# WEB WARE FOR CULTIVAR GRAIN YIELD EVALUATION AND SELECTION

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## Abstract

The variable weather conditions and climatic zones in western Canada often lead to differences in regional adaptation of cultivars that must be identified so that cropping risks can be reduced and returns maximized. Regional testing programs have been developed to provide a database for the determination of average grain yields for target areas, but in recent years the number of new cultivar releases has increased dramatically and the available resources for regional testing has been reduced. Attempts to deal with these problems have lead to web based systems that allow visitors to make head-to-head comparisons among cultivars of interest. However, the limitations associated with the comparison of means persist in these systems and considerable information of importance remains buried in the data files. This paper describes an interactive web-based model for head-to-head cultivar grain yield comparisons that calculates relative yields based on the growing season environmental potential at any prospective location in western Canada. By adapting and combining the databases from cooperative and provincial testing programs this decision-making tool also offers the opportunity to make plant breeding programs more effective while reducing the need for extensive post-registration regional testing.

## Background and Operation

An ability to identify differences in cultivar performance is important at all steps in crop production and marketing systems so that the industry can maximize returns and reduce cropping risks. Traditionally this need has been met by regional testing programs that provide a database for the determination of average cultivar grain yields for target areas (Table 1). In recent years the number of cultivars in testing programs has increased dramatically while public resources for regional testing has been significantly reduced with the result that the present advisory system is in danger of being seriously compromised or lost in Saskatchewan. This paper describes an interactive system for head-to-head cultivar grain yield comparisons that reduces the need for extensive post-registration regional testing by accessing data from both the western Canadian cooperative cultivar registration system and provincial regional trials. This data is then used to determine relative cultivar yields based on the growing season environmental potential. The following information is provided to give the user an understanding of the input requirements and the practical applications of this web based decision-making tool for cultivar selection (http://www.usask.ca/agriculture/plantsci/winter_cereals/linear/select.htm).

The database employed by the cultivar selector is the same as that used by the Provincial Advisory Councils on Grain Crops in Alberta, Saskatchewan and Manitoba to determine the relative winter wheat cultivar performance reported in provincial Variety of Grain Crops bulletins. It includes cultivar grain yields from 189 winter wheat trials grown in western Canada between 1988 and 2002. This provides a total of 1158 data points that have been loaded into two files. One file includes the data from all trials grown outside of the primary rust hazard area in southern Manitoba. Data from irrigation trials located in rust nurseries outside of southern

Manitoba has also been removed from this file. A second file includes data from the entire prairie region for cultivars that have a moderately susceptible or better rust rating. This gives the user the option of comparing cultivar yield potential both inside and outside the rust hazard area.

**Table 1. Main characteristics of winter wheat cultivars - Varieties of Grain Crops Saskatchewan 2003.**

| | | Grain Yield (% CDC Kestrel) | | | ------ Resistance to * ------ | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Variety** | **Years tested** | **Areas 1 and 2** | **Areas 3 and 4** | **Irrigation** | **Lodging** | **Winter Damage** | **Stem Rust** | **Leaf Rust** | **Bunt** |
| **CDC Kestrel** | 12 | 100 | 100 | 100 | G | G | P | P | P |
| **AC Bellatrix** | 4 | 101 | 97 | N/A | G | G | VP | P | G |
| **CDC Clair** | 12 | 100 | 102 | 97 | G | G | P | P | P |
| **CDC Osprey** | 12 | 100 | 100 | 91 | G | G | P | P | P |
| **CDC Harrier** | 9 | 103 | 98 | 106 | G | G | G | P | P |
| **CDC Falcon** | 8 | 99 | 93 | 114 | VG | G | VG | G | P |
| **CDC Raptor** | 7 | 100 | 100 | 108 | VG | G | VG | G | P |
| **CDC Buteo** | 5 | 96 | 97 | 109 | G | G | G | G | P |
| **McClintock** | 5 | 98 | 99 | 109 | G | F | VG | VG | P |

