1681 Varietal Contributions to Changes in Yield and Fiber Quality in Recent Decades

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ABBREVIATIONS

D&PL for Delta and Pine Land Company

OVT for University Official Cultivar Trials

LSM for Least Square Mean

ABSTRACT

Yield and quality of US Cotton (*Gossypium hirsutum* L.) has been widely discussed the past decade. Since 1993, D&PL has maintained a data base comprised of company and university data. This database was used to compare cultivar yield and quality by year of first commercial sale according to four time groups: Group 1 (prior to 1996); Group 2 (1996 to 1998); Group 3 (1999 to 2001); and Group 4 (2002 to 2005). Orthogonal contrasts were made comparing all cultivars between adjacent groups as well as between D&PL and non-D&PL cultivars within a time group. Yields increased an average of only 1.4 kg lint yr^{-1} between Group 1 and 2 with modest fiber quality improvement. Yield increased 35.8 kg lint yr^{-1} between Group 2 and 3, but had reduced fiber quality. Between the last two groups, yield increased an average of 9.1 kg lint yr^{-1} with substantial fiber quality improvement. Only slight differences in yield were observed among D&PL and non-D&PL cultivars for Groups 1, 2, and 3. However, D&PL cultivars had an average advantage of 64 kg lint ha^{-1} for the recent Group 4. Average fiber quality of D&PL cultivars was marginally higher in Group 1, but lower in Group 2 and 3 compared to other non-D&PL cultivars. For the recent Group 4, D&PL culitvars had slightly better length and length uniformity, similar micronaire, but lower strength than other cultivars. When lint yield gross return was estimated according to the 2006 loan rate within Group 4 cultivars, D&PL cultivars returned an average \$71.36 ha^{-1} more than non-D&PL cultivars.

KEYWORDS: cotton, fiber quality, cultivar, yield

INTRODUCTION

Many segments of the industry have expressed concern about the yield and fiber quality of US cotton during the recent decades. Data to support these concerns have been summarized by Meredith (2002 and 2003); and Lewis (2003). Detailed yield and fiber quality comparisons of seven D&PL cultivar sets (conventional parent, Bollgard®, Roundup Ready®, or stacked trait version), grown in multiple locations and years suggested 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. Hequet and Ethridge (2002) confirmed the equivalency of fiber quality for transgenic versions compared to their conventional parents. Stability of the conventional parents and transgenic versions were shown to be identical (Kerby et al. 2001). Yield and fiber quality of the 58 cultivars that were planted on the most US acres during the period 1995 to 2001 showed an average yield increase of 6.6 kg lint ha^{-1} yr^{-1}, but a modest fiber length reduction of 0.04 mm yr^{-1} and an increase of 0.013 micronaire yr^{-1} during the period due to cultivars planted by growers (Kerby et al. 2002).

Meredith (2002) demonstrated from multiple location data that there has been a yield penalty associated with the development of cultivars with high fiber quality traits. In addition, US grower incentive to plant high fiber quality cultivars has not been promoted by historical US cotton loan programs (Lewis 2003). In past history, maximum economic return has been realized from cultivars with the highest yield potential.

D&PL cultivars releasead in recent years have shown substantial improvement in yield while at the same time improving fiber quality over popular cultivars during the late 1990's (Lege et al., 2003; Lege and Williams 2004; Lege and McGowen, 2005; and Speed et al., 2005). Kerby and Hugie (2006) presented a summary of multi–year data for D&PL cultivars that demonstrated yield and fiber quality progress was minimal in the period leading up to transgenic cultivars and in the early years of transgenic cultivars. However, they also reported that in the five previous years, the rate of yield increase was five times greater than in the previous 20 years accompanied by significant fiber quality improvement.

D&PL has developed a proprietary data base system that includes all University Official Cultivar Trial (OVT) data as well as D&PL trial data.. Kerby et al. (2003) has reported good agreement between D&PL and OVT data sources (R^2 ranged between 0.67 to 0.76 depending on Region of the US). This manuscript reports the average change in yield and fiber quality during the past several decades using all popular cultivars sold (not just D&PL as was the case with Kerby and Hugie, 2006) in the picker areas of Texas and East of Texas based upon our proprietary data set.

