CULTIVAR

Registration of 'NC-Tinius' Soybean

A. J. Cardinal,* S. Wang, D. T. Bowman, and V. R. Pantalone

ABSTRACT

'NC-Tinius' soybean [*Glycine max* (L.,) Merr.] (Reg. No. CV-503, PI 664027) was cooperatively developed and released by North Carolina State University (NCSU) and the North Carolina Agricultural Research Service. It was first tested in North Carolina yield trials in 2003. NC-Tinius is a determinate, maturity-group-V, conventional cultivar. It is a high-yielding conventional line adapted to the northern and central regions of eastern North Carolina. It was derived from the cross of the low-palmitate and low-linolenate conventional line TN99-76,077 to a high-yielding conventional line V91-3036. In the NCSU breeding trials (11 environments), NC-Tinius averaged 3443 kg ha^{-1}, or 353 kg ha^{-1} more than '5601T', under full-season conditions. In eight average- to high-yield environments in the North Carolina Official Variety Trials, NC-Tinius produced significantly higher yields (4031 kg ha^{-1}) than did the standard cultivar 5601T in narrow (19 cm) row spacing. Seed protein and oil contents were similar to those of 5601T. NC-Tinius is resistant to *Soybean mosaic virus* (G1), frogeye leaf spot (caused by *Cercospora sojina* Hara), bacterial pustule [caused by *Xanthomonas campestris* pv. *glycines* (Nakano) Dye], and stem canker (caused by *Diaporthe phaseolorum* var. *meridionalis*) and is moderately resistant to sudden death syndrome (caused by *Fusarium solani* f. sp. *glycines*).

'NC-Tinius' soybean [*Glycine max* (L.) Merr.] (Reg. No. CV-503, PI 664027) was developed using a modified single-seed-descent breeding method (Brim, 1966a) from a cross of the conventional (i.e, non-GMO) lines TN99-76,077 and V91-3036. It is an F_6-derived selection that was tested as NCC02-22219 in multiple environments in North Carolina and the southeastern USA from 2003 to 2009. NC-Tinius exhibited yields in the northern and central regions of eastern North Carolina (especially Edgecombe, Lenoir, Washington, and Columbus Counties) that were significantly higher than those of the maturity group V checks '5601T' and '5002T' (Pantalone et al., 2003, 2004). NC-Tinius is potentially acceptable for organic markets because it is a conventional soybean. It is best adapted to high-yield locations in northern and central regions of eastern North Carolina. It does not perform well in low-yield environments (<1680 kg ha^{-1}) in North Carolina or in other regions of the southern USA.

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Abbreviations: NCSU, North Carolina State University.

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Methods

Development of Breeding Line

NC-Tinius was developed by crossing conventional lines TN99-76,077 and V91-3036. Its pedigree is shown in Figure 1. The line TN99-76,077 (female parent) was crossed with V91-3036 (male parent) in the summer of 1999 at the East Tennessee Research and Education Center at Knoxville. F_1 seeds from the cross were sent to Los Ganzos S.A., Rancho Los Angeles in Costa Rica and planted in January 2000 in a nursery under artificial lighting to extend the length of the day and thus delay flowering. Individual F_1 plants and later generations were assumed to be self-pollinated (self-pollination rates are 99.5% between rows; Ray et al., 2003). The F_2 seeds were harvested from individual F_1 plants. Then the population was grown in a continuous year-round nursery (but without extending the day length artificially) for generation advancement (~4000 seeds per generation) without selection via single-pod descent (one pod per plant) to the F_5 generation. In 2001, the F_6 seeds were harvested and were bulk planted in 3-m rows spaced 91 cm apart at the Peanut Belt Research Station located in Lewiston, NC. Six hundred F_6 plants were harvested individually, and $F_{6:7}$ seed from each plant was planted in 3-m plant-rows spaced 91 cm at the Tidewater Research Station, Plymouth, NC in 2002. Plant-row number 22219 was harvested in bulk. This seed, designated NCC02-22219, was used for yield trials in the following year and was eventually named NC-Tinius on its release in 2010.