**Table 2. Relative grain yields of winter wheat cultivars compared to CDC Clair grown outside the rust hazard area of western Canada - Cultivar Selector 2003.**

| | Low Moisture Potential | | | | Bushels / Acre | | | | | High Moisture Potential |
|---|---|---|---|---|---|---|---|---|---|---|
| | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
| AC Bellatrix | 117% | 109% | 104% | 101% | 99% | 97% | 96% | 95% | 94% | 93% |
| AC Radiant | 130% | 116% | 107% | 102% | 98% | 95% | 92% | 90% | 89% | 87% |
| AC Readymade | 103% | 97% | 93% | 90% | 89% | 87% | 86% | 85% | 85% | 84% |
| AC Tempest | 96% | 93% | 92% | 91% | 90% | 90% | 89% | 89% | 89% | 88% |
| CDC Buteo | 96% | 96% | 96% | 96% | 96% | 96% | 96% | 97% | 97% | 97% |
| CDC Falcon | 95% | 95% | 96% | 96% | 96% | 96% | 96% | 96% | 96% | 96% |
| CDC Harrier | 104% | 103% | 102% | 101% | 101% | 101% | 100% | 100% | 100% | 100% |
| CDC Kestrel | 108% | 105% | 103% | 101% | 100% | 99% | 99% | 98% | 98% | 97% |
| CDC Osprey | 105% | 101% | 99% | 98% | 97% | 96% | 96% | 95% | 95% | 94% |
| CDC Ptarmigan | 118% | 114% | 112% | 111% | 109% | 109% | 108% | 108% | 107% | 107% |
| CDC Raptor | 109% | 104% | 101% | 98% | 97% | 96% | 95% | 94% | 93% | 93% |
| McClintock | 105% | 101% | 99% | 97% | 96% | 95% | 95% | 94% | 94% | 93% |

Once a decision has been made on the rust risk level, the user then selects the cultivar a that is to be used as the basis for further comparison. It is recommended that the user pick a base cultivar that they have grown and are familiar with. The web-ware then sorts the aggregated yield data file and selects all the trials in which the base cultivar and each of the remaining cultivars were grown so that head-to-head grain yield comparisons can be made.

The head-to-head comparison is performed by regressing the yield of the base cultivar at each trial with the comparative yields from the other cultivars. Careful inspection of these regressions was performed to ensure that linearity assumptions remained valid throughout the range in observed yields. This process results in a family of regression equations that can then be used to compare the yield of each cultivar relative (%) to the base cultivar. This information is printed out in a tabular form (Table 2) giving the relative cultivar performance at 10 bu/acre increments from 30 bu/acre to the maximum grain yield achieved in the highest yielding trial (rounded down to the nearest 10 bu/acre). The linear equations allow for comparisons to be made across the full range of potential yields rather than restricting the inferences to the mean yields found in any one region trial.

The increased range of inference between the base cultivar and all others comes with some cautions. First, because all cultivars are not grown in the same trials, the head-to-head comparisons are specific to the base cultivar selected. This means that once a base cultivar is set, comparisons are not valid among the remaining cultivars in the table. For example, when CDC Clair has been selected as the based cultivar, it is valid to infer that CDC Ptarmigan (114%) will out yield CDC Clair by 14% at CDC Clair potential yield of 40 bu/ac (Table 2). However, it is not valid to conclude that CDC Kestrel (105%) is 9% lower yielding than CDC Ptarmigan (114%). Logic would dictate that the comparisons among cultivars should be valid as the base cultivar is a constant. Despite this fact, simple subtractive inferences can be incorrect because the head to head data used in the linear regressions will differ upon selecting either CDC Kestrel or CDC Ptarmigan as the base cultivar. Secondly, one must remember that the grain yields (bu/acre) at the top of the table are based on the yield potential of the selected cultivar and updates (including reverse comparisons) will be reported using 10 bu/acre grain yield increments for the newly selected cultivar.

The number of tests where head-to-head comparisons have been made and the coefficients of determination ($r^2$) are reported as part of the output. Data from a minimum of 15 trials is required before head-to-head comparisons will be made. Generally, comparisons with a $r^2$ of .9 or larger can be considered to have excellent predictive value.