MATERIALS AND METHODS

To estimate the cultivar contribution to changes in lint yield and fiber quality during recent decades, the most popular cultivars during a common period of years were selected for comparison. The US cotton growing area is diverse with some regions having substantial differences in popular cultivars. Cultivars common to the San Joaquin Valley of California, Southern California and Arizona, the High Desert Areas of New Mexico and Southwest Texas, and the areas where stripper cultivars are more common (High Plains and Rolling Plains of Texas, Oklahoma, and Kansas) are unique. In order to provide a degree of uniformity in the type (picker vs. stripper) cultivars present in a trial, data from the Western Regions described above were excluded from the analysis. A test location was excluded unless there was a minimum of five cultivars present from the pool of cultivars included in a

time period. Cultivars were excluded if they were not present in at least 200 test locations, had approximate proportional representation in D&PL or University data sets, and the cultivar was planted on at least 0.5 percent of the US acres in at least one year. Percentage of acres planted to a cultivar was based upon the USDA-AMS "Cultivars Planted Reports" which is released each August (2006 U.S.D.A. Agricultural Marketing – Cotton Program).

Cultivars were assigned to a year group according to the first year of general availability to growers. Cultivar and year grouping was as follows: Group 1, cultivars before 1996 (before technology introduction); Group 2, cultivars from 1996 to 1998 (new conventional cultivars and cultivars with technology from conventional cultivars released in Group 1); Group 3, cultivars from 1999 to 2001 (new conventional cultivars and cultivars with technology from more recent cultivars); and Group 4, cultivars from 2002 to 2005 (cultivars with technology with more recent genetic backgrounds). Cultivars placed into each year group by brand (company) designation along with their year of first commercial availability are given in Table 1.

For all statistical analyses, JMP 5.2 (2002) from the SAS Institute was employed. Cultivar mean at a location was used as the experimental unit. One-way analysis was used to calculate a General Linear Model for Least Square Means (LSM's) for each cultivar mean using location as replications. We have confidence that cultivar LSM's represent a good estimate of balanced data because of the restrictions applied for inclusion of cultivar and location in the analysis. Additionally, Kerby and Hugie (2006) used all available head to head combinations of 45 cultivars (565 sets of cultivars with 89,135 locations of data) and compared the results to LSM's using a General Linear Model for the same 45 cultivars. The results were nearly identical for both methods. Cultivar LSM's in this study were separated using Student's t. Three sets of analysis were conducted: Cultivar LSM's were calculated for cultivars present in Groups 1 and 2, Groups 2 and 3, and Groups 3 and 4. Orthogonal contrasts were computed for cultivars making up a year group within the two group analysis (for example Group 1 versus Group 2). Orthogonal contrasts were also conducted for D&PL cultivars compared to non-D&PL cultivars within each of the four year groups (see Table 1 for listings).

Both D&PL and University OVT data were used in the analysis. Kerby et al. (2003) demonstrated good agreement between D&PL and University OVT data (R^2 ranged between 0.67 to 0.76 depending on Region of the US). To ensure that this data did not have a cultivar performance bias according to source of data, Groups 3 and 4 were compared using D&PL varietal means and University OVT varietal means. The resulting R^2 of 0.71 (n = 29) demonstrated the same level of agreement between the two data sets as did the previously cited Kerby et al. (2003) data. Group 1 versus Group 2 had a combined 25 cultivars with data from 1264 locations with 55 percent of the data represented by University OVT's. Data were restricted to tests conducted between 1995 and 2001. Group 2 versus Group 3 had a combined 25 cultivars with data from 1378 locations with 63 percent of the data represented by University OVT's. Data were restricted to tests conducted between 1997 to 2002. Group 3 versus Group 4 had a combined 29 cultivars from 2045 locations with 58 percent of the data represented by University OVT's. Data were restricted to test conducted between 1999 to 2006.

Fiber quality analysis for the D&PL samples were from the D&PL HVI line at Scott, MS. All of these samples were spindle harvested and an approximate 4 kg sample of seed cotton was ginned at Scott, MS or Hartsville, SC using a research gin with a lint cleaner. University OVT fiber quality data were generated from various different HVI lines depending on University preference.. For some University OVT's, fiber samples were from spindle harvested samples

run through a research gin with a lint cleaner, but in other states, a small research gin without lint cleaner was used. The 2006 USDA loan chart (**www.plainscotton.org/2006LoanPage.html**) was used to establish loan price.