Breeding-Line Evaluation

Yield Trials

In 2003 and 2004, NC-Tinius was tested against other lines and commodity checks of similar maturity at Plymouth and Kinston, NC. In the combined analysis across locations

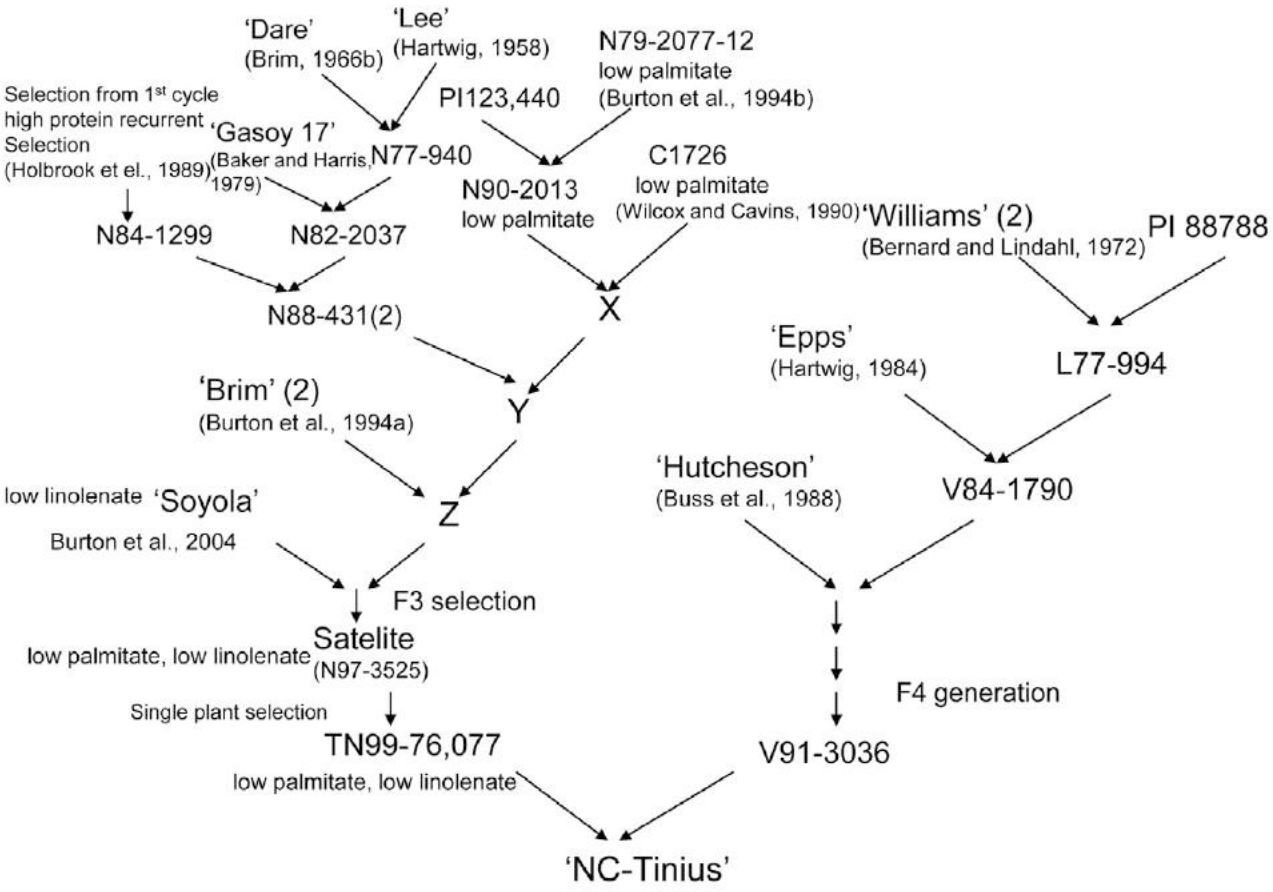

Figure 1. Pedigree of NC-Tinius soybean.

