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Project report submitted to the Organic Farming Research Foundation:

GENERAL TOPIC: BREEDING FOR ORGANIC FARMING SYSTEMS

Project Title:

Development of Wheat Varieties for Organic Farmers

FINAL PROJECT REPORT

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Statement of Importance of OFRF Funding to Our Program

Our research in organic wheat breeding at Washington State University began with an OFRF grant in 2002. The funds provided allowed us to recruit some of the best graduate students in the nation. These students today are performing groundbreaking research in organic crop production. We feel strongly that the association with the OFRF gave us credibility within a community in which we were new. Since our initial grant, we have obtained over \$750,000 in competitive funding for our organic wheat research. We are greatly indebted to the staff and administrators at the OFRF. Thank you.

Project Summary

From the mid-1950's on, most wheat in the U.S. has been selected and bred for high-input, traditional agricultural conditions. These conditions include the common use of artificial fertilizers and chemical herbicides and fungicides, practices that are not allowed under current certified organic standards. We believe that traits specifically adapted to and useful for organic wheat production have been lost from the gene pool of modern wheat varieties due to the intensive chemical management common in current wheat-breeding programs. In response, we have initiated a breeding program that focuses on selection under certified organic production systems and incorporates parental material from historical wheat varieties grown before the widespread use of modern day chemicals.

We have two primary objectives we would like to answer with this research: 1) Do varieties grown pre-1950's contain genes that could prove beneficial to organic wheat farmers? and; 2) Will wheat lines bred under a low-input organic environment be better adapted to these conditions and result in varieties particularly well suited to organic farming systems?

Problem Addressed

Field crops such as wheat, which are grown on large-scale acreage, present organic growers with unique challenges in managing weeds, pests and fertility. Successful cereal production requires varieties that are highly adapted to local climatic conditions and disease pressures. This is true for both conventional and organic production systems, but there are aspects of organic production systems that may make the ideotype required different from conventional systems. We believe that there is great potential for improving the characteristics of cereals that will make them superior for use in organic production. In spite of the fact that organic wheat cereal production is increasing rapidly in all wheat growing areas, there has to date been little attention paid by public wheat breeders to evaluate and develop cultivars adapted specifically to organic production systems.

Project Objectives

We are taking multiple steps towards supporting organic producers as an important component of our breeding program. The reasons for doing this are numerous. One important reason is that the development of varieties that produce reliably with low inputs will benefit not only organic producers and the environment, but conventional growers as well. We have also included here an explanation of the rationale and scope of our larger program.

1. Evaluation of current adapted cultivars, cultivar mixes, and advanced breeding material under organic production conditions. Our advanced breeding lines and modern checks were evaluated in four certified organic locations each year from 2002 to 2006 for yield and test weight. These are randomized complete block design experiments, with four replications for each genotype. The highest yielding breeding lines with good quality and test weight were advanced in each location for further evaluation in the next year. These best lines from these nurseries are the most likely candidates for varietal release specifically for organic farms in the near future. Results from two nurseries at St. Andrews are shown in Tables 5 and 6.

2. Establishment of a breeding program specifically to address the unique needs of organic wheat producers in Washington State. It is important to address the question “Are the best varieties in conventional farming systems the best varieties in organic farming systems?” The answer to this question will determine our breeding process and how best to select for organic farming systems. To address this question we set up a two-year study for which results are given in Figures 1-3 and Tables 1 and 2. Rigorously addressing the potential yield gains from a dedicated organic breeding program will encourage breeders working in other areas and with other crops to similarly provide support to their local organic producers. Lines developed in our program carrying important traits should prove to be useful parental germplasm for other breeders interested in developing lines tailored for organic agriculture.

Parental selection is the most important step in a breeding program. Varieties developed before the rapid wide-scale adoption of chemical fertilizers and biocides in the 1950’s may contain useful traits for weed competitiveness and nutrient use efficiency that have been lost as breeders have increasingly relied on chemical pest and fertility management in breeding nurseries and yield trials. For several years we have included in our breeding nurseries old wheat varieties to evaluate their suitability as parental material for low input situations (see Figure 2). Many of these old varieties have been discontinued for good reasons, disease susceptibility being chief among them. Crosses between these lines and current elite cultivars with good disease resistance should permit us to combine the best traits of the old and new varieties. One hundred and sixty-three of these old spring and winter wheats, representing those grown in the Pacific Northwest (PNW) from 1843-1955, are now part of the breeding program. The breeding lines we develop will not only be useful to farmers in Washington State, but to farmers and breeders in the greater Pacific Northwest as well. The traits relating to seedling disease resistance, quality (i.e. organic milling and artisan bakeries), and possibly competitive ability (e.g. coleoptile length) should be widely adaptable throughout the U.S.

The experiment was conducted at two sites in 2002-2003 and at three sites in 2004-2005. Four of the five site-years showed highly significant variety x system interactions, indicating that there is little to no correlation between the ranking of varieties for yield between conventional and organic systems. From this data we can draw two inferences. First, yield in organic farming systems are not currently optimized and second, the development of organic crop breeding programs appears to be vital to the continued improvement and competitiveness of organic wheat farming.

In our second year field evaluations of historical and modern wheat varieties, we identified varieties that 1) contain weed suppression traits (such as plant height, juvenile

growth habit, leaf area index, allelopathic potential, and coleoptile length); 2) are suited to out-competing weeds; 3) yield well under low-input conditions; 4) yield well under different mechanical tillage systems; 5) contain high levels of micronutrients and; 6) are resistant or moderately resistant to the current race(s) of stripe rust and dwarf bunt. It is our objective to select for these traits each generation in the field as we develop varieties uniquely suited to organic farming systems.

In our breeding program, we work closely with farmers in an evolutionary-participatory breeding project, where the farmers will begin to develop their own varieties. These varieties will be optimally adapted to their system of farming. We are continuing to evaluate and identify advanced breeding lines that do particularly well in organic systems in an effort to release wheat varieties for organic farmers.

3. Establishment of certified organic fields at Washington State University, Spillman Agronomy Farm and Lind Dryland Experimental Station. We have successfully taken two fields totaling 11 acres at the Spillman Agronomy Farm and completed the transition to full organic certification. In addition, we have transitioned 4 acres to certified organic at the Washington State University (WSU) Lind Dryland Experimental Station. Both sites are certified by the Washington State Department of Agriculture. This provides us with on-station, certified organic test plots for our breeding work. This is important in allowing us to address the potential for gains through selection under organic conditions, which permits a greater level of control over inputs and management practices (we can do things such as introduce weeds and diseases). The results from these test plots will then be combined with those plot locations on the private land of organic and conventional farmer collaborators.

4. Training of a graduate student of plant genetics in organic agriculture. This is a time of increasingly polarized debates surrounding the future directions of American agriculture. Plant geneticists currently have a disproportionately strong voice in this debate. Developing germplasm for organic production necessitates a breadth of agricultural knowledge and a willingness to critically evaluate assumptions. Training geneticists to think critically about farming systems promises to add more diversity to the debate in the future. We have also recently recruited two Ph.D. graduate students and one post-doctoral researcher to start working on organic wheat breeding projects.

5. Baking tests of organic wheats. Does wheat perform differently in terms of flour and dough functionality when it is grown in organic fields? Do the older wheats indeed have unique and desirable end-use qualities that are lacking in our modern wheats? We have evaluated historical soft white, hard red and hard white spring and winter wheat varieties for several traits important to overall quality and marketability. Baking and milling tests are performed on all wheats from the organic fields. Full evaluation of bread, cookie, cake and noodles are done at the USDA Western Wheat Quality Laboratory in Pullman, WA. In addition, we collaborated with Dr. Phil Reeves to analyze the micronutrient content of seven different minerals in each variety.

Methodology

1. Evaluation of current adapted cultivars, cultivar mixes, and advanced breeding material under organic production conditions. Our current certified organic breeding program evaluates the performance of advanced breeding lines relative to widely grown cultivars in four locations in Washington State representing a wide range of soil, climatic and disease pressures within the state. These locations include Spillman Agronomy Farm in Pullman (certified organic by Washington State Department of Agriculture [WSDA] since 2002), the Lind Dryland Research Station in Lind (transitional organic 2003-2005, certified organic by WSDA 2006), the DeLong Farm in St. John (certified organic since 1994), and the Jorgensen Farm in St. Andrews (certified organic since 2000). Organic farmers cooperate by applying the same fertility, weed and pest treatments to the breeding nurseries as their normal wheat fields. Seeding rate is typically 45 g/plot in Pullman and St. John and 25 g/plot in Lind and St. Andrews. Perfect Blend 4-4-4 Organic Fertilizer is incorporated with seed at planting at various fertilizer rates, depending on the location and nature of the experiment. Plots are managed organically with no herbicides or pesticides. Weeds are controlled with a rotary hoe and with manual hoeing. Selection criteria in the field varies considerably by location, but broadly focuses on disease resistance (stripe rust, foot rot, *Cephalosporium* stripe), weed competitiveness and weed tolerance, yield and test weight.

