Progress Report: Organic Cropping Research for the Northwest

Title: Evaluating and developing varieties for organic systems

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Keywords: Plant breeding, organic, wheat

Abstract:

Our most important finding from the granting period is that there is little to no correlation between the ranking of varieties for yield between conventional and organic systems. This is important because it suggests that yield in organic farming systems are not currently optimized. The development of organic crop breeding programs appears to be vital to the continued improvement and competitiveness of organic farming as a whole. We will continue this experiment next year to confirm these trends and to obtain a more statistically powerful demonstration of the important contribution that plant breeding can make to optimizing yield and other traits important to organic agriculture.

In field evaluations of historical varieties, we identified varieties highly capable of suppressing weeds, we identified breeding lines suited to out-competing weeds, we identified varieties that yield well under low-input conditions, and we identified varieties that yield well under different cultivation systems. In evaluation of stripe rust resistance for the current race, we found 15 varieties of historical spring wheat and 18 varieties of historical winter wheat with complete resistance to local pathogen races. We also found over 20 varieties in each market class with promising signs of durable or horizontal resistance.

In our breeding program, we worked closely with four 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.

Objectives:

Our *specific* objectives for the 2004 year included:

1. Answer the question, “Are the highest yielding varieties in conventional systems also the highest yielding varieties in organic systems?”

2. Evaluate historical wheat varieties for their ability to suppress weeds, their ability to yield well in organic fields and their ability to yield well under different tillage systems.
3. Evaluate historical varieties and advanced breeding lines for quality traits.
4. Evaluate historical varieties and advanced breeding lines for resistance to stripe rust.
5. Expand our farmer participatory breeding project to incorporate more farmers in the varietal development process on their own farms.
6. Evaluate advanced breeding lines and modern cultivars for yield and test weight under organic production conditions.
7. Incorporate the traits for long coleoptile and emergence from deep planting in our modern wheat varieties.

Proceedures:

Objective 1: We grew a nursery consisting of 35 soft white winter breeding lines and modern varieties (genotypes) in two locations under two types of agronomic systems: organic and conventional. This was a fully factorial 2 X 2 X 35 split-plot design experiment, with the genotypes replicated four times in each nursery. Each genotype was evaluated for yield and test weight. Results from this experiment can be found in Figures 1-4 in the appendix.

Objective 2: We grew 71 spring wheat varieties (63 historical and 8 modern) in a randomized, replicated split-plot field trial. These plots were treated with an organic fertilizer at approximately 40#/acre. Yield was taken for each variety in two types of cultivation systems (no-cultivation and rotary harrow used four times). In addition, weed biomass (g/plot of dry weight) was taken for each variety at the end of the season before harvest. This gave us an indication of weed suppression ability of the varieties. Results from the first year of this experiment can be found in Figures 5-6 in the appendix.

Objective 3: We 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. Overall results from the baking and milling of historical varieties can be found in Tables 1-3 in the appendix.

Objective 4: We evaluated all of our varieties and breeding lines in the organic nurseries for resistance to stripe rust. Rust resistance was scored as a percentage of the plant leaf area infected in a plot, from visual inspection. Further data is needed to report on the outcome of this objective. We will continue this research in 2005-2006.

Objective 5: At Spillman Farm in Pullman, we grew out unselected, early generation populations from crosses designed specifically for our cooperating farmers. These populations were harvested in bulk and a subsample replanted on the fields of four farmer cooperators. These populations will now be pressured by both natural selection and farmer assisted selection and develop into genetically diverse landraces highly adapted to the farming systems and agroenvironments of the farmers. Our paper titled *Breeding for organic and low-input farming systems: An evolutionary participatory breeding method for inbred cereal grains* was accepted for publication by the journal Renewable Agriculture and Food Systems on July 1st 2004 and is currently in press. This paper outlines the reasoning and methods of evolutionary participatory cereal breeding.

Objective 6: Our advanced breeding lines and modern checks were evaluated in three locations 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 will be advanced in each location for further evaluation next year. These lines are the most likely candidates for varietal release specifically for organic farms in the near future. Results in Tables 4-5 in appendix.

Objective 7: To determine the gene action, transmission and response to selection of the gene(s) responsible for coleoptile length in wheat, we are conducting a diallel study of 7 winter wheat varieties with a range of coleoptile lengths. This year we obtained results from the parents and F_2 populations and replanted subsamples of these populations to test for response to selection. In addition, we are conducting field trials at the Dryland Research Station in Lind with populations derived from crosses of modern varieties to historical long coleoptile cultivars. These populations are subjected to pressures of deep planting and soil crusting, and natural selection determines the best emerging plants and these plants make up the population replanted the next year. Results from these two experiments can be found in Tables 6-7 in the appendix.

Progress Towards Objectives:

Many of our experiments are in the first year of multiyear trials. Our most important preliminary conclusion was that the highest yielding varieties in conventional systems are not the highest yielding varieties in organic systems. This tells 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 occur within these organic systems. Additionally, we found significant variation in weed suppression ability of the 71 cultivars tested. We found particular cultivars that are better adapted to weed competition than to repeated harrowing and vice versa. We identified historical and modern spring and winter wheat cultivars that yield well in low-input and organic conditions.

