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ZHANG L. X., WANG R. F. and HESKETH J. D. *Separating photoperiod and temperature effects on the degree day requirement for floral events in soybean.* BIOTRONICS **24**, 59–64, 1995. A date–of–planting study of time from emergence (VE) to floral bud initiation (R0, detection of floral bud primordium) and first flower (R1) was carried out at Urbana IL USA for soybean genotypes representing maturity groups (MG) 00 through VIII. Growing degree days (GDD), base 10℃ with a cutoff at 30℃, were calculated for VE–R0, R0–R1 and VE–R1 and were plotted against the averge photoperiod between events. We found a temperature relationship among GDD values between events for MG's 00–I; subtracting these GDD values from those of MG II or greater and plotting the residual or adjusted GDD (AGDD) values (or 1/AGDD values) vs. average photoperiod improved the linear or curvilinear relationship involved. Photoperiod effects on R0–R1 were significant for later –maturing genotypes (MG IV+or greater) as reported earlier. These phenology–temperature–photoperiod relationships greatly improve our ablility to predict phenology with computers for real world situations.

Key words: soybean; phenology; photoperiod; temperature; degree days.

INTRODUCTION

It had been difficult previously (*11*) to show from a soybean [*Glycine max* (L.) Merr.] field date–of–planting study a photoperiod effect on days, or growing degree days, to first flower for strains adapted to the Urbana latitude; whereas such effects had been easy to show for later–maturing but unadapted strains. Growth cabinet and greenhouse studies have shown that the thermal requirement for soybean floral bud growth from initiation to open flower was affected by photoperiod, but only for late maturing strains not adapted to the Urbana (40°) or Beltsville (39°) latitudes. Photoperiod effects on soybean phenology have been studied extensively in the past (e.g., *2, 3, 5, 7, 10*). More information about temperature and photoperiod effects on floral bud growth rates are needed, such as the timing and strength of the response, in order to understand and quantify better how the environment controls the date of floral bud initiation and flowering among different strains in soybean. Field data are needed to supplement controlled environment research for use in models for predicting crop phenology.

MATERIALS AND METHODS

Soybean was planted in a Flanagan silt loam (fine, montmorillonitic, mesic Aquic Arguidoll) soil at the University of Illinois Agronomy South Farm at Urbana. We grew 18 genotypes (MG 00 through VIII, Table 1) at five planting dates during the 1993 growing season. The five planting dates ranged from early May to late July with approximately 15 to 20 days between plantings. Plants were dissected using a light microscope to estimate dates that the floral bud primordium (R0) first appeared in each genetic strain or cultivar for each planting date. Growing degree days (GDD) were calculated by averaging the minimum and maximum daily temperatures and subtracting 10℃. Seedling emergence dates, flowering dates (approximately 50% of plants with a flower), and the node of the first floral bud (average of three plants per plot) were also recorded for each plant strain and planting date. Average photoperiods were calculated for seedling emergence to floral bud initiation, from floral bud initiation to first flower, and from seedling emergence to first flower.

Table 1. Comparison of coefficients and r^2 between Growing degree days (GDD) and adjusted GDD (AGDD) and reciprocal of AGDD for floral bud initiation (VE–R0). Roman letters indicate maturity groups, and "d" and "i" indicate stem termination habits, determinate and indeterminate, respectively.