and years, it ranked third for seed yield. In 2005, it was grown at Plymouth, and in the combined analysis across locations and years, it ranked third for seed yield. In 2006, NC-Tinius was entered into the Maturity Group V, Preliminary Tests of the Uniform Soybean Tests Southern States (Gillen and Shelton, 2006). In addition it was retested in Kinston and Plymouth as a part of the NCSU breeding program and entered in the North Carolina Official Variety Trials (http://www.ncovt.com; verified 21 June 2011). Based on 2006 results, NC-Tinius was advanced and tested in the Maturity Group V Uniform Test of the Uniform Soybean Tests Southern States in 2007 and 2008 (Gillen and Shelton, 2007, 2008). It was reentered into the North Carolina Official Variety Trials in 2007, 2008, and 2009 and retested as part of the NCSU breeding program at Clinton, Caswell, and Plymouth in 2008.

Plot Technique

In the NCSU breeding program in North Carolina, all plots consisted of four 97-cm-wide rows arranged in a randomized complete block design and were end-trimmed near maturity. The harvested plot area was approximately 7.65 m^2. Plant populations were approximately 272,000 plants ha^{-1}.

In the Uniform Soybean Tests Southern States, field plots generally consisted of four rows. Rows were end-trimmed at maturity, and the two middle rows were harvested for yield determination. Among locations, row widths varied from 36 to 102 cm, with the majority of plots planted in 76-cm-wide rows. The length of the harvested rows ranged from 4.6 to 6.5 m. Plant populations were approximately 344,000 plants ha^{-1}. Alleys between the plots were approximately 1 m wide.

In the North Carolina Official Variety Trials program, individual plots consisted of eight rows that were 7.3 m long with 19 cm between rows. Neither border rows nor end-trimming were employed, so the harvested plot area was approximately 11.1 m^2. The alleys between the ranges of plots were 1.8 m wide. Plant populations were approximately 430,000 plants ha^{-1}. A lack of end-trimming or absence of border rows causes yield inflation in most soybean field trials (Boerma et al., 1976; Heatherly and Tyler, 1998; Meis et al., 2002); thus, yield estimates were reduced by 10% on all plots as a correction factor in the standard N North Carolina Official Variety Trials protocol for data analysis.

Traits Evaluated

Agronomic traits evaluated in the yield trials included flowering date, maturity, lodging, plant height, seed quality, 100-seed weight, and disease reactions. In the Uniform Soybean Tests Southern States, seed protein and seed oil content were analyzed using near-infrared spectroscopy (AACC, 1999). The near-infrared analyses were performed at the National Center for Agricultural Utilization Research, USDA-ARS, Peoria, IL.

Statistical Analysis

Seed yield and other agronomic traits were evaluated in the field based on a randomized complete block experimental design. For yield, the number of replications within an individual test was two in 2003 and three thereafter for the NCSU breeding program, two in 2006 and three thereafter for Uniform Soybean Tests Southern States, and five for the North Carolina Official Variety Trials. For Uniform Soybean Tests Southern States, oil and protein data were taken from a composite of all reps for each entry within a trial. Seed size and seed-quality data were collected in only one replication at some locations. For other traits, data were collected on all replications.

Mixed-model analyses were performed using SAS (SAS Institute, 2007). Within any individual year, location and replication were considered random effects and genotypes fixed. Fisher's protected LSD was employed for comparisons of genotypes over locations using the genotype × location mean square as the error estimate (data not shown). Since most breeding lines were discarded during the first few years in the NCSU breeding program, assessment of NC-Tinius across years was done by comparing it with the check cultivars and with the promising new breeding lines that were common across all years; the analysis was performed on this subset of the original data. Least squares means from each line for each location and year were obtained and used for the combined analysis across years and locations. A mixed model with environments as a random effect and experiment(environment) and lines as fixed effects was used. Preplanned *t* test comparisons were made between NC-Tinius and checks of similar maturity. Standard errors of the differences of least squares means were calculated.