RESULTS AND DISCUSSION

Change between Group 1 and Group 2

There was a difference of 7.5 years in the average year of first commercial sale for the cultivars comprising Group 1 and Group 2. Lint yield and all fiber quality characteristics showed significant changes for Group 2 compared to Group 1 (Table 2). While they are all statistically significant, some have little agronomic value and are significant because of the high number of locations in the analysis. Yield increased only 10.7 kg ha^{-1} during this period (1.4 kg ha^{-1} yr^{-1}). This modest increase in yield was accompanied by an equally modest increase in average fiber length (0.1 mm), a 4.5 kN m kg^{-1} increase in fiber strength, a 0.06 reduction in average micronaire, and a 0.1 decrease in fiber length uniformity. These quality changes were minor and accounted for a change from an average discount of $0.74 per 218 kg bale to a premium of $0.96 per bale. This swing of $1.70 per bale amounted to an average increase of only $ 0.008 kg^{-1} lint.

For the Group 1 time period, eight D&PL cultivars produced 11.8 kg ha^{-1} less on average than three non-D&PL cultivars (Table 2). D&PL cultivars had slightly longer fiber length (0.2 mm), were 6.4 kN m kg^{-1} lower in fiber strength, averaged 0.06 higher micronaire, and were 0.3 lower in fiber length uniformity, with D&PL cultivars having an average $1.57 less discount per bale than non-D&PL cultivars. For the Group 2 time period, ten D&PL cultivars had equivalent yield to four non-D&PL cultivars (Table 2). D&PL cultivars had statistically lower fiber length, fiber strength, higher micronaire, and lower uniformity than the non-D&PL cultivars. While significant, these differences were minor resulting in only an average difference of $2.75 per bale in premium.

Change between Group 2 and Group 3

There was only a difference of 2.4 years in the average year of first commercial sale for the cultivars comprising Group 2 and Group 3. There were substantial shifts in yield and fiber quality in this average 2.4 year time span (Table 3). Yield increased an astounding 86.0 kg ha^{-1} during this period (35.8 kg ha^{-1} yr^{-1}). This large improvement in yield was accompanied by significant reductions in fiber quality. For Group 3, fiber length decreased by 0.4 mm, fiber strength decreased by an average of 6.4 kN m kg^{-1}, micronaire increased dramatically by 0.20, but fiber length uniformity improved by 0.3. These quality changes resulted in an average decrease in loan price of $4.80 per bale (an average decline of 2.20 cents kg^{-1} lint). However, the decrease of $4.80 per bale was far more than offset by the average increase in yield of 86.0 kg ha^{-1}. Between Group 2 and Group 3 there was a net revenue increase of $74.13 ha^{-1} ($98.61 due to increased yield minus $24.48 for decreased loan value on the average yield) for the cultivars of Group 3 compared to Group 2. This underscores the point made by Lewis (2003) that the level of fiber quality textile mills desired was not being communicated to growers with the proper incentive. Discounts averaged 2.20 cents kg^{-1} during Group 3, but would have needed to be 8.87 cents kg^{-1} to overcome the yield advantage of the cultivars in Group 3.

For the Group 3 time period, seven D&PL cultivars produced an average 9.3 kg lint ha^{-1} more than the four non-D&PL cultivars (Table 3). These D&PL cultivars were 0.2 mm shorter, 14.3 kN m kg^{-1} lower in fiber strength, the same in micronaire, and 0.3 lower in

fiber length uniformity than the non-D&PL cultivars. Average fiber quality applied to the 2006 US loan price would have resulted in an average discount of $2.41 bale for D&PL cultivars and a discount of $2.63 for the non-D&PL cultivars.

Change between Group 3 and Group 4

There was a difference of 4.2 years in the average year of first commercial sale for the cultivars comprising Group 3 and Group 4. There were good increases in yield and substantial fiber quality improvements in the 4.2 year time span (Table 4). Yield increased an additional 37.9 kg ha^{-1} during this period (9.1 kg ha^{-1} yr^{-1}). This good improvement in yield was accompanied by significant improvements in fiber quality. For Group 4, average fiber length increased by 0.4 mm, fiber strength increased by 10.3 kN m kg^{-1}, micronaire declined sharply by 0.30, but fiber length uniformity declined by 0.3. These quality changes resulted in an average improvement in loan price of $3.80 per bale.

