat.

This year's report, in conjunction with reports from the past three years in *Partners in Progress Wheat Research at OSU*, constitutes the final report on this project. In 2007 additional observations of FHS date were taken for various varieties at Stillwater, Goodwell, and El Reno. Together with the original FHS database (10 years) used in model development, we now have 13 potential years of observations from north central Oklahoma. However, as was seen in last year's report, we dropped 2006 from the analysis due to the extreme drought that was in place during the period up to FHS; the historic dryness was seen to delay onset of FHS well past (one to three weeks) model predictions. In addition, for early FHS varieties, in 2005 the FHS date was missed (as it occurred before observations started) and in 2001 the observed FHS date was marked as questionable; thus two years are omitted from the analysis for early varieties. In summary, we now have 10 years of FHS observations for early varieties and 12 years for middle and late varieties. These FHS observations were taken on ungrazed dryland wheat planted in September or October.

Earlier, optimal soil-temperature based models to predict FHS date were developed. The models use the Mesonet-measured 4-inch soil temperatures under sod cover and are based on degree-day accumulations from specific start dates and with specific temperature thresholds (TLOW). Information on these models can be found in *Partners in Progress Wheat Research at OSU 2005*.

Taking the start dates and TLOW values for each of the three wheat categories, we decided to utilize all the available years of FHS observations in north central Oklahoma to fine tune the models with a view toward applying them operationally. With the additional years of data, the accumulated soil degree-day model predictor (the total degree days to FHS averaged over all the years) changed slightly over what was reported earlier.

Table 1 shows the performance of these revised, fine-tuned soil degree-day based models versus two calendar-based methods for each of the three wheat categories. The first calendar-based method uses the average observed FHS date over the period of record as the model predictor, and the second method employs the often used March 15 date for the onset of FHS. An analysis of model error for each of the models is given, where model error is defined as the predicted FHS date given by the model minus the observed FHS date (in days). A positive error represents a model overprediction (FHS occurred earlier), while a negative error represents a model underprediction (FHS occurred later).

Table 1. Performance of optimal soil degree-day based models for first hollow stem (FHS) occurrence versus two calendar-based methods for the three classes of winter wheat varieties.

	Early FHS Varieties			Middle FHS Varieties			Late FHS Varieties		
Model Error (days) [Model - observed FHS Date]	Soil-based Model (1)	Average Observed FHS Date (2)	March 15	Soil-based Model (3)	Average Observed FHS Date (4)	March 15	Soil-based Model (5)	Average Observed FHS Date (6)	March 15
Mean Error	-0.2	-0.1	16.2	0.4	-0.5	8.7	0	0.2	0.5
Mean Absolute Error5.2	6.3	16.6	4.2	7.7	10.4	4.3	6.7	6.8	
Maximum	12.0	6.0	22.0	9.0	14.0	23.0	9.0	15.0	15.0
Minimum	-9.0	-19.0	-2.0	-7.0	-15.0	-5.0	-10.0	-14.0	-14.0
Range	21.0	25.0	24.0	16.0	29.0	28.0	19.0	29.0	29.0
Standard Deviation	6.8	8.2	8.0	5.3	9.5	9.4	5.5	8.9	8.8
% Late Predictions	40%	70%	90%	42%	58%	75%	50%	42%	50%
Average # Days Late	6.2	4.4	18.2	5.6	6.1	12.8	4.3	8.4	7.3

(1) TLOW = 31°F, SDATE = Dec. 22; 4" Soil (Sod Cover) Degree Days = 756 [10 years data]
(2) FHS Date = Julian Day 58 (Feb. 27) [10 years data]
(3) TLOW = 31°F, SDATE = Dec. 22; 4" Soil (Sod Cover) Degree Days = 878 [12 years data]
(4) FHS Date = Julian Day 65 (March 6 in nonleap years) [12 years data]
(5) TLOW = 34°F, SDATE = Jan. 1; 4" Soil (Sod Cover) Degree Days = 709 [12 years data]
(6) FHS Date = Julian Day 74 (March 15 in nonleap years) [12 years data]

The following statistics of model error are given: the mean or average error over the period of record; the mean absolute error - meaning the average number of days, whether positive or negative, that the prediction is off; the maximum error (positive); the minimum error (negative); the total error range; and the standard deviation. In addition, since a model overprediction (positive error) is more critical than an underprediction, the percent of late predictions is given as well as the average error (days late) for this subset of predictions.

It can be easily seen that the soil degree-day based model outperforms each of the two calendar-based methods for every FHS wheat category. One can see that the mean errors for the soil-based and average calendar date models are almost zero, meaning the negative and positive errors average close to zero. However, the March 15 model overpredicts FHS on the average by 16 days for the early varieties and by about 9 days for the middle varieties. With the exception of the late varieties, March 15 is clearly always too late in estimating FHS.

