

The Seven Wonders of the Maize Yield World

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(adapted from: http://cropphysiology.cropsci.illinois.edu/research/seven_wonders.html)

Maize grain yield is the final product of numerous factors that affect crop growth and development during the growing season. Maize is undoubtedly the crop that shows the largest response to technology and management. Growers make critical decisions every year regarding the inputs needed to maximize the profitability of their farm based on the potential yield gain of a given input factor. Data collected over many years and locations by the Crop Physiology Laboratory has led to the identification and ranking of seven categorical management factors that impact yield. These 'Seven Wonders of the Maize Yield World' provide a framework for understanding the value of different management factors as well as their potential interactions.

The Seven Wonders are shown in Table 1. They are ranked in order from the factor with the greatest impact on yield (Weather, #1) to the factor with the least contribution to yield (Growth Regulators, # 7). The values represent a range of responses based on our research. For example, the weather can influence yield by more than 4.4 tons/hectare

Table 1. The Seven Wonders of the Corn Yield World. Values for each factor are presented in tons/hectare as well as percentage of the total (16.3 tons/hectare).

Rank	Factor	Value	
		tons/hectare	%
1	Weather	4.4+	27
2	Nitrogen	4.0	26
3	Hybrid	3.1	19
4	Crop Rotation	1.6	10
5	Plant Population	1.3	8
6	Tillage	0.9	6
7	Growth Regulators	0.6	4
TOTAL =		16.3 ton	100%

There are two important aspects of the Seven Wonders:

1. The higher a factor is on the list, the more control it exerts over the factors below it.
2. The factors interact!

In a favourable year, Weather and Nitrogen (N) combine to contribute more than 50% of total yield. On average, the maximum response to nitrogen over an unfertilized check plot treatment is approximately 4.4 tons/hectare (Table 1 and Figure 1). The weather, however, influences every aspect of nitrogen fertilizer management including its application, the potential for loss, its availability, and its utilization by the plant. In a drought year such as 2005 (Figure 1, left), the weather limited the yield response to N application to approximately 1.3 tons/hectare, while in a year with excess spring precipitation such as 2009 (Figure 1, right) the lower linear response to N is indicative of weather-induced N loss.

The weather influences the success of all of our management efforts. Irrigation, particularly with sub-surface drip systems is an efficient way to help mitigate the weather impact of insufficient rainfall, while at the same time being able to supply key mineral nutrients (including nitrogen) at the right time through fertigation.