We have striven to work with farmers in the development of varieties suited to their agroecosystem. This is a long-term objective, however the first steps in this project are in place. 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 two years in the form of significant soil crusting.

Outputs

Publications:
Lyon, S. et al., 2004. Developing winter wheat varieties specifically for emergence from deep planting, Wheat Life, March 2004
Murphy, K, et al., in press. Breeding for organic and low-input farming systems: An evolutionary participatory breeding method for inbred cereal grains. *Renewable Agriculture and Food Systems.*

Invited talks:
K. Murphy, June 2004. Organic Wheat Breeding, WSU Organic Field Day, Pullman, WA
K. Murphy, January 2004. Organic Seed Breeding and Production Conference, Organic Seed Alliance, Corvallis, OR
S. Jones, January 2004. Breeding in the public domain for a sustainable future. Organic wheat breeding was highlighted, EcoFarm Conference, Monterey, CA

Presentations and Abstracts:

Murphy, K. et al., November 2004. Poster presentations (2): Organic Plant Breeding I and II. WSU/OSU symposium entitled: Getting the Bugs to Work for You: Biological Control in Organic Agriculture, Portland, OR.
S.Jones, June-August 2004. Organic wheat breeding and farmer participatory plant breeding, various field days throughout WA state.

Impact
Breeding is a long-term process and any impact is yet to be determined.

Institution/State: Dept. of Crop and Soil Sciences, Washington State University, WA

Funding Amount(s): $21,317

Organic Research Land:
Spillman Agronomy Farm, Pullman, WA: 11 acres certified organic
Lind Dryland Research Farm, Lind, WA: 4 acres to begin transition to certified organic this winter
On-farm: Our breeding plots on the fields of our certified organic cooperating farms total approximately 1 acre.

Farmer Cooperators (4):
Joe and Sara DeLong, St. John, WA
Keith and Owen Jorgensen, St. Andrews, WA
Jim Moore and Lexi Roach, Kahlotus, WA
Randy Suess, Colfax, WA

Appendix

Figure 1. This figure shows the difference between yield rank for each cultivar (35 total) in both organic and conventional systems in **Pullman**, WA. The x-axis shows side-by-side comparisons in rank for yield (y-axis). Cultivars are ranked by yield from 1 to 35, with 1 being the highest yield and 35 being the lowest. This demonstrates the importance of breeding in an organic system, as the highest yielding cultivars in a conventional are not the highest yielding cultivars in an organic system. If we only kept the top 10 ranking cultivars in a conventional system, we would be discarding many of the top yielding cultivars in the organic system.

