Planting Outcome Effects on Corn Yield

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Summary

- Uniformity of plant emergence, planting timing, plant population, and evenness of plant spacing are four outcomes of planting that can influence final corn yield.

- Research has shown that delayed emergence can reduce the yield of individual plants in a stand; however, the notion that a plant emerging more than 48 hours after its neighbors is a "weed" is clearly not supported.

- Corn yield potential declines as planting is delayed beyond the optimum planting window for a given geography, and the yield penalty tends to be greater in northern areas where the growing season is shorter.

- Optimum plant population can be influenced by factors such as yield level, hybrid, and weather conditions.

- The CoV and singulation readings on the planter monitor are valuable real-time indicators of meter performance but poor predictors of the agronomic consequences of common, realistic non-ideal planting outcomes.

- Within-row plant spacing uniformity <u>does</u> impact grain yield; however, whole-field impacts on grain yield are usually relatively small, averaging about 1 to 2%.

- By far, a skip is the planting outcome that contributes the most to yield loss, whereas occasional doubles have no negative impact.

Four Planting Outcomes for Success

Planning and execution associated with corn planting are critical if growers are to maximize the genetic potential of today's elite corn hybrids. The simple secret for success is to "do everything right." Many of these key management decisions are made well before the planting season, including choice of hybrid, crop rotation, tillage system, nutrient placement, target planting rate, and row spacing.

This Crop Insights will focus on the four planting outcomes that are achieved during planting itself. The relative impacts these four factors have on grain yield were recently summarized by Dr. Jeff Coulter from the University of Minnesota[4] and are presented below.

These goals and their estimated typical impact on yield include:

1. Achieve uniform emergence (5-9%)
2. Plant within the optimum window (2-5%)
3. Achieve the correct population (1-2%)
4. Achieve uniform plant spacing (1-2%)

Photo courtesy of Deere and Co.

The latest research related to achieving each of these four planting outcomes will be discussed and, in several cases, suggest the need to rethink conventional wisdom regarding their importance in affecting grain yield.

1. Achieve Uniform Plant Emergence

A primary goal of corn growers is to achieve stands containing uniformly large-sized plants that consistently produce one full-sized ear each. Small, delayed or "runt" plants rarely, if ever, produce full-sized ears. Traditionally, growers have assumed that the primary cause of these smaller, undesirable plants was a delay in the time of emergence. And often the cause for delayed emergence was assumed to be inconsistent seeding depth. Logically, late-emerging plants are less able to compete for limited light, nutrient, and moisture resources with earlier-emerging and larger neighbors. Several studies have indeed documented significant yield loss when the development of plants within the stand was delayed (Nafziger et al., 1991; Ford and Hicks, 1992; Liu et al., 2004a, 2004c). These studies typically used multiple planting dates 7 to 28 days apart to achieve varying degrees of delayed plant growth. These studies are valuable in demonstrating certain aspects of plant-to-plant competition and give some guidance for making replant decisions. But they are of little value in understanding the

effects of time of emergence on individual plant yield in stands planted all on the same day, as is typical in commercial corn production. They also do not indicate the relative importance of time of emergence versus other factors occurring after stand establishment or how final plant yield is impacted by each.

Multiple factors shown to affect plant yield

There is widespread agreement that large plants exhibiting well-synchronized silk emergence and pollen shed produce the largest and most consistent-sized ears (Pagano et al., 2007; Kovács and Vyn, 2014). However, these studies have also shown that time of emergence has relatively little effect on plant biomass and final grain yield. In a 2-year study in Indiana, Murua (2002) documented that time of emergence in conventionally-planted corn stands only explained about 4% of the variation in individual plant yield. A similar study by Kovács and Vyn (2014) found that value to be only about 1%.

Other studies from Argentina found that even when corn canopies emerge uniformly, they can develop well-established plant hierarchies as early as the V4 growth stage (Pagano et al., 2007; Maddonni and Otegui, 2004). These differences in plant size within the stand are probably explained by "other" factors such as moisture availability, compaction, soil textural differences, nutrient acquisition or insect damage, and clearly not time of emergence. The notion that a plant emerging more than 48 hours after its neighbors is a "weed" is clearly not supported by these studies. In fact, Kovács and Vyn (2014) further warn, "the importance of ultra-uniform seedling emergence times for adjacent plants within the row can easily be overstated."