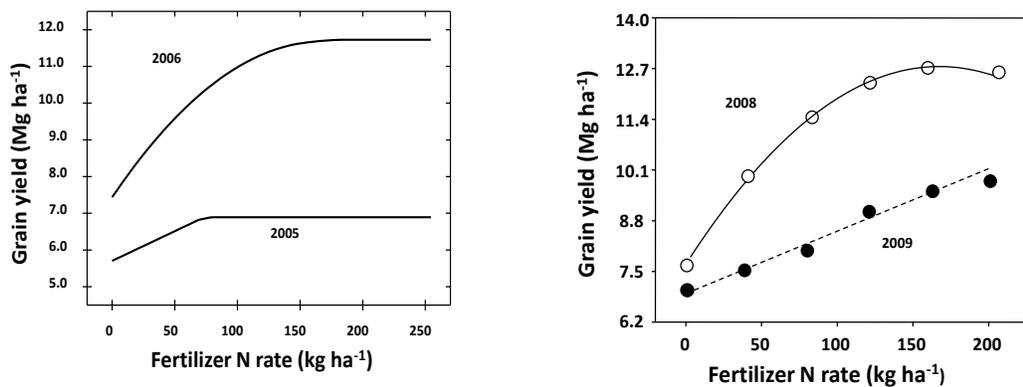


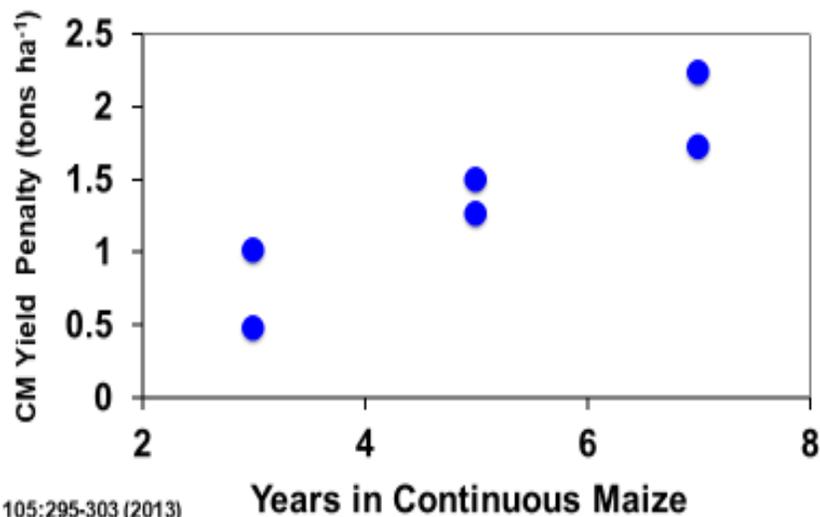
Figure 1. Some examples of the interaction between weather and N fertilization on grain yield of maize. Graph on the left is of multiple hybrids grown at the same site in Champaign, IL USA in 2005 and 2006, while graph on the right is of multiple hybrids grown at the same site in DeKalb, IL USA in 2008 and 2009. The lower yield in 2005 compared to 2006 (left) is due to drought which limited the need for, and the response to fertilizer N, while the lower yield in 2009 compared to 2008 (right) is due to N loss from excess Spring precipitation.

Nitrogen use also interacts strongly with the third wonder of the maize yield world, hybrid selection, and there is considerable interest in improving the efficiency of N use with genetics or biotechnology. Hybrid selection is probably the most important decision made by farmers each year, and most do not realize the large differences in yield potential among elite commercial hybrids. Maize hybrids can vary by 3.1 tons/hectare, or more when grown in the same field in our research trials (Tables 1 and 2). This variation can be attributed to hybrid interactions with weather (e.g., differences in drought and heat tolerance), as well as interactions with N and plant population. The interactions of hybrid, N rate, and plant population are particularly important, since these are three of the management factors under the farmer's control that have the greatest impact on grain yield.

Table 2. Range in yield among 44 elite commercial hybrids grown at Harrisburg, IL in 2017. Hybrids were grown using levels of fertilizer N (300 kg/hectare), and at plant densities (79,000 plants/hectare) that were presumed to be adequate for maximal yields.

Rank	Yield tons/ha	Rank	Yield tons/ha	Rank	Yield tons/ha	Rank	Yield tons/ha
1	20.1	12	18.8	23	18.0	34	17.1
2	19.7	13	18.6	24	17.9	35	17.1
3	19.6	14	18.4	25	17.9	36	17.0
4	19.6	15	18.4	26	17.7	37	17.0
5	19.6	16	18.3	27	17.5	38	17.0
6	19.4	17	18.3	28	17.4	39	16.7
7	19.4	18	18.1	29	17.3	40	16.7
8	19.3	19	18.0	30	17.2	41	16.6
9	19.0	20	18.0	31	17.2	42	16.5
10	18.9	21	18.0	32	17.1	43	16.5
11	18.9	22	18.0	33	17.1	44	16.3

Crop Rotation (continuous maize versus maize following soybean) is the fourth wonder of the corn yield world. Maize grown continuously yields less than when grown in rotation with soybean (an average of 1.6 tons/hectare less), in what is known as the continuous maize yield penalty, and this penalty increases with the number of years of continuous maize (Figure 2). Accumulation of residue in continuous maize is one of the main causes of the penalty as this additional residue influences the availability of key nutrients like N, P and S (Figure 3). Although continuous maize requires more fertilizer N for optimal yield (40 to 60 kg more N/hectare), there is no amount of additional N that can completely overcome the continuous maize yield penalty. In addition to influencing nutrient availability, the accumulation of maize residue can also lead to a build-up of autotoxic compounds that reduce corn growth and yield.



