

So You Have a Yield Map?

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Understanding a map that shows yield is only possible if you understand how the yield was “built” by the plant. Carl Sprengel was the first agronomist to formalize how crop yield could be built by adding nutrient elements. Although Justus Von Liebig is often credited for the “law of the minimum”, Sprengel was the first to report “...when a plant needs 12 substances to develop, it will not grow if any one of these is not available in a sufficiently large amount as required by the nature of plant.”

The classic “all or nothing” representation of this statement is the barrel that has one short stave causing “Lost Yield Potential” (Figure 1.). Although an enduring example, it is no doubt a gross oversimplification of the dynamic and responsive biological system. A more instructive analogy might be one that illustrates “building”, just as the plant builds yield in each spot in the field given the resources it has available over that growing season.



Figure 1. Carl Sprengel’s research on nutrient limitations; greatly oversimplified and popularized by Justus Von Liebig.

Let us look at the building analogy of a house. When finishing the interior, hanging 4 by 8 sheets of drywall requires screws. It is recommended to use 18 screws per sheet. If we need to hang 100 sheets to complete interior and have only 1750 screws, will we be able to sheet the interior? Strictly speaking we have insufficient screws and will leave 2.77 sheets of drywall not hung. Practically, the prudent builder or resource user would recognize the constraint as the build was nearing completion and would ration screws to complete the build. Perhaps hanging

the last sheets with only a few screws, then going back to already built areas removing some screws to finish the build.

Plants do a similar budgeting when they build yield with constrained resources. In dryland agriculture, water is most often the resource constraining the maximum genetic yield potential. Most of the crop plants we use in western Canada have evolved in environments sensitive to water resource constraints. Therefore as water becomes constrained in the year the plant will respond to “finish the build” as best they can. Wheat growers have seen this when tillers die-back, florets abort, and/or kernels shrivel.

Understanding the fully rendered analogy of building yield and building a house will help guide us toward building optimized crop yields. One must understand that the blueprint is the genetic potential for that crop within the given environment. This blueprint sets the amount and type of resources needed. Completing an optimal build requires understanding the resources supplied to the site and how additional resources that we might supply will be helpful. This is not a trivial constrained resource problem since both the house and the plant have several interchangeable ways to “finish the build”.

Now if we look at our yield map and extrapolate this thinking so that each location in the field is a new building site, the scale of the problem grows exponentially. It is little wonder that simple linear approximations, managing by soil zones or rules of thumb very often fail (Dobermann et al., 2004). This complex constrained resource problem requires a more powerful computer simulation to test and compare how changing resource constraints will impact yield. Western Ag’s patented PRS™ technology is the only means currently available to growers to assess resource supplies and calculate optimum allocations of additional resources.

How the PRS™ Forecaster came about.

In 1997 an effort was made to tie together the new Plant Root Simulator (PRS™ probe) test of soil nutrient supply with a mechanistic nutrient uptake model. The very detailed concepts of Barber’s Flux model (Barber, 1995) were used along with more highly aggregated modeling efforts applied to grain yield and nutrient responses (Flaten et al., 1988). The modeling approach began by simplifying the soil-climate-plant system and systematically adding complexity that accounted for the most likely exceptional scenarios. Resources defined by this procedure have a fundamental impact on the soil-climate-plant system. The entire approach, called “Constrained Resource Modeling”, proved a useful level of aggregation for crop nutrition modeling in western Canada.

Selecting an appropriate scale of aggregation for the resources controlling yield is essential to developing a model that is understood by the grower. For example, the supply and demand for water can be mechanistically modeled with daily precipitation data, infiltration, drainage, root suction potentials, transpiration and water demand for photosynthesis.

The net outcome of such a mechanistic description should result in different levels of plant growth with changes in precipitation. However, at the scale the grower sees, the constraint to yield by water has a more simplified functional description. Too little water available during the growing season means low yield. Increases in water result in increased yields. Although the grower also knows, that past some point, too much water restricts yield. The grower has just

defined the generic bell-shaped curve that results when the finite resource (water) is the only factor constraining yield, illustrated in Figure 2. With over 1200 site yields plotted against available water, the boundary clearly forms where water is the only constraint to more yield. The lower yields at equivalent levels of available water often occur, however, the reason for the lower yield is some factor other than water.