How much does uniform emergence affect plant yield?

Determining the exact effect of uniform emergence is difficult, in part because studies have used different ways to measure and express emergence uniformity. Some of the different measures used include calendar or growing degree days from planting to emergence, time to 50% emergence, number of leaf stage growth differences and days of emergence delay after the mean emergence date of the plant stand. Ford and Hicks (1992) measured a 6% yield loss when every second plant had a 1-leaf stage delay and a 5% yield loss when every sixth plant had a 2-leaf delay. Liu et al. (2004a, 2004c) found that yield decreased 2% per day whenever the time to 50% emergence was delayed by more than 3 days. Nishikawa and Kudo (1973) report that per plant yield declines by 5% for every day in emergence delay after the mean emergence date of the plant stand. And finally, Murua (2002) measured an average of 2.3% yield loss for every additional day's delay in emergence of individual plants.

These results suggest that delays in emergence can result in average yield losses in the 5 to 9% range proposed by Coulter. Careful attention to managing planting depth, seed trench compaction, surface crusting, seed furrow closure and surface residue will minimize these yield losses. But beyond that, attention to other factors, such as uniform moisture and nutrient availability, soil compaction and disease and insect protection may be even more important in achieving uniform stands at physiological maturity with low plant-to-plant variability in ear size and maximum grain yield.

2. Plant within the Optimum Window

Timely planting of full-season hybrids allows the corn crop to take full advantage of the available growing season. Numerous studies have shown that corn yield potential declines as planting is delayed beyond the optimum planting window for a given geography (Coulter, 2012; Farnham, 2001; Myers and Wiebold, 2013; Nafziger, 2008).

Yield reduction with delayed planting

Results of DuPont Pioneer planting date studies conducted over 18 growing seasons show that yield was maximized when corn was planted within the two week period around the optimum planting date (Jeschke and Paszkiewicz, 2013). The optimum planting date was April 16 for the central Corn Belt and April 30 for the northern Corn Belt. Yield declined for planting dates following the optimum window and the rate of yield decline increased with delay duration. The yield penalty associated with delayed planting was greater in the northern Corn Belt where the growing season is shorter. Yield of corn planted four weeks following the optimum date was reduced by 7% in the central Corn Belt, compared to over 15% in the northern Corn Belt (Figure 1).
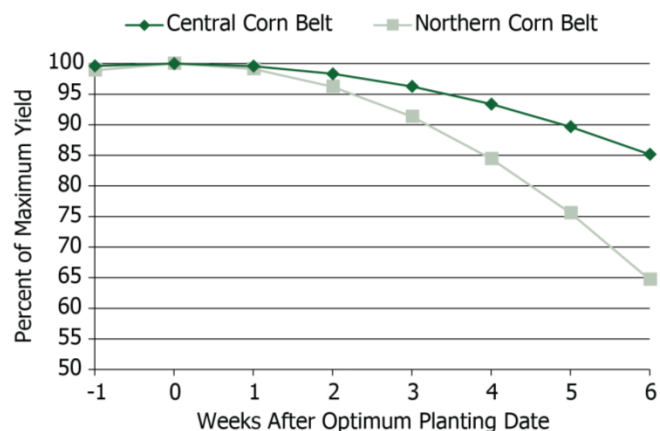

Figure 1. Planting date effect on corn yield for the central and northern Corn Belt, based on DuPont Pioneer planting date studies conducted at 17 locations over 18 years.

(Central Corn Belt locations in NE, central IA, central IL, and central IN. Northern Corn Belt locations in northern IA, southern and central MN, southwest SD, central MI, and southern ON.)

Factors that influence planting timing

The ability to get corn planted within the optimum planting window is largely driven by weather conditions during this time. The number of suitable days can vary greatly from year to year. For example, an analysis of USDA data by Irwin and Good (2014) showed that the number of days suitable for fieldwork in Illinois from 1970-2013 during the three weeks spanning April 30 to May 20 ranged from as many as 19 to as few as 4 across these years (Figure 2). On average, slightly over half (11.5) of the days in the three-week period were suitable for field work.
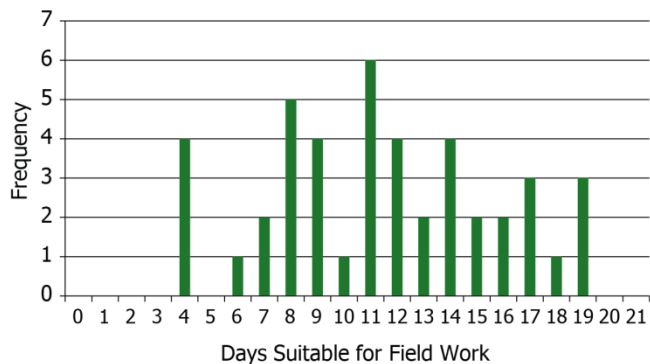
Figure 2. Number of days suitable for fieldwork in Illinois during April 30 – May 20 from 1970 to 2013.