## Importance of Genotype x Environment Interactions in Cultivar Selection

The logic behind the need for regional testing assumes that the variable weather conditions and climatic zones in western Canada often lead to differences in regional adaptation of cultivars. In other words, there are important genotype by environment (G x E) interactions that can only be identified by collecting performance data from several years at a number of locations within each sub region.

Mean performance is the basis for selection in most plant breeding programs and, over the years, this procedure has improved the yield potential of western Canadian cultivar releases. A similar use of regional data is employed when farmers make their decisions on which cultivar to select for their production system. In most cultivar assessment programs, the target area is sampled over several seasons to establish a database and cultivars with the highest average yield are considered to be the best adapted. However, this approach is based on the assumption that the climate is consistent both within the region and over the years. If the cultivar rankings change for the different environments normally expected within a region, important information on G x E interactions is lost in the data files when only mean values are available for consideration.

Soil available moisture is recognized as the main factor responsible for differences in cultivar performance in well managed production systems in western Canada and winter wheat cultivar yield rank has been shown to change significantly between widely different soil moisture environments (Domitruk et al. 2001). A number of statistical methods have been developed to identify these differences in grain yield potential and provide an improved alternative to selection based on average performance. As early as 1938, Yates and Cochran fitted a simple linear regression of cultivar yield on the environmental mean of all cultivars in a multi-location cultivar evaluation test and there have been numerous more recent reports where linear regression has been used to describe cultivar performance. Relative cultivar response to improving environmental conditions in western Canada has been shown to be very predictable and can be effectively described by simple linear regression.

While variation in the performance of a cultivar is mainly associated with changes in the volume and distribution of growing season moisture supply, there are other factors that can contribute to G x E interactions. These variables place restrictions on the expression of cultivar yield potential with the result that linear regression coefficients do not provide an adequate measure of performance in all situations. Susceptibility to lodging and rust are notable examples of these kinds of yield limiting variables for winter wheat grown in western Canada.

Soil Available Moisture: The soil zones in western Canada are normally used as the basis for regional groupings. They reflect historical differences in spring soil moisture reserves and growing season precipitation, which normally increases as one moves from the brown through the dark brown to the black and gray soils. However, the premises on which these regions are defined ignores the fact that there are transition areas and not sharp changes in climate as you move from soil zone to soil zone. Also, short term weather variability does not recognize historical trends and analyses of yield data on a provincial basis often reveals larger genotype x year than genotype x location interactions indicating that annual climatic differences can have a larger influence on relative cultivar performance than regional differences. Changes in the timing and intensity of drought stress also contributes to G x E interaction and this variation is difficult, if not impossible, to predict. When the differences in the management skills of farmers and their assessment of risk are added to the equation it quickly becomes evident that there is no single best recommendation that can be made to cover all possibilities. In the final analyses, the only way to deal with these variable risk factors and differences in expectations is to provide farmers and their advisors with the necessary information so they can make their own individual decisions. It is the farmer who is making the investment and the final decision on what cultivar will be grown should be dependent on their judgement and expectations.

The cultivar selection tool described in this paper takes a page out of the fertilizer recommendation strategy book and allows the farmer/advisor to select cultivars based on their own experience and yield expectations. Because certain cultivars perform better in low yielding environments while others perform better in high yielding environments, a wide range of climatic conditions must be sampled to provide reliable yield comparisons. As a minimum, drought, average moisture and optimum (irrigated) environments must be sampled to provide the necessary range in the database. The data used by the cultivar selector was collected from both dry land and irrigation trials grown throughout western Canada, which satisfies this requirement.

The cultivar selector option that compares grain yield performance outside of the rust hazard area gives the best picture of cultivar grain yield potential for western Canada. These comparisons show that there are large differences in the relative performance of most cultivars when grown in high and low moisture stress environments (Table 2). The soft white winter wheat cultivar CDC Ptarmigan is a notable exception to this generalization, as it demonstrates good stability and high yield potential over the entire range of crop water environments sampled. This suggests that there is still plenty of opportunity for plant breeders to raise the average performance and general adaptability of cultivars in the hard red winter wheat class. It should also be noted that, while CDC Ptarmigan is commercially available in the USA, its Canadian registration was withdrawn because of grain quality restrictions.