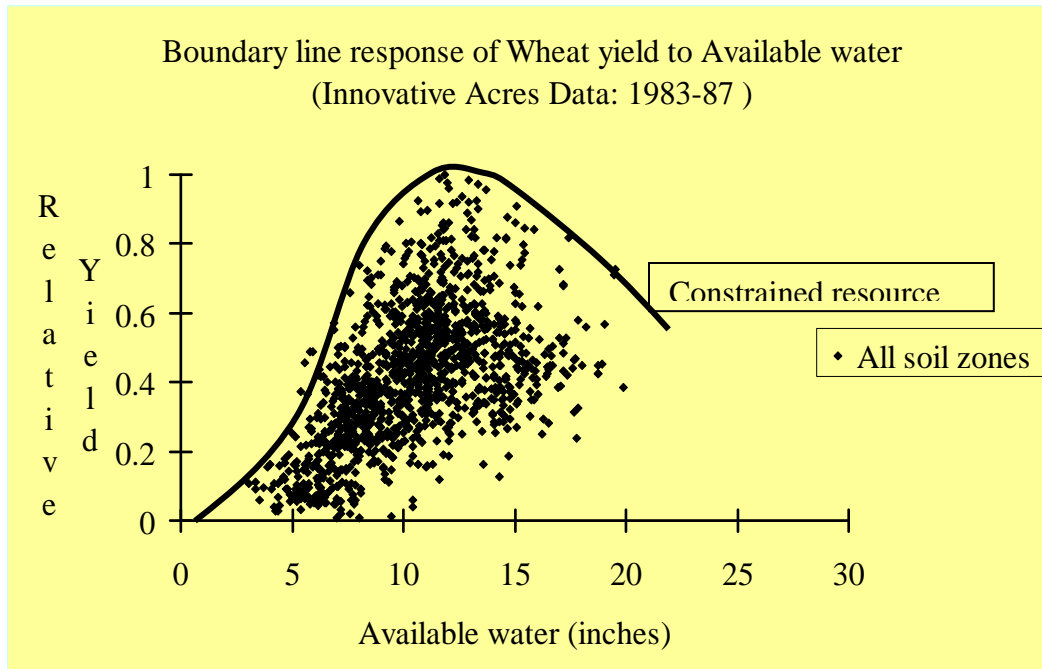


Figure 2. Scatter plot of relative spring wheat yield as a function of the available soil water showing the boundary of the resource constraint (de Jong, 1988).

Similar treatment of other critical constraining factors such as heat, soil texture, soil density, soil pH, and soil EC resulted in a set of overriding controls that growers identify with. Selecting grower-tracked data as the key input variables also eliminated a common problem of most research-derived mechanistic models; that being the requirement for scientific data on the soil and/or crop to be measured and entered into the model (Acock et al., 2001).

The PRS™ Forecaster (Greer et al., 2003) uses a yield equation where the sufficiency of these overriding constraining resources scales the requirement for all other resources. For example, if water is a severe constraint in one location, the response to other limiting nutrients is scaled downward. Building yields using this scaling of a constrained resource model allows us to calculate the marginal improvements of adding any or all nutrients simultaneously. This multiplicative approach is superior to a simple additive yield model because it can account for interactions that occur when multiple factors change.

The work of Shimshi (1969) taken from Mengel and Kirkby, 1982 provides a textbook example of a multiplicative effect of water and N fertilizer on corn yields (Figure 3.). The line indicates a moderate 5000 kg/ha (90 bu/ac) yield. Logically, where water is severely limiting (-2.0 bar)

there is no way to obtain 5000 kg corn/ha. This is the special case in which the barrel stave analogy is correct. Water is so limiting that no amount of N fertilizer can achieve the yield. However, where water is generally more sufficient (-1.6 to -0.2 bar), the modest 5000 kg/ha yield can be achieved with N rates between 50 and 350 kg/ha. This data confirms that where marginally sufficient resources are supplied, the plant can use them in varied combination to build the same yield outcome.

The essential learning in this illustration is that by increasing water sufficiency and decreasing N sufficiency the same final yield can be built. The multiplicative building of yields is by no means limited to water and N. Any changes in sufficiency of any factors controlling yield can result in a similar yield if those factors are only marginally sufficient to begin with.