For the Uniform Soybean Tests Southern States, mixed-model analyses were performed across locations and years using the original data from the "east" area (Maryland, Virginia, and North Carolina) and using all the data excluding the "west" area. Lines were considered a fixed effect and environments, replication(environments) were considered random effects. For traits that had only one replication available per location and year, the replication(environment) effect was dropped from the model. Since all the entries were not the same across years, the data was unbalanced and preplanned *t* test comparisons were made between NC-Tinius and the checks of similar maturity that were grown together in all the tests.

Seed Purification and Increase

Seed purification of NC-Tinius began in 2003 and continued in subsequent years. Plants from 2003 ($F_{6:8}$) test plots were rogued to remove visible off-type plants, and the harvested seed was planted in yield trials in 2004. Off-type plants from 2004 ($F_{6:9}$) test plots in Kinston were removed, and seed harvested from those plots was then planted in yield trials in 2005. Also, this seed was planted in increase blocks consisting of 8 rows by 6 ranges, 7 rows by 15 ranges, 8 rows by 7 ranges with 3.05-m rows and 96.5-cm row spacing at Clayton, NC in 2006, 2007, and 2008, respectively. Each year the increase blocks were rogued at flowering and at maturity to eliminate off-type plants. The outside rows served as borders and were not harvested for seed increase. Before harvest, the plot combine was cleaned to eliminate extraneous seed. Seed harvested from these increases was used for yield trials in the Uniform Soybean Tests Southern States, North Carolina Official Variety Trials, and NCSU breeding program. In 2007, 52 plants were harvested individually and seed from each plant was planted in individual rows that were 3.05 m long. The flowering date, flowering color, maturity date, pubescence, and pod color were recorded. Each row was harvested individually, and 8 rows that matured a few days later than the other rows were discarded. The color of the hilum was noted for the seed harvested from each row. Seed from 44 rows was bulked ($F_{6:10}$) and formed the breeder-seed lot for increase by NC Foundation Seed (Raleigh, NC).

Characteristics

Agronomic and Botanical Description

NC-Tinius matured 2 d earlier than 5601T and 5 d later than 5002T in the NCSU breeding trials in eastern North Carolina (Table 1). In the Uniform Soybean Tests Southern States, however, NC-Tinius and 5601T matured within a day of each other and NC-Tinius averaged 2–4 d later than 5002T (Tables 2 and 3). NC-Tinius has dull yellow seed with a buff hilum. Plants have green cotyledons, a green hypocotyl, a determinate growth habit, oval dark-green leaves, purple flowers, gray pubescence, and a brown pod wall. In Uniform Soybean Tests Southern States, NC-Tinius had similar lodging scores as 5601T and 5002T (Gillen and Shelton, 2006, 2007, 2008), with average lodging scores (on

Table 1. Least squares means of agronomic traits for NC-Tinius and soybean check cultivars in the NCSU breeding program from the analysis across years and locations (11 environments) at Plymouth, Kinston, and Clinton, NC from 2003 to 2008.

Cultivar	Yield	SE†	Maturity date	SE	Flowering date	SE	Height	SE
	kg ha^{-1}		1 Sept. = day 1		1 June = day 1		cm	
No. of environments	11		9		7		5	
NC-Tinius	3443		40.8		43.0		86	
5002T	3149		35.6		40.5		75	
5601T	3089		42.8		40.8		82	
NC-Tinius vs. 5002T	294 NS‡	221	5.2***	1.4	2.5 NS	1.4	11 NS	6.3
NC-Tinius vs. 5601T	353**	135	–2.0*	1.0	2.2**	0.6	4 NS	3.5

*Significant at $p < 0.05$.

**Significant at $p < 0.01$.

***Significant at $p < 0.001$.

†SE, standard error of a difference of least squares means.

‡NS, not significant.

Table 2. Least squares means of agronomic traits for NC-Tinius and soybean check cultivars in the Uniform Soybean Tests Southern States from the analysis of locations in the eastern USA in 2006 (1 environment, Maryland) and 2008 (2 environments, Virginia and North Carolina).

