Published September, 2004

NOTES

EFFECT OF SOYBEAN STEM GROWTH HABIT ON HEIGHT AND NODE NUMBER AFTER BEGINNING BLOOM IN THE MIDSOUTHERN USA

LARRY G. HEATHERLY* AND JAMES R. SMITH

Abstract

There are two broad types of stem growth habit in soybean [*Glycine max* (L.) Merr.]: indeterminate [generally maturity group (MG) IV and earlier] and determinate (generally MG V and later). Field studies of irrigated April and May plantings were conducted on Sharkey clay soil (very-fine, smectitic, thermic Chromic Epiaquert) at Stoneville, MS (lat. 33°26′ N), to determine if current expectations for stem growth habit are valid in genetic backgrounds of indeterminate MG IV and determinate MG V cultivars that are used in the early soybean production system (ESPS) in the midsouthern USA. All cultivars increased height and node number between beginning bloom (R1) and stem termination (ST), but the increases were greater for MG IV cultivars. Height and node number were greater at R1 for MG V than for MG IV cultivars, and greater for MG IV cultivars at ST. Averaged across planting date and year, MG V cultivars increased height and node number after R1 by 23 cm and 3.7 nodes, respectively. These results indicate that determinate MG V cultivars are capable of producing significant increases in height and node number after R1.

IN A LARGE PORTION of the midsouthern USA, the ESPS is the paradigm for soybean management (Bowers, 1995; Boquet, 1998; Heatherly, 1999; Heatherly and Spurlock, 1999), and includes both indeterminate (mainly MG IV) and determinate (MG V) cultivars planted from late March through early May (Heatherly, 1999; Heatherly and Spurlock, 1999; Bowers, 2000). Cultivars from MGs IV and V yielded similarly in the ESPS even though growth patterns of indeterminate and determinate stem types were different (Heatherly, 1999). The ESPS replaced May and June plantings of determinate MG V and VI cultivars, which comprised the previous soybean production system. Use of the ESPS raises concerns about plants achieving enough height to form an effective canopy and to be harvestable because earlier planting will result in shorter plants regardless of cultivar.

Bernard (1972) defined stem growth habit for soybean in terms of the timing of the termination of apical stem growth. A determinate stem terminates apical growth abruptly and generally produces a thick stem tip because growth in stem girth continues after growth in stem length has ceased. An indeterminate stem continues terminal growth as long as lateral growth continues, and produces a stem that is tapered in thickness from tip to base.

There is a wide range in the abruptness of ST among soybean genotypes from various parts of the world. Accessions in the USDA soybean germplasm collection are scored phenotypically from 1 (very determinate) to 5 (very indeterminate) (Bernard et al., 1998). Stem termination scores of <2.0 and ≥ 2.5 are considered determinate and indeterminate, respectively. A ST score ≥ 2.0 and <2.5 is considered semideterminate. However, stem scores may vary according to the environment in which plants grow. Bernard (1972) observed that under short photoperiod conditions or under adverse growing conditions, it can be difficult to distinguish between determinate and indeterminate stem types.

Bernard (1972) determined that the recessive genotype dt_1dt_1 was responsible for the determinate phenotype in two genetic backgrounds ('Harosoy' and 'Clark' isolines) at Urbana, IL (40°07′ N lat). The dominant gene pair Dt_1Dt_1 determined the indeterminate phenotype, while Dt_1dt_1 was expressed phenotypically as semideterminate in the same two backgrounds. A second gene (dominant Dt_2), independent of the Dt_1 locus, also produced a semideterminate phenotype in the presence of Dt_1__; dt_1 is epistatic to Dt_2-dt_2. However, Bernard (1972) observed that in other genetic backgrounds, Dt_2__ and dt_1dt_1 can be indistinguishable, and that Dt_1Dt_1 may be modified by other genetic factors to appear almost as determinate as Dt_2__.

At Urbana, IL, in the two genetic backgrounds reported by Bernard (1972), dt_1dt_1 caused stem growth to terminate abruptly at the onset of flowering. The gene pair dt_1dt_1 reduced the final height of Harosoy (MG II) by 61% and that of Clark (MG IV) by 45%, and the final node number from 20 to 7 and from 22 to 12 in Harosoy and Clark isolines, respectively. Hence, the major effect of dt_1dt_1 in the Harosoy and Clark backgrounds was a reduction in stem length through a reduction in node number.

