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Cultivar maturity and potential yield of soybean

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ABSTRACT

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Soybean (*Glycine max* (L.) Merrill) cultivars from maturity groups 00, I, III, and V were grown in the field to evaluate the relationship between the length of the total growth cycle and potential yield. Cultivars from maturity group 00 and I were grown in narrow rows (0.38 m) to obtain maximum insolation interception. The length of the vegetative growth period increased by 35 days from maturity group 00 to V. Plant size (total nodes per plant and maximum vegetative mass in g m^{-2}) also increased with increasing maturity group. All cultivars reached maximum insolation interception soon after initial flowering. The crop growth rate of control plots (measured between growth stages R1 and R5) was not related to plant size. Shade (30 and 63%) from growth stage R1 to R7 was used to create variation in crop growth rate within a cultivar. For each cultivar, the number of seeds m^{-2} increased linearly with increasing crop growth rate. After adjusting for cultivar differences in individual seed growth rate, there were no cultivar differences in seeds m^{-2} at a constant crop growth rate. Thus, seeds m^{-2} was related to crop growth rate, not to the size of the plant. The maturity group 00 cultivar tended to have a shorter seed-filling period but there were no consistent differences among the others. These data suggest that the longer vegetative growth period of later-maturing cultivars does not provide a higher yield potential and that shorter-season cultivars may have equal yield potential if exposed to a similar environment.

INTRODUCTION

Yield of a grain crop is a function of the rate of canopy photosynthesis, the proportion of photosynthate that is partitioned to the seed and the length of the seed growth period (Charles-Edwards, 1982). Canopy photosynthesis is, in turn, influenced by the amount of insolation intercepted by the leaves and will reach a maximum as insolation interception approaches 100% (Hawkins, 1982; Wells, 1991).

Soybean yields are often highly correlated with seeds m^{-2} (Shibles et al., 1975) which is determined during the early stages of reproductive growth. Charles-Edwards and his associates (Charles-Edwards, 1984; Charles-Ed-

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wards et al., 1986) suggested that the number of reproductive sinks (Ng) is a function of canopy photosynthesis (P_F), the proportion of canopy photosynthesis partitioned to reproductive growth (γ) and the minimum assimilate requirement for continued development of an individual reproductive sink (Ag), as described by equation 1.

$$Ng = P_F \gamma / Ag \qquad (1)$$

Egli and Yu (1991) evaluated this equation using seeds m^{-2} as an estimate of Ng, crop growth rate (CGR) as an estimate of P_F and individual seed growth rate (SGR) as an estimate of Ag. They found that equation 1 explained the observed variation in seeds m^{-2} for several soybean cultivars with genetic differences in SGR.

Grain yield is also a function of the duration of seed fill in soybean (Gay et al., 1980; Smith and Nelson, 1986a). There is genetic variation for this character (Smith and Nelson, 1987; Pfeiffer and Egli, 1988) and, in some cases, seed-fill duration was positively correlated with the date of maturity (Metz et al., 1985; Pfeiffer and Egli, 1988). Smith and Nelson (1986b) selected divergently for filling-period duration and found that lines that fell in maturity group (MG) III had longer seed-fill durations than lines in MG I. However, in other comparisons, the length of the seed-filling period was not necessarily associated with the length of the total growth period (Egli et al., 1981; Beaver and Cooper, 1982; Zeiher et al., 1982).

Temperature, insolation, rainfall, soil physical characteristics, and soil fertility influence crop productivity. Time is also an important determinant of productivity (Loomis et al., 1971; Cooper, 1975). The time that environmental conditions are favorable for plant growth varies from as little as 75 days or less at high latitudes to 365 days in the tropics (de Wit, 1967). Productivity in any environment depends, in part, on how well crop plants utilize the available time.

It is generally accepted that the highest soybean yields are obtained from cultivars that have a total growth cycle that uses most of the available growing season (Pendleton and Hartwig, 1973), although Johnson (1987) suggested that there were adapted cultivars differing by 20 to 30 days in the length of their total growth cycle that produced similar yields. Yield differences among cultivars with differences in the length of their total growth cycle could occur because critical growth stages fell in more or less favorable environments (Bunting, 1971; Shibles, 1980). However, in the absence of environmental effects, yields would respond to changes in the length of the total growth cycle only if there were differences in canopy photosynthesis, partitioning or the duration of seed fill.