Cultivar	Yield	Maturity date	Height	Lodging	Protein	Oil	Seed quality	Seed size
	kg ha^{-1}	1 Sept. = day 1	cm	1–5[†]	g kg^{-1}		1–5[‡]	g 100 seed^{-1}
NC-Tinius	3716	49.7	74	2.2	419	199	1.6	16.1
5002T	3055	45.2	58	1.9	421	200	2.2	14.7
5601T	3530	50.8	71	1.7	413	191	1.5	12.8
NC-Tinius vs. 5002T	661*	4.5	16 NS[§]	0.3 NS	–2 NS	–2 NS	–0.6**	1.4***
NC-Tinius vs. 5601T	186 NS	–1.2	3 NS	0.5 NS	6 NS	8 NS	0.1 NS	3.3[¶]
SE of difference of least squares means	286	Not estimable	8	0.3	8.6	5	0.22	0.4

*Significant at $p < 0.05$.

**Significant at $p < 0.01$.

***Significant at $p < 0.001$.

[†]1 =no lodging; 5 = prostrate.

[‡]1 = very good; 5 = very poor.

[§]NS, not significant.

[¶]Significant at $p < 0.0001$.

Table 3. Least squares means of agronomic traits for NC-Tinius and soybean check cultivars in the Uniform Soybean Tests Southern States from the analysis across locations in 2006, 2007, and 2008 (30 environments, excluding "west" area).

Cultivar	Yield	Maturity date	Height	Lodging	Protein	Oil	Seed quality	Seed size
	kg ha^{-1}	1 Sept. = day 1	cm	1–5[†]	g kg^{-1}		1–5[‡]	g 100 seed^{-1}
NC-Tinius	3423	35.6	77	2.1	423	204	2.1	15.9
5002T	3597	33.1	69	1.8	410	208	2.3	14.8
5601T	3468	36.5	77	1.8	422	199	1.9	13.5
NC-Tinius vs. 5002T	–174 NS[§]	2.5**	8**	0.3 NS	13**	–4 NS	–0.2 NS	1.1**
NC-Tinius vs. 5601T	–45 NS	–1.0 NS	0 NS	0.3 NS	2 NS	5 NS	0.2 NS	2.4[¶]
SE of difference of least squares means	107	0.9	2.3	0.2	4	3	0.1	0.4

**Significant at $p < 0.01$.

[†]1 = no lodging; 5 = prostrate.

[‡]1 = very good; 5 = very poor.

[§]NS, not significant.

[¶]Significant at $p < 0.0001$.

a 1–5 scale where 1 = all plants are erect; 5 = all plants prostrate) of 2.1–2.2, compared with average scores of 1.7–1.8 for 5601T and 1.8–1.9 for 5002T (Tables 2 and 3). NC-Tinius (74–86 cm) was as tall as 5601T (71–82 cm) and significantly taller than 5002T (58–75 cm) (Tables 1, 2, and 3).

Yield Performance

NC-Tinius is specifically adapted to high-yield environments in northern and central regions of eastern North Carolina. In the NCSU breeding trials with above average yield (11 environments), NC-Tinius averaged 3443 kg ha^{-1} or 353 kg ha^{-1} more than 5601T, under full-season conditions (Table 1). In eight average- to high-yield environments in the North Carolina Official Variety Trials and excluding the very low-yield environments in 2007, NC-Tinius produced significantly higher yields (4031 kg ha^{-1}) than did the standard cultivar 5601T in narrow (19 cm) row spacing (Table 4). In the Uniform Soybean Tests Southern States over three environments (Maryland, Virginia, and North Carolina), NC-Tinius yielded 186 kg ha^{-1} more (but not significantly more) than the standard control cultivar 5601T and 661 kg ha^{-1} more than 5002T in a wide range of row widths under full-season conditions (Table 2). However, when grown across several states in the southern United States over 30 environments, NC-Tinius tended to yield less (but not significantly less) than both 5601T and 5002T (Table 3). NC-Tinius does not perform well in low-yield environments (<1680 kg ha^{-1}) in North Carolina (data not shown).