A third allele (dt_1-t) was reported at the dt_1 locus by Thompson et al. (1997). In a Clark background at Urbana, IL, Dt_1dt_1-t was found to be intermediate in height to Dt_1Dt_1 and dt_1-tdt_1-t, while dt_1-tdt_1 was found to be intermediate in height to dt_1-tdt_1-t and dt_1dt_1. In their study, Dt_1 was not completely dominant to dt_1-t and dt_1-t was not completely dominant to dt_1. Indeterminate (Dt_1Dt_1), tall determinate (dt_1-tdt_1-t), and determinate (dt_1dt_1) phenotypes differed in final plant height, timing of termination of the main stem, and final node number. The gene pair dt_1dt_1 had approximately one-third the final height of Dt_1Dt_1 and approximately one-half the

L.G. Heatherly, P.O. Box 343, and J.R. Smith, P.O. Box 345, USDA-ARS, Crop Genetics and Prod. Res. Unit, Stoneville, MS 38776. Received 24 Oct. 2003 *Corresponding author (lheatherly@ars.usda.gov).

Published in Crop Sci. 44:1855–1858 (2004).

Abbreviations: ESPS, early soybean production system; MG, maturity group; R1, beginning bloom; R6, full seed; SCN, soybean cyst nematode; ST, stem termination.

final height of dt_1-tdt_1-t. The gene pair dt_1-tdt_1-t expressed itself similarly to Dt_2Dt_2 in terms of final plant height, timing of main ST, and final node number.

Egli and Leggett (1973) compared similar maturity genotypes 'Kent' (indeterminate, MG IV) and 'D66-5566' (determinate, MG IV) for stem growth and node production at Lexington, KY (38°02′N lat), and made observations consistent with those of Bernard (1972) and Lin and Nelson (1988). Line D66-5566 reached more than 80% of its final height and produced >90% of its final node number by R1. In contrast, Kent reached <50% of its final height and <60% of its final node number by R1.

From the above studies, as well as from the presentations of others (Fehr and Caviness, 1977; Hicks, 1978; Johnson, 1987; Ritchie et al., 1997; Thompson et al., 1997; Ashlock and Purcell, 2000), an expectation developed that all determinate cultivars grow very little in height after R1. However, only a limited number of environments and genotypes have been studied, and casual observations in past experiments conducted at Stoneville, MS (33°26′N lat) have not been consistent with this expectation. Data from additional latitudes, genotypes, MGs, and production systems are needed to verify if stem growth of determinate cultivars terminates abruptly in situations other than those previously cited. The answer has important implications for the use of determinate cultivars in the ESPS that is used in the midsouthern USA. Assumed changes in soybean plant stature after R1 can affect choice of planting date and cultivar, selection of row spacing and seeding rate, and management decisions. The objective of this research was to determine if current expectations for determinate stem growth are valid in genotypes used in the ESPS in the midsouthern USA.

Materials and Methods

Field studies were conducted on Sharkey clay at the Delta Research and Extension Center near Stoneville, MS, in 2002 and 2003. Plantings of MG IV indeterminate 'Asgrow AG4403' and 'Hornbeck HBK4891' and MG V determinate 'Asgrow AG5701' and 'Pioneer P9594' were made on 16 Apr. and 8 May 2002, and on 3 Apr. and 6 May 2003. Stem growth habit of the selected cultivars was designated as either indeterminate or determinate by each cultivar's originator; information on the specific alleles and loci affecting stem growth habit is not available as per communication with a representative of each company (2003). Determinate MG V cultivars were used instead of determinate MG IV cultivars because it was assumed that the latter (if suitable agronomic types had been available) would fail to make adequate growth in the midsouthern USA, especially in early plantings. Also, indeterminate MG IV and determinate MG V cultivars are those predominantly used in the ESPS (Heatherly and Bowers, 1998; Heatherly, 1999).

Experimental design was a randomized complete block with four replicates of each cultivar within separate but adjacent planting date units. Row spacing was 50 cm and seeding rate was 295 to 345 thousand seeds ha^{-1}. The row spacing and seeding rate are within the recommended ranges for optimum yield (Heatherly and Elmore, 2004). Plots were maintained weed-free with postemergence applications of labeled herbicides. All plots were furrow-irrigated with rollout vinyl pipe. Irrigation of the earlier plantings was initiated on 4 June 2002 and 2003, which was at or near R1 of MG V cultivars, and was continued through full seed (R6) of all cultivars. Irrigation of the later plantings was initiated on 20 June 2002 and 26 June 2003, which was near the time of R1 of MG IV cultivars, and was continued through R6 of all cultivars. Irrigations after the first application each year were applied whenever soil water potential at the 30-cm depth, as measured by tensiometers, decreased to about −50 kPa.

