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YIELD AND QUALITY IMPROVEMENT OF SIGNIFICANT D&PL VARIETIES DURING THE LAST 25-YEARS

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Abstract

The US cotton production system has experienced many changes in recent decades. Technologies such as improved insect control (boll weevil eradication in many areas, in plant worm control with Bollgard®, and new chemistries), more weed control options including chemistries and transgenic herbicide tolerant cottons, improved seed treatment fungicides, increased acres with irrigation capacity, and reported improvements in varieties through breeding should have all contributed to potential yield improvement on the farm. Reports of yield stagnation and a decline in fiber quality were common points of discussion and interest during the late 1990's and early 2000's. It is a challenge for researchers to compare results over sufficient geographies and years to determine any real change due to varieties. Delta and Pine Land Company has an aggressive testing program that includes results from on-farm large plots tests with grower cooperators, small plot testing by the company, and University official variety trials. Additionally, beginning in 1994, the company has accumulated all available sources of variety testing data (company and public) into one common database and has developed query tools to extract and analyze variety performance data. This extensive database was used to analyze the yield and fiber quality of 45 D&PL varieties released between 1981 and 2005 to demonstrate variety contribution to yield and fiber quality. Data was analyzed by two methods. One included 89,135 head-to-head (H2H) comparisons from 565 different variety comparison combinations (two varieties at a time using only data where both varieties were in the same trial – environment). The second method utilized SAS-GLM for calculating Least Square Means (LSM) by dividing the 45 varieties up into four groups based on its year of release and comparing adjacent year groupings. Four groups result in three comparisons of adjacent groups. A total of 1557 test locations from 1994 to 2005 met the criteria for use in this analysis. Both methods for estimating genetic progress resulted in nearly identical results for estimated yield improvement. G2 (1989 to 1995) showed yield improvement averaging about 3.1 lbs/A/yr over G1 (1981 to 1988). G3 (1996 to 2000) had yields that averaged 3.3 lbs/A/yr over G2. G4 (2001 to 2005) had yields that averaged 15.0 lbs/A/yr over G3. Fiber quality was only evaluated using LSM generated using SAS-GLM. G2 vs G1 showed modest improvements in length, strength, and uniformity, but had a small increase in micronaire. G3 vs G2 was the opposite showing modest declines in length and strength, no change in uniformity, but a small decline in micronaire. The recent five years (G4 vs G3) demonstrate an average increase in 0.1 (0.003 inches) staple/yr, strength has increased 0.06 g/tex/yr, micronaire has decreased by 0.01/yr, and uniformity has improved by 0.015/yr. Over the 25 year period significant progress has been made in both yield and fiber quality. Most of that progress has been made in the last five years.

Introduction

The concept of a US yield plateau with negative changes in fiber quality was a significant point of discussion at the end of the century and during the early years of the 21st century. Data to support these concerns have been summarized by Meredith 2002 and 2003; and Lewis 2003. Transgenic technologies were introduced commercially in 1996. Detailed yield and fiber quality comparisons of seven D&PL variety sets (conventional parent, Bollgard®, Roundup Ready®, or stacked trait version), grown in multiple locations and years showed differences to be of minor magnitude and the result of plant selection in a backcross breeding program (Kerby et al. 2000). Lege et al. (2001) reported similar results. Stability of the conventional parents and transgenic versions were shown to be identical (Kerby et al. 2001). Yield and fiber quality of the 58 varieties that were planted on the most US acres during the period 1995 to 2001 showed an average yield increase of 5.9 lbs/A/yr, but a reduction of 0.05 staple/yr and an increase of 0.013 micronaire/yr during the period due to varieties selected by growers (Kerby et al. 2002).

Delta and Pine Land Company have reported variety releases in recent years that have shown substantial improvement in yield while at the same time improving fiber quality over popular varieties during the late 1990's (Lege et al., 2003; Lege and Leske, 2003; Lege and Williams 2004; Lege and McGowen, 2005; and Speed et al., 2005). Delta and Pine Land Company has extensive on farm variety testing and tests these same varieties in public sector trials. D&PL has developed proprietary software that allow for data storage of all public official variety trials

and its own research and on-farm testing. This manuscript will review data for 45 D&PL varieties released between 1981 and 2005 and make direct comparisons of yield and fiber changes over the past 25 years.