It is commonly believed that larger planters and improved technology have increased the pace at which the U.S. corn crop can be planted, although examinations of USDA planting data have shown this is not actually the case (Irwin and Good, 2011; Kucharik, 2006). Although larger planters have enabled a single operator to cover more acres in a day than was possible in the past, the total number of planters in use has declined as farm operations have consolidated. Planting data show that, in general, the U.S. corn crop is planted much earlier now than it was 30 years ago; however, the pace at which it is planted has not accelerated, and weather is the primary factor that determines planting pro-gress. Since yield losses only occur on acres planted fol-lowing the optimum window, typical farm-wide yield losses due to planting delays likely average no more than 2-5%.

3. Achieve the Correct Population

Unlike planting timing, which is often heavily influenced by weather conditions, plant population is a yield determining factor largely within the control of the grower. Determining and achieving the ideal population to maximize yield is complicated however, as the optimum population in a given situation can be influenced by a number of factors such as yield level, hybrid, and weather conditions.
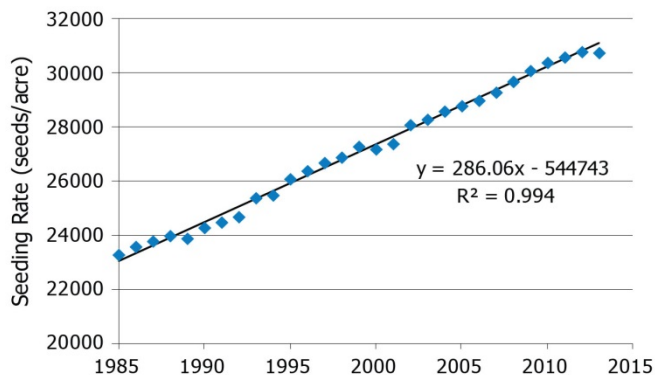

$$y = 286.06x - 544743$$
$$R^2 = 0.994$$

Figure 3. Average corn seeding rates reported by growers in North America, 1985 to 2013. Source: DuPont Pioneer Brand Concentration Survey 2013.

In general, optimum populations for corn have steadily increased over time. Higher populations accompanied by improved stress tolerance in hybrids have contributed to

incremental yield gains. Average corn seeding rates used by growers in the U.S. and Canada have increased from about 23,000 seeds/acre in 1985 to over 30,000 seeds/acre today or approximately 300 seeds/acre per year (Figure 3).

Factors that can influence optimum population

Yield Level: DuPont Pioneer and university studies have shown that corn hybrid response to plant population varies by yield level. The population required to maximize yield increases as yield level increases. When grouped by yield level, results from DuPont Pioneer plant population trials showed that the economic optimum seeding rate increased from approximately 27,000 seeds/acre at yield levels below 130 bu/acre to over 38,000 seeds/acre at yield levels above 250 bu/acre (Figure 4). An Iowa State University study comparing corn yield response to plant population across soils with different corn suitability ratings found similar results. The most productive soils tended to have a higher optimum population for maximum yield (Woli et al., 2014).
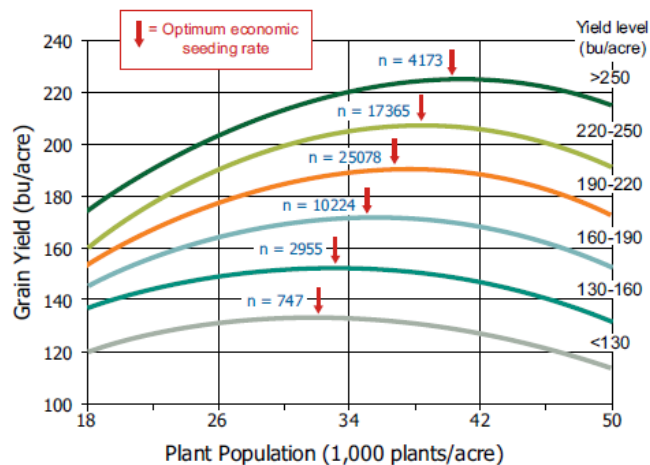

Figure 4. Corn yield response to population and optimum economic seeding rate by location yield level, 2006 to 2012.