At R1 of each cultivar each year, height from the soil surface to the main stem apex was measured and node number (unifoliolate node = one) was counted to include the node of the uppermost unrolled trifoliolate on five plants in each plot. At ST (final main-stem leaf full-sized) of the same five plants of each cultivar, height from the soil surface to the final main-stem node was measured and node number was counted. From these measurements, increases in height and node number between R1 and ST were calculated.

Analyses were conducted on data from individual planting dates within each year. Analysis of variance [PROC MIXED (SAS Institute, 1996)] was used to determine differences in height and node number among cultivars within R1 and ST sample dates and to compare increases in height and node number of each cultivar between R1 and ST sample dates within each planting date of each year. Mean separations were achieved with an LSD (0.05).

Results and Discussion

All cultivars in both plantings of both years significantly increased plant height and node number between R1 and ST dates (Table 1). Within each planting date and year, MG V determinate cultivars were taller and generally had more nodes than MG IV indeterminate cultivars at the R1 date, whereas the opposite occurred at the ST date. Thus, the increase in height and node number between R1 and ST dates was greater for MG IV than for MG V cultivars in all cases. The greater height and node number at R1 of MG V likely was the result of the R1 stage occurring 2 to 3 wk later than R1 of MG IV (Table 1).

Final height and node number of MG IV indeterminate cultivars was greater than final height and node number of MG V determinate cultivars at the ST date in all cases. Kilgore-Norquest and Sneller (2000) developed near-isogenic soybean lines (derived from 'Williams 82' × 'Narow' and 'R85-336' × 'Walters') that contrasted in stem growth habit, and found that final height of indeterminates was greater than that of determinates in both nonirrigated and irrigated May and June plantings in Arkansas. Ouattara and Weaver (1994) grew near-isogenic soybean lines differing in growth habit in late June–early July plantings in Alabama and found that indeterminate lines were taller and had more mainstem nodes at maturity than did determinate lines. Even though the indeterminate cultivars used in the current study were about 3 wk earlier-maturing than the determinate cultivars, height and node differences between the two types followed the same pattern as those in the cited studies that used near-isogenic lines.

In the April planting, height increases between R1 and ST ranged from 43 to 73 cm for MG IV cultivars and from 9 to 33 cm for MG V cultivars across the 2 yr (Table 1). In the May planting, height increases between

Table 1. Plant height and node number at beginning bloom (R1) and main stem termination (ST) of maturity group (MG) IV indeterminate and MG V determinate soybean cultivars planted on two dates at Stoneville, MS, in 2002 and 2003.

Date of planting	Cultivar (MG)	Date† R1	Date† ST	ST days after R1	Plant height‡ R1	Plant height‡ ST	Plant height‡ Diff.	Node no.§ R1	Node no.§ ST	Node no.§ Diff.
					cm	cm	cm			
				2002						
16 Apr.	AG4403 (IV)	19 May	8 July	50	14	86	72	4.8	15.7	10.9
	HBK4891 (IV)	19 May	8 July	50	14	87	73	5.3	17.4	12.0
	AG5701 (V)	7 June	3 July	26	39	72	33	8.2	12.6	4.4
	P9594 (V)	7 June	3 July	26	47	69	22	8.2	11.9	3.7
	LSD (0.05)					3/2¶	4		1.4/1.3	1.9
8 May	AG4403	19 June	26 July	37	23	96	73	8.3	16.6	8.3
	HBK4891	19 June	26 July	37	23	97	74	7.2	16.2	9.0
	AG5701	3 July	19 July	15	58	83	25	9.1	12.6	3.5
	P9594	2 July	16 July	15	60	83	23	9.5	12.7	3.2
	LSD (0.05)					6/6	8		1.5/1.3	1.9
				2003						
3 Apr.	AG4403 (IV)	12 May	25 June	44	13	66	53	5.4	14.6	9.2
	HBK4891 (IV)	13 May	7 July	55	15	58	43	6.6	16.2	9.7
	AG5701 (V)	31 May	4 July	34	38	53	15	8.2	10.6	2.4
	P9594 (V)	2 June	7 July	35	35	44	9	8.9	10.8	1.9
	LSD (0.05)					5/3	4		0.9/0.7	0.9
6 May	AG4403	13 June	27 July	44	23	93	70	6.3	18.8	12.5
	HBK4891	16 June	25 July	39	23	88	65	7.5	20.0	12.5
	AG5701	30 June	25 July	25	42	81	39	7.9	13.6	5.7
	P9594	3 July	24 July	21	40	61	21	9.1	14.2	5.1
	LSD (0.05)					7/5	7		1.1/0.8	1.1

† R1 = date of beginning bloom; ST = date of stem termination (uppermost leaf reached full size).
‡ Height from soil surface to stem apex.
§ Number of main stem nodes, with unifoliolate node as one.
¶ First number for comparing cultivar means within R1 or ST, second number for comparing cultivar means across R1 and ST.