100-Seed Weight, Protein and Oil Content, and Seed Quality

NC-Tinius had significantly larger seeds than 5601T and 5002T in the Uniform Soybean Tests Southern States, with an average 100-seed weight of 15.9–16.1 g (Tables 2 and 3). The average seed protein (419–423 g kg^{-1}) and oil concentration

Table 4. Agronomic comparison of NC-Tinius and check soybean cultivars in the North Carolina State University Official Variety Trials in 8 environments in 2006, 2008, and 2009 grown in narrow-row trials (19 cm between rows).

Cultivar	Yield
	kg ha^{-1}
NC-Tinius	4031
5601T	3720
Fowler	3750
NC-Tinius vs. 5601T	311*
NC-Tinius vs. Fowler	281*
SE of difference of least squares means	130

*Significant at $p < 0.05$.

(199–204 g kg^{-1}) on a 0% moisture basis of NC-Tinius was similar to that of 5601T (Tables 2 and 3), and its average protein concentration was higher than that of 5002T when grown throughout the southern United States. (Table 3).

Seed-quality ratings (on a 1–5 scale where 1 = very good, and 5 = very poor) were significantly better for NC-Tinius than for 5002T but were similar to those of 5601T in Soybean Tests Southern States in Maryland, Virginia, and North Carolina (Table 2). The seed-quality rating of NC-Tinius in the Uniform Soybean Tests Southern States was similar to that of both 5601T and 5002T (Table 3) throughout the southern United States.

Disease Resistance

Results from the Uniform Soybean Tests Southern States indicate that NC-Tinius is resistant to *Soybean mosaic virus* strain G1, but susceptible to *Soybean mosaic virus* strain S95-52. NC-Tinius is susceptible to root knot nematode [*Meloidogyne arenaria* (Neal) Chitwood] as well as to HG types 1.2.5.7, 7, and 1.3.5.6.7 (races 2, 3, and 14, respectively) of soybean cyst nematode (*Heterodera glycines* Ichinohe) (Gillen and Shelton, 2006, 2007, 2008). NC-Tinius is resistant to stem canker (caused by *Diaporthe phaseolorum* var. *meridionalis*) and moderately resistant to sudden death syndrome (caused by *Fusarum solani* f. sp. *glycines*) (Gillen and Shelton, 2006, 2007, 2008). Although not confirmed by independent tests, NC-Tinius appears resistant to both frogeye leaf spot (caused by *Cercospora sojina* Hara) and bacterial pustule [caused by *Xanthomonas campestris* pv. *glycines* (Nakano) Dye] because it has never shown any symptoms for these diseases in test plots in North Carolina, even when the diseases were clearly present in the field on other genotypes (data not shown). NC-Tinius appears to be slightly susceptible to bacteria blight (caused by *Pseudomonas syringae* pv. *glycinea*) because low levels of symptoms were observed in the Kinston and Plymouth in 2004 and 2010.

Availability

Breeder seed of NC-Tinius will be maintained by the NCSU soybean breeding program, Raleigh, NC. Small quantities can be obtained by request from Andrea J. Cardinal. Certified seed will be available from NC Foundation Seed Producers (Raleigh, NC). Seed of this release will be available for research purposes and for use as parental stock in the development and commercialization of new cultivars from the National Plant Germplasm System. It is requested that appropriate recognition be made if this germplasm contributes to the development of a new breeding line or cultivar.

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References

American Association of Cereal Chemists (AACC). 1999. Near infrared methods: Guidelines for model development and maintenance. Am. Assoc. Cereal Chem., St. Paul, MN.