Lodging: Due to its susceptibility to lodging, the cultivar Norstar provides an excellent example of why relative cultivar performance does not always have a simple interpretation. Norstar was particularly well adapted to conditions of drought stress and it was the dominant winter wheat cultivar in western Canada until the appearance of the strong-strawed semi-dwarf options in the early 1990's. However its susceptibility to lodging placed restrictions on the expression of its yield potential and head-to head comparisons show that Norstar does not have a linear yield relationship with the more recent cultivar releases (Figure 1). We have removed Norstar from the comparisons available to the cultivar selector because of its nonlinear grain yield relationships with the rest of the cultivars and the fact that pedigreed seed is no longer available.

The yield limitations imposed by susceptibility to lodging emphasize the need for an understanding of grain yield targets and relative cultivar performance over a wide range of environments so that management inputs, such as fertilizer, can be optimised and quality targets achieved. For example, Norstar will start to lodge once grain yields reach approximately 45 bu/acre. Not only does this put a cap on the expression of grain yield potential, but it also limits the opportunity to fully exploit management opportunities. When compared to Norstar, the short, strong straw of cultivar releases starting with CDC Kestrel in 1991 allow for the use of higher nitrogen fertilizer rates thereby providing the farmer with the opportunity to achieve both a much higher grain protein concentration and greatly increased grain yield. In some of the higher moisture regions of the eastern prairies, experienced winter wheat growers now manage for target grain yields of 80 plus bu/acre.