The general objective of this research was to investigate the potential yield of soybean cultivars with large differences in the time from planting to maturity. Two factors that are important in determining yield are seeds m^{-2} and the duration of seed fill. Consequently, the specific objectives were to investigate the effects of cultivar maturity on the determination of seeds m^{-2} and duration of seed fill.

MATERIALS AND METHODS

Field experiments were conducted for two years at Lexington, KY (38° N latitude) with four soybean cultivars of varying maturity. The cultivars included McCall (MG 00–indeterminate growth habit), Hardin (MG I–indeterminate), Harper (MG III–indeterminate), and Essex (MG V–determinate). Maturity group III cultivars are early and MG V cultivars are full season at Lexington, while MG 00 and I are not grown commercially in Kentucky. Seeds of these four cultivars were sown on 24 May 1989 and 11 June 1990. In 1989, additional plots of McCall and Hardin were sown on 26 June. Harper and Essex were sown in 0.76-m rows (26 seeds m^{-1} of row) while McCall and Hardin were sown in 0.38-m rows (26 seeds m^{-1}). All rows were 6 m long and there were twelve (McCall, Hardin) or six (Harper, Essex) rows per plot. The soil type in 1989 was a Maury silt loam (fine mixed mesic, Typic Palendalf) and a Lanton silt loam (fine-silty, mixed thermic, Cumulic Hapaquoll) in 1990. Soil moisture status was monitored with vacuum gauge tensiometers placed approximately 20 cm below the soil surface and all plots were irrigated as needed to minimize moisture stress.

Commercial shade cloth was placed over plots at growth stage R1 (Fehr and Caviness, 1977) and left in place until maturity (except for McCall) to reduce insolation (by 30 or 63%) and create variation in crop growth rate (CGR) and seed m^{-2} (Egli and Yu, 1991). A limited supply of shade cloth required movement of the shade cloth from McCall to Essex when Essex reached growth stage R1. McCall was at late growth stage R6 at this time and changes in canopy photosynthesis would no longer affect seed number. All cultivars had 0, 30, and 63% shade treatments except in 1989 when McCall had an additional late-planted control treatment and Hardin had only early- and late-planted control treatments and a late-planted 63% shade treatment.

Crop growth rate was determined from four samples (0.7 m^2) of total above-ground biomass taken between growth stage R1 and R5 as described previously (Egli and Yu, 1991). Individual seed growth rate was estimated from marked pods with two samples (20 pods per sample) taken 14 days apart (Egli and Yu, 1991). The effective filling period was calculated from final seed size from the marked pods and SGR (Daynard et al., 1971). Total seed growth rate (g m^{-2} land area day^{-1}) was estimated from (SGR) × (seeds m^{-2}). Reproductive growth stages were measured weekly (every three days as the plants approached R7) on 10 consecutive plants in the row on two replications. The dates of growth stages R1 and R5 were estimated by linear interpolation and R7 as when 50% of the plants were at or past R7.

Interception of photosynthetically active radiation (PAR) by the plant canopy was estimated on the control treatment at growth stage R1 at approximately solar noon with a Li-Cor line quantum sensor. Radiation-use efficiencies (g/MJ) were calculated by dividing the CGR (including only aboveground biomass) by the average daily insolation measured at a weather station approximately 2 km from the site of the experiments, over the period used to estimate CGR. As interception of PAR by all cultivars was near 80% or higher by growth stage R1 and complete ground cover was achieved soon after R1, insolation was not adjusted for interception.

Yield was estimated from 4.9 m of one (0.76-m row spacing) or two (0.38-m row spacing) bordered rows. Seed size was estimated from a subsample from the yield sample and seed m^{-2} was calculated from yield and seed size (Egli and Yu, 1991).

The experimental design was a randomized complete block with four replications in 1989 and a split plot with cultivars as main plots and shade treatments as subplots with main plots in a randomized complete block design with four replications in 1990. The 1989 data for Harper and Essex were included in a previous publication (Egli and Yu, 1991).