Materials and Methods

Forty-five significant D&PL varieties released for commercial sale between 1981 and 2005 are included in this analysis. These varieties were divided into four time periods based on year of release: Group1 (G1) = 1981 to 1988; group 2 (G2) = 1989 to 1995; group 3 (G 3) = 1996 to 2000; and group 4 (G4) = 2001 to 2005 (see Table 1 for variety grouping and year of release). The first two groups contained only conventional releases. G3 is dominated by transgenic versions of many of the conventional materials in G1 or G2. G4 represents new germplasm, most of which have transgenic traits.

Yield trends were established by two different methods for comparison. One method was to compare adjacent groups using SAS-GLM computing a Least Square Mean (LSM). Three varieties are in G1, six varieties for G2, twenty varieties for G3, and sixteen varieties for G4. For the G1 vs G2 comparison, locations were excluded unless number of varieties present was five or more; for G2 vs G3, or G3 vs G4, a minimum of 10 varieties had to be present in a test location to be considered in the analysis. All sources of data were considered across all regions of the US, and for all years from 1994 to 2004. D&PL large plot on-farm data accounted for 49% of the total data, University small plot OVT's 34%, D&PL small plots 10%, and University County Agent large plot trials 7%. Orthogonal contrasts were made between varieties where LSM's were calculated for all varieties of adjacent group comparisons (G1 vs G2; G2 vs G3; and G3 vs G4). An "F" value was calculated for the orthogonal contrast (for example the varieties of G1 contrasted as a group against the varieties of G2, etc.) and the P>F was computed for the three sets of variety comparisons. Group (year) contrasts were made for lint yield, fiber length, fiber strength, micronaire, and uniformity.

Yield comparisons between groups were also compared using only balanced head-to-head (H2H) data. As with the other method, this method also utilized all sources of data from all regions of the US for the years 1994 to 2005. This method utilized all H2H data for the various combinations of the 45 varieties where the varieties were not released in the same year. A difference between two varieties was calculated as pounds of lint/A/year for the difference. The data contained a total of 565 sets (number of combinations of two varieties) of H2H's with a total of 89,135 H2H comparisons. A H2H comparison of varieties was not included unless it contained a minimum of 15 locations.

Results and Discussion

Average US Grower Yield Over Time from USDA-AMS data

Yields from 1865 to about 1935 were essentially flat. Since that time, there has been progress. There have been some periods of step increase, and some periods with what appears to be a flat line. During this time there have been many changes. Meredith (2002) listed some of the changes as technology improvement in diseases, insects, weed control, irrigation, mechanization, and breeding. Another factor for consideration is the basis for calculating yield. Skip row configurations came into calculations of US yield in the late 1950's. Yield was reported on a "planted" acre with the obvious advantage of a 2 x 1 over solid planting, etc.

This manuscript covers yield and fiber quality changes due to varieties during the past 25 years. In this time interval US average grower yields have been correlated to year (R^2 = 0.448) and have increased an average of 7.4 lbs/A/yr (Figure 1). As indicated by Lewis (2002), the late 1980's and 1990's do appear to be a period of little to no yield increase. However, the last three years represent the three highest US yields on record. Average yield increase during the past 25 years is close to the average trend of the period 1935 to 2005.

Head-to-Head Variety Comparisons for Lint Yield Progress

Table 2 summarizes lint yield data for various group comparisons. The table is organized into three main groups: Comparisons between adjacent groups (G1 vs G2; G2 vs G3; and G3 vs G4); comparisons between non-adjacent groups (G1 vs G3; G1 vs G4; and G2 vs G4); and comparisons between varieties within the same group, but with a different release date.

Twenty sets of variety contrasts with 3,568 H2H comparisons for G1 vs G2 indicate an average yield increase of 3.0 lbs/A/yr. G2 vs G3 had an average increase of 3.6 lbs/A/yr based on 107 variety contrasts with 9,304 H2H's. Yield increase was greater in the G3 vs G4 contrast averaging 15.3 lbs/A/yr based on 134 variety sets with a total of 29,151 H2H's. These data suggest yield improvement has been higher in the last five years (G4) than for the previous 20 years (G1, G2, and G3). This comparison eliminates differences in technology improvement as described by Meredith 2002 because they are based on H2H comparisons across the country and over years (all 89,135 comparisons are based on the same two paired varieties being grown under the same environmental and management conditions. The "all" summary line at the bottom of Table 2 represents equal weight for each of the 565 variety sets. While it shows the average yield improvement to be 8.6 lbs/A/yr, G3 vs G4 accounts for most of the average increase.