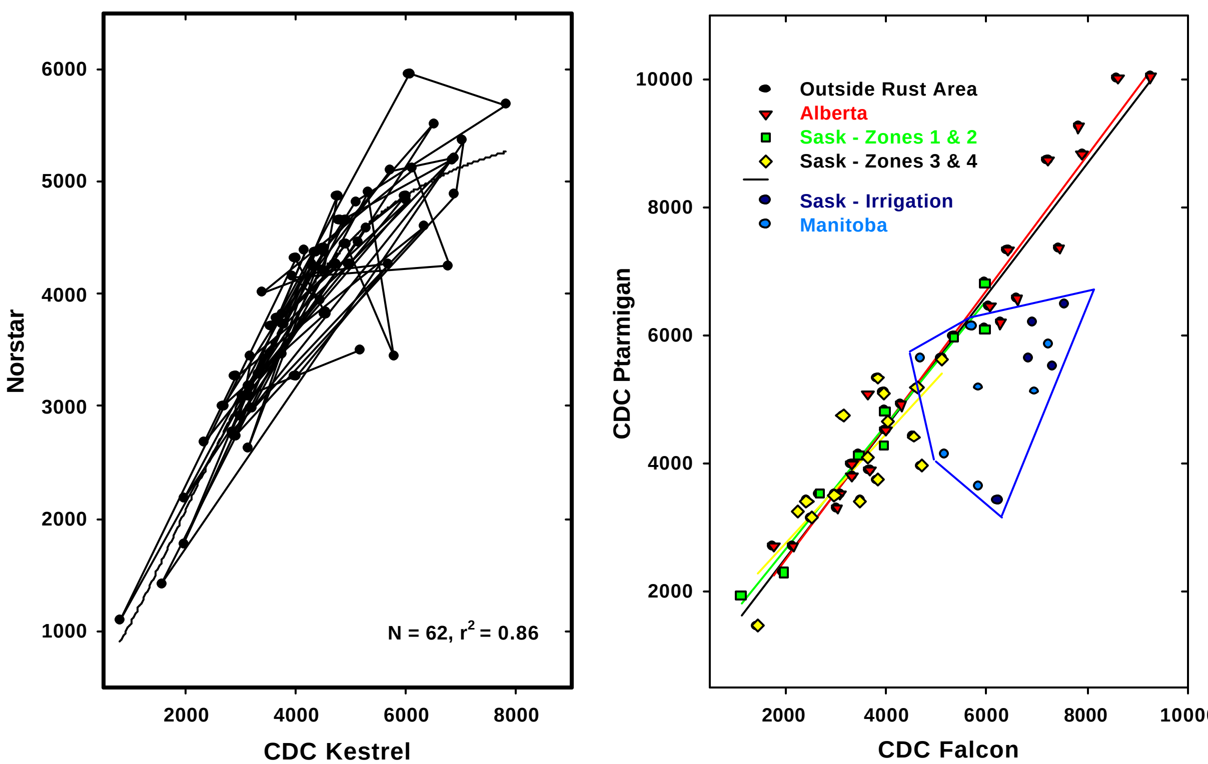


**Figure 1. The grain yields (kg/ha) of CDC Kestrel vs Norstar and CDC Falcon vs CDC Ptarmigan.**

Disease Resistance: Recent winter wheat cultivar releases have provided growers with a high level of protection from rust. However, there are still large differences in the rust resistance of registered cultivars with the result that head-to-head grain yield comparisons do not always have linear relationships in the rust hazard area. Consequently, the cultivar selector divides the western Canadian prairies into two regions based on the risk of yield loss due to rust. The extensive database available to the cultivar selector indicates that, on most years, measurable losses in grain yield due to rust are restricted to cultivars like CDC Ptarmigan that have a very susceptible stem rust rating (Figure 1). For this reason, grain yield data for cultivars with a very susceptible rust rating have been removed from the data file for the rust hazard region. This means that it is now up to the user to determine the risk of stem rust for their individual situation and select the appropriate rust hazard option.

The main rust hazard area in western Canada is the southeastern part of the prairies. However, this region can expand into western Saskatchewan towards the Alberta border in years of severe epidemics, such as was experienced 1986. Although two thirds of the rust damage was a result of sub-optimal management practices that delayed crop maturity, 1986 clearly demonstrated the need for better rust resistance in winter wheat cultivars. In order to manage this level of risk, at least a moderately susceptible level of resistance is advised for well-managed winter wheat. Where there are known deficiencies in the management package, i.e., late seeding dates, phosphate deficiencies, etc., a higher level of rust resistance should be considered. However, in these sub-optimal situations it must also be remembered that other variables, such as cultivar winter hardiness, must also be given major consideration.

There are a number of diseases other than rust that attack winter wheat, especially in high moisture environments. However, the current database gives no indication of major yield reductions due to any disease other than rust. For example, a significant yield advantage in highly productive environments does not seem to be associated with the superior disease package offered by McClintock (Figure 2). However, yield reductions may be directly related to available moisture if the effect of a disease is chronic and progressive. In these instances, disease losses do not present a problem to the cultivar selector because the head-to-head comparisons over a wide range of environments will have a linear relationship and a grower will be provided with the correct comparative data and inferences on best performance.