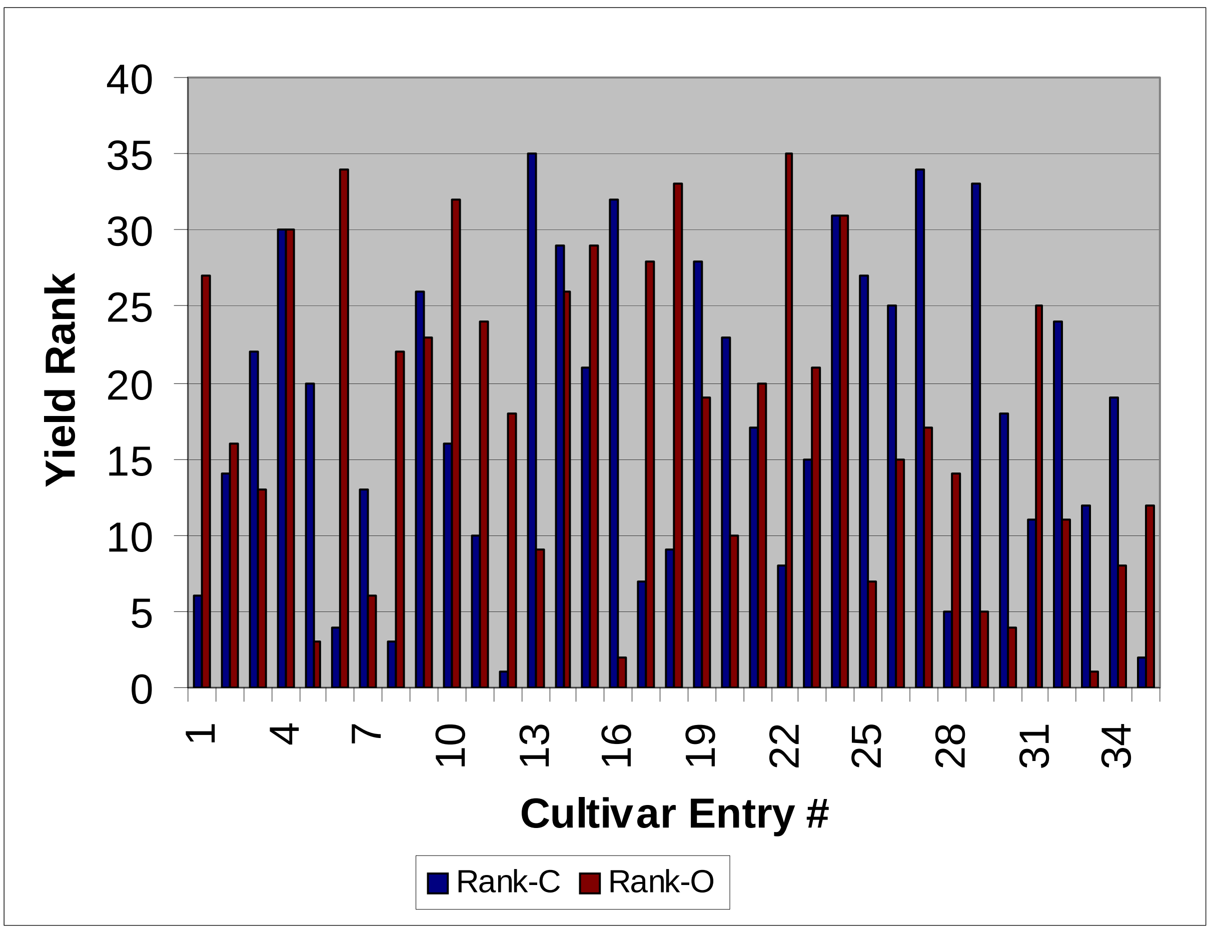

Figure 2. This figure shows the difference between yield rank for each cultivar (35 total) in both organic and conventional systems in **Douglas County**, WA. The x-axis shows side-by-side comparisons in rank for yield (y-axis). Cultivars are ranked by yield from 1 to 35, with 1 being the highest yield and 35 being the lowest. Again, this demonstrates the importance of breeding in an organic system, as the highest yielding cultivars in a conventional are not the highest yielding cultivars in an organic system. If we only kept the top 10 ranking cultivars in a conventional system, we would be discarding many of the top yielding cultivars in the organic system.