R1 and ST ranged from 65 to 74 cm for MG IV cultivars and from 21 to 39 cm for MG V cultivars across the 2 yr. In the April planting, increases in node number between R1 and ST ranged from 9.2 to 12 for MG IV cultivars and from 1.9 to 4.4 for MG V cultivars across the 2 yr. In the May planting, increases in node number ranged from 8.3 to 12.5 for MG IV cultivars and from 3.2 to 5.7 for MG V cultivars across the 2 yr.

In three of the four planting-date-by-year combinations, height increases of AG5701 between R1 and ST were significantly greater than height increases of P9594 between R1 and ST (Table 1). Hence, there is apparent genotypic variability for stem growth after R1 for determinate stem types. This may be because of the diversity of genetic backgrounds in which the *dt* loci operate, or it may be because of the specific *dt* alleles and loci present. In either case, it indicates that breeders may be able to select for height increases after R1 in determinate breeding populations intended for the ESPS. This is especially important for plantings that are made in early April, as was the case in 2003 (Table 1), where ensuring adequate plant stature is critical for achieving maximum yield.

In 2002, MG IV indeterminate cultivars (AG4403 and HBK4891) increased height by an average of 72 and 74 cm and node number by an average of 11.4 and 8.6 in the April and May plantings, respectively (Table 1). With MG V determinate cultivars (AG5701 and P9594), height increases after R1 averaged 28 cm in the April planting and 24 cm in the May planting, whereas node increases after R1 averaged 4.0 in the April planting and 3.4 in the May planting. In 2003, MG IV cultivars increased height after R1 by an average of 48 cm in the April planting and 68 cm in the May planting, whereas node number increased after R1 by an average of 9.4 in the April planting and 12.5 in the May planting. With MG V determinate cultivars, height increases after R1 averaged 12 cm in the April planting and 30 cm in the May planting, whereas node increases after R1 averaged 2.2 in the April planting and 5.4 in the May planting.

In this study conducted in the central midsouthern USA, growth at R1 in determinate MG V cultivars was generally less than two-thirds of full height and less than three-fourths of final node number, and canopy closure had not been achieved regardless of planting date. Height and node number increases after R1 in determinate MG V cultivars were significant, ranging from 9 to 33 cm and 1.9 to 4.4 nodes in the April planting and from 21 to 39 cm and 3.2 to 5.7 nodes in the May planting. Even though these cultivars did not grow as much after R1 as did the indeterminate MG IV cultivars, the growth increases translated into meaningful canopy development following bloom and resulted in canopy closure by ST. These findings are different from those that would have been expected based on earlier studies, such as that of Egli and Leggett (1973) at Lexington, KY. Not all determinate genotypes terminate stem growth at R1 in all environments. They are capable of considerable postanthesis stem growth in the ESPS in midsouthern USA growing areas.

The above-noted genotype differences for increases in plant height bring up an important issue. Although it is likely that both MG V cultivars in this study are determinate due to dt_1dt_1, this is not known. This situation is likely very common for many current determinant cultivars. It is possible that the dt_1-t allele could be present in the southern USA determinate breeding pool. One possible point of introgression could have been through 'Peking'. Peking, once thought to be dt_1dt_1 and now determined to be dt_1-tdt_1-t (Thompson et al., 1997), was used to introduce resistance to races 1 and 3 of soybean cyst nematode (SCN; *Heterodera glycines* Ichinohe) into determinate soybean (Brim and Ross, 1966; Hartwig and Epps, 1968). However, as backcrossing was used in the above conversions, it is unlikely that the dt_1-t allele was introgressed. Also, because P9594 is susceptible to SCN and because AG5701 has resistance to races 3 and 14 of SCN (presumably through PI 88788), it is unlikely that either has dt_1-t through Peking. Furthermore, it is not known to what extent Dt_2 has been used in southern USA determinate cultivars. However, since the height of both dt_1-t and Dt_2 were more similar to Dt_1 than to dt_1 in the study of Thompson et al. (1997), it is likely that the dissimilarity between heights of indeterminate and determinate cultivars in the current study was due to differences between Dt_1 and dt_1.