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Figure 2. The magnitude of the continuous maize yield penalty (difference between continuous maize and a maize-soybean rotation) for two fields that progress for seven years in continuous maize.



Figure 3. Differences in surface residue and crop appearance between seventh year continuous maize (left) and maize grown in rotation with soybean (right). Note the symptoms of N deficiency on the lower leaves of continuous maize (left) due to the residue immobilizing N. Picture taken at the R2 growth stage.

Plant Population (or Plant Density) must increase as we strive to achieve higher yields, and plant populations have steadily increased in the US over the last 50 years (Figure 4). Still we find that many farmers would benefit from correcting plant populations that are too low, especially if the other yield wonders are optimized. The difficulty is that plant population interacts heavily with other yield wonders, with high plant populations being particularly susceptible to unfavourable weather conditions. Similarly, some hybrids are clearly more tolerant to high populations than others, and crop rotation and tillage can impact plant population by altering seed germination and seedling emergence.

High plant populations also result in increased inter-plant competition that has be managed, and we are evaluating narrowing the row spacing as one way to manage a higher population of plants. Compared to 76 cm row spacing, narrowing the rows to 51 cm increases the inter-row plant spacing, resulting in greater ground coverage and higher canopy photosynthesis, even with the same number of plants (Figure 5).

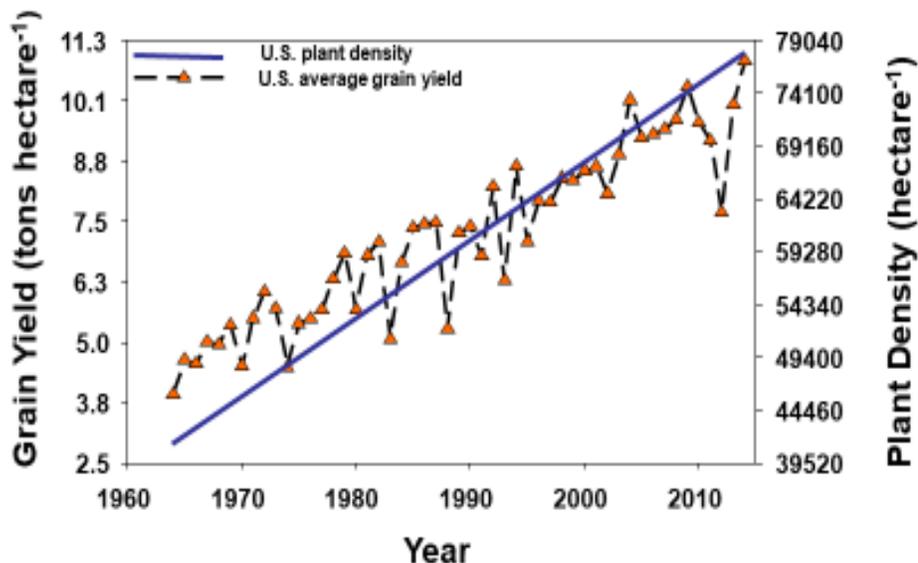


Figure 4. The average grain yield of maize (orange line) and the average planting density (blue line) in the US over the last 50 years. Note the close association between the increase in plant density and grain yield.