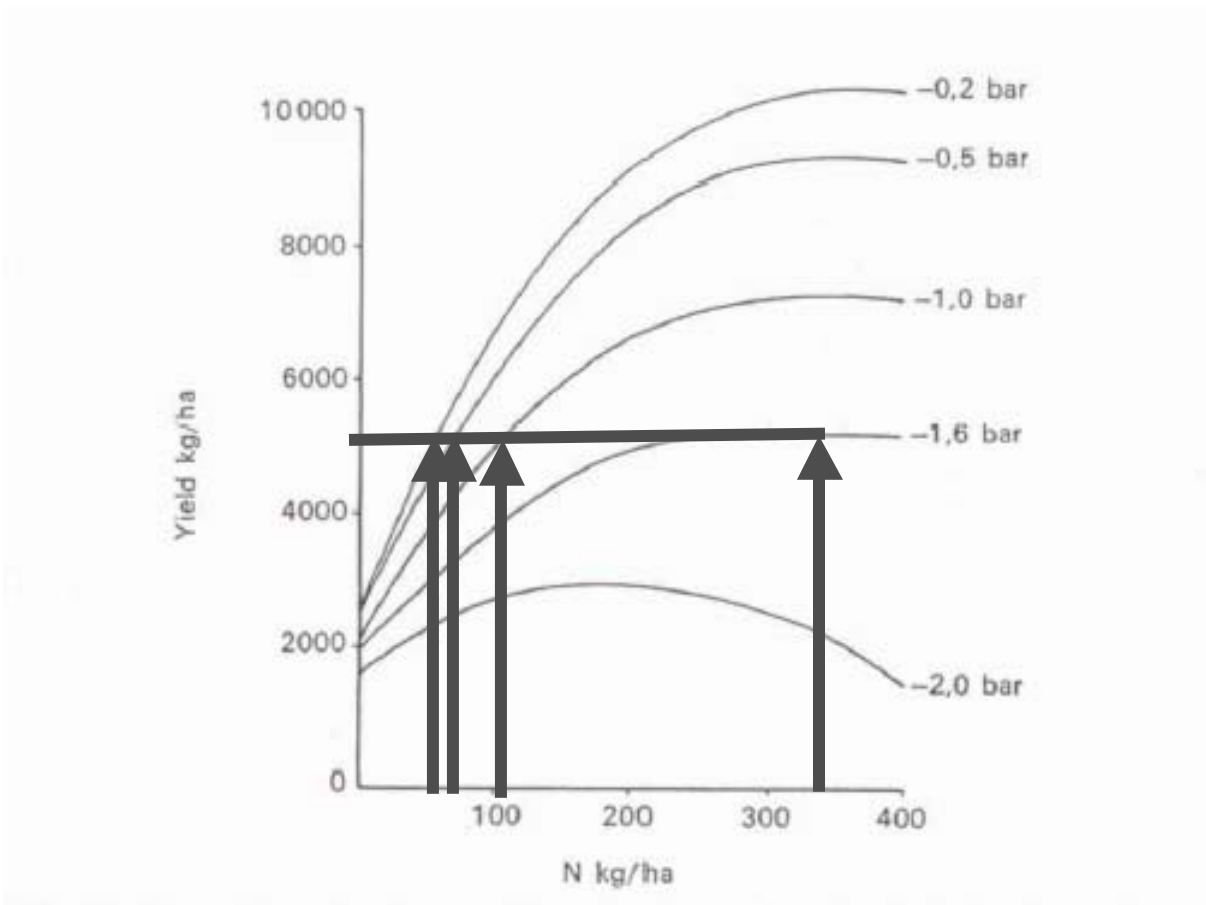


Figure 3. Effect of increasing the rate of N application on the grain yield of maize (corn) at different soil moisture levels (after Shimshi, 1969).

The PRS™ Forecaster uses precisely this type of crop yield simulation model to render yield under any changing scenario of Water, Heat, Soil Density, Soil pH, Soil EC, N supply, P supply, K supply, and S supply. Currently, 17 different crop types can be modeled with the PRS™ Forecaster for the Northern Great Plains and the Pacific Northwest.

So what does this all mean when I look at a yield map?

Yield maps show the interplay of all factors constraining yield in each location on that year. Thus any yields on the map below the maximum genetic potential yield, although the same numeric value, are very likely built from very different constrained resources. Without knowing the manageable resource constraints, it is not possible to know how the yields on the map were built. Therefore, the yield map becomes only valuable as a picture of what yields were and not HOW the yields came to be. Similarly, any vegetation map or greenness measure is a diagnosis or index of what and not why.

The why's of a yield map can at best be inferred from the spatial patterns and features. Leaving one to broadly extrapolate the constraints to yield. To illustrate this, Figure 4 has marked three areas having yields above 50 bu/ac. One strip that has an additional 34lb/ac N applied can be generally seen going across the map. Does that mean that I can increase yields all over with N? One might use the supporting logic that the old barn site, concur with the use of N as this area will likely have more N supply. Convincing ourselves to use more N is simple because it is always needed in large amounts. Although an easy answer, particularly when N is a small cost relative to the crop, it is not always the best way to increase of net profit. Given differences in the cost of K and N a more optimal build of 50 bu/ac can be achieved with K (Figure 4). At this site soil supply of N is sufficient for the modest 50 bu/ac yield. This example demonstrates the necessity of knowing the soil supply rate of all nutrients as a first step to optimizing the build of any yield.