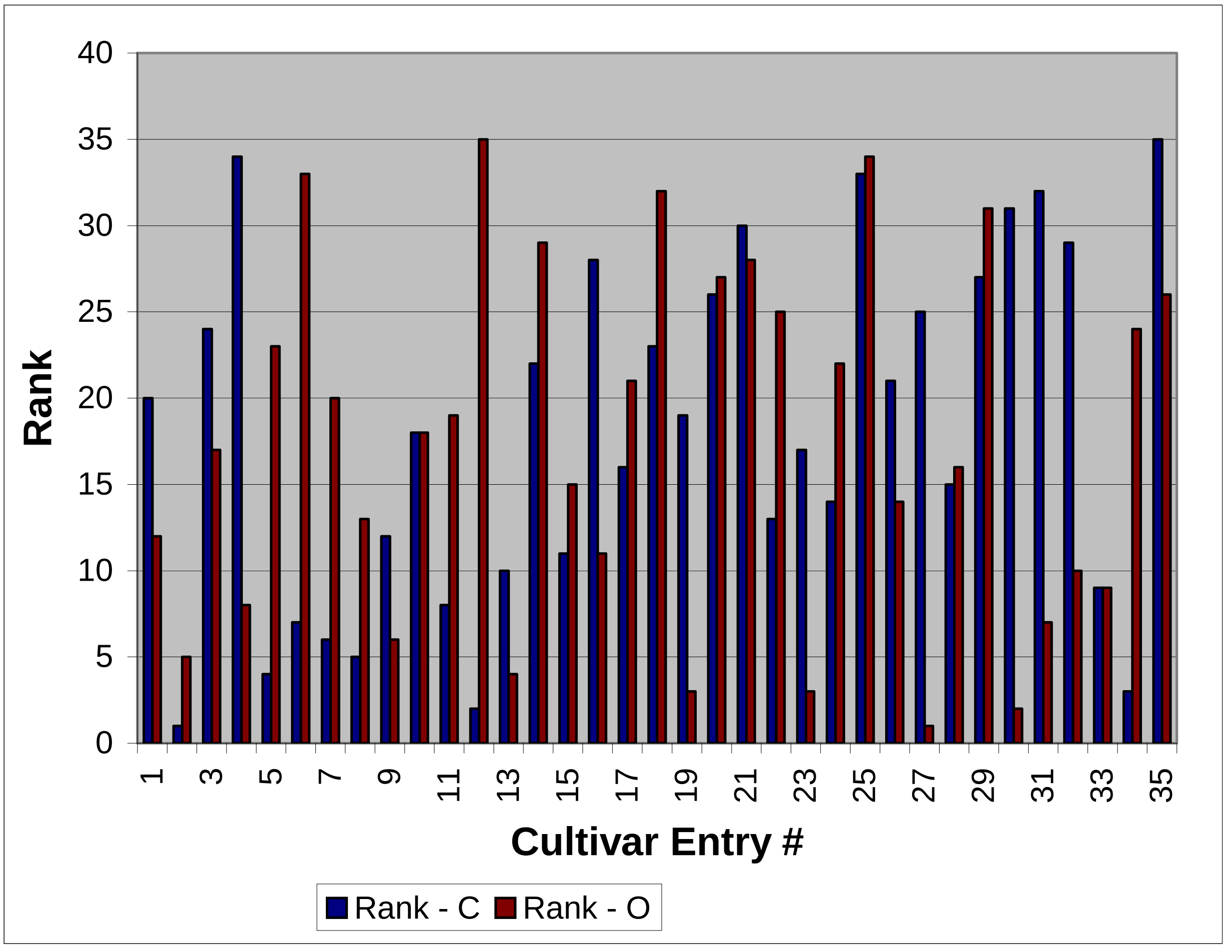

Figure 3. Regression plot of wheat genotype ranking between two systems, organic and conventional, for 35 genotypes in **Pullman**, WA. This regression plot quantifies the relationship between the highest yielding cultivars in conventional systems and the highest yielding cultivars in organic systems. This graph shows that while there is a relationship between rank in cultivars for yield between two systems, it is too small to reliably select for yield in conventional systems and expect yield in organic systems to be optimized.

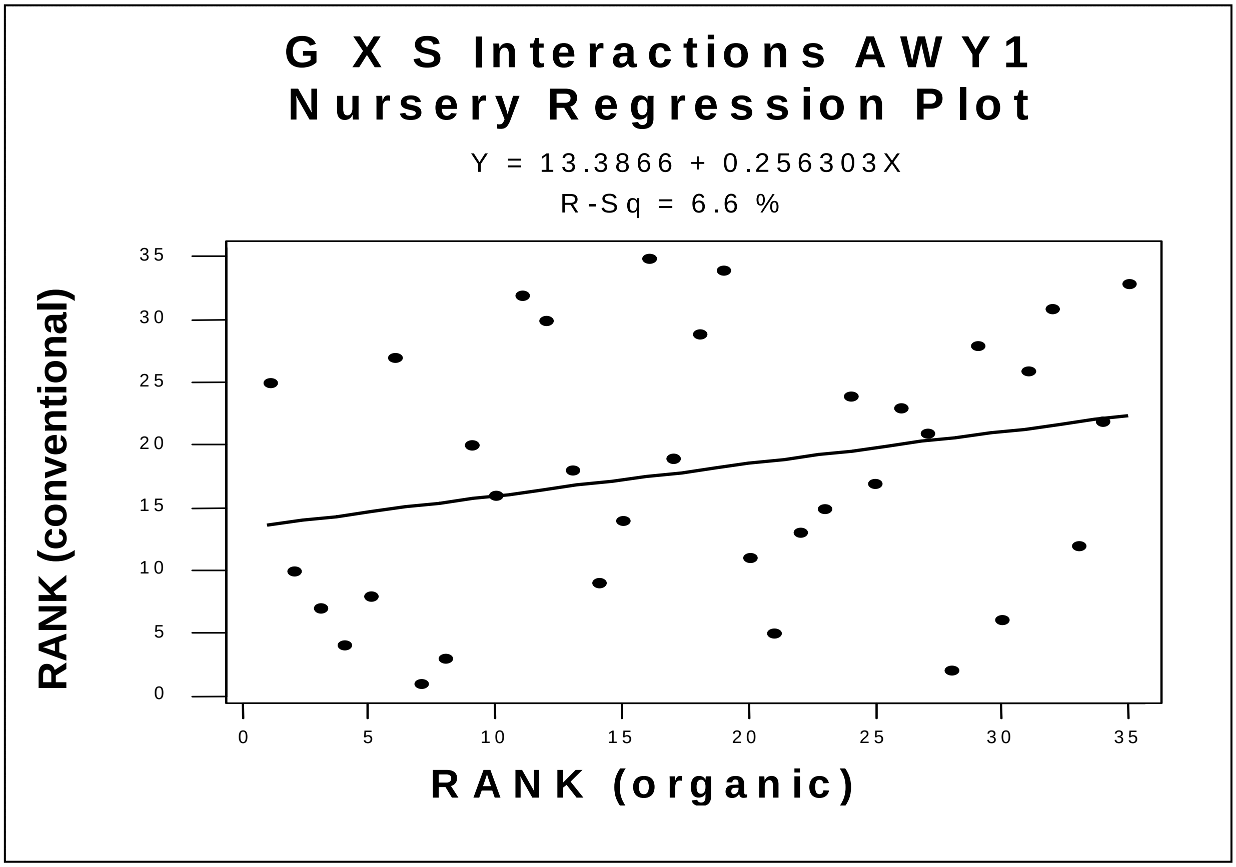

Figure 4. Regression plot of wheat genotype ranking between two systems, organic and conventional, for 35 genotypes in **Douglas County**, WA. This regression plot quantifies the relationship between the highest yielding cultivars in conventional systems and the highest yielding cultivars in organic systems. This graph shows that **no relationship** between rank in cultivars for yield between two systems, thus suggesting that selection for yield in conventional systems will not increase yield in organic systems.