A wide variety of different cultural practices will be applied at each test plot location. This diversity of management practices will be essential if we are to determine whether there are general characteristics that suit wheat for organic production. In the past five field seasons (harvested in 2001-2006), we have partnered with the Jorgensen Brothers Ranch to evaluate our soft white winter wheat common and club breeding nurseries and our hard red winter wheat breeding nurseries in their certified organic fields in Douglas County, Washington. These three market classes represent the vast majority of wheat produced in Washington State and there is currently considerable market demand for organically grown hard red, soft white and club wheats (Keith Jorgensen, personal communication). In the past four field seasons (2002-2006), we have harvested yield trials on Joe and Sara DeLong's certified organic fields in St. John, Washington, and again will plant yield trials in the current 2006 field season. We are also conducting weed competition studies at the DeLong farm.

To determine whether the highest yielding varieties in organic systems are also the highest yielding varieties in conventional systems, randomized complete block nurseries with four replicates of 35 advanced soft white winter wheat breeding lines (F_7 to F_9) were grown in paired organic and conventional systems in five locations (site/years) in Washington State. All 35 advanced lines were selected from the F_2 generation in conventionally managed fields. Locations 1 and 2 were evaluated in 2002-2003 and locations 3, 4 and 5 were evaluated in 2004-2005. The 35 genotypes represent the most promising lines in the WSU winter wheat breeding program each year and have been selected entirely in conventional systems. The organic and conventional nurseries were separated by buffer strips (7m minimum), though otherwise located in similar microclimatic conditions with comparable soil properties. The conventional nurseries were treated according to standard agricultural practice, including the use of crop-protection chemicals and inorganic fertilizer. The organic nurseries were located on certified organic ground and treated according to the regulations set by the USDA

National Organic Program. Locations 2 (2002-2003), 4 and 5 (2004-2005) are at the Spillman Agronomy Farm near Pullman in Whitman County, Washington (latitude 46°73'N, longitude 117°18'W) on a Palouse silt loam soil, where annual precipitation is >500 mm/year. The organic fields at Spillman Farm have been certified organic since 2002. The conventional nursery was fertilized with 100.8 kg/ha of N, 22.7 kg/ha of phosphate and 17.0 kg/ha of sulphur incorporated into the soil within a week of planting. Seed was treated with Raxil[®]-Thiram fungicide (Tebuconazole, Thiram) and Gaucho[®] 480 (Imidacloprid) insecticide before planting at all conventional locations. Weed control in these conventional nurseries was accomplished with one application of 140g of Sencor (Metribuzin) and 1.2 l/ha of Bronate (Bromoxynil) and hand weeding throughout the growing season. The conventional system was managed as a 2-year winter wheat/summer fallow rotation. The organic nursery was fertilized with PerfectBlend[®] 4-4-4 organic fertilizer at the rate of 6.05 kg/ha each of N, P, and K, placed with the seed at planting. No fungicidal or insecticidal seed treatments were used at the organic locations. Weeds were left in the field until the week before harvest. The two-year rotation in the organic systems was winter pea plowdown/winter wheat. The winter pea rotation provided supplemental nitrogen at approximately 33 to 40 kg/ha as measured by soil tests. Plots in Whitman County consisted of seven rows at 18 cm spacing, 2.5 m long and 1.25 m wide.

Locations 1 (2002-2003) and 3 (2004-2005) represent two farms near St. Andrews in Douglas County, Washington, (latitude 47°47'N, longitude 119°22'W) on a Timentwa loam soil type with similar weather patterns and winter wheat/summer fallow cropping rotations. The annual precipitation in this region is approximately 300mm/year. The conventional nursery was fertilized with 46.0 kg/ha of N and sprayed with 23.5 g/ha Harmony Extra (Tribenuron methyl, Thifensulfuron methyl) and 0.5 l/ha Buctril (Bromoxynil) herbicide with a non-ionic surfactant. The organic nursery was fertilized with PerfectBlend 4-4-4 organic fertilizer at the rate of 3.35 kg/ha, drilled with the seed at planting. The organic farm in Douglas County has been certified since 2000. Weeds were left in the field until the week before harvest. Plots consisted of four rows at 30 cm spacing, 2.5 m long and 1.25 m wide.

Each year, we selected seed from a wide range of plants to establish families for further evaluation. In addition, we bulked together a diverse mixture of seed from promising plants and continued our evolutionary-participatory breeding program. We took the bulked seed and planted it 6-8 inches deep under severely crusted soil at the Lind field station for three consecutive years. Percentage emergence was measured 2, 4, and 6 weeks after planting.

2. Establishment of a breeding program specifically to address the unique needs of organic wheat producers in Washington State. We anticipate that our traditional breeding protocols will also prove to be efficient for breeding for organic production, with the differences being initial parent selection and management of test plots. We plan to continue our use of genetic diversity to address the needs of the growers. Given the wide range of cultural practices and environmental conditions between different organic farms, we are initiating an evolutionary/participatory breeding program that will address the unique requirements of individual wheat growers in Washington.

3. *Training of a graduate student of plant genetics in organic agriculture.* Kevin Murphy will continue graduate work in the organic wheat-breeding program along with two new Ph.D. students.

4. *Baking, Milling and Mineral Content tests on organic wheats.* Baking and milling tests are performed on all wheats from the organic fields. Full evaluation of bread, cookie, cake and noodles are done at the USDA Western Wheat Quality Laboratory in Pullman, WA. Parameters evaluated include ash content, protein content, moisture content, falling number, flour color, single kernel hardness, milling test, gluten test, mixography, and levels of calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), phosphorus (P), selenium (Se), and zinc (Zn). These tests are performed as a free service to the breeding program.

Mineral content evaluations were performed in collaboration with Dr. Philip Reeves of the USDA-ARS Grand Forks Human Nutrition Research Center in North Dakota. A randomized complete block design nursery of 63 spring wheat varieties (56 historical, 7 modern) was grown in Pullman, Washington in 2004 and 2005 on a Palouse silt loam soil. The historical varieties were selected randomly from a larger group of spring wheat varieties that were widely grown in the Pacific Northwest region of the U.S. from 1842 to 1965. The seven modern varieties were among the most widely grown spring wheat cultivars in the Washington State, USA, in 2003, representing approximately 69% of the total spring wheat acreage in the state (USDA, 2005). Thirty-seven varieties were in the soft white market class, twenty varieties were in the hard red market class, four varieties were in the hard white market class and two varieties were in the soft red market class. There were three replicates of each variety in 2004 and four replicates of each variety in 2005. The nurseries were fertilized with PerfectBlend[®] fertilizer at the rate of 6.05 kg/ha each of N, P, and K, drilled with the seed at planting. No fungicidal or insecticidal seed treatments were used. This management practice was intended to reflect low-input wheat production in the Pacific Northwest. Plots consisted of seven rows at 18 cm spacing, 2.5 m long and 1.25 m wide. Plots were harvested with a Hege plot combine with stainless steel sieves and cleaned with a Hege seed cleaner with stainless steel sieves.

Results

Our most important result was that the highest yielding varieties in conventional systems are not the highest yielding varieties in organic systems (See Figures 1 and 3, Tables 1 and 2). An analysis of variance showed highly significant genotype x system interactions for yield between systems in four of five locations ($P < 0.001$). Genotypic ranking analysis using Spearman's rank correlation coefficient (R_S) shows no significant correlation between genotypic ranking for yield in four of five locations ($R_S = -0.03, 0.26, 0.08$ and 0.11). Our results suggest that indirect selection would be considerably less efficient than direct selection for both yield ($RE = 0.28$) and test weight ($RE = 0.53$). RE is the relative efficiency of indirect selection and is based on values of relative efficiency for both indirect and direct selection (data not shown). Indirect selection in this case refers to selection for yield in one system when the target environment is the other system.

Additionally, the genetic correlation coefficients (r_G) indicate robust genetic independence for yield ($r_G = 0.25$) and moderate genetic independence for test weight ($r_G = 0.53$) in 35 genotypes between organic and conventional systems. An r_G of 1.0 indicates that the traits in question are controlled by the same alleles in both systems and a separate breeding program is not justified. As r_G approaches 0, genetic independence increases, indicating an increasing need for separate breeding programs for the distinct crop management systems (Atlin and Frey, 1989). Because r_G is an average inverse measure of genotype x productivity-level interaction for the entire population, single genotypes may have significantly smaller or larger interactions with systems than the r_G estimate (Atlin and Frey, 1990).