Hybrid Maturity: Research has shown that early maturity hybrids (<100 CRM) may require higher populations to maximize yield. Figure 5 shows the yield response of hybrids to plant population grouped by CRM range in DuPont Pioneer trials conducted from 2006-2012.
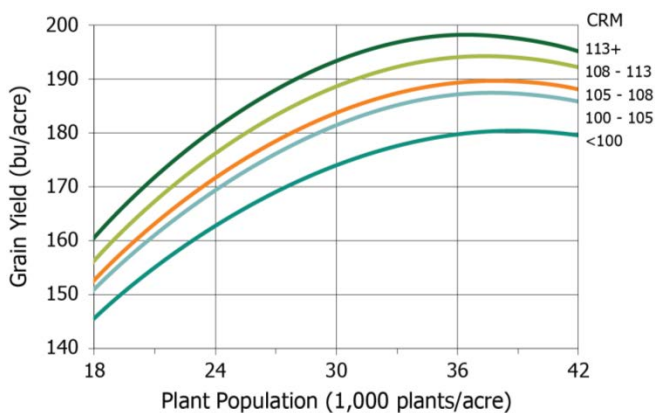

Figure 5. Yield response to plant population for corn hybrids from five maturity (CRM) ranges, 2006 to 2012.

Although this trend can still be detected when examining the response curves closely, it is a smaller difference than in the past. This change may be the result of different genetic backgrounds predominant in early maturities historically vs. currently, or other unknown factors.

Hybrid Genetics: Yield response to plant population can also vary based on hybrid genetics. Figure 6 shows an example of two hybrid families with the same CRM that have been shown to differ in their response to plant population in DuPont Pioneer research trials. One hybrid family (Pioneer® hybrid P1142) has a plant population response that is typical of current 111 CRM hybrids; whereas the other (Pioneer® hybrid P1151) tends to achieve maximum yield at higher plant populations. DuPont Pioneer offers growers an online planting rate calculator that provides recommendations based on a selected hybrid, grain price, seed cost, and yield level.[5]
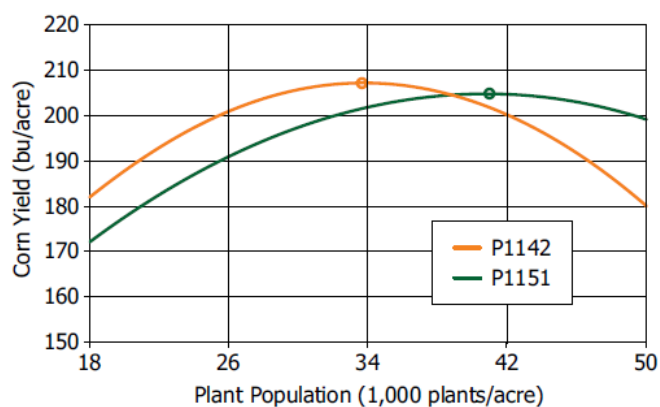

Figure 6. Corn yield response to plant population of two hybrid families with similar comparative relative maturity.

Yield impact of high or low population

A plant population that is too high or too low can negatively impact yield. A low population may limit yield potential when growing conditions are favorable, while a high population may result in reduced performance and standability under stress conditions. In general however, modern hybrids tend to have a relatively wide margin of error when it comes to ideal population. For example, both of the hybrid families shown in Figure 6 could be as much as 4,000 plants/acre over or under the optimum population and still have less than 2 bu/acre variation in yield.

One reason for this is the improvements in stress tolerance that have resulted from decades of targeted breeding. A common stress response of older corn hybrids was "barrenness," or the inability to produce an ear. Even as recently as 30 years ago, some of the best hybrids were prone to barrenness when population thresholds were exceeded. Modern corn hybrids are better able to produce an ear under moisture and density stress, even though ears are progressively smaller under increasing stress. This means that when plant density optimums are exceeded, yields tend to level off rather than drop abruptly. This hybrid

characteristic has changed the risk/reward equation in the growers' favor. Because the risk that excess populations will decrease yields under dry conditions is reduced, growers can more confidently plant higher populations that support increased yields when favorable conditions develop.