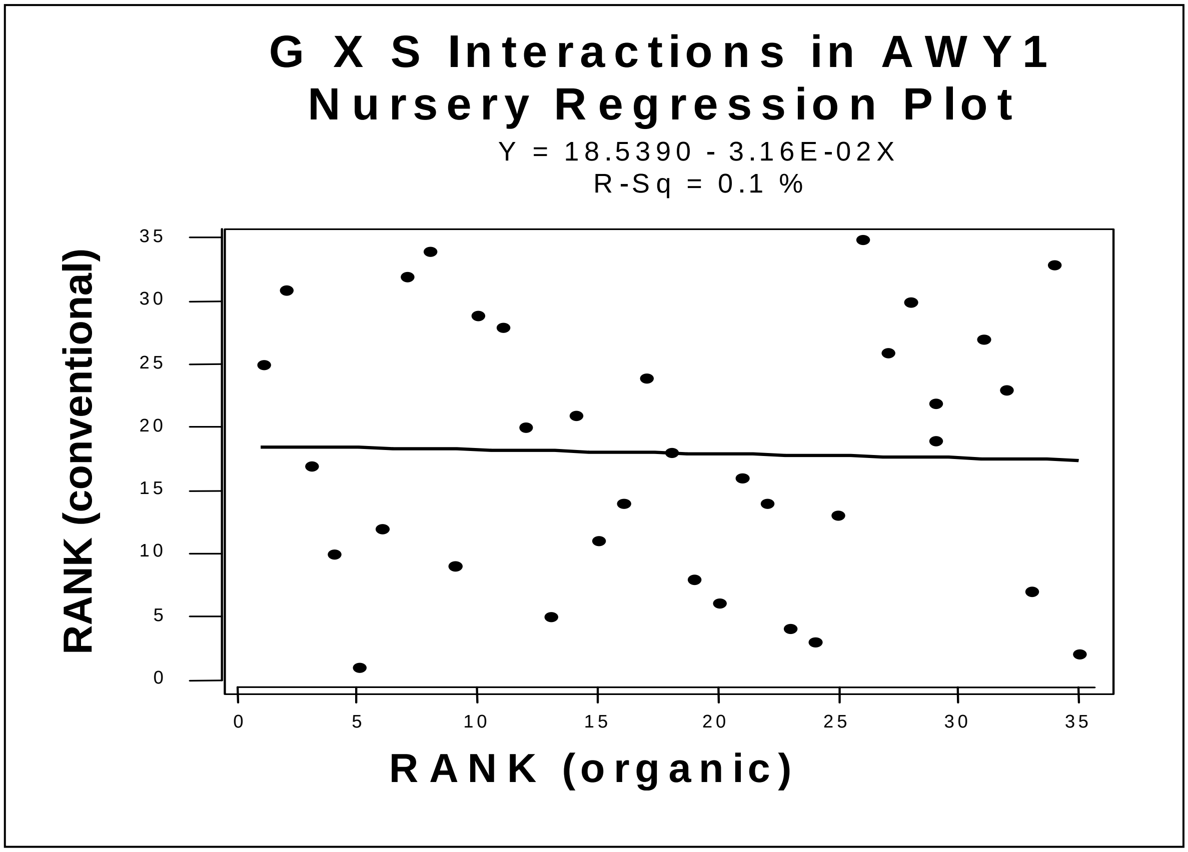

Figure 5. Genotypic weed suppression variability, measured as mean weed biomass/plot (g), of 63 historical spring wheat varieties and 8 modern spring wheat varieties (red lines) in Pullman, WA in 2004. This figure shows significant variation in weed suppression ability of different cultivars. Part of this competition study was conducted on the DeLong farm in an extremely weedy field (see Figure 6). This is an important trait we hope to incorporate into all cultivars bred for organic wheat farmers.