	GDD				Adjusted GDD						1/AGDD		
	a	b	c	r_0^2	a	b	c	r_1^2	$r_1^2-r_0^2$	$r_1^2-r_0^2$ average for MG	a	b	r^2
Temperature correction:					184	−13.8	0.9	0.989					
L63-3117 (II, i)	7896	−1066.9	36.7	0.494	16485	−2208.8	74.0	0.973	0.479		2.3206	−0.14648	0.782
Jack (II, i)	11729	−1578.0	53.8	0.507	14159	−1952.3	65.7	0.871	0.364	0.37	0.55770	−0.03430	0.753
Gnome (II, d)	18598	−2510.2	85.5	0.611	26639	−3587.4	120.9	0.870	0.259	(II)	0.34115	−0.02116	0.949
L63-2404 (III, i)	19956	−2709.3	92.8	0.959	28205	−3813.9	129.1	0.972	0.013		0.38312	−0.02402	0.970
Williams (III, i)	23164	−3140.4	107.3	0.922	31943	−4316.1	145.9	0.947	0.025	0.04	0.38682	−0.02428	0.968
Hobbit (III, d)	21603	−2923.1	99.8	0.781	30878	−4167.2	140.8	0.869	0.088	(III)	0.23612	−0.01461	0.943
L63-3016 (IV, d)	22130	−3013.5	103.5	0.850	26604	−3617.3	123.2	0.924	0.074		0.24545	−0.01532	0.990
Pixie (IV, d)	40436	−5447.6	184.4	0.892	46257	−6229.4	209.9	0.941	0.049	0.06	0.25817	−0.01610	0.936
Clark-63 (IV, i)	32862	−4433.9	150.5	0.931	39027	−5261.8	177.5	0.985	0.054	(VI)	0.25236	−0.01571	0.946
L74-441 (IV+, i)	9972	−1402.4	50.6	0.877	14525	−2027.8	71.3	0.945	0.068		0.07295	−0.00441	0.792
L66-546 (V−, d)	9066	−1303.4	48.1	0.839	13871	−1962.8	69.8	0.897	0.058	0.05	0.06738	−0.00410	0.964
L65-3366 (V)	28311	−3929.3	137.7	0.950	32866	−4554.5	158.4	0.961	0.011	(VI+−V)	0.07756	−0.00480	0.991
Bradford (VI, d)	51319	−7071.0	245.2	0.981	42168	−5868.1	205.0	0.977	−0.004		0.05572	−0.00346	0.995
Centennial (VII, d)	55446	−7631.3	246.3	0.968	48174	−6679.3	232.5	0.970	0.002	0.00	0.04104	−0.00251	0.984
Cook (VIII, d)	67650	−9285.0	320.3	0.981	60472	−8347.8	289.1	0.981	0.000	(VI−VIII)	0.03808	−0.00233	0.959

RESULTS AND DISCUSSION

Fig. 1 shows temperature effects on degree days (base 10℃) from seedling emergence (VE) to first floral bud (R0) and to first flower (R1), as well as from R0 to R1, for very early maturing genotypes (MG 00–I, Acme, L71–920 and L65–778). Temperatures used were the average for the time period involved (VE–R0, VE–R1, and R0–R1). Tables 1–3 show fits of first and second order equations for GDD from VE to R0 or R1, as well as from R0 to R1, vs. the average photoperiod during the time period involved, for the other, later-maturing genotypes tested. In general the later the strain matured the better the r^2 value. The temperature–GDD equations for the three early-maturing genotypes then were used to estimate the average temperature effect on GDD between the same events for the later-maturing strains and such estimates were subtracted from