RESULTS

Yields of Hardin (early planted), Harper, and Essex without shade were not significantly different in either year (Table 1), but yield of McCall was significantly lower (18 to 20% less than Hardin). Decreasing insolation from R1 to R7 with shade decreased yield and the decrease was larger for 63% shade. Late planting also decreased yield in 1989. Most of these yield decreases were associated with fewer seeds m^{-2}; effects of the shade treatments or planting dates on seed size were not consistent (Table 1).

Shade had no significant effect on SGR, so cultivar means are shown in Table 2. There were significant differences in individual seed growth rates among cultivars with Essex having the lowest rate and McCall and Harper, the highest rates.

The shade treatments had minimal effects on phenological development; consequently, only cultivar means are shown in Table 3. The total growth cycle increased from approximately 80 days for the earliest cultivar, McCall to more than 130 days for the latest cultivar, Essex. All phenological periods increased as maturity was delayed; however, the increases in seed-filling period were not always proportionate to increases in the vegetative growth period (planting to R5).

Both EFP and the R5–R7 period provide an estimate of the duration of seed fill. The EFP of McCall was significantly shorter than Harper and Essex

TABLE 1

Effect of cultivar and shade treatments on yield and yield components, 1989–1990

Cultivar	Treatment	Yield (g m^{-2})		Seed (no. m^{-2})		Seed size (mg seed^{-1})	
		1989[a]	1990	1989	1990	1989	1990
McCall	Control	313	235	1945	1805	161	131
	30% shade	267	214	1564	1483	171	145
	63% shade	164	124	1097	795	150	154
	Late planted	236	–	1599	–	147	–
Hardin	Control	381	295	2548	2126	149	139
	30% shade	–	216	–	1447	–	149
	63% shade	–	143	–	958	–	150
	Late planted	292	–	2001	–	146	–
	Late planted 63%	134	–	992	–	135	–
Harper	Control	383	291	1782	1554	215	186
	30% shade	299	228	1400	1215	214	188
	63% shade	174	139	867	698	200	200
Essex	Control	399	261	2551	1762	156	148
	30% shade	253	209	1710	1356	148	154
	63% shade	173	130	1169	878	147	149
LSD (0.05)[b]		36	37	167	240	13	10
CV		9	12	7	12	5	5

[a] 1989 data for Harper and Essex were reported previously in Egli and Yu (1991).
[b] For comparison of any two means within a year.

TABLE 2

Cultivar effects on seed growth rate and radiation-use efficiency, 1989–1990

Cultivar	Seed growth rate[a] (mg seed^{-1} day^{-1})			Radiation-use efficiency[b] (g MJ^{-1})	
	1989	1990	$\bar{X}$	1989	1990
McCall	5.8	5.9	5.8	0.84	0.66
Hardin	4.8	5.0	4.9	0.63	0.66
Harper	5.9	6.5	6.2	0.84	0.58
Essex	4.3	3.8	4.0	0.84	0.57
LSD (0.05)	0.6	0.4			
CV (%)	13	15			

[a] Shade treatments had no significant effect ($P \geq 0.05$) on seed growth rate. Therefore, only cultivar means are presented.
[b] Average for growth stage R1 to R5, control treatments only. The late-planted controls for McCall and Hardin in 1989 were not included. Calculated using total insolation.

in 1989 while the EFP of Essex was significantly longer in 1990 (Table 3). McCall also had a shorter R5–R7 period than Hardin and Harper in both years. Since the R5 growth stage occurs earlier in the seed-filling period on

TABLE 3

Phenological development of four soybean cultivars from MG 00 to MG V

Cultivar	Length of phenological periods (days)						Effective filling period (days)	
	Plt[a] to R5		R5 to R7		Total		1989	1990
	1989[b]	1990	1989	1990	1989	1990		
McCall[c]	55	55	27	29	82	83	24	25
Hardin	63	60	32	36	95	96	30	27
Harper	74	73	39	38	112	111	33	24
Essex	92	88	50	44	141	132	34	37
LSD (0.05)							7	4
CV							17	15

[a] Planting.
[b] The 1989 means do not include the late-planted treatments with McCall and Hardin.
[c] Shade treatments had minimal effects on the rate of development; therefore, only cultivar means are presented.