The broad-sense heritability (h^2) estimates in Tables 1 and 2 represent the repeatability or the genetic basis of the relationship between genotypes in two different systems. Broad-sense heritability eliminates variation due to differences in the location and environment. With crop varieties bred in and adapted to the unique conditions inherent in organic systems, organic agriculture will be better able to realize its full potential as a high-yielding alternative to conventional agriculture. These results tell us that breeding for organic agriculture should be conducted in certified organic fields. It also illustrates the point that yield in organic systems has not been optimized and will not be fully optimized until breeding and selection occurs within these organic systems.

In our weed competition study, we found significant variation in weed suppression ability of the 63 spring wheat cultivars tested. We found particular cultivars that are better adapted to weed competition than to repeated harrowing and vice versa. Data from this study are currently being analyzed and will be published and available in the spring of 2007.

Assessment of historical and modern spring wheat varieties under “low input” conditions demonstrated that while the highest yielding varieties are modern varieties, some varieties from the 1930s and 1940s are high yielding under these conditions and might contain potential for improvement (Figure 2). For example, two varieties, Canus and Spinkota--ranked 3 and 4, respectively, out of 63--may contain traits that are particularly suited to organic conditions.

The relationship between yield and mineral content was tested using 56 historical and seven modern spring wheat varieties grown together under low-input agronomic conditions in the state of Washington, USA, during the 2004 and 2005 growing seasons. Highly significant differences ($P < 0.0001$) among the 63 wheat varieties were found for yield and for mineral content of all eight nutrients (Table 3). Modern varieties had significantly higher yields than the historical varieties ($P < 0.0001$). Mean yield for historical varieties was 1090 ± 79 kg/ha, while mean yield for the modern varieties was 1915 ± 242 kg/ha. For seven of the eight minerals tested, the historical varieties had significantly higher grain mineral content than the modern varieties (Table 3). Only Ca showed no significant difference between the historical and modern era ($P = 0.07$). Highly significant variation exists among wheat varieties for mineral content of each nutrient, indicating the potential for genetic improvement (Table 4).

Tables 5 and 6 show data from the advanced soft white wheat nursery and the low rainfall wheat nursery in St. Andrews, Washington, from 2005.

Tables 7 to 9 show baking and milling end-use quality rankings of historical wheat varieties in relation to a modern control or check variety. These data are invaluable for helping us determine appropriate parents in our crossing schemes.

We began collaborations with Dr. Blair Goates of USDA-ARS, Aberdeen, Idaho, to test for dwarf bunt resistance in our wheat cultivars and breeding lines (Table 10). The nursery tested represents our best soft white wheat breeding lines. Dwarf bunt is of particular concern to organic farmers as currently the pathogen is controlled using fungicidal seed treatments that are not available for use by organic farmers. Cheyenne is the susceptible check variety and breeding lines of particular interest (AWY 24, AWY 25 and AWY34) show genetic resistance to dwarf bunt. Results shown in Table 10 show three breeding lines in particular with good resistance to dwarf bunt. These tests will be repeated over several years to identify advanced breeding lines with resistance to dwarf bunt.

We have striven to work with farmers in the development of varieties suited to their agroecosystems. We have identified historical wheat cultivars with excellent quality characteristics (and many more with poor quality characteristics), and included these cultivars in our crossing scheme. We are getting closer to understanding the gene action and response to selection of the gene(s) responsible for long coleoptile in wheat. Additionally, our population selection for superior emergence properties has received strong natural selection over the past three years in the form of significant soil crusting and low soil moisture (see Table 11). We have had the incredible “good fortune” to have had rain showers that caused severe soil crusting on our emergence studies each of the last two years at the Lind Experiment Station. When rain showers occurred shortly after planting this nursery, even the farm manager of the Lind station was sure that “nothing will emerge through that crust.” But as the data show (Table 11), some breeding lines had as high as 80% emergence through a thick crust. Not all breeding lines emerged as well, but since they are still segregating, we definitely will advance the seed from the plants that survived such harsh natural selection.

Conclusions and Discussion

There exists little genetic correlation between the ranking of varieties for yield between chemical and organic systems. This is important because it suggests that yield in organic farming systems are not currently optimized. Consumer demand and concerns about the impacts of conventional agriculture on the environment and human health have spurred the growth of organic farming systems; however, organic agriculture is often criticized as low-yielding and unable to produce enough food to supply the world’s population. Using wheat as a model crop species, we show that poorly adapted varieties are partially responsible for the lower yields often found in organic farming systems when compared with conventional farming systems. Our results demonstrate that the highest yielding, best quality soft white winter wheat genotypes in conventional systems are not the highest yielding, best quality genotypes in organic systems.

In our breeding lines, progeny derived from crosses between historical and modern varieties showed remarkable diversity. Our evaluations indicate sufficient variation for selection and allow us to identify plants with an adaptive edge that will thrive under organic conditions. While many of the wheat plants were covered in rust or were completely lodged by around mid-July of each year, a significant percentage

showed varying degrees of resistance and many withstood the winds. Some breeding lines showed good emergence even through a thick crust that formed after planting (see photo at right). If we continue to plant bulk seed deeply each year, every variety we release in the future will have enhanced emergence rates. This is a way of maximizing the strength of natural selection to maintain diversity while increasing production and adaptability to organic conditions.



Another important finding is the decrease in modern varieties of essential micro and macronutrients. Approximately three billion people worldwide are nutrient deficient. We evaluated 63 historical and modern wheat varieties for grain yield and mineral nutrient content of calcium, copper, iron, magnesium, manganese, phosphorus, selenium, and zinc. While grain yield has increased, mineral nutrient content has decreased significantly in modern grains for all minerals except calcium. Our results show that modern wheat varieties require increased consumption of whole wheat bread to achieve the same percentage of the recommended dietary allowance (RDA) levels attainable by historical varieties high in mineral content. Selenium and iron concentrations were not associated with yield, suggesting the possibility for uncomplicated improvement, while weak to moderate negative correlations between yield and the other six minerals suggest a possible biological trade-off, and genetic improvement for these minerals may be more difficult to achieve.

We feel that active selection for mineral content, dwarf bunt and stripe rust resistance, weed competitiveness and weed tolerance, quality, emergence and yield in organic systems will assist us in the development of wheat varieties specifically adapted to the agronomic conditions and potential marketing opportunities of organic farmers.

Outreach

Personnel of the Washington State Winter Wheat Breeding Program typically give up to 30 talks each year at field days, including the WSU Organic Field Day held July 2003 and June 2004, and to producer organizations throughout the state. Our interest in breeding for organic production has figured prominently in these talks for the past five years. We have been gratified by the overwhelmingly positive reaction among wheat producers to this new direction in our program. We publish our results in academic journals, trade journals, and in the popular press. In the past few years, we have published articles in Tilth Producers Quarterly (Spring 2003), In Good Tilth (February 2003), Wheat Life (March 2004, February 2006) and Sustaining the Pacific Northwest (Winter 2003, Winter 2006 in press).

Additionally, a paper titled *Breeding for organic and low-input farming systems: An evolutionary participatory breeding method for inbred cereal grains* was published in the journal Renewable Agriculture and Food Systems in 2005.

Presentations and Workshops

International Plant Breeding Symposium: Breeding for enhanced mineral nutrient content in wheat. Mexico City, Mexico. August 2006.

Symposium on Sustainable Agriculture, Communities, and Environments in the Pacific Northwest: Participatory Wheat Breeding in the Pacific Northwest. Richland, WA. May 2006.

Organic Grain Production Workshop: WSU Organic Wheat Breeding Program: Objectives and Results. Spokane, WA. December 2005.

7th International Wheat Conference: Genetic assessment of the need for organic plant breeding programs in winter wheat (*Triticum aestivum*, L.). Mar del Plata, Argentina. December 2005.

Crop Science Society of America-Agronomy Society of America-Soil Science Society of America Annual Meeting: Participatory Breeding Program for Cereals. Salt Lake City, Utah. November 2005.

Crop Science Society of America-Agronomy Society of America-Soil Science Society of America Annual Meeting: Breeding Wheat for Organic Systems. Salt Lake City, Utah. November 2005.

WSU Organic Field Day: Organic Wheat Breeding. Pullman, WA. June 2004.