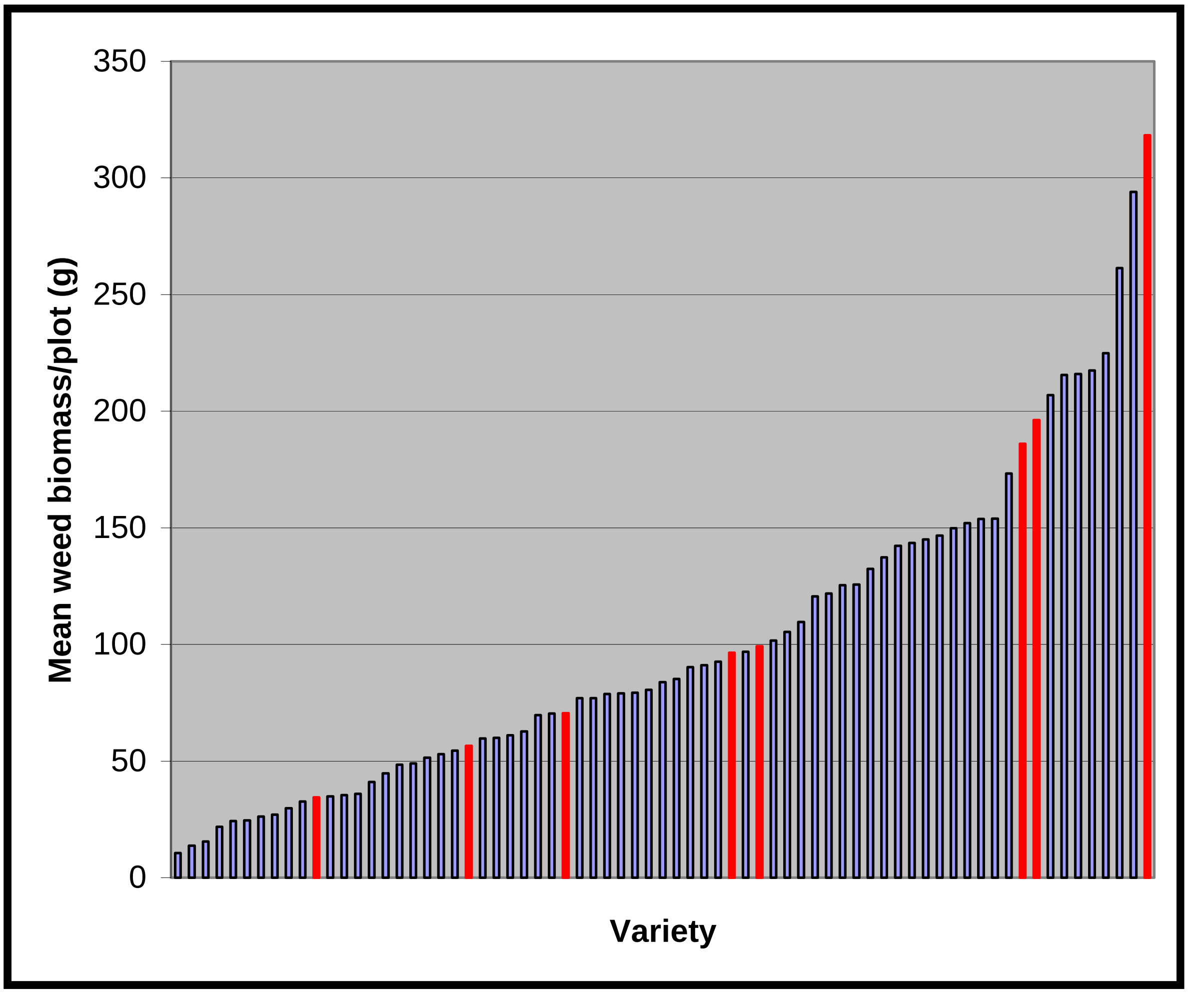

Figure 6. This graph shows the variation in yield (y-axis, grams per plot) of 71 historical spring wheat varieties in Pullman under two types of tillage systems. The blue dots

represent the yield under a minimum tillage cultivation practice with a rotary harrow used four times after planting. The
red dots represent a no-till system. Generally, tillage reduced yield, however a few cultivars are well adapted to tillage cultivation for weeds and yielded significantly higher under a tillage system. In addition, a few cultivars appear to be particularly well adapted to a no-till system.