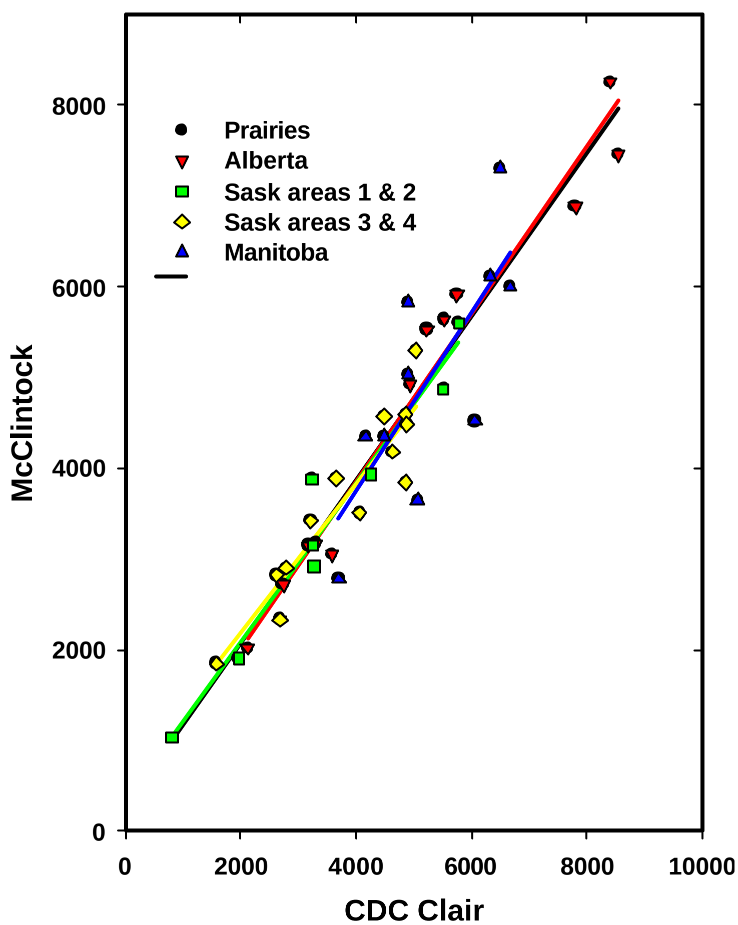


Figure 2. The grain yield (kg/ha) of CDC Clair vs McClintock

## General Discussion

The cultivar selector is an interactive system for head-to-head cultivar grain yield comparisons that reduces the need for extensive post-registration regional testing by accessing data from both the western Canadian cooperative cultivar registration system and provincial regional trials. Even though it uses the same database, the cultivar selector provides a more detail description of cultivar yield potential and the importance of G x E interactions than the regional means reported in the Varieties of Grain Crops publications.

This paper focuses on winter wheat, but the cultivar selector can be used for any crop kind as long as a few basis conditions are met. 1) As always, the old adage of garbage in, garbage out applies and there is a risk that the cultivar selector could mislead users if there is not a high level of quality control on the data entering the system. It goes without saying that field crews must be experienced and competent, i.e., samples that are spilled prior to yield determination must be noted, etc. In order to minimize the opportunity for bias entering the system, rules for the acceptance or rejection of data on an individual entry must be laid down ahead of time. For example, the reasons for the removal of yield data for an individual entry must be identified prior to harvest, i.e., an entry with poor germination should be flagged for removal in the spring. After grain yield has been recorded, except under exceptional circumstances, a high experimental error should be the only reason for rejecting data and, in this instance, the data for the whole test site should be discarded. A CV of greater than 15 percent is a common rule of thumb for discarding data from an entire test. 2) The database must include a wide range of moisture levels and a resultant wide yield range in order.to anchor the ends of the regression lines. As a minimum, drought, average moisture and optimumly moist (irrigated) environments must be sampled to provide the necessary range in the database. A further assumption with these cultivar trials is that other yield restrictions in fertility, soil physical properties, weed control, and management are either not present or similarly restricting to each cultivar. 3) The yield relationships for cultivars must be evaluated for linearity and coefficients of determination should be reported to provide some indication of the predictive value of the output.

A number of observations can be made from simple visual inspection of the scatter of data about the regression lines (Figures 1 and 2). The scatter provides an indication of the variation between cultivars within individual trials. Understanding that there are reasons to explain every observed grain yield, one can inspect the scatter plots for major deviations or clusters of data points which stand out from the linear trend, such as the cluster associated with high yields and the occurrence of rust shown in Figure 1. A single isolated data point that deviates widely from the regression line suggests a measurement mistake, which could be edited out of the data file. We have not made any effort to edit the current data files, but these isolated deviants usually represent little more than curiosities. The fact they have not been noted prior to harvest and only happen once indicates that the circumstances that produced them in the first place are unlikely to be of practical significance.

It is important that regional cultivar adaptation be identified early, before exceptional genotypes are lost from breeding programs. Therefore, it is of higher priority that resources be committed to timely (early generation) grain yield evaluation in breeding programs than regional testing after cultivars are registered for production. As mentioned earlier, data from dry, average moisture and optimum or irrigated environments best satisfies the need to identify both high performance niche and broadly adapted genotypes. This should be followed up with more extensive testing to meet regional requirements and identify instances where unusual performance may lead to nonlinear grain yield relationships with the current dominant commercial cultivars and recent releases. If this minimum data package was required at the time of registration, there should be a minimal need for additional regional testing.

## References


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