Organic Seed Alliance, Organic Seed Breeding and Production Conference: Overview of the WSU Organic Wheat Breeding Program. Corvallis, OR. January 2004.

WSU Organic Field Day: Organic Wheat Breeding. Pullman, WA. July 2003.

WSU/OSU symposium entitled: Getting the Bugs to Work for You: Biological Control in Organic Agriculture. Organic Plant Breeding I and II. Portland, OR. November 2004.

Washington Tilth annual conference. Organic Plant Breeding: Using wheat as a model. Yakima, WA. November 2002.

We are members of the Western Region of the Sustainable Agriculture Working Group and feel that its newsletters will also be an important way to reach organic producers in the future. Members of our program have attended meetings of organic producers in Saskatchewan (Canadian Sustainable Agriculture Network), in Alberta (Alberta Organic Producers Association), in Washington State (Tilth Producers) and Oregon (Tilth Producers, Western Sustainable Agriculture Working Group and Farmer's Genome Project) during the past three years to describe our plans to dedicate a large part of our program to breeding support for organic producers.

In August of 2002, we gave invited talks at the International Federation of Organic Agricultural Movements in Victoria, Canada on our work with organic and perennial wheat breeding. In 2005, graduate students in this program have given talks at the American Association of Agronomy in Salt Lake City, Utah, the International Wheat Conference in Argentina and at the Organic Grain Production Workshop in Spokane, Washington. These meetings provided an excellent opportunity to hear producer's research priorities as well as to gain valuable critiques of our own work.

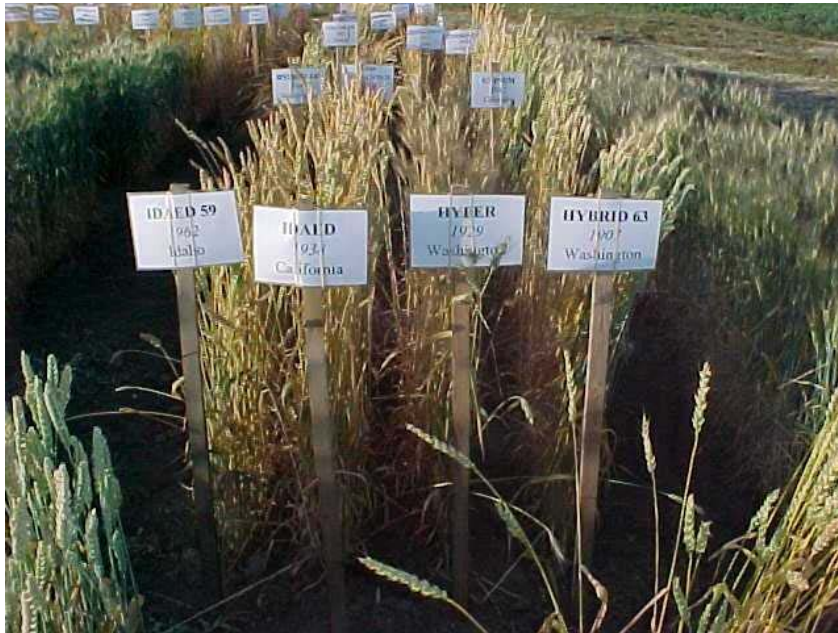
We are compiling a comprehensive database of the 163 heirloom varieties used as parent lines in our crosses, detailing observed and researched traits for each variety. Once completed, this will be posted on our website and will be easily accessible by anyone interested. This should prove to be a valuable resource for future organic wheat breeders worldwide and an important template for organic crop breeders in general.

This project will not only disseminate information, but also a tangible product. The wheat lines that we produce will be freely available to all wheat farmers and public breeders that request them. We also collaborate with organic researchers in Canada, England, Japan, Syria, Nepal, China and Germany.

Organic Spring Wheat Nursery at Spillman Farm, July 2006



Historical varieties in organic systems, Spillman Farm.



References

- Acciares, H.A., Chidichimo, H.O., Sarandon, S.J. (2001) Traits related to competitive ability of wheat (*Triticum aestivum*) varieties against Italian Ryegrass (*Lolium multiflorum*). *Biological Agriculture and Horticulture: an international journal* 19:275-286.
- Ammon, H.U., and Kunz, P. (1982) Influence of the competition of short stalked grain varieties on the development of some weeds in Switzerland. *Mitteilungen für die Schweizerische Landwirtschaft* 30:12-17.
- Atlin, G.N., and Frey, K.J. (1989) Breeding crop varieties for low-input agriculture. *American Journal of Alternative Agriculture* 4:53-58.
- Atlin, G.N., and Frey, K.J. (1990) Selecting oat lines for low yield in low-productivity environments. *Crop Science* 30:556-561.
- Beghestani, A., Lemieux, C., Leroux, G.D., Simard, R. (1999) Determination of allelochemicals in spring cereal cultivars of different competitiveness. *Weed Science* 47: 498-504.
- Cosser, N., Gooding, M., Froud-Williams, R. (1996) The impact of wheat cultivar, sowing date and grazing on weed seed bank of an organic farming system. *Rotations and Cropping Systems* 16: 429-432.

Farahabkash, A., and Murphy, K.J. (1989) Competitiveness of wheat cultivars with broadleaf weeds in relation to nitrogen and fluroxypyr applications. *Tests of Agrochemicals and Cultivars* 10:128-129.

Kappler, B., Lyon, D., Miller, S., Stahlman, P., Wicks, G. (1997) Jointed goatgrass competitiveness is influenced by winter wheat seeding rate. *Proceedings of the Western Society of Weed Science* 50:58.

May, L., Van Sanford, A., MacKown, C., Cornelius, P.L. (1991) Genetic variation for nitrogen use in soft red x hard red winter wheat populations. *Crop science* 31: 626-630.

Ogg, A.J., and Seefeldt, S.S. (1999) Characterizing traits that enhance the competitiveness of winter wheat against jointed goatgrass. *Weed Science* 47: 74-80.

Ortiz-Monasterio, R., Sayre, K., Rajaram, S., McMahon, M. (1997) Genetic progress in wheat yield and nitrogen use efficiency under four nitrogen rates. *Crop Science* 37: 898-904.

Raun, W., and Johnson, G. (1993) Improving nitrogen use efficiency for cereal production. *Agronomy Journal* 50: 301-309.

Richards, M.C., and Heppel, V. (1990) Cereal varieties for the organic and low input grower. *British Crop Protection Council Monograph* 45: 147-155.

Scott, J. (1999) Selecting Milling Wheat for Organic Production in New Brunswick. *Seeds of Diversity Magazine*, May, 1999.

Simmonds, N. (1979) *Principles of Crop Improvement*. Longman, New York.

Stoeppler, H., Koelsch, E., Vogtmann, H. (1988) Suitability of winter wheat varieties for ecological agriculture. *In Global perspectives on agroecology and sustainable agricultural systems*. 407-412. Agroecology Program, Santa Cruz, CA, publisher

USDA (2005) *Washington Wheat Varieties*. National Agricultural Statistics Service. <http://www.nass.usda.gov/wa/whtvar05.pdf>.

Van Sanford, A., and MacKown, C. (1986) Variation in nitrogen use efficiency among soft red winter wheat genotypes. *Theoretical and Applied Genetics* 72: 158-163.

Weiner, J., Griepentrog, H.W., Kristensen, L. (2001) Suppression of weeds by spring wheat *Triticum aestivum* increases with crop density and spatial uniformity. *Journal of Applied Ecology* 38: 784-790.

Wolfe, M. (2000) *Elm Farm Research Center Bulletin*, (supplement) 2000. Elm Farm Research Center, Newbury, England, publisher.

Appendix

Figure 1. Yield (Fig. 1A) and test weight (Fig. 1B) in organic vs. conventional wheat nurseries. The striped bars denote the organic nurseries and the shaded bars denote the conventional nurseries. Results are two-year nursery means \pm s.e.m.