Baker, S.H, and H. B. Harris. 1979. Registration of Gasoy 17 soybeans. Crop Sci. 19:130. doi:10.2135/cropsci1979.0011183X001900010036x

Bernard, R.L., and D.A. Lindahl. 1972. Registration of 'Williams' soybean. Crop Sci. 12:716. doi:10.2135/cropsci1972.0011183X001200050067x

Boerma, H.R., W.H. Marchant, and M.B. Parker. 1976. Response of soybean in maturity groups V, VI, VII, and VIII to end-trimming. Agron. J. 68:723–725. doi:10.2134/agronj1976.00021962006800050009x

Brim, C.A. 1966a. A modified pedigree method of selection in soybean. Crop Sci. 6:220. doi:10.2135/cropsci1966.0011183X000600020041x

Brim, C.A. 1966b. Registration of 'Dare' soybeans. Crop Sci. 6:95. doi:10.2135/cropsci1966.0011183X000600010039x

Burton, J.W., T.E. Carter, Jr., and E.B. Huie. 1994a. Registration of 'Brim' soybean. Crop Sci. 34:301. doi:10.2135/cropsci1994.0011183X003400010058x

Burton, J.W., R.F. Wilson, and C.A. Brim. 1994b. Registration of N79-2077-12 and N87-2122-4, two soybean germplasm lines with reduced palmitic acid in seed oil. Crop Sci. 34:313.

Burton, J.W., R.F. Wilson, W. Novitzky, and T.E. Carter, Jr. 2004. Registration of 'Soyola' soybean. Crop Sci. 44:687-688. doi:10.2135/cropsci2004.687a

Buss, G.R., H.M. Camper, Jr., and C.W. Roane. 1988. Registration of 'Hutcheson' soybean. Crop Sci. 28:1024-1025. doi:10.2135/cropsci1988.0011183X002800060042x

Gillen, A.M., and G.W. Shelton. 2006. Uniform Soybean Tests, Southern States, 2006. USDA-ARS, Stoneville, MS.

Gillen, A.M., and G.W. Shelton. 2007. Uniform Soybean Tests, Southern States, 2007. USDA-ARS, Stoneville, MS.

Gillen, A.M., and G.W. Shelton. 2008. Uniform Soybean Tests, Southern States, 2008. USDA-ARS, Stoneville, MS.

Hartwig, E.E. 1958. Registration of 'Lee' soybean. Agron. J. 50:690-691. doi:10.2134/agronj1958.00021962005000110016x

Hartwig, E.E. 1984. Registration of 'Epps' soybean. Crop Sci. 24:998. doi:10.2135/cropsci1984.0011183X002400050047x

Heatherly, L.G., and J.T. Tyler. 1998. Response of non-irrigated maturity group V determinate soybean to end-trimming. Crop Sci. 38:272–274. doi:10.2135/cropsci1998.0011183X003800010046x

Holbrook, C.C., J.W. Burton, and T.E. Carter. 1989. Evaluation of recurrent restricted index selection for increasing yield while holding seed protein constant in soybean. Crop Sci. 29:324–329. doi:10.2135/cropsci1989.0011183X002900020019x

Meis, S.J., W.T. Schapaugh, Jr., and G.A. Milliken. 2002. Relative performance of soybean in end-trimmed and plant-to-length plots. Crop Sci. 42:700–704. doi:10.2135/cropsci2002.0700

Pantalone, V.R., F.L. Allen, and D. Landau-Ellis. 2003. 5 Registration of '560IT' soybean. Crop Sci. 43:1123–1124. doi:10.2135/cropsci2003.1123

Pantalone, V.R., F.L. Allen, and D. Landau-Ellis. 2004. Registration of '5002T' soybean. Crop Sci. 44:1483–1484. doi:10.2135/cropsci2004.1483a

Ray, J.D., T.C. Kilen, C.A. Abel, and R.L. Paris. 2003. Soybean natural cross-pollination rates under field conditions. Environ. Biosafety Res. 2:133–138. doi:10.1051/ebr:2003005

SAS Institute. 2007. The SAS system for Microsoft Windows. Release 9.1.3. SAS Inst., Cary, NC.

Wilcox, R.F., and J.F. Cavins. 1990. Registration of C1726 and C1727 soybean germplasm with altered levels of palmitic acid in seed oil of soybean. Crop Sci. 30:240. doi:10.2135/cropsci1990.0011183X003000010069x