Lint Yield and Fiber Quality Least Square Mean Comparisons for Adjacent Variety Groups

Least Square Means (LSM's) were calculated for all varieties by comparing adjacent groups. G1 vs G2 contained only conventional varieties. Three varieties in G1 were contrasted to the six varieties in G2 (Table 2). Differences between variety groups are highly statistically significant for lint yield and all fiber quality variables. This in part is due to the very high number of test locations in the data, as well as the power of an orthogonal contrast between groups. The average release date of G1 was 1982.3 compared to 1992.0 for G2. The significantly higher yield of G2 by 31 lbs/A, when divided by the difference in the average release year (9.7), results in a lint yield increase that averaged 3.20 lbs/A/yr for G2 over G1. There was a modest increase in fiber length averaging 0.0008 inches per year. While statistically significant, this rate of increase would require 39 years to increase the average staple length by 1 (0.031 inches). Strength increased an average of 0.082 g/tex/yr. This is a modest change and would require 12 years to increase the average strength by 1 g/tex. Micronaire increased an average of 0.011/yr and at this rate would raise micronaire by an average of 0.1 in 9 years. Uniformity increased at a rate of 0.02 per year. While significant, this is a modest difference that would require 50 years to raise the uniformity by 1.

G2 vs G3 has two different sets of contrasts listed in Table 4. G2 contains only conventional varieties while G3 is comprised of six conventional varieties and fourteen transgenic varieties. The first set is for all varieties (six in G2 vs twenty in G3) while the second set of orthogonal contrasts in Table 4 are for conventional varieties only (six in G2 vs six in G3). Differences between G3 and G2 were significant for yield and all fiber quality measures except uniformity. Lint yield increased at an average rate of 3.03 lbs/A for all varieties, but 6.34 lbs/A when comparing only conventional varieties. This suggests an improvement in the genetic gain of conventional materials over the previous period, but also demonstrates the lag time associated with bringing transgenic varieties to the market. Fiber length for G3 compared to G2 decreased an average of 0.001 inches/yr for both conventional only or all varieties. While statistically significant, it is a modest change that would require 31 years of the same trend to decrease staple length by 1. Fiber strength decreased an average of 0.045 g/tex/yr for all varieties, but increased by nearly the same amount for the conventional only comparisons of G3 vs G2 (Table 4). Micronaire comparisons of G3 vs G2 showed a significant, but modest decline of 0.005/yr for all varieties but a modest increase of 0.008/yr for conventional only contrasts. Uniformity of G3 vs G2 were not different when comparing all varieties, but G3 had an average increase of 0.052/yr compared to G2 when only conventional contrasts were considered.

G3 vs G4 has two different sets of orthogonal contrasts listed in Table 5. The first is for all twenty varieties in G3 contrasted to all sixteen varieties in G4, while the second is for six conventional varieties in G3 contrasted with the four conventional varieties in G4. G4 showed a highly significant increase of 14.7 lbs/A/yr for all varieties as well as conventional only. This increase is much higher than noted in the previous period, and the rate of increase is similar for transgenic and conventional varieties indicating a mature breeding effort for varieties containing one or both of the transgenic genes. Fiber length increased an average of 0.003 inches/yr for all varieties and 0.008 inches/yr for conventional varieties. While highly significant, the increase for conventional varieties is of commercial importance and at the same rate would increase staple length by 1 in four year. Fiber strength improved an average of 0.062 g/tex/yr for all varieties and 0.127 g/tex/yr for conventional varieties. Micronaire declined for both sets of contrasts (all varieties and conventional) while uniformity slightly improved for all varieties, but declined slightly in conventional varieties.