† = significant genotype x system interactions at $P < 0.001$

*, *** = significant difference between organic and conventional nurseries

(* = $P < 0.05$; *** = $P < 0.0001$)

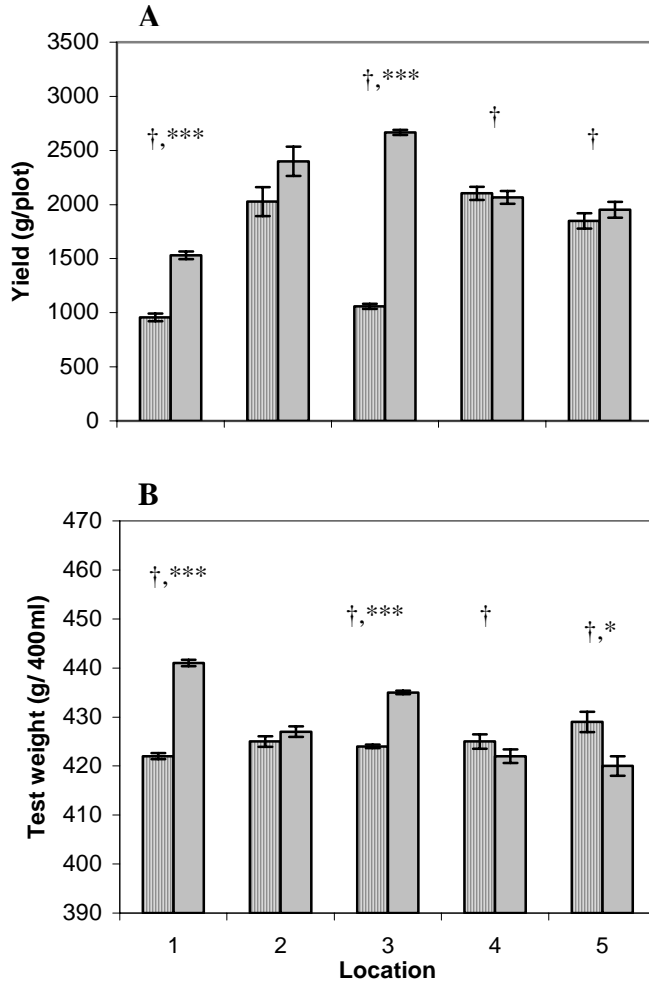


Figure 2. This figure shows the grain yield of historical and modern spring wheat varieties grown in low-input conditions (no herbicides or hand weeding, organic fertilizer [4-4-4], no fungicides). Results are two-year means from the Pullman nursery.

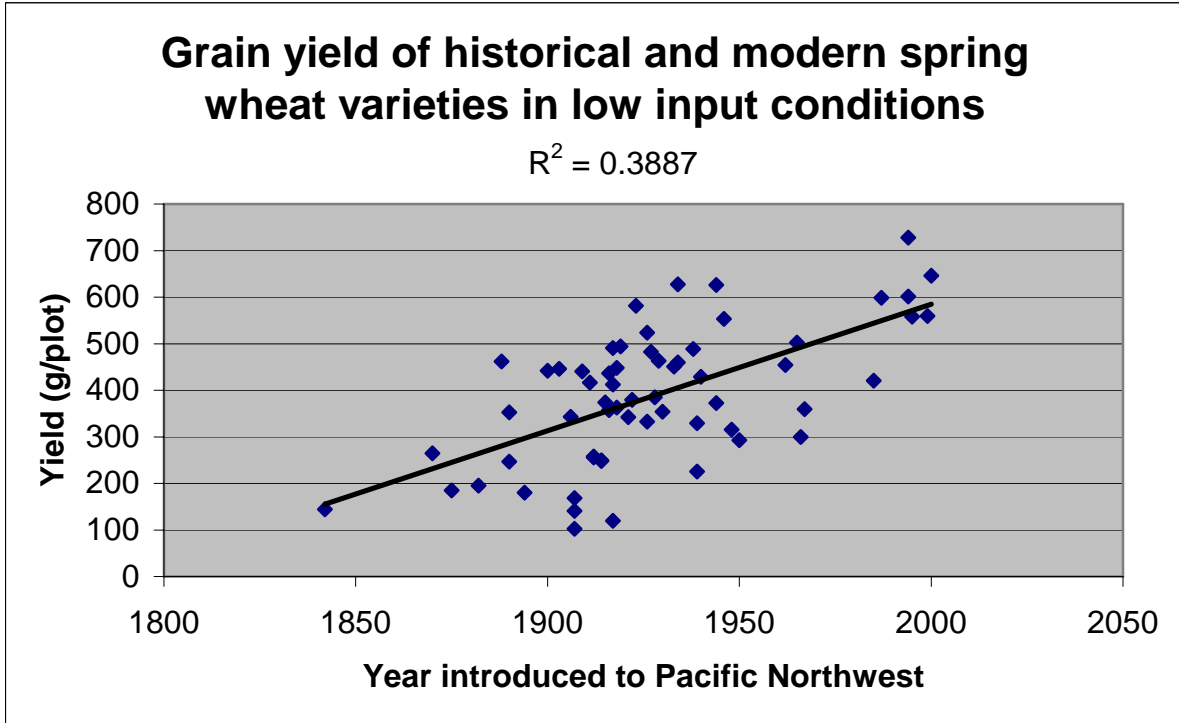


Figure 3. Genotypic change in rank between organic and conventional wheat nurseries. The top five ranking genotypes for yield in both organic and conventional systems were compared at each location. Genotypes are ranked from one = highest yield to 35 = lowest yield. If the lines were horizontal in this figure, no change in rank would occur. The extent of crossover interaction here indicates that the highest yielding varieties in organic systems are usually not the highest yielding varieties in conventional systems. Results are two-year means.

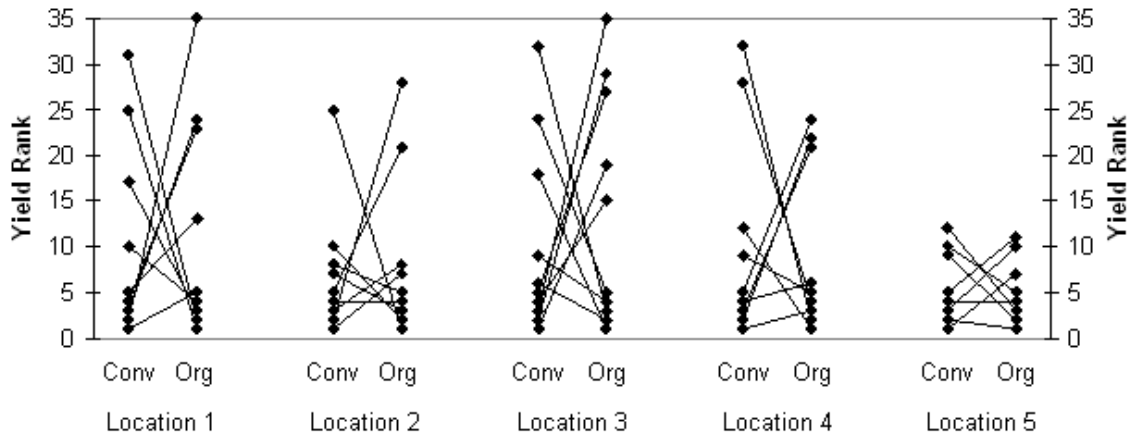


Table 1. Differences in yield between organic and conventional systems. Mean yield, number of observations (N), P-value for genotype by system interaction (G x S) with degrees of freedom (df), broad-sense heritability (h^2) \pm s.e.m., genetic correlation coefficient (r_G) and relative efficiency of indirect selection (RE) measured in paired organic/conventional experiments with 35 soft white winter wheat genotypes at each of five locations.

<i>Location</i>	<i>System</i>	<i>Yield</i> (grams/3.5m ²)	<i>N</i>	<i>G x S (df)</i>	<i>h²</i>	<i>r_G</i>	<i>RE</i>
1	Organic	956	140	<0.0001 (34)	0.51 \pm 0.06	0.034	0.043
	Conventional	1530	140		0.84 \pm 0.02		
2	Organic	2028	140	0.1435 (34)	0.40 \pm 0.07	0.021	0.025
	Conventional	2400	140		0.47 \pm 0.05		
3	Organic	1058	140	0.0092 (34)	0.61 \pm 0.05	0.099	0.103
	Conventional	2668	140		0.65 \pm 0.05		
4	Organic	2105	130	0.0007 (34)	0.89 \pm 0.02	0.655	0.761
	Conventional	2068	140		0.93 \pm 0.01		
5	Organic	1850	130	<0.0001 (34)	0.70 \pm 0.05	0.450	0.459
	Conventional	1952	140		0.93 \pm 0.01		
Mean	Organic	1599	680	----	0.62 \pm 0.02	0.25	0.28
	Conventional	2124	700		0.79 \pm 0.01		

Table 2. Differences in test weight between organic and conventional systems. Mean test weight (TW), number of observations (N), P-value for genotype by system interaction (G x S) with degrees of freedom (df), broad-sense heritability (h^2) \pm s.e.m., genetic correlation coefficient (r_G) and relative efficiency of indirect selection (RE) measured in paired organic/conventional experiments with 35 soft white winter wheat genotypes at each of five locations.