4. Achieve Uniform Plant Spacing

Growers instinctively prefer corn stands with uniform plant-to-plant spacing. A "picket-fence" stand is both aesthetically pleasing and presumably higher yielding.

How is plant spacing uniformity measured?

Seeding specialists and agronomists have long used two related statistics, coefficient of variation (CoV) and standard deviation (SD), as the preferred metrics to quantify meter performance and plant spacing uniformity. A SD value of 2.0 inches or the corresponding CoV value of 0.33 are widely cited as the thresholds above which, corn yield loss would be expected (Nielsen, 2001). The CoV is easily calculated by dividing the SD by the average plant spacing. For example, the SD corresponding to a CoV of 0.33 at an average spacing of 6.0 inches is 2.0 inches. More recently, engineers have also devised a "singulation" metric as an indicator of seed spacing uniformity, although there is no industry standard as to how it is calculated.

Spacing metrics poorly correlated to yield

Agronomists have long known that the various planting outcomes that result in increasing CoV and SD, and declining singulation values can have widely different impacts on resulting individual-plant grain yield (Nafziger, 1996; Doerge et al., 2002 and Nafziger, 2006). Thus, the use of easy-to-measure plant spacing metrics that are poorly correlated with individual plant yields has unfortunately created a tradeoff between convenience and accuracy. This has no doubt contributed to inconsistent results in past research seeking to explain the impact of within-row plant spacing on corn grain yield (Krall, 1977; Nafziger, 1996; Nielsen, 2001; Doerge and Hall, 2000; Doerge et al., 2002; Lauer and Rankin, 2004; Liu et al., 2004a, 2004b, 2004c; Nielsen, 2006).

Table 1. Corn grain yields resulting from various planting outcomes. Yield impacts are averaged across four study locations.

Planting Outcome	Plant Spacing			Loss/Gain in Grain Weight**	Grain Yield ***
				lbs. of grain	% of yield @ perfect spacing
Perfect Spacing				0	100
% yield*	100	100	100		
Skip				-0.26	73
% yield	110		110		
Double				0.13	113
% yield	100	70 70	100		
Seed Misplaced by ¼				0	101
% yield	98	101	104		
Seed Misplaced by ½				0	100
% yield	94	98	108		
Seed Misplaced by ¾				-0.04	96
% yield	87 88		112		

*% Yield of individual plants compared to plants at perfect spacing.
**The gain or loss of yield of the 2-, 3- or 4-plant groupings depicted in Table 1 compared to 3 plants at perfect spacing.
***The yield of the 2-, 3- or 4-plant groupings depicted in Table 1 as a % of 3 plants at perfect spacing.

Individual plant yield determinations provide new insights

A 2002 DuPont Pioneer study (Doerge et al.) uniquely allows for quantifying the impacts of common and realistic non-ideal planting outcomes on grain yield. This study was conducted in four different environments (two in Iowa, one in Missouri and one in Minnesota), across a wide yield range of 109 to 206 bu/acre, and using hybrids with three very different genetic pedigrees. In this study, within-row spacing measurements and grain yields were determined on >6,000 individual plants.

Major Findings:

1) As expected, differences in grain yields resulting from common non-ideal planting outcomes were indeed observed and are listed in Table 1.
2) These non-ideal planting outcomes typically, but not always, resulted in lower grain yield. The notable exception is that a double slightly increased yield. But yield losses for all other planting outcomes varied over a rather wide range, from zero to -0.26 lbs. grain for the two- or three-plant groupings depicted in Table 1.

3) By far, a skip is the planting outcome that contributes the most to yield loss. Plants adjacent to a skip only partially compensate for the missing plant.

4) In general, yield loss due to misplaced plants is negligible if plants are displaced from their preferred location by no more than ½ of the normal plant-to-plant distance.

Conclusions:

1. The CoV and singulation readings on the planter monitor are valuable real-time indicators of meter performance but poor predictors of the agronomic consequences of common, realistic non-ideal planting outcomes.

2. **The planting outcome causing the greatest yield loss is % skips**. A skip is defined as an in-trench distance between seeds of ≥1.75 times the desired plant-to-plant distance (for example, at 34,848 plants/acre in 30-inch rows, the average distance between seeds or plants would be 6.0 inches, and a skip would therefore be a plant-to-plant distance of ≥1.75 x 6.0, or 10.5 inches).