The soil-based model has the lowest mean absolute error of any model in any wheat category, being off on the average 5.2 days for early varieties, 4.2 days for middle varieties, and 4.3 days for late varieties. The soil-based model also has the lowest range of error in each wheat category as compared to the calendar methods; this is especially true for middle and late varieties. The standard deviation of model error is also lowest for the soil-based model, ranging from 5.3 to 6.8 days.

Finally, with respect to late predictions (FHS predicted too late), with the exception of the late varieties, the soil-based model has a lower percentage of late predictions. Although the percentages are similar between the models for the late FHS category, the average number of days late is much lower for the soil-based model.

We now proceed to discuss each model separately and to develop a predictive model based on the Gaussian or normal probability distribution. For each wheat category, the accumulated soil degree-days to FHS over the period of record will be shown, and then, using the statistics from Table 1, a predictive model utilizing the normal distribution is developed.

The rationale for using the normal distribution is as follows. Ten or 12 years of FHS observations are obviously not a large enough database to adequately capture what would occur, say, over 100 years of such observations. However, we are limited to what we have, that is, 10 to 12 years. If we assume the degree-day accumulations of each soil-based model are normally distributed over the wide range of weather/soil conditions that would be encountered over those 100 years, then as the number of years of actual observations increase, the degree-day distribution observed would approach the normal distribution. Thus, using the normal distribution is a way to artificially expand the years of observations and hopefully arrive at a more reliable model. Using the normal distribution, one can then arrive at probabilities for FHS occurrence based on threshold values of soil degree-day accumulations. The assumption, again, of this approach is that the degree-day accumulations to FHS are normally distributed; they may not be, but 10 to 12 years of data is not enough to justify another probability distribution at this point. Of course, another approach would simply be to limit ourselves to the 10 to 12 years of data, and develop probabilities just based on this small period of record.

Figure 1 shows the actual distribution of accumulated soil degree days to FHS (grouped into ranges spanning 100 degree days) for the 10-year period of record for the early FHS wheat category. This distribution does appear to be Gaussian or normally distributed. Using the standard deviation and mean from Table 1, the probabilities for FHS occurrence can be easily calculated and are shown in Table 2. The normal distribution is such that 95% of the expected values (soil degree days to FHS, in our case) lie within two standard deviations of the mean; these degree-day values are given by the 2.5% and 97.5% cumulative probability levels, respectively.

Similarly, Figure 2 shows the distribution of accumulated soil degree days for the 12-year period of record for the middle FHS wheat category. Assuming a normal distribution, the probabilities for FHS occurrence are shown in Table 3.

Finally, Figure 3 shows the degree-day distribution for the 12-year period of record for the late FHS wheat varieties. Using the normal distribution, the probabilities for this wheat category are shown in Table 4.

For each of the three FHS wheat categories, these probability tables can be used to predict not only the average (50% cumulative probability level) or best FHS date estimate for any given year, but also the earliest possible degree-day based FHS date. Such a date could be used as an indicator as to when to begin scouting for FHS. This would give producers time to get into the fields to scout for FHS before it actually occurs. To prevent grain yield decline in grazed fields, it is important to monitor FHS before it occurs, rather than after the fact. What probability threshold should be used to signify this earliest possible date is debatable - one could use the 2.5% level, the 5% level, or the 10% level. In any given year, daily Mesonet soil temperatures at 4 inches under sod cover could be used to indicate when this earliest date occurs, giving growers a heads up as to when to begin scouting. If a soil temperature forecast could be developed using a 10-day air temperature forecast, then we could actually get to the point of forecasting the earliest and average FHS dates up to 10 days in the future, rather than just relying on Mesonet to indicate when these dates have been reached (no lead time). Of course, getting an operational system for FHS based on Mesonet would be a useful first step.

Finally, we must address the issue of geographical location within Oklahoma. The data used in developing the models in this last report are all for wheat fields in north central Oklahoma (Marshall and Stillwater). In *Partners in Progress Wheat Research at OSU 2006*, it was seen that altering the start dates appeared to give better results for independent FHS data taken at Goodwell and Altus. El Reno FHS data appeared to be better predicted using the start dates developed for Marshall/Stillwater. For Goodwell, moving back the start dates by one week (Dec. 15 for early and middle varieties, and Dec. 22 for late varieties) appeared to work better; for Altus, moving forward the start dates by two weeks (Jan. 8 for early and middle varieties; Jan. 15 for late varieties) appeared to work better. This indicated some type of latitude dependency on how the wheat plant develops. However, only two years of data (2004, 2005) were available at Goodwell and Altus with which to make these assessments and we are reluctant to recommend altering the Marshall/Stillwater start dates based on only two years of data. It should be mentioned, however, that the revised start dates also worked better at Goodwell in 2007. More years of reliable observations at these and other locations are needed before we can feel confident in recommending a change in the start dates used in the three models. Having said that, we are also reluctant to apply these models outside north central Oklahoma using the start dates developed for that database. All that can be said in confidence is that for dryland wheat planted in September or October in north central Oklahoma, the models presented in this report for predicting FHS date are superior to the two calendar methods discussed. This, by itself, is an achievement and should be able to lead to a useful operational product on Mesonet, at least for this part of the state.