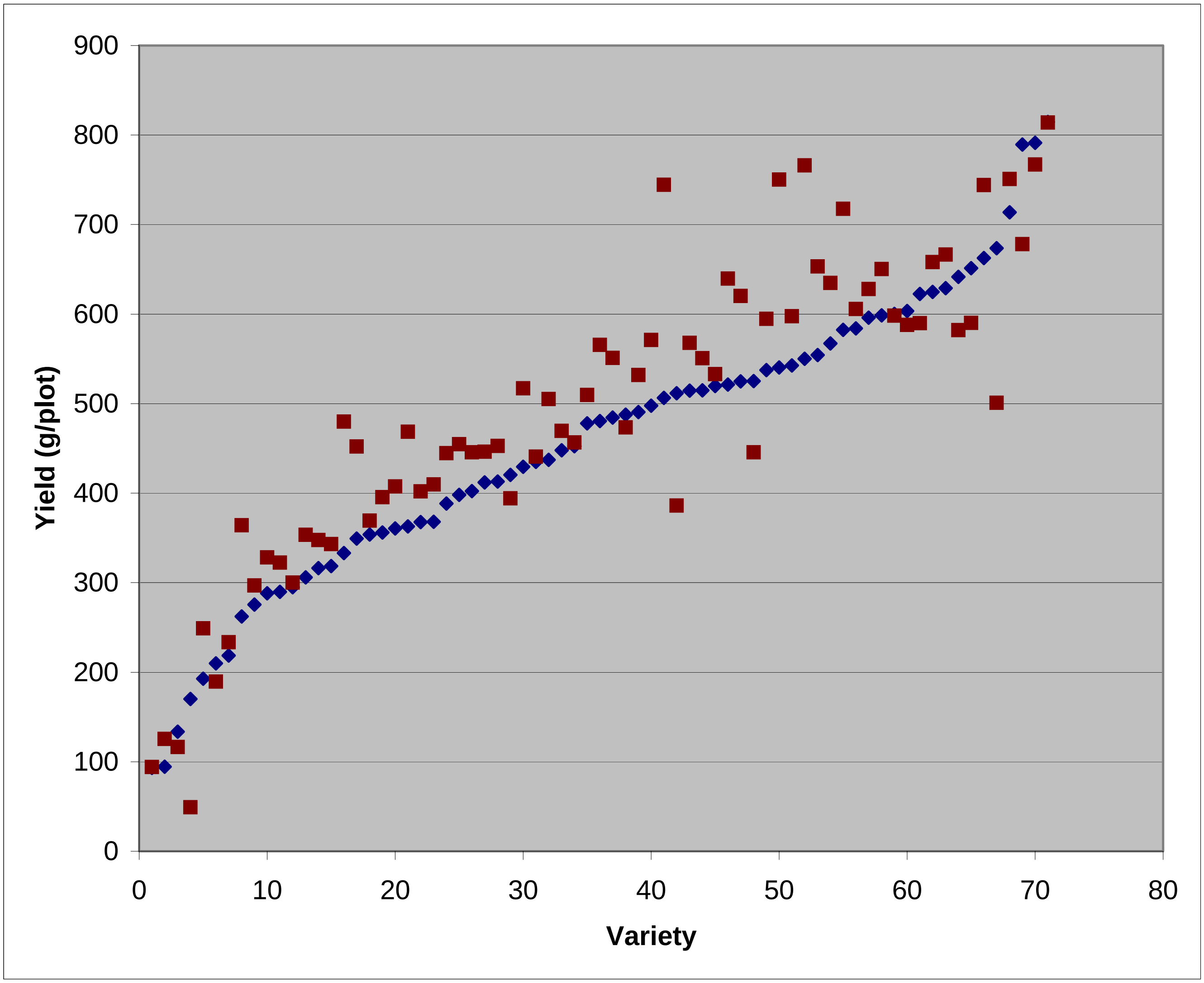

Table 1. Hard spring wheat quality of historical varieties in relationship to modern check variety (Finley). We have made crosses with all the historical varieties showing excellent potential to improve the quality of hard wheat.

Color Scheme	
(green)	Excellent Potential
(white)	Acceptable
(red)	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
HYPRID 63		

Table 2. Soft white winter wheat quality of historical varieties in relationship to modern check variety (Eltan). We have made crosses with both the historical varieties showing excellent potential to improve the quality of hard wheat.

Color Scheme

Green	**Excellent Potential**
White	**Acceptable**
Red	**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 3. Soft white spring wheat quality of historical varieties in relationship to modern check variety (Eltan). We have made crosses with both the historical varieties showing excellent potential to improve the quality of hard wheat.

Color Scheme	
Green	Excellent Potential
White	Acceptable
Red	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 4. Yield and test weight results from our organic nursery in Pullman, WA. Varieties are ranked according to yield, and lines 1 and 2-17 show promise for yielding well under organic conditions.

	KF6 Pullman				
Rank	**Entry**	**Variety**	**Bu/a**	**T.wt**	**Yield stat**
1	7	6K990023-5	62.15	58.55	A
2	3	Buchanan - check	58.31	59.70	AB
3	11	6K990165-1	55.16	59.25	AB
4	33	6K990234-2	52.76	57.00	ABC
5	12	6K990025-1	52.59	60.60	ABC
6	20	6K990158-3	51.14	57.35	ABC
7	16	6K990139-2	50.08	57.25	ABC
8	29	6K990220-1	49.65	59.75	ABC
9	22	6K990191-3	48.59	59.45	ABC
10	6	6K990015-3	48.36	58.40	ABC
11	36	6K990333-1	47.36	58.60	ABC
12	28	6K990211-1	47.12	60.05	ABC
13	38	6K990386-1	46.49	60.40	ABC
14	19	6K990158-1	46.43	57.10	ABC
15	10	6K990113-1	45.65	58.40	ABC
16	14	6K990135-3	45.08	60.55	ABC
17	24	6K990197-1	44.97	58.35	ABC
18	2	Finley - check	44.77	62.00	ABC
19	1	Eltan - check	44.45	59.35	ABC
20	4	Estica - check	43.76	53.95	ABC
21	27	6K990206-1	43.14	59.20	ABC
22	13	6K990135-2	42.84	59.85	ABC
23	15	6K990135-5	42.80	62.20	ABC
24	5	Rod - check	42.47	57.50	ABC
25	23	6K990194-1	42.40	58.95	ABC
26	17	6K990153-1	42.32	58.25	ABC
27	8	6K990026-1	41.85	58.75	ABC
28	34	6K990234-3	41.46	57.90	ABC
29	31	6K990221-2	40.40	57.35	ABC
30	25	6K990198-4	39.97	57.60	ABC
31	37	6K990384-2	39.56	56.90	ABC
32	26	6K990203-1	38.93	57.50	ABC
33	30	6K990221-1	38.63	58.70	ABC
34	18	6K990153-3	37.09	58.35	BC
35	32	6K990225-1	36.96	57.80	BC
36	9	6K990079-1	36.48	57.45	BC
37	39	6K990027-2	35.88	59.85	BC
38	40	6K990385-1	35.78	59.95	BC
39	21	6K990181-2	35.39	56.70	BC
40	35	6K990282-2	30.41	58.05	C
	Nursery mean		**44.24**	**58.62**	
	CV %		39.73	1.32	
	LSD @.05		24.61	1.09	

Table 5. Yield and test weight results from our organic nursery in Douglas County, WA. Varieties are ranked according to yield, and lines 2-5 and 7-9 show promise for yielding well under organic conditions.