Discussion and Conclusions

Yield improvement was demonstrated by two methods that are in substantial agreement. Yield of varieties in G2 increased over varieties in G1 by an average of 3.0 lbs/A/yr in H2H data and by 3.2 where least square means were contrasted between the groups. G3 yield (for all varieties as this was the only way H2H data were accumulated) increased over G2 by an average of 3.6 lbs/A/yr compared to 3.0 lbs/A/yr where least square means were contrasted between the groups. G4 yield increased over G3 by an average of 14.7 lbs/A/y compared to 15.3 lbs/A/yr where least square means were contrasted between the groups. These are very similar and demonstrate the utility of least square means estimating the differences between varieties as long as the sample size is adequate. The average yield increase was 0.8%/yr over this 25 year period, but averaged 1.3%/yr in the recent five years. Other researchers have reported improvements in corn and soybeans. Niebur et al. (2004) reported corn yields have improved an average of 1.0%/yr from 1930 to the present. Soybean yields have been reported to be increasing at a rate of 0.6%/yr in the Southern USA (Ustun et al., 2001), and roughly 1%/yr in the Northern USA and Canada (Wilcox 2001). The average genetic gain for these 45 Delta and Pine Land Company varieties for cotton demonstrate progress that is equivalent to that noted for corn and soybeans.

Figure 2 summarizes the yield gains through the years apparent in the forty-five D&PL varieties in this study. The data in Figure 2 is based on the LSM of varieties between adjacent group contrasts (comparing varieties of the same color grouping to the adjacent color grouping). This figure clearly demonstrates minimal gains in yield with new variety releases until the late 1990's when yield improvement for new variety releases has been rapid. Fiber quality trends were only calculated using LSM analysis of the four groupings by year of release. Trends in fiber quality over the 25-year period indicate generally similar fiber length until a small decrease in the late 1990's followed by fiber length improvement since 2000. Fiber strength has been a little more variable and decreased in the late 1990's but has increased in the last five years. Micronaire was lower in the early 1980's but increased in the late 1980's and 1990's, but has declined significantly with the new variety releases since 2000. Uniformity was lowest in the early 1980's, but while variable has shown modest increases during recent years.

Yield and fiber quality of the most significant D&PL varieties released during the past 25 years quantitatively demonstrate that recent releases have both outstanding yield and fiber quality potential. Recent years results (G4 or 2001 to 2005) are significantly improved over previous years and demonstrate the contributions of eleven coordinated worldwide cotton breeding efforts of Delta and Pine Land Company that are focused on germplasm improvement.

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Table 1. Forty-five D&PL varieties according to year of commercial release (color coded groupings) and the number of trial locations for each variety.

Variety	No. Tests	Year of Release	Variety	No. Tests	Year of Release	Variety	No. Tests	Year of Release
DP 90	484	1981	DP 5690 RR	660	1997	DP 565	576	2001
DP 20	458	1983	SG 821	545	1997	PM 1199 RR	600	2001
DP 50	640	1983	DP 436 RR	1293	1998	SG 215 BG/RR	1204	2001
DP 51	932	1989	DP 458 B/RR	1659	1998	DP 449 BG/RR	947	2002
DP 5415	943	1990	DP 655 B/RR	751	1998	DP 555 BG/RR	1241	2002
DP 5690	538	1990	DP 388	453	1999	DP 424 BGII/RR	432	2003
DP 5409	902	1994	DP 451 B/RR	1712	1999	DP 444 BG/RR	850	2003
SG 501	766	1994	DP 675	373	1999	DP 493	354	2003
SG 125	1164	1995	PM 1218 BG/RR	1333	1999	DP 432 RR	333	2004
NuCOTN 33 B	1663	1996	PM 1560 BG/RR	529	1999	DP 434 RR	299	2004
NuCOTN 35 B	686	1996	SG 747	1200	1999	DP 488 BG/RR	342	2004
DP 20 B	820	1997	SG 105	771	2000	DP 494 RR	325	2004
DP 50 B	287	1997	SG 501 BR	1033	2000	DP 393	248	2005
DP 5111	506	1997	SG 521 R	783	2000	DP 445 BG/RR	249	2005
DP 5415 RR	1217	1997	DP 491	683	2001	DP 455 BG/RR	263	2005
Group 1			Group 3					
Group 2			Group 4					

Table 2. Average yield increase between various year group comparisons using all sources of data for all years of testing (1994 to 2005) using the H2H method.