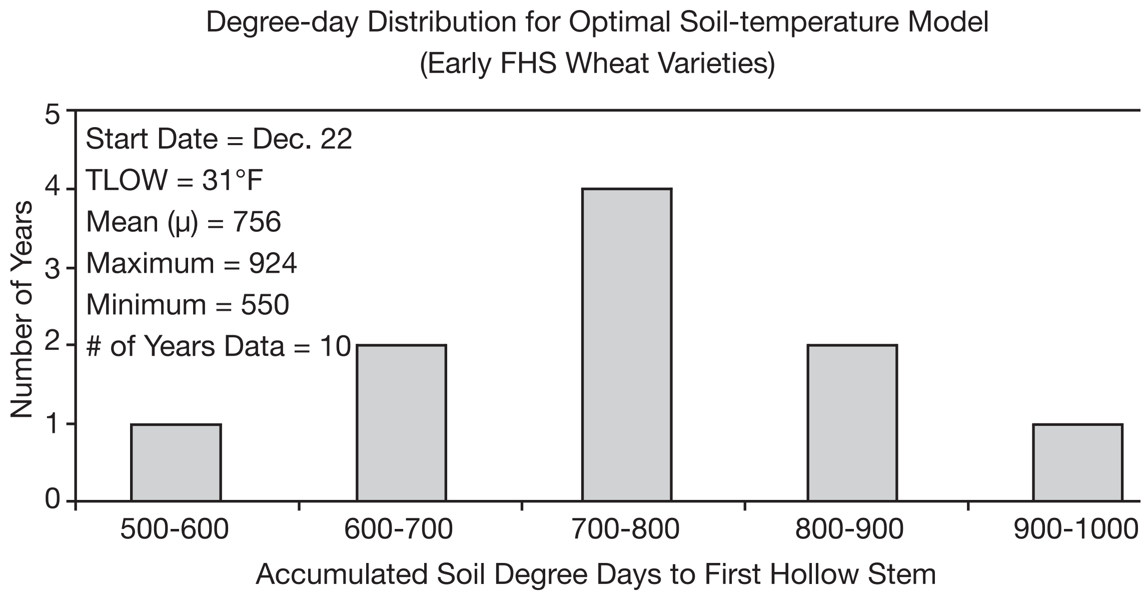

Figure 1. Distribution of accumulated soil degree days to first hollow stem for early FHS wheat varieties. Ten years of FHS data from north central Oklahoma are utilized.

Table 2. Predictive model for early FHS wheat varieties. The normal distribution is applied to the 10 years of data from north central Oklahoma. Accumulated soil degree days utilize a TLOW of 31°F and a start date of December 22.

PREDICTIVE MODEL (Early FHS Wheat Varieties) Based on Normal Distribution		
Cumulative Probability of FHS Occurrence	Accumulated Soil Degree Days	Probability that FHS Occurs after this Value
2.5%	536	97.5%
5%	572	95%
10%	612	90%
25%	680	75%
50% (µ)	756	50%
75%	832	25%
90%	900	10%
95%	940	5%
97.5%	976	2.5%