	WA Nursery				
Rank	**Entry**	**Variety**	**Bu/a**	**T.wt**	**Yield stat**
1	3	Buchanan	50.84	62.20	A
2	22	6K990184-4	48.31	59.90	AB
3	40	6K990385-1	47.30	60.55	ABC
4	34	6K990156-5	46.05	58.30	ABCD
5	29	6K990135-2	45.61	61.40	ABCDE
6	2	Finley	45.60	63.35	ABCDE
7	11	6K990340-1	45.08	59.60	ABCDEF
8	16	6K990241-1	44.60	60.00	ABCDEF
9	39	6K990143-2	44.02	60.60	ABCDEFG
10	1	Eltan	43.97	59.75	ABCDEFG
11	33	6K990157-1	43.93	58.00	ABCDEFG
12	14	6K990312-1	43.41	59.50	ABCDEFGH
13	36	6K990025-1	43.11	61.50	ABCDEFGH
14	37	6K990027-2	42.89	60.05	ABCDEFGHI
15	21	6K990191-4	42.20	58.35	BCDEFGHI
16	35	6K990026-1	41.61	60.00	BCDEFGHI
17	5	Rod	41.37	58.85	BCDEFGHI
18	30	6K990135-5	40.93	62.25	BCDEFGHIJ
19	20	6K990196-1	40.70	57.60	BCDEFGHIJK
20	17	6K990224-1	40.55	60.40	BCDEFGHIJKL
21	31	6K990165-1	40.47	61.35	BCDEFGHIJKL
22	38	6K990027-1	40.23	60.90	BCDEFGHIJKL
23	13	6K990242-1	39.65	59.60	CDEFGHIJKL
24	32	6K990370-1	38.39	60.30	DEFGHIJKLM
25	15	6K990282-1	37.70	59.65	EFGHIJKLM
26	28	6K990135-1	37.36	61.10	FGHIJKLM
27	19	6K990197-1	35.86	58.15	GHIJKLMN
28	10	6K990165-1	35.24	60.40	HIJKLMN
29	8	6K990164-2	34.73	57.30	IJKLMNO
30	25	6K990128-3	33.05	60.90	JKLMNO
31	12	6k990341-1	32.92	60.40	JKLMNO
32	24	6K990067-4	32.67	58.35	KLMNO
33	26	6K990128-1	32.65	62.00	KLMNO
34	27	6K990135-3	32.44	60.80	LMNO
35	18	6K990182-1	31.34	58.00	MNOP
36	4	Estica	31.22	55.20	MNOP
37	6	6K990401-2	30.39	57.20	MNOP
38	23	6K990067-1	28.68	59.70	NOP
39	7	6K990390-1	26.93	58.35	OP
40	9	6K990393-1	24.08	57.90	P
	Nursery mean		**38.95**	**59.74**	
	CV %		15.06	1.27	
	LSD @.05		8.21	1.06	

Table 6. Long Coleoptile/Emergence Nursery (F_2, F_3, F_4 and parents) with average emergence score. Planted September 8, 2004. Emergence scale of 1-9 (9=perfect stand). We have had the incredible 'good fortune' to have rain showers that caused severe soil crusting on our emergence studies for 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" (see Figure 8). But as the data above shows, 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.

Variety/Pedigree	Emergence	Variety/Pedigree	Emergence
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

Table 6 continued on the next page.

Variety/Pedigree	Emergence	Variety/Pedigree	Emergence
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		

Table 7. Diallel study for long coleoptile transmission and response to selection: F_2 coleoptile length (10 days after planting). This study will help us determine the best way to incorporate the long coleoptile trait, which is highly correlated to emergence from deep plantings, into modern wheat varieties.

Cross	Mean Coleoptile length (mm)	Standard deviation
Madsen	65.8	24.1
Finley	82.5	96.2
Moro	99.4	254.1
Rod	64.0	19.0
Finch	74.4	24.9
Eltan	68.6	91.1
Genesse Giant	101.2	239.0
Pride of Genesse	87.0	143.2
Golden Cross	102.8	381.1
Athena	92.0	272.3
White Odessa	93.2	123.1
Eltan/Genesse Giant	81.1	215.8
Eltan/Pride of Genesse	80.3	125.2
Eltan/Golden Cross	80.9	262.8
Eltan/Athena	78.9	239.8
Eltan/PI 178383	101.2	309.2
Eltan/White Odessa	78.9	133.6
Genesse Giant/Pride of Genesse	78.8	158.9
Genesse Giant/Golden Cross	80.5	248.4
Genesse Giant/Athena	78.3	336.1
PI 178383/Genesse Giant	97.9	585.9
White Odessa/Genesse Giant-	87.5	426.3
Pride of Genesse/Golden Cross	91.1	352.0
Pride of Genesse/Athena	83.7	199.6
PI 178383/Pride of Genesse	108.6	530.9
White Odessa/Pride of Genesse	89.9	303.5
Athena/Golden Cross	97.9	260.7
Golden Cross/PI 178383	96.1	394.3
White Odessa/Golden Cross	85.6	230.1
Athena/PI 178383	92.3	677.6