For the Group 4 time period, eleven D&PL cultivars produced an average 63.6 kg lint ha^{-1} more than the seven non-D&PL cultivars (Table 4). These D&PL cultivars were 0.2 mm longer, 7.3 kN m kg^{-1} lower in fiber strength, the same in micronaire and fiber length uniformity as the non-D&PLcultivars. The weighting of quality using the 2006 US loan price would have resulted in an average premium of $6.50 per bale for D&PL cultivars compared to $7.12 for the non-D&PL cultivars.

Summary and Discussion

Concerns about US fiber quality and limited genetic gain suggested by many and documented by Meredith (2002 and 2003) during the early years of utilization of transgenic cultivars appears to have been justified. Figure 1 represents a summary of the average $ ha^{-1} based on average yield multiplied by the 2006 US loan rate, plus or minus the premium or discount. Extensive data from thousands of field trials reported herein demonstrate that for the eleven transgenic and three conventional cultivars from Group 2 (1996 to 1998), they had an average increase of only $1.70 ha^{-1} yr^{-1} over Group 1 cultivars. There was minimal change in yield and fiber quality between these two time periods. The new cultivars of Group 2 were almost exclusively transgenic introgressions of conventional cultivars popular during the Group 1 time period. A minimum of four to five years are required to introgress transgenic traits into conventional cultivars. The launch of transgenic cultivars in 1996 would have required the beginning of backcrossing in 1990 to 1991. The similarity of cultivars between Groups 1 and 2 should not be surprising. D&PL and non-D&PL cultivars followed a similar trend in yield and quality.

Group 3 contains seven transgenic cultivars from improved conventional germplasm along with 4 new conventional cultivars. When this newer genetic material was compared to Group 2 there was a large increase in yield averaging 35.8 kg lint yr^{-1}. This increase was associated with a decrease in fiber quality (decreased length and strength and increased micronaire). Yield increase was much larger than the discounts resulting in substantially higher grower returns (Figure 1). Grower plantings of Group 3 cultivars corresponded to the time when cotton merchants and mills expressed concern about the US crop, but growers were following the economics and planting these cultivars which had much higher return. At this same time, US textile mills were in decline and an increasingly larger percentage of US cotton was moving into export markets.

For the most recently released cultivars in Group 4, all eleven D&PL cultivars and the seven other non-D&PL cultivars all contain technology (compare Table 1). These cultivars

represent breeding efforts during the period when investments in cultivar development increased due to higher returns based on transgenic seeds. Group 4 cultivars seem to have satisfied the grower needs as well as mill needs because they represent an increase in yield that averaged 9.1 kg^{-1} yr^{-1} over the Group 3 cultivars that showed such an outstanding yield increase from the previous Group 2. A major difference with the yield improvement in Group 4 was that these cultivars also came with vastly improved fiber quality. Most of the non-D&PL cultivars represent transgenic versions of previously grown conventional cultivars while nearly all of the D&PL cultivars represent technology in new advanced germplasm. The progress of D&PL and non-D&PL cultivars for the previous year groups (Groups 1, 2, and 3) was roughly equivalent. Within Group 4 cultivars, D&PL cultivars averaged \$34.99 ha^{-1} yr^{-1} increase over Group 3 cultivars while the non-D&PL averaged only \$17.87 ha^{-1} yr^{-1}. Average yield of D&PL cultivars was 63.6 kg ha^{-1} more than non-D&PL cultivars with a premium that was only \$0.62 per bale less than the non-D&PL cultivars. The greater yield and value (\$ ha^{-1} yr^{-1}) increase for D&PL cultivars compared to non-D&PL cultivars during the Group 4 time frame provides evidence that the high investment by D&PL in fourteen worldwide breeding programs is bringing new cultivars with technology to the market that meet both grower and mill needs.

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Table 1. D&PL and non-D&PL cultivars (other) represented within each Group (time period).