Group	# Var Sets	# H2H Trials	Lint Yield	Yr Rel	Group	Yield	Yr Rel	Delta # Years	Lbs/A/yr >	% per Yr
1	**20**	**3,568**	**906.1**	**1982.2**	**2**	**934.8**	**1991.8**	**9.6**	**3.0**	**0.32**
2	**107**	**9,304**	**983.8**	**1992.1**	**3**	**1005.0**	**1998.0**	**5.9**	**3.6**	**0.36**
3	**134**	**29,151**	**1071.5**	**1998.3**	**4**	**1137.2**	**2002.6**	**4.3**	**15.3**	**1.35**
1	51	2,512	939.5	1982.3	3	998.7	1998.0	15.7	3.8	0.38
1	5	220	985.0	1981.0	4	1128.4	2001.2	20.2	7.1	0.63
2	10	492	1096.4	1991.2	4	1227.3	2001.1	9.9	13.2	1.08
2	13	3,060	932.2	1990.2	2	957.2	1993.8	3.5	7.1	0.74
3	134	23,701	975.4	1997.1	3	997.0	1998.9	1.8	12.3	1.24
4	91	16,985	1163.8	2002.1	4	1194.3	2004.0	1.9	15.8	1.32
All	**565**	**89,135**	**1030.1**	**1995.3**	**All**	**1072.9**	**2000.3**	**5.0**	**8.6**	**0.80**

Table 3. Average yield and fiber quality of the three D&PL varieties released between 1981 and 1988 (G1) orthogonally contrasted to the six D&PL varieties released between 1989 and 1995 (G2) based on 568 test locations across the US between 1994 and 2000 using GLM-Least Square Means.

Variety	Yr Rel	Lint	Length	Strength	Mic	Unif
Group 1	1982.3	928.6	1.102	28.57	4.30	82.27
Group 2	1992.0	959.6	1.109	29.36	4.41	82.46
Contrast F		76.1	34.9	192	126	14.6
Contrast p > F		$4x10^{-18}$	$4x10^{-9}$	$7x10^{-42}$	$2x10^{-28}$	0.0002
Mean Change Per Year		3.20	0.0008	0.082	0.011	0.020

Table 4. Average yield and fiber quality of the six D&PL varieties released between 1989 and 1995 (G2) orthogonally contrasted to the twenty D&PL varieties released between 1996 and 2000 (G3) based on 374 test locations across the US between 1996 and 2002 using GLM – Least Square Means.

Variety	Yr Rel	Lint	Length	Strength	Mic	Unif
Group 2 All	1992.0	969.4	1.111	29.35	4.50	83.09
Group 3 All	1998.1	987.9	1.102	29.07	4.47	83.08
Contrast F		22.3	57.4	27.6	10.2	<1
Contrast p > F		$2x10^{-6}$	$5x10^{-14}$	$2x10^{-7}$	0.0014	NS
Mean Change Per Year		3.03	-0.001	-0.045	-0.005	-0.001
Group 2 Conv.	1992.0	969.4	1.111	29.35	4.50	83.09
Group 3 Conv.	1998.5	1010.6	1.103	29.61	4.56	83.43
Contrast F		79.2	26.3	18.3	20.2	69.6
Contrast p > F		$8x10^{-19}$	$3x10^{-7}$	$2x10^{-5}$	$7x10^{-6}$	$1x10^{-16}$
Mean Change Per Year		6.34	-0.001	0.040	0.008	0.052

Table 5. Average yield and fiber quality of the twenty D&PL varieties released between 1996 and 2000 (G3) orthogonally contrasted to the sixteen D&PL varieties released between 2001 and 2005 (G4) based on 615 test locations across the US between 1998 and 2004 using GLM – Least Square Means.

Variety	Yr Rel	Lint	Length	Strength	Mic	Unif
Group 3 All	1998.1	1042	1.111	29.73	4.44	83.06
Group 4 All	2003.0	1114	1.124	30.03	4.39	83.13
Contrast F		292	260	45.4	32.1	5.5
Contrast p > F		$2.7x10^{-64}$	$2.1x10^{-57}$	$1.7x10^{-11}$	$1.5x10^{-8}$	0.019
Mean Change Per Year		14.72	0.003	0.062	-0.010	0.015
Group 3 Conv.	1998.5	1058	1.114	30.34	4.51	83.40
Group 4 Conv.	2002.5	1117	1.144	30.85	4.45	83.16
Contrast F		62.3	459	37.6	14.6	19.5
Contrast p > F		$3.4x10^{-15}$	$1.9x10^{-98}$	$9.1x10^{-10}$	0.0001	$1x10^{-5}$
Mean Change Per Year		14.73	0.008	0.127	-0.014	-0.062