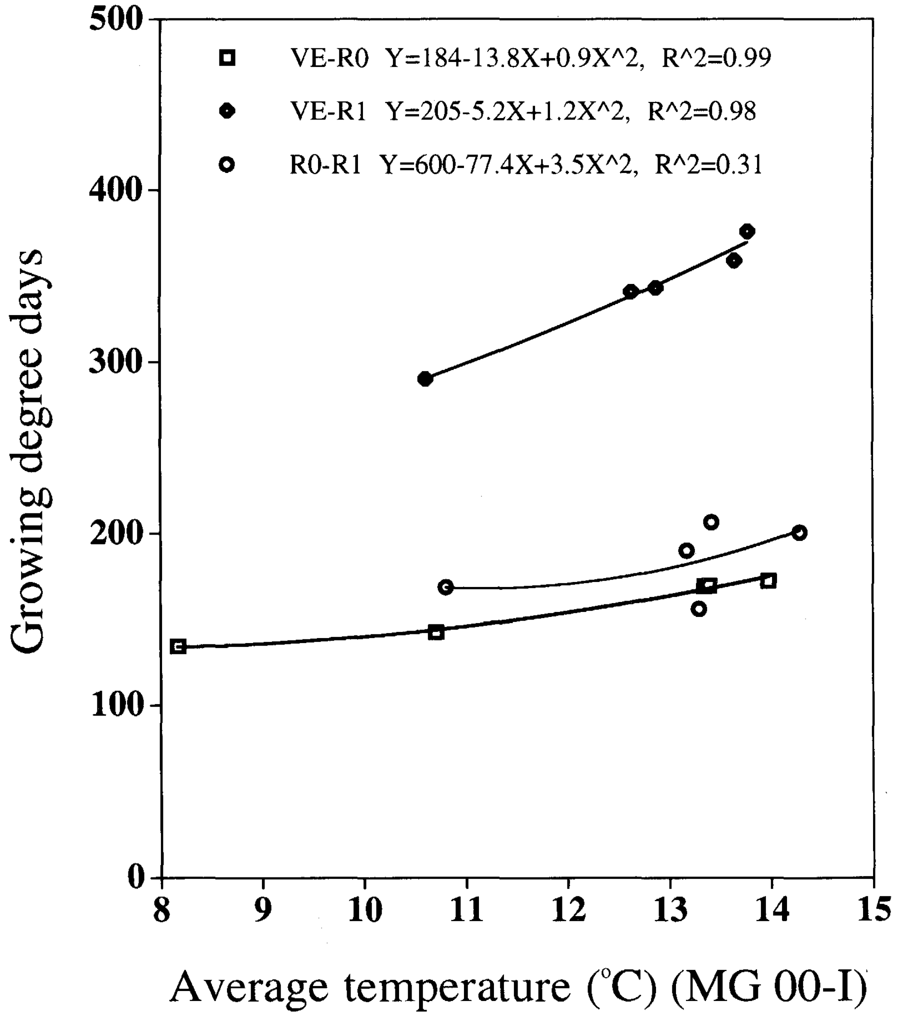

Fig. 1. Average Growing Degree Days from emergence to floral bud initiation (R0) and flowering (R1) and from R0 to R1 for cv. Acme (MG 00) and Clark isoline L71–920 (MG I).

Table 2. Comparison of coefficients and r^2 between growing degree days (GDD), adjusted GDD (AGDD) and reciprocal of AGDD for flowering (VE–R1). Roman letters indicate maturity groups, and "d" and "i" indicate stem termination habits, determinate and indeterminate, respectively.

	GDD				Adjusted GDD						1/AGDD		
	a	b	c	r_0^2	a	b	c	r_1^2	r_1^2–r_0^2	r_1^2–r_0^2 average for MG	a	b	r^2
Temperature correction:					205	–5.2	1.2	0.976					
L63–3117 (II, i)	5321	–673.5	22.9	0.061	2924	–406.9	14.3	0.791	0.730		0.53823	–0.03309	0.903
Jack (II, i)	4588	–595.6	21.1	0.186	3045	–438.9	16.0	0.768	0.582	0.54	0.30911	–0.01904	0.961
Gnome (II, d)	9628	–1297.4	45.6	0.687	11289	–1575.1	55.1	0.992	0.305	(II)	0.22667	–0.01413	0.995
L63–2404 (III, i)	7013	–929.0	32.7	0.585	7898	–1105.0	38.9	0.972	0.387		0.13532	–0.00821	0.987
Williams (III, i)	5438	–725.4	26.1	0.662	9732	–1360.9	47.8	0.980	0.318	0.31	0.14598	–0.00895	0.992
Hobbit (III, d)	11404	–1536.9	53.7	0.768	15340	–2123.6	73.8	0.979	0.211	(III)	0.15150	–0.00933	0.997
L63–3016 (IV, d)	3430	–478.8	18.7	0.762	10431	–1479.3	52.7	1.000	0.238		0.16255	–0.01013	0.991
Pixie (IV, d)	8738	–1199.1	43.1	0.864	15502	–2167.0	76.0	0.989	0.125	0.16	0.16449	–0.01025	0.992
Clark–63 (IV, i)	2013	–274.3	11.4	0.850	8303	–1184.6	42.5	0.977	0.127	(IV)	0.15140	–0.01025	0.993
L74–441 (IV+, i)	15057	–2147.8	79.0	0.967	19266	–2767.7	100.1	0.997	0.030		0.04744	–0.00940	0.988
L66–546 (V–, d)	10166	–1503.0	58.0	0.978	19527	–2824.0	102.9	0.991	0.013	0.02	0.04266	–0.00290	0.974
L65–3366 (V)	12392	–1841.5	70.9	0.994	24371	–3524.0	128.3	0.997	0.003	(IV+–V)	0.04860	–0.00307	0.974
Bradford (VI, d)	24839	–3643.6	136.4	0.995	36979	–5354.0	195.0	0.999	0.004		0.02560	–0.00157	0.962
Centennial (VII, d)	33818	–4910.7	181.2	0.999	43929	–6344.3	230.3	0.999	0.000	0.00	0.02906	–0.00183	0.926
Cook (VIII, d)	43485	–6282.9	229.9	1.000	54622	–7857.2	283.9	0.998	–0.002	(VI–VIII)	0.02950	–0.00186	0.925