<i>Location</i>	<i>System</i>	<i>TW</i> (grams/400ml)	<i>N</i>	<i>G x S (df)</i>	<i>h²</i>	<i>r_G</i>	<i>RE</i>
1	Organic	422	140	0.0004 (34)	0.96 \pm 0.01	0.576	0.537
	Conventional	441	140		0.84 \pm 0.03		
2	Organic	425	140	0.264 (34)	0.83 \pm 0.03	0.577	0.610
	Conventional	427	140		0.93 \pm 0.01		
3	Organic	424	140	<0.0001 (34)	0.92 \pm 0.01	0.447	0.429
	Conventional	435	140		0.86 \pm 0.02		
4	Organic	425	130	0.0007 (34)	0.88 \pm 0.02	0.636	0.654
	Conventional	422	140		0.93 \pm 0.01		
5	Organic	428	130	<0.0001 (34)	0.84 \pm 0.03	0.402	0.426
	Conventional	420	140		0.90 \pm 0.01		
Mean	Organic	425	680	----	0.62 \pm 0.02	0.53	0.53
	Conventional	429	700		0.79 \pm 0.01		

Table 3. Mineral content in historical and modern wheat varieties.

Mineral content is given in mg/kg dry weight \pm standard error for all minerals except Se, which is given in ug/kg. Data are means from 2004-2005 trials at Spillman Farm in Pullman, WA. A significant negative value in the grain yield/mineral content correlation column indicates that increased yield was correlated with decreased concentration of that mineral.

*, **, ***: $P < 0.05$, 0.01 and 0.0001 , respectively.

Ns = not significant.

The 95% confidence interval for the grain yield/mineral content correlation is shown in parentheses.

<i>Mineral</i>	Mineral Content			<i>Grain Yield/Mineral Content Correlation</i>
	Historical (1842-1965)	Modern (2003)	% Change	
Ca	421.58 \pm 10.90	398.49 \pm 16.12	- 6	-0.41 ***
Cu	4.76 \pm 0.13	4.10 \pm 0.23	- 16 ***	-0.17 ***
Fe	35.73 \pm 1.00	32.31 \pm 1.75	- 11 **	0.05 ns
Mg	1402.62 \pm 21.01	1307.6 \pm 25.63	- 7 ***	-0.35 ***
Mn	49.98 \pm 1.22	46.75 \pm 3.14	- 7 *	-0.17 **
P	3797.08 \pm 55.65	3492.7 \pm 119.25	- 9 ***	-0.25 ***
Se	16.17 \pm 1.74	10.75 \pm 2.73	- 50 *	-0.38 ***
Zn	33.85 \pm 0.92	27.18 \pm 1.88	- 25 ***	-0.06 ns

Table 4. This table shows the mineral content of 63 spring wheat varieties (blue=historical, magenta=modern) and check varieties (green). Eight minerals (Ca, Cu, Fe, Mg, Mn, P, Zn, and Se) were tested for each variety. Significant variation exists within this germplasm base to suggest the possibility of breeding for higher mineral content. This work is done in collaboration with Dr. Phillip Reeves of the USDA-ARS Grand Forks Human Nutrition Research Center in North Dakota.

	Ca	Cu	Fe	Mg	Mn	P	Zn	Se
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	µg/kg
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
Allen	390.9	4.36	43.48	1488	43.51	4187	30.01	19.32
Awned Onas	413.0	3.66	33.99	1340	44.42	3238	24.95	10.87
Baart 46	310.6	4.21	40.47	1580	40.39	3772	24.70	4.83
Beaver	353.7	3.38	30.44	1294	40.30	3481	26.22	6.02
Big Club	463.8	3.71	42.84	1443	45.87	4096	30.59	8.86
Big Club 43	426.9	4.03	44.83	1289	41.30	3889	26.25	8.67
Bluechaff Club	395.2	4.85	37.06	1367	33.80	3841	26.00	7.20
Bunyip	412.2	4.72	39.86	1484	49.90	3855	30.23	10.55
Currawa	410.1	4.53	43.55	1457	48.88	3933	27.32	7.93
Dicklow	443.9	4.00	32.63	1276	40.91	3209	24.77	8.81
Early Baart	604.1	4.62	37.27	1524	44.00	3860	28.70	5.81
Federation	461.1	4.46	39.06	1377	49.23	3477	30.04	4.94
Federation 67	444.6	4.46	39.10	1455	46.68	3698	28.64	6.58
Galgalos	346.1	4.53	44.26	1365	43.58	3812	30.62	10.56
Gypsum	423.8	5.33	46.36	1436	41.76	3973	32.28	3.48
Hard Fed	383.9	4.85	44.62	1538	51.42	4104	34.43	1.72
Hybrid 143	426.0	5.24	42.44	1561	43.84	4041	30.31	4.30
Hybrid 63	433.6	5.31	38.30	1494	36.53	3850	30.50	3.02
Hyper	568.8	6.38	44.91	1598	55.18	4361	31.98	1.82
Idaed 20	348.6	4.52	40.34	1279	47.32	3824	28.94	2.02
Idaed 59	479.0	5.51	52.22	1723	56.79	4738	36.17	3.91
Indian	396.3	5.72	48.84	1681	52.81	4772	34.38	4.08
Lemhi	479.8	5.73	38.14	1424	43.22	3429	29.44	2.07
Lemhi 66	463.8	5.33	42.42	1426	45.68	3412	28.93	3.40
Little Club	487.6	5.26	42.95	1492	43.21	3661	27.41	2.68
Mackey	461.2	5.71	49.92	1452	46.02	4096	37.63	3.15
New Zealand	356.5	5.43	50.02	1398	41.43	3954	32.61	5.84
Onas	384.5	5.44	36.62	1322	40.58	3424	26.31	2.58
Oregon Zimmerman	352.2	5.13	34.28	1415	40.33	4001	31.83	2.51
Pacific Bluestem	359.8	4.23	36.83	1414	44.73	3824	32.11	5.58
Picraw	396.9	4.62	32.09	1332	42.34	3531	27.24	3.21
Rink	388.3	4.94	36.07	1351	37.26	3431	21.79	2.91
Sonora	501.6	4.99	41.28	1436	47.04	4075	29.65	4.97
Surprise	376.8	4.71	31.87	1156	34.96	3080	21.68	5.47
White Federation	419.0	4.63	38.19	1330	45.31	3438	29.32	4.07
White Marquis	481.4	4.57	34.14	1367	47.39	4293	33.19	4.96
Wilber	282.6	5.16	41.66	1445	38.53	3849	25.80	2.61

Table 4 continued.

	Ca	Cu	Fe	Mg	Mn	P	Zn	Se
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	µg/kg
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
Huston	414.9	4.81	39.18	1369	44.05	3875	29.29	5.59
Hybrid 123	461.7	5.07	40.22	1277	34.56	3709	29.39	4.38
Red Fife	370.6	4.81	41.53	1433	41.30	3893	29.47	3.67
Canadian Red	376.1	4.48	44.13	1324	47.72	3518	31.27	5.07
Cadet	338.4	4.86	34.76	1487	43.46	3794	32.29	4.27
Canus	474.0	4.02	37.58	1379	43.85	3838	31.59	5.67
Ceres	500.4	4.54	28.09	1484	53.28	4196	27.93	5.21
Comet	437.7	3.86	40.43	1364	44.08	3682	30.6	5.82
Flomar	433.4	4.12	42.33	1410	45.60	3779	30.65	3.81
Henry	386.4	5.09	36.80	1394	39.71	3908	33.96	5.17
Hope	377.8	3.99	33.82	1378	46.01	3600	30.85	2.68
Komar	483.1	4.11	32.34	1427	41.98	3978	28.86	2.03
Lagoda	407.0	4.19	40.32	1355	39.58	3857	29.19	4.47
Marquis	408.2	3.79	30.27	1292	35.94	3794	30.37	3.14
Pilot	430.9	3.74	32.61	1435	47.67	3873	31.04	4.19
Preston	441.3	5.08	32.89	1359	41.14	3664	29.47	4.13
Red Bobs	322.3	3.13	31.43	1086	34.99	3235	26.9	2.07
Reliance	396.7	3.28	32.02	1192	34.37	3351	25.16	2.91
Reward	417.0	5.06	38.75	1314	48.17	4062	35.73	5.35
Rival	458.8	5.77	37.92	1557	47.60	4266	38.87	6.79
Ruby	381.4	3.75	37.95	1205	36.72	3449	25.76	5.67
Sea Island	524.0	4.43	33.29	1282	41.35	3643	26.95	5.92
Spinkota	370.8	3.82	47.59	1382	45.87	3707	29.86	6.25
Supreme	378.5	3.57	35.29	1156	39.81	3323	28.86	4.49
Thatcher	418.7	4.12	26.86	1208	38.48	3233	22.8	4.44
Zak	411.0	3.83	41.40	1271	42.96	3086	22.23	6.30
Alpowa	395.6	3.74	32.83	1285	31.81	3297	21.53	4.98
Scarlet	409.6	3.96	36.74	1280	42.32	3276	24.24	6.39
Westbred Express	444.7	4.93	35.28	1328	47.23	3353	22.98	6.92
Wawawai	343.3	4.29	35.96	1346	41.64	3398	24.15	3.93
Wakanz	444.9	4.09	35.50	1222	36.11	3044	20.86	3.94
Penawawa	426.4	3.59	32.15	1263	37.65	3185	22.82	7.11
Durum Std 1	323.0	3.69	38.47	924	15.16	2418	23.02	1.43
Durum Std 2	293.2	4.58	43.87	1140	17.09	2899	24.38	1.22
Durum Std 3	252.2	3.87	36.42	963	14.74	2547	22.01	1.33
Durum Std 4	281.0	3.99	36.95	961	15.20	2461	21.66	1.22
Durum Std 5	271.1	4.14	39.35	1025	15.81	2616	22.50	1.14
Durum Std 6	291.7	4.18	41.09	1077	16.39	2746	23.55	1.25
Mean Standards ± SD	285.4	4.08	39.36	1015	15.73	2614	22.85	1.27