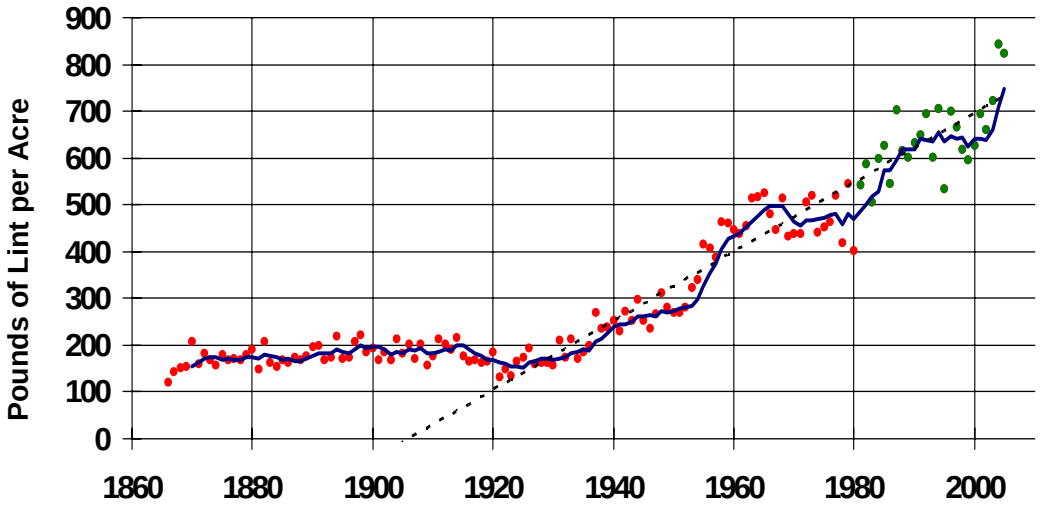

Figure 1. US yield data from the USDA National Agricultural Statistic Services. Year 2005 is the December estimate. The solid line represents a running 5-year average. For the period 1981 through 2005 (green dots) yield increased an average of 7.4 lbs/A/yr (R^2 = 0.448). The dashed line represents the regression line (for 1981 to 2005) extended back to earlier years.

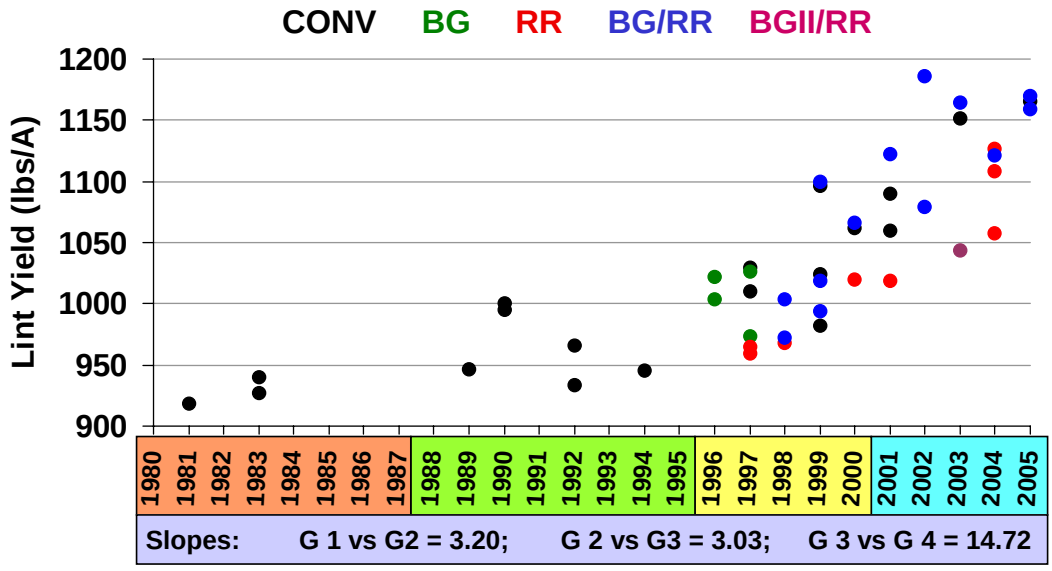

Figure 2. Least Square Mean Lint Yield for the 45 significant D&PL varieties released between 1981 to 2005.