Tall determinate (dt_1-t) and semideterminate (Dt_2) MG V phenotypes may be preferable to conventional MG V determinate (dt_1) types in the ESPS. They would likely provide greater post-R1 plant height increases and quicker canopy closure. Future research should investigate these opportunities for the ESPS.

Acknowledgments

The authors appreciate the technical assistance provided by Sandra Mosley and John Amos, and resources provided by the Delta Research and Extension Center of Mississippi State University.

References

Ashlock, L., and L. Purcell. 2000. Growth and development. p. 7–12. *In* L. Ashlock (ed.) Arkansas soybean handbook. Univ. Arkansas Coop. Ext. Service, Little Rock.

Bernard, R.L. 1972. Two genes affecting stem termination in soybeans. Crop Sci. 12:235–239.

Bernard, R.L., C.R. Cremeens, R.L. Cooper, F.I. Collins, O.A. Krober, K.L. Athow, F.A. Laviolette, C.J. Coble, and R.L. Nelson. 1998. Evaluation of the USDA soybean Germplasm Collection: Maturity groups 000–IV (FC 01.547-PI 266.807). USDA-ARS Tech. Bull. 1844. U.S. Gov. Print. Office, Washington, DC.

Boquet, D.J. 1998. Yield and risk utilizing short-season soybean production in the mid-southern USA. Crop Sci. 38:1004–1011.

Bowers, G.R. 1995. An early soybean production system for drought avoidance. J. Prod. Agric. 8:112–119.

Bowers, G.R. 2000. Row spacing in the early soybean production system. Agron. J. 92:524–531.

Brim, C.A., and J.P. Ross. 1966. Registration of Pickett soybean. Crop Sci. 6:305.

Egli, D.B., and J.E. Leggett. 1973. Dry matter accumulation patterns in determinate and indeterminate soybeans. Crop Sci. 13:220–222.

Fehr, W.R., and C.E. Caviness. 1977. Stages of soybean development. Spec. Rep. 80. Iowa Agric. Exp. Stn., Ames.

Hartwig, E.E., and J.M. Epps. 1968. Dyer soybean. Crop Sci. 8:402.

Heatherly, L.G. 1999. Early soybean production system (ESPS). p. 103–118. *In* L.G. Heatherly and H.F. Hodges (ed.) Soybean production in the mid-south. CRC Press, Boca Raton, FL.

Heatherly, L.G., and G.R. Bowers. 1998. Early soybean production system handbook. USB 6009–091998–11000. United Soybean Board, St. Louis, MO.

Heatherly, L.G., and R.W. Elmore. 2004. Managing inputs for peak production. p. 451–536. *In* R. Boerma and J. Specht (ed.) Soybeans: Improvement, production, and uses. 3rd ed. Agron. Monogr. 16. ASA, CSSA, and SSSA, Madison, WI.

Heatherly, L.G., and S.R. Spurlock. 1999. Yield and economics of traditional and early soybean production system (ESPS) seedings in the midsouthern USA. Field Crops Res. 63:35–45.

Hicks, D.R. 1978. Growth and development. p. 17–44. *In* A.G. Norman (ed.) Soybean physiology, agronomy, and utilization. Academic Press, New York.

Johnson, R.R. 1987. Crop management. p. 355–390. *In* J.R. Wilcox (ed.) Soybeans: Improvement, production, and uses. 2nd ed. Agron. Monogr. 16. ASA, CSSA, and SSSA, Madison, WI.

Kilgore-Norquest, L., and C.H. Sneller. 2000. Effect of stem termination on soybean traits in southern U.S. production systems. Crop Sci. 40:83–90.

Lin, M.S., and R.L. Nelson. 1988. Relationship between plant height and flowering date in determinate soybean. Crop Sci. 28:27–30.

Ouattara, S., and D.B. Weaver. 1994. Effect of growth habit on yield and agronomic characteristics of late-planted soybean. Crop Sci. 34:870–873.

Ritchie, S.W., J.J. Hanway, H.E. Thompson, and G.O. Benson. 1997. How a soybean plant develops. Spec. Rep. 53. Iowa State Univ., Coop. Ext. Serv., Ames.

SAS Institute. 1996. SAS system for mixed models. SAS Inst., Cary, NC.

Thompson, J.A., R.L. Bernard, and R.L. Nelson. 1997. A third allele at the soybean dt_1 locus. Crop Sci. 37:757–762.