3. Not all skips are caused by the planter. Missing plants resulting from unsuccessful germination or emergence will reduce grain yield just as much as planter skips and are to be equally avoided. <u>Emerged</u> plant spacing, along with population, gives the best prediction of yield performance.

4. <u>**Occasional**</u> **doubles do not negatively impact yield**. A true planter double, or two seeds held in one cell of the planter meter, is not necessarily a bad thing. First of all, there is at least enough increase in yield from a double to offset the cost of the extra seed that is being planted. And if having an occasional double (i.e. 1-2%) helps ensure fewer or no skips, then such an outcome would be preferred. This would be the case if adjusting the planter vacuum setting upward could reduce the occurrence of empty cells, even if the higher vacuum setting increases doubles slightly.

Table 2. The contribution of five common non-ideal planting outcomes to two statistics used to describe seed and plant spacing uniformity, including Coefficient of Variation and Standard Deviation.

Planting Outcome	Resulting CoV*	Resulting SD*	Resulting Yield Loss or Gain*
		inches	bu/acre
Perfect spacing	0	0	0
1% Skips	0.10	0.78	-1.3
1% Doubles	0.10	0.78	+0.7
1% Seed Misplaced by ¼	0.04	0.28	0
1% Seed Misplaced by ½	0.07	0.55	0
1% Seed Misplaced by ¾	0.11	0.83	-0.2

*Compared to perfect plant spacing.
Plant population assumed = 34,848/acre or mean spacing = 6.0 in.

Past inconsistent research results explained

There are several explanations for the lack of agreement in the results from past plant spacing studies, which were all conducted by highly-qualified researchers. First of all, different planting outcomes that contribute to SD, CoV or singulation can have completely different effects on individual plant yield (Table 2). Skips are highly detrimental to yield, doubles can be slightly positive, and misplaced plants have no effect on yield until plants are displaced from their preferred location by more than 1/2 the normal plant-to-plant distance. Second, no two fields can be expected to have the same amount or combination of non-ideal planting outcomes. Thus, it is no wonder that comparisons from aggregated, plot- or field-wide plant spacing studies are contradictory if the sources of plant spacing non-uniformity are not considered. Unfortunately, this lack of consideration has been true of most plant spacing studies.

Other sources of confounding include the manner in which some field experiments have been conducted. For example, some studies have used highly artificial groupings of plants to achieve pre-determined levels of plant spacing variability. In addition to being unrepresentative of "real-world" conditions, they often employ only different levels of misplaced plants (no skips or doubles) to achieve the desired spacing treatments. Tables 1 and 2 indicate that these types of plant arrangements will have little to no impact on yield. Other plant spacing studies may have been compromised by the use of overplanting and thinning to achieve the desired plant spacing arrangements and populations. These practices are potentially confounding because corn plants can sense the presence of neighboring plants beginning very shortly after emergence due to subtle differences in the ratios of red: far red light they receive (Liu et al., 2009). These light quality differences can act as an early signal of pending competition that can initiate a shade avoidance response in the remaining plants. Thus overplanting and thinning can unintentionally result in plants that have been pre-conditioned to exhibit less favorable crop architecture and lower grain yield potential.

In contrast, when individual plant yields arising from different planting outcomes <u>are</u> considered, research results have been amazingly consistent. For example, Nafziger (1996) found that 10% skips in four Illinois experiments resulted in an average 8.1% decrease in yield (at 30,000 plants/acre) while the findings from the DuPont Pioneer study (Doerge et al., 2002) measured a corresponding 8.9% yield decrease (at a similar plant population). Likewise, the Illinois studies measured a yield increase of 4.2% for 10% doubles while the Pioneer data revealed a 4.7% yield increase. These similarities are notable since the genetics used in these two sets of experiments were released at least a decade apart.

Clearly, the key messages on within-row plant spacing uniformity are: 1) it <u>does</u> impact grain yield and can be explained, 2) whole-field impacts on grain yield are usually relatively small, averaging about 1 to 2%, and 3) growers should work to minimize or eliminate skips and not worry about occasional doubles or slightly misplaced plants.

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[5] https://www.pioneer.com/home/site/us/agronomy/tools/plantingratecalculator/