Group 1 [z]		Group 2 [y]		Group 3 [x]		Group 4 [w]	
Brand	**1st Year [v]**	**Brand**	**1st Year**	**Brand**	**1st Year**	**Brand**	**1st Year**
D&PL		**D&PL**		**D&PL**		**D&PL**	
DP 20	1983	DP20 B	1997	DeltaPEARL	2000	DP 432 RR	2004
DP 50	1983	DP32 B	1997	DP 451 B/RR	1999	DP 434 RR	2004
DP 51	1989	DP436 RR	1998	PM 1218 BG/RR	1999	DP 444 BG/RR	2003
DP 5409	1994	DP458 B/RR	1998	SG 125 BR	1999	DP 445 BG/RR	2005
DP 5415	1990	DP 5415 RR	1997	SG 215 BR	1999	DP 449 BG/RR	2002
DP 5690	1990	DP 5690 RR	1997	SG 501 BR	1999	DP 454 BG/RR	2005
SG 125	1995	DP 655 B/RR	1998	SG 747	1999	DP 455 BG/RR	2005
SG 501	1994	NuCOTN 33 B	1996			DP 488 BG/RR	2004
		NuCOTN 35 B	1996			DP 494 RR	2004
		PM 1220 BG/RR	1997			DP 515 BG/RR	2006
						DP 555 BG/RR	2002
Other		**Other**		**Other**		**Other**	
LA 887	1990	BXN 47	1996	FM 958	2001	FM 958 LL	2004
ST 132	1985	FM 832	1998	PSC 355	2000	FM 960 BR	2004
ST 474	1993	FM 989	1998	ST 4793 RR	2000	FM 960 RR	2004
		ST 373	1997	ST 4892 BR	2000	FM 989 B/RR	2002
						FM 989 RR	2002
						ST 5242 BR	2004
						ST 5599 BR	2003
Average 1st Year		**Average 1st Year**		**Average 1st Year**		**Average 1st Year**	
D&PL	**1989.8**	**D&PL**	**1997.1**	**D&PL**	**1999.1**	**D&PL**	**2004.0**
Other	**1989.3**	**Other**	**1997.3**	**Other**	**2000.3**	**Other**	**2003.3**

[z] Group 1 represents 1995 and earlier

[y] Group 2 represents 1996, 1997, and 1998

[x] Group 3 represents 1999, 2000, and 2001

[w] Group 4 represents 2002, 2003, 2004, and 2005

[v] First Year of commercial availability for sale

Table 2. Yield and fiber quality change between cultivars in Group 1 (before 1996) and cultivars in Group 2 (1996 to 1998) and comparison of D&PL cultivar performance compared to non-D&PL cultivars within year groups.

Group	1st Year	Lint kg ha^{-1}	Length mm	Strength kN m kg^{-1}	Micronaire	Uniformity	PADJUST $/218 kg bale [z]
Group 1	1989.6	1033.5	28.0	282.9	4.45	82.7	-0.74
Group 2	1997.1	1044.2	28.1	287.4	4.39	82.6	0.96
p>F		0.0004	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Change yr^{-1}		1.4	0.014	0.061	-0.009	-0.009	0.226
% yr^{-1}		0.14	0.05	0.21	-0.20	-0.01	
Within Group 1							
D&PL	1989.8	1030.2	28.1	281.2	4.47	82.6	-0.31
Others	1989.3	1042.4	27.9	287.6	4.41	82.9	-1.88
p>F		0.0082	< 0.0001	< 0.0001	< 0.0001	9.9×10^{-8}	0.0031
Within Group 2							
D&PL	1997.1	1045.5	27.9	285.5	4.43	82.5	0.17
Others	1997.3	1040.9	28.6	292.2	4.26	83.0	2.92
p>F		0.25	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[z] PADJUST is the price adjustment per 218 kg bale based on the 2006 US loan rate of $1.1466 kg lint +/- premiums/discounts

Table 3. Yield and fiber quality change between cultivars in Group 2 (1996 to 1998) and cultivars in Group 3 (1999 to 2001) and comparison of D&PL cultivar performance compared to non-D&PL cultivars within year groups.

Group	1st Year	Lint kg ha-1	Length mm	Strength kN m kg-1	Micronaire	Uniformity	PADJUST $/218 kg bale [z]
Group 2	1997.1	1025.5	28.1	286.4	4.44	82.5	2.31
Group 3	1999.5	1111.5	27.7	280.0	4.64	82.8	-2.49
p>F		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Change yr -1		35.8	-0.16	-0.27	0.08	0.12	-2.00
% yr -1		2.89	-0.49	-0.61	2.20	0.15	
Within Group 2							
D&PL	1997.1	1025.0	28.0	287.1	4.46	82.5	2.37
Others	1997.3	1021.7	28.6	291.8	4.33	82.9	4.20
p>F		0.19	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Within Group 3							
D&PL	1999.1	1114.9	27.6	274.8	4.62	82.7	-2.41
Others	2000.3	1105.6	27.8	289.1	4.68	83.0	-2.63
p>F		< 0.0001	< 0.0001	< 0.0001	0.155	< 0.0001	0.014

[z] PADJUST is the price adjustment per 218 kg bale based on the 2006 US loan rate of $1.1466 kg lint +/- premiums/discounts.