TABLE 4

Effect of cultivars on nodes per plant and vegetative mass at growth stage R5 on the control treatments

Cultivar	Nodes per plant[a]		Vegetative mass at growth stage R5[b] ($g\ m^{-2}$)	
	1989	1990	1989	1990
McCall	14	10	308	302
Hardin	13	11	381	362
Harper	20	18	461	396
Essex	36	21	705	539
LSD (0.05)	4	2	60	40
CV	17	10	16	12

[a] Total number of nodes on main stem and branches.
[b] Vegetative mass at growth stage R5 represents the maximum vegetative mass.

determinate cultivars, the R5–R7 period of Essex cannot be compared validly with the other cultivars (Pfeiffer and Egli, 1988).

The two-year average vegetative mass at growth stage R5 [maximum vegetative mass (Egli et al., 1985)] of the unshaded plots increased from 305 g m^{-2} for McCall to 622 g m^{-2} for Essex (Table 4). Cultivar differences were significant ($\alpha=0.05$) in both years. Total nodes per plant on the control treatments increased as the length of total growth period increased (Table 4). Essex had more than twice as many nodes per plant as McCall.

Crop growth rates varied from about 6 to 17 g m^{-2} day^{-1} (Fig. 1). The range in CGR was similar for Harper and McCall; however, maximum rates were lower for Hardin and Essex. There was a significant linear relationship

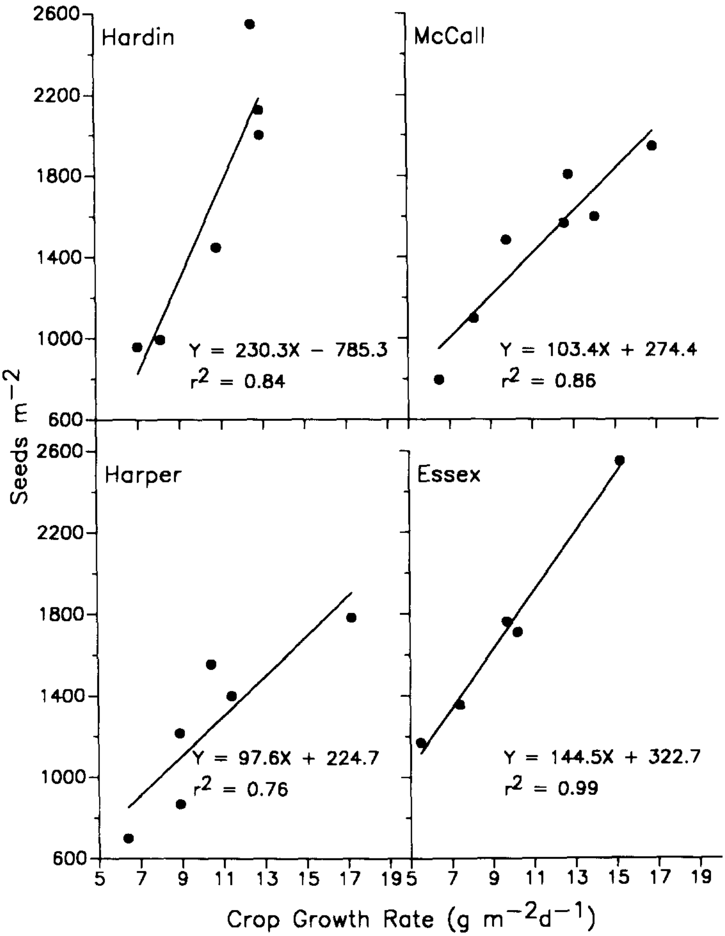

Fig. 1. The relationship between seeds m^{-2} and crop growth rate by cultivar, 1989–1990.

between seeds m^{-2} and CGR for each cultivar. There was an inverse relationship between seeds m^{-2} at a constant CGR, and SGR (Table 2) across cultivars. Essex, for example, had the lowest SGR and produced more seeds than McCall and Harper, which had the highest SGR. Total seed growth rate, (g m^{-2} land area day^{-1}) calculated by multiplying seeds m^{-2} by SGR, increased as CGR increased for all