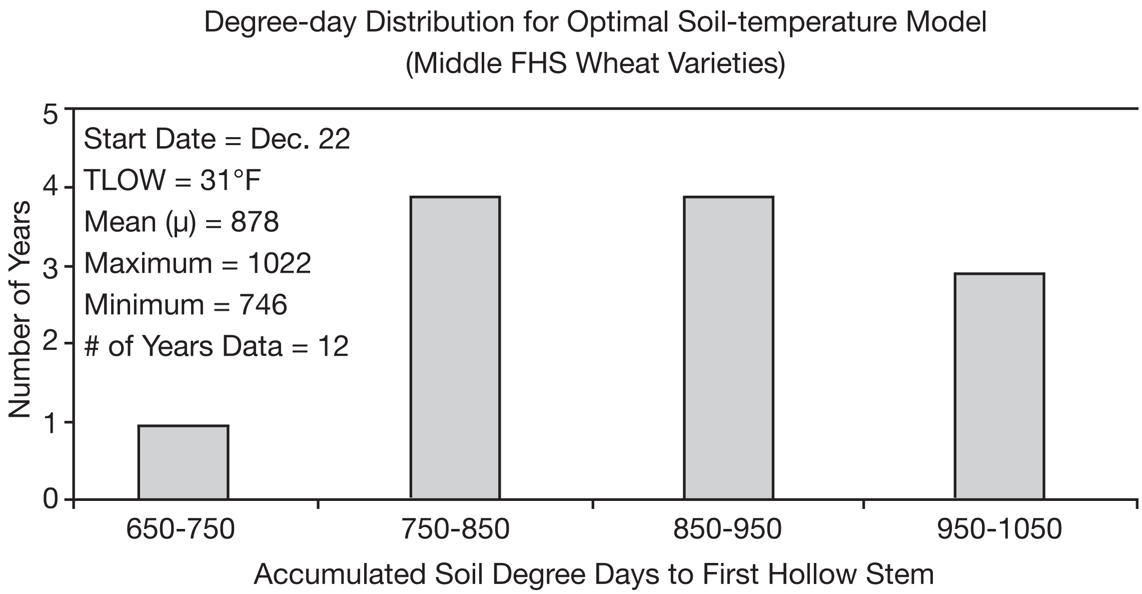

Figure 2. Distribution of accumulated soil degree days to first hollow stem for middle FHS wheat varieties. Twelve years of FHS data from north central Oklahoma are utilized.

Table 3. Predictive model for middle FHS wheat varieties. The normal distribution is applied to the 12 years of data from north central Oklahoma. Accumulated soil degree days utilize a TLOW of 31°F and a start date of December 22.

PREDICTIVE MODEL (Middle FHS Wheat Varieties) Based on Normal Distribution		
Cumulative Probability of FHS Occurrence	Accumulated Soil Degree Days	Probability that FHS Occurs after this Value
2.5%	698	97.5%
5%	727	95%
10%	760	90%
25%	816	75%
50% (µ)	878	50%
75%	940	25%
90%	996	10%
95%	1029	5%
97.5%	1058	2.5%

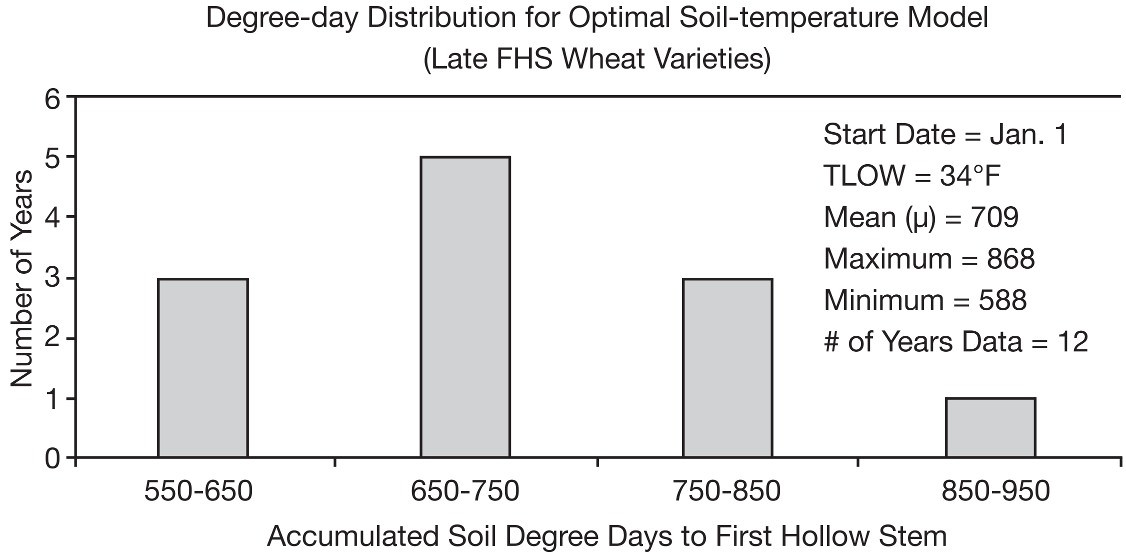

Figure 3. Distribution of accumulated soil degree days to first hollow stem for late FHS wheat varieties. Twelve years of FHS data from north central Oklahoma are utilized.

Table 4. Predictive model for late FHS wheat varieties. The normal distribution is applied to the 12 years of data from north central Oklahoma. Accumulated soil degree days utilize a TLOW of 34°F and a start date of January 1.

PREDICTIVE MODEL (Late FHS Wheat Varieties) Based on Normal Distribution		
Cumulative Probability of FHS Occurrence	Accumulated Soil Degree Days	Probability that FHS Occurs after this Value
2.5%	529	97.5%
5%	558	95%
10%	591	90%
25%	647	75%
50% (μ)	709	50%
75%	771	25%
90%	827	10%
95%	860	5%
97.5%	889	2.5%

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