The only tool currently available to measure soil supply and model yield outcomes is the PRS™ technology. The base of this award winning technology was developed at the University of Saskatchewan in 1991 and commercialized by Western Ag Innovations in 1998. Since this time the PRS™ Forecaster has been delivered by Western Ag Labs to more than 10,000,000 acres across western Canada and North Dakota.

Conclusion:

Interpretation of the yield map should begin with an understanding of how yield is built. Simple interpretation of one factor being limiting to result in low or medium yields is very often an incorrect inference. Since N and water are the largest interacting factors, it is important to characterize the both how much water response can exist in each site in the field and how the N supply matches up with that water response.

The PRS™ technology is the only currently available tool to show the dynamic response of each yield constraint and optimize the yield based on multiple factor constraints.

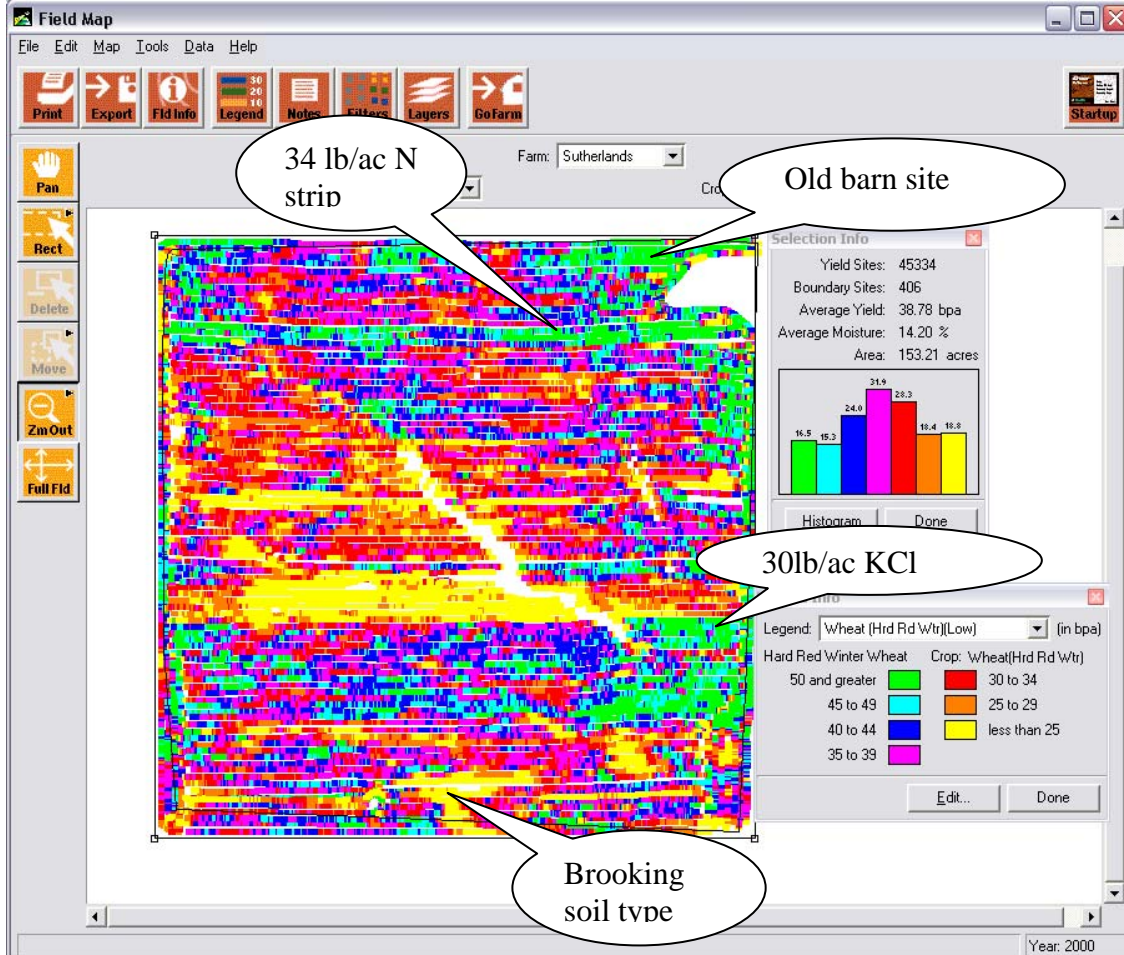


Figure 4. Yield map of CDC Clair at Ceylon, Sk. seeded on chemfallow in 1999-2000.

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