Table 3. Comparison of coefficients and r^2 between growing degree days (GDD) and adjusted GDD (AGDD) for floral bud development (R0–R1). Roman letters indicate maturity groups, and "d" and "i" indicate stem termination habits, determinate and indeterminate, respectively.

	GDD				Adjusted GDD					
	a	b	c	r_0^2	a	b	c	r_1^2	r_1^2–r_0^2	r_1^2–r_0^2 average for MG
Temperature correction:					600	–77.4	3.5	0.308		
L63–3117 (II, i)	10808	–1415.6	47.1	0.441	–10472	1403	–47.0	0.559	0.118	
Jack (II, i)	5948	–780.5	26.5	0.135	–12853	1717	–57.2	0.828	0.693	0.17
Gnome (II, d)	15218	–2045.3	69.6	0.996	2529	–376	13.9	0.683	–0.313	(II)
L63–2404 (III, i)	5289	–671.4	22.2	0.770	–6922	941	–31.9	0.294	–0.476	
Williams (III, i)	3928	–488.7	16.0	0.822	–9591	1304	–44.2	0.532	–0.290	–0.24
Hobbit (III, d)	6731	–886.1	30.1	0.460	–6670	889	–29.5	0.505	0.045	(III)
L63–3016 (IV, d)	7149	–944.3	32.1	0.606	–7969	1063	–35.4	0.545	–0.061	
Pexie (IV, d)	7720	–1025.8	35.0	0.483	–7938	1056	–35.0	0.451	–0.032	–0.07
Clark–63 (IV, i)	6174	–418.3	27.7	0.577	–6611	890	–29.9	0.446	–0.131	(IV)
L74–441 (IV+, i)	9866	–1415.1	51.8	0.925	8382	–1228	45.1	0.970	0.045	
L66–546 (V–, d)	10905	–1569.0	57.6	0.935	11541	–1679	61.2	0.975	0.040	0.04
L65–3366 (V)	7961	–1143.6	42.3	0.897	9926	–1444	52.8	0.923	0.026	(IV+–V)
Bradford (VI, d)	25347	–3638.1	131.7	0.975	32198	–4619	165.9	0.990	0.015	
Centennial (VII, d)	27552	–3987.0	145.2	0.971	29476	–4283	155.6	0.974	0.003	0.00
Cook (VIII, d)	32858	–4758.7	173.2	0.962	33415	–4868	177.3	0.952	–0.010	(VI–VIII)

measured GDD values, leaving a residue AGDD. First and second order equations were then fitted to these residual AGDD or 1/AGDD values vs. average photoperiods between events, giving better r^2 values for the earlier maturing genotypes. Fig. 2 shows the general shapes of the relationships involved for flowering or R1. Presumably photoperiod overwhelmed the temperature effect for later maturing genotypes, but of course these later genotypes were not adapted to soybean production at the Urbana latitude. The maximum photoperiod at Urbana was 15.8 h; stronger photoperiod effects on GDD from R0 to R1 might be expected in earlier genotypes if longer daylengths had prevailed, such as at the higher latitudes, or if there had been a wider range of temperatures after the different planting dates. Going to 7℃ as a base temperature did not remove the temperature effect discussed above but did give similar or sometimes better r^2 values for fits of equations to data.