Table 5. Results from the advanced soft white wheat nursery in St. Andrews, WA, 2005. Entries are ranked according to yield. Bu/a = bushels per acre. T.wt = test weight.

St Andrews Organic					
AWY1 Nursery			nursery mean		
Rank	Entry #	Variety	Bu/a	T.wt	
1	4	Stephens	47.8	58.2	A
2	13	J950060-1	46.1	58.5	AB
3	30	J970067-1	45.2	57.1	ABC
4	5	Masami	44.5	59.2	ABCD
5	2	Eltan	44.5	58.0	ABCD
6	27	J970041-5	43.4	57.6	ABCDE
7	31	J970092-3	43.2	58.3	ABCDEF
8	32	J970284-2	42.6	59.4	ABCDEFG
9	33	J970536-1	42.4	60.5	ABCDEFGH
10	28	J970057-3	41.7	56.9	ABCDEFGH
11	23	J960793-4	41.6	58.1	ABCDEFGH
12	26	J961273-1	40.9	58.8	ABCDEFGHI
13	8	WA7971	40.7	58.4	ABCDEFGHI
14	1	Madsen	40.3	58.3	ABCDEFGHI
15	14	J950081-1	40.3	60.3	ABCDEFGHI
16	34	J970611-1	40.1	59.3	ABCDEFGHI
17	3	Finch	40.1	61.1	ABCDEFGHI
18	16	J950409-10-3	38.8	59.7	ABCDEFGHI
19	22	J960793-3	38.7	57.6	ABCDEFGHI
20	25	J960805-4	38.1	59.1	ABCDEFGHIJ
21	19	J00C0013	38.0	59.2	ABCDEFGHIJ
22	15	J950409-10-2	37.3	59.6	ABCDEFGHIJ
23	6	WA7935C	36.2	58.2	BCDEFGHIJ
24	9	WA7972	35.8	58.3	BCDEFGHIJ
25	12	J950052-1	35.6	58.7	BCDEFGHIJ
26	7	WA7970	35.4	59.0	BCDEFGHIJ
27	21	J960793-1	35.1	58.4	BCDEFGHIJ
28	20	J01C0009-11	34.7	59.5	CDEFGHIJ
29	11	WA7974	33.6	58.6	DEFGHIJ
30	24	J960805-2	32.1	59.3	EFGHIJ
31	29	J970057-5	31.9	58.8	FGHIJ
32	18	J950409-10-5	31.4	59.7	GHIJ
33	10	J950289-001	31.3	59.1	HIJ
34	17	J950409-10-4	29.8	59.6	IJ
35	35	J971058-2	27.3	60.9	J
Nursery mean			38.5	58.9	

Table 6. Results from the low rainfall wheat nursery in St. Andrews, WA, 2005. Entries are ranked according to yield.

Bu/a = bushels per acre. T.wt = test weight.

Adv. Low rainfall Organic - St Andrews				nursery mean		
Rank	Entry #	Variety	Pedigree	Bu/a	T.wt	
1	2	Masami-check		42.3	60.0	A
2	9	6K000157-9	Eltan/Estica//Eltan	41.9	57.1	A
3	5	6K000072-2	Estica/Rod//WPB470	41.0	61.1	AB
4	3	Buchanan-check		40.6	58.5	AB
5	21	7K990184-4	Estica/Finley SSD-17	40.5	59.5	AB
6	22	7K990241-1	Estica/Finley SSD-75	39.1	60.7	AB
7	1	Eltan-check		38.3	58.0	AB
8	4	6K000075-7	Estica/Rod//WPB470	37.1	63.0	ABC
9	12	6K000201-1	Buchanan/Estica//Finle	36.2	60.8	ABC
10	23	7K990135-2	WPB470/Eltan	35.7	59.7	ABCD
11	11	6K000157-6	Eltan/Estica//Eltan	33.9	56.5	ABCDE
12	8	6K000197-3	Buchanan/Estica//Finle	33.9	58.9	ABCDE
13	6	6K000078-2	Estica/Rod//WPB470	33.6	60.0	ABCDE
14	18	4K020070-Bulk	Bunyip/Finch	32.3	60.6	ABCDEF
15	7	6K000157-1	Eltan/Estica//Eltan	31.5	55.5	BCDEF
16	24	7K990385-1	WA 7836/WA 7833-1	31.4	59.0	BCDEF
17	10	6K000199-4	Buchanan/Estica//Finle	30.9	59.1	BCDEF
18	13	4K020027-Bulk	Hyper/Eltan	27.6	59.2	CDEFG
19	17	4K020087-Bulk	Idaed 59/Eltan	25.5	59.7	DEFG
20	20	4K020093-Bulk	Big Club 43/Edwin	25.0	58.3	EFG
21	14	4K020001-Bulk	Surprise/Eltan	24.9	57.4	EFG
22	25	7K990027-2	Eltan/WA 7832	24.8	60.0	EFG
23	19	4K020214-Bulk	Hood/Eltan	22.7	56.6	FG
24	16	4K020129-Bulk	Eaton/Lewjain	22.3	59.3	FG
25	15	4K020079-Bulk	Rink/Eltan	20.1	56.7	G
Nursery mean				32.5	59.0	
CV %				22.49	1.67	
LSD @.05				10.30	1.38	

Table 7. Hard spring wheat quality of historical varieties in relationship to modern check variety (Finley). Data from 2004 trial at Pullman. We have made crosses with all the historical varieties showing excellent potential to improve the quality of hard wheat.

Color Scheme	
	Excellent Potential
	Acceptable
	Bad

RANKINGS		
VARIETY	SUM	SCORE
CADET	0.14	0.48
WHITE MARQUIS	-3.68	0.40
WHITE FEDERATION	-4.16	0.34
HARD FEDERATION	-5.06	0.24
REWARD	-5.06	0.24
CANUS	-3.97	0.23
FLOMAR	-6.16	0.22
FINLEY	0.00	0.00
WHITE FIFE	-6.81	-0.17
HARD FEDERATION 31	-4.12	-0.18
CANADIAN RED	-3.60	-0.29
PREMIER	-0.60	-0.55
RELIANCE	-1.48	-0.62
SEA ISLAND	-8.16	-0.63
PILOT	-6.75	-0.64
HOPE	-6.04	-0.67
COMET	-5.06	-0.67
RUBY	-5.07	-0.68
UTAC	-5.21	-0.68
HENRY	-5.48	-0.69
REGENT	-6.63	-0.84
SUPREME	-8.75	-0.84
THATCHER	-8.97	-0.88
MARQUIS	-11.07	-0.93
KOMAR	-6.10	-1.25
CERES	-9.63	-1.30
PRESTON	-11.47	-1.52
RED BOBS	-8.85	-1.58
RIVAL	-8.85	-1.58
SPINKOTA	-15.95	-1.85
HYBRID 63		

Table 8. Soft white winter wheat quality of historical varieties in relationship to modern check variety (Eltan). Data from 2004 trial at Pullman. We have made crosses with both the historical varieties showing excellent potential to improve the quality of hard wheat.