Table 4. Yield and fiber quality change between cultivars in Group 3 (1999 to 2001) and cultivars in Group 4 (2002 to 2005) and comparison of D&PL cultivar performance compared to non-D&PL cultivars within year groups.

Group	1st Year	Lint kg ha-1	Length mm	Strength kN m kg-1	Micronaire	Uniformity	PADJUST $/218 kg bale [z]
Group 3	1999.5	1180.6	27.9	286.3	4.48	82.8	2.94
Group 4	2003.7	1218.5	28.3	296.6	4.18	82.5	6.74
p>F		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Change yr -1		9.1	0.10	2.47	-0.07	-0.07	0.91
% yr -1		0.77	0.36	0.86	-1.59	-0.09	
Within Group 3							
D&PL	1999.1	1177.5	27.8	280.6	4.46	82.7	2.73
Others	2000.3	1185.9	28.0	296.3	4.51	83.0	3.30
p>F		0.017	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0064
Within Group 4							
D&PL	2004.0	1243.2	28.4	293.8	4.19	82.5	6.50
Others	2003.3	1179.7	28.2	301.1	4.17	82.5	7.12
p>F		< 0.0001	< 0.0001	< 0.0001	0.957	0.052	0.0005

[z] PADJUST is the price adjustment per 218 kg bale based on the 2006 US loan rate of $1.1466 kg lint +/- premiums/discounts.

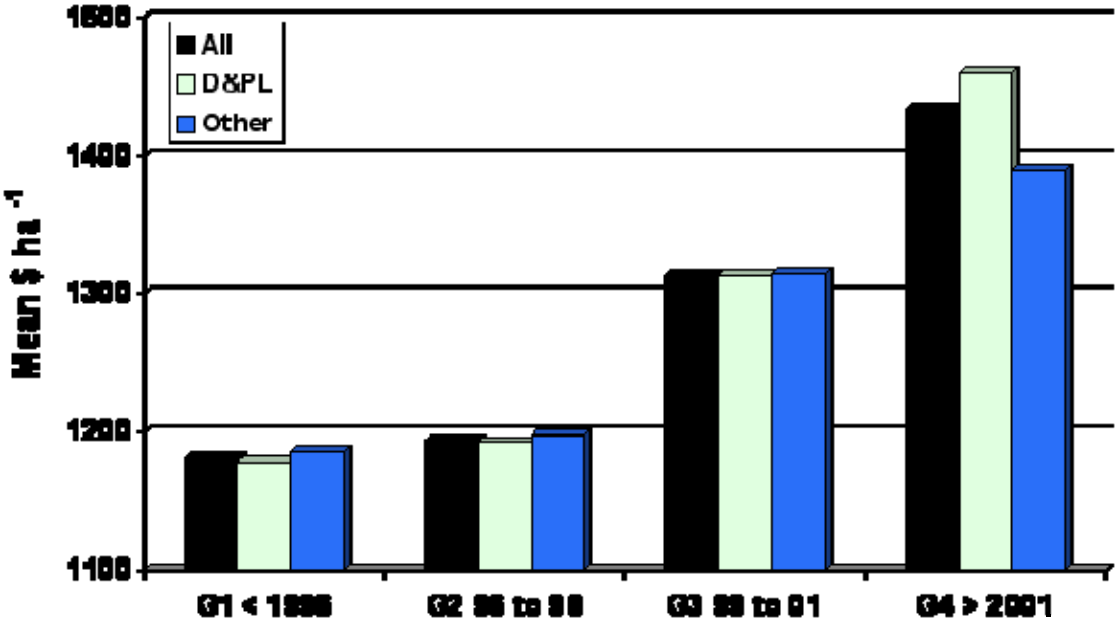

Figure Caption

Figure 1. Average return in $ ha^{-1} for the cultivars in each of the four groups. Within each group, performance of cultivars are separated into those belonging to D&PL or to non-D&PL cultivars as a group.