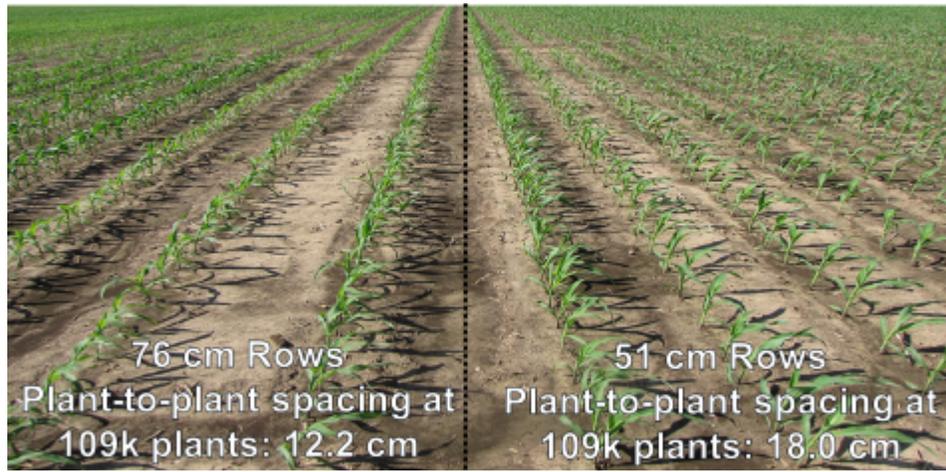


Figure 5. Comparison of 76 cm row spacing (left) and 51 cm row spacing (right) with the same population of plants (109,000 plants/hectare). By narrowing the row spacing more land area is covered by green plant tissue resulting in greater light interception and higher canopy photosynthesis, and there is more distance between the plants within the row.

Tillage can vary widely in its mechanism, timing, and degree. There is no one-size-fits-all approach to tillage, and practices may vary according to geography and the other yield wonders. In some geographies, no-tillage systems help to conserve soil moisture, while in others tillage is needed to help warm the soil and allow for earlier planting. Tillage can also be an important component of crop rotation, due to the accumulation of crop residues, and the effect of crop rotation and tillage on soil tilth can be striking (Figure 6). In this example, tillage was needed to bury the accumulated residue from continuous maize production, thereby allowing more contact with soil microbes for degradation. However, extra passes were required to prepare a suitable seedbed. In contrast, minimal tillage was required to prepare a light, even seedbed when soybean was the previous crop.



Figure 6. Effect of crop rotation (continuous corn versus soybean) on soil tilth. Third year corn is shown on the right, while soybean as previous crop is shown on the left. Photo taken after spring tillage activities (chisel plow followed by field cultivator).

The seventh wonder of the corn yield world (Growth Regulators and Biologicals) encompasses a wide variety of products that can modulate corn growth and yield. These products include seed treatments for more uniform rapid emergence, in-furrow applications to stimulate root growth and nutrient uptake, foliar products to up-regulate important physiological processes and/or to relieve plant stress, among others. The 'greening' or 'plant health' effect associated with application of strobilurin fungicides is a good example (Figure 7). We have documented this effect in the absence of yield-limiting disease, especially under intensive management systems where all other factors are optimized. Although it is difficult to experimentally separate physiological effects from disease control, we believe that strobilurin fungicides elicit a change in the ethylene-mediated senescence trajectory of source leaves.



Figure 7. The physiological greening effect associated with application of a strobilurin fungicide. A strobilurin-containing fungicide was applied at VT/R1 to the plot shown on the right compared to untreated plants on the left. Photos taken 50 days after application.

Some Final Comments.

The Seven Wonders approach assumes a few key prerequisites. These prerequisites include drainage, pest/weed control, proper soil pH, and adequate levels of P and K based on soil tests. Crop production would not be possible in many parts of the US without tile drainage. Similarly, weeds and other pests do not add yield. Good weed control, along with proper soil pH and nutrient levels are key prerequisites for maize production, and are necessary to allow the Seven Wonders of the Maize Yield World to express their positive impact on grain yield.

Using the Seven Wonders concept and recognizing the need to combine management factors to drive increased yields we developed a systems approach of enhanced management practices and inputs that we compared to a standard management system similar to that used by most growers. Using an Omission/Addition experimental design, where each factor is either added one at a time to the standard management system, or removed one at a time from the enhanced management system, we documented an average yield increase of 3.1 tons/hectare from enhanced management. Although the relative importance of a management factor varied for different sites and years, in all cases the value of a given factor when combined with the other factors in the enhanced management system was greater than when the factor was provided alone. These trials show that single production factors cannot guarantee high maize yields, but rather it is the positive interaction among multiple single factors that gives farmers the greatest opportunity to achieve high maize yields.