Color Scheme	
	Excellent Potential
	Acceptable
	Bad

Rankings		
VARIETY	SUM	SCORE
HYBRID128	-6.45	0.51
ALICEL	-4.07	0.27
ELTAN	0.00	0.00
TRIPLET	-5.31	-0.05
ODESSA	-6.61	-0.12
RUDDY	-7.13	-0.16
ARCO	-7.31	-0.22
FLORENCE	-7.35	-0.24
HOOD	-10.01	-0.24
HARVEST QUEEN	-3.83	-0.32
ALBIT	-9.29	-0.52
SUN	-8.14	-0.67
ELMAR	-11.88	-0.68
WILHEMINIA	-3.37	-0.72
REQUA	-7.90	-0.76
GOLDEN CROSS	-6.62	-0.79
THORNE	-9.25	-0.79
OMAR	-10.56	-0.87
SATISFACTION	-7.57	-0.87
GOLDCOIN	-9.04	-0.91
GOLDEN	-5.88	-0.93
DRUCHAMP	-8.21	-0.98
RED RUSSIAN	-11.82	-1.00
PRIDE OF GENESEE	-7.27	-1.03
GENESEE GIANT	-9.71	-1.03
TRIUMPH	-6.55	-1.15
POWERCLUB	-7.43	-1.23
LOFTHOUSE	-10.66	-1.24
REX	-9.87	-1.33
EATON	-10.89	-1.38
GOLD DROP	-9.46	-1.52
CHEYENNE	-6.24	-1.63
MEDITERRANEAN	-5.69	-1.67
BURT	-5.65	-1.84
REXM2	-13.57	-2.08
ALBA	-14.55	-2.09

Table 9. Soft white spring wheat quality of historical varieties in relationship to modern check variety (Eltan). Data from 2004 trial at Pullman. We have made crosses with both the historical varieties showing excellent potential to improve the quality of hard wheat.

Color Scheme	
	Excellent Potential
	Acceptable
	Bad

RANKINGS		
VARIETY	SUM	SCORE
DALE	-5.82	0.25
PURPLESTRAW	-4.93	0.12
ELTAN	0.00	0.00
EARLY BAART	-2.26	-0.10
BIG CLUB	-3.41	-0.22
BLUECHAFF CLUB	-5.81	-0.44
GYPSUM	-6.63	-0.53
INDIAN	-1.58	-0.55
PACIFIC BLUESTEM 37	-7.69	-0.57
DICKLOW	-5.02	-0.66
FEDERATION 67	-2.16	-0.69
HYBRID 123	-6.52	-0.75
BIG CLUB 43	-9.00	-0.83
TOUSE	-4.73	-0.84
MACKEY	-5.31	-0.85
SURPRISE	-10.50	-0.87
ALLEN	-0.35	-0.87
RED FIFE	-7.52	-0.90
LEMHI 66	-8.66	-0.92
PACIFIC BLUESTEM	-7.14	-0.98
BEAVER	-3.41	-0.99
WILBUR	-8.16	-1.05
WORLD SEEDS I	-8.21	-1.08
ROMONA	-2.40	-1.10
OREGON ZIMMERMAN	-8.22	-1.10
SCHLANSTEDT	-6.90	-1.18
RINK	-9.00	-1.21
LITTLE CLUB	-8.24	-1.21
HUSTON	-4.72	-1.27
FEDERATION	-8.26	-1.33
BUNYIP	-5.41	-1.35
HYPRID 143	-5.80	-1.36
NEW ZEALAND	-8.39	-1.37
IDEAD 59	-3.92	-1.37

Table 10. This table shows the results from a dwarf bunt trial performed in collaboration with Dr. Blair Goates, USDA-ARS, Aberdeen, Idaho, 2005. Percent bunt is the average percent of head row with bunt on the seedheads as determined by visual inspection.

Variety Name	Variety Number	Rep I		Rep II	
		Row	% Bunt	Row	% Bunt
AWY 1	Madsen	592	25	1272	70
AWY 2	Eltan	593	8	1273	35
AWY 3	Finch	594	8	1274	30
AWY 4	Stephens	595	60	1275	80
AWY 5	Masami	596	25	1276	60
AWY 6	WA7935C	597	50	1277	30
AWY 7	WA7970	598	70	1278	90
AWY 8	WA7971	599	90	1279	90
AWY 9	WA7972	600	25	1280	35
Cheyenne		601	90	1281	95
AWY 10	J950289-001	602	35	1282	30
AWY 11	WA7974	603	95	1283	90
AWY 12	J950052-1	604	95	1284	80
AWY 13	J950060-1	605	95	1285	80
AWY 14	J950081-1	606	50	1286	70
AWY 15	J950409-10-2	607	75	1287	80
AWY 16	J950409-10-3	608	65	1288	80
AWY 17	J950409-10-4	609	70	1289	80
AWY 18	J950409-10-5	610	90	1290	90
AWY 19	J00C0013	611	70	1291	80
AWY 20	J01C0009-11	612	70	1292	90
AWY 21	J960793-1	613	75	1293	65
AWY 22	J960793-3	614	65	1294	75
AWY 23	J960793-4	615	75	1295	50
AWY 24	J960805-2	616	5	1296	4
AWY 25	J960805-4	617	5	1297	2F
AWY 26	J961273-1	618	35	1298	35
AWY 27	J970041-5	619	60	1299	90
AWY 28	J970057-3	620	50	1300	30
Cheyenne		621	95	1301	95
AWY 29	J970057-5	622	6	1302	18
AWY 30	J970067-1	623	40	1303	20
AWY 31	J970092-3	624	100	1304	40
AWY 32	J970284-2	625	75	1305	80
AWY 33	J970536-1	626	70	1306	90
AWY 34	J970611-1	627	2	1307	0
AWY 35	J971058-2	628	80	1308	80

Table 11. Long Coleoptile/Emergence Nursery (F₂, F₃, F₄ and parents) with average emergence score. Planted September 8, 2004. Emergence scale of 1-9 (9=perfect stand). Emergence was recorded 2, 4, and 6 weeks after planting. Data represent average values.

<u>Variety/Pedigree</u>	<u>Emergence</u>	<u>Variety/Pedigree</u>	<u>Emergence</u>
Hope/Buchanan	8.0	Rink/Eltan	4.3
Hope/Buchanan	7.0	Surprise/Eltan	4.2
Lemhi	6.8	Thorne	4.0
Hyper	6.8	Delmar	4.0
Idaed 59	6.5	Lemhi/Eltan	4.0
Bunyip/Finch//Hyper/Eltan	6.4	Hyper/Eltan	4.0
Fultz	6.3	Hyper/Eltan//Finch	4.0
Dual	6.0	Currawa/Madsen//Rink/Eltan	4.0
Bunyip/Finch//Hyper/Eltan	5.8	Golden Cross/Finley	3.8
Pride of Genesse/Buchanan	5.8	Edwin	3.8
Buchanan	5.5	Flomar/Golden Spike	3.8
Moro	5.5	Currawa	3.7
Big Club 43	5.5	Pride of Genesse	3.7
Pride of Genesse/Buchanan	5.5	Hyper/Eltan//Finch	3.6
Elmar/Edwin	5.4	Rink/Eltan	3.5
Dicklow/Lewjain	5.4	Flomar/Gary	3.3
Big Club 43/Edwin	5.4	Canus/Finley	3.3
Big Club 43/Edwin	5.4	Surprise/Eltan//Finch	3.2
Bunyip	5.3	Finley	3.0
Dicklow	5.3	Flomar	3.0
Eaton/Lewjain	5.2	Dual/Finley	3.0
Hyper/Madsen//Lemhi/Eltan	5.0	Delmar/Finley	3.0
Dicklow/Lewjain	4.8	Flomar/Gary	3.0
Surprise/Eltan	4.8	Lemhi/Eltan	3.0
Hyper/Madsen//Lemhi/Eltan	4.8	Idaed 59/Eltan//Finch	2.8
Elmar/Edwin	4.6	Idaed 59/Eltan//Finch	2.8
Eaton/Lewjain	4.6	Thorne/Finley	2.6
Delmar/Finley	4.6	Golden Cross/Finley	2.6
Canus	4.5	Eltan	2.5
Surprise	4.5	Golden Cross	2.5
Fultz/Finley	4.5	Thorne/Finley	2.2
Flomar/Golden Spike	4.5	Gary	2.0
Surprise/Eltan//Finch	4.4	Finch	1.8
Elmar	4.3	Eaton	1.8
Rink	4.3	Madsen	1.5
Fultz/Finley	4.3	Hope	1.5
Dual/Finley	4.3	Lewjain	1.3
Canus/Finley	4.3	Golden Spike	1.0
Hyper/Eltan	4.3		