Photoperiod effects on GDD from R0 to R1 were strongest for the late-maturing unadapted strains. Temperature effects on GDD between these two events were not as strong, and making adjustments for a temperature effect did not improve the goodness of fit of our equations to the data, as it did for adjusted GDD values for the VE–R0 and VE–R1 growth periods. Photoperiod does appear to affect GDD needed for the R0–R1 period, as reported earlier (*1, 6*).

Acock et al. (*1*) did not find an effect of changing daylength on time to flower, but it had been reported by others in the field (*4*). In our case going back to emergence for calculating an average photoperiod for floral initiation gave better r^2 values for fit of equations to data for the early genotypes; it is likely that early MG's, 'early' being a relative term for cultivars adapted to a latitude, sensed and responded to photoperiod long before a floral bud

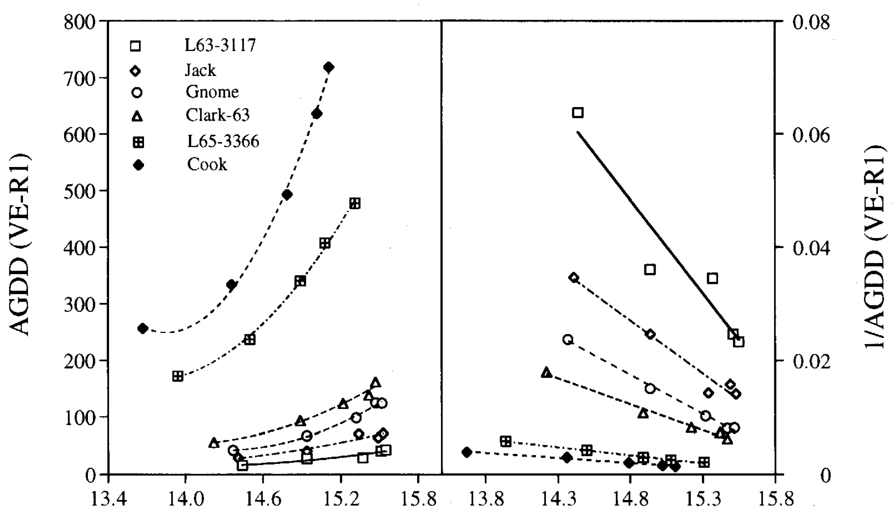

Fig. 2. Adjusted GDD (AGDD) or 1/(AGDD) vs. average photoperiod from emergence to flowering for different genotypes. AGDD=GDD minus a value taken from Fig. 1 for the average temperature from emergence to flowering.

primordium or R0 was detected by dissection. The photoperiod effects we and others have described may not be important when cultivars adapted to the latitude of growth are planted during May in the northern hemisphere; they may become important when crops are planted during other parts of the growing season at the lower, warmer latitudes. Our results for genotypes adapted to those latitudes may not be useful because of rapidly changing photoperiods from R0 through R1 at our latitude. Cultivars with new genes for photoperiod insensitivity (*8, 9*) will complicate future analyses of the problem.

Our five data points and the first or second order equations used to fit the data require large r^2 values for statistical significance at the 5% level, but the replication over genotypes and consistency of results strengthens our case. It is important to be able to predict stages of growth for modeling and management purposes; the results reported here have been made part of a soybean phenology and physiology model. More date-of-planting studies are needed at other latitudes, using appropriate 'very early' genotypes for each latitude to test for temperature effects on GDD requirement between floral events and to make appropriate adjustments for adapted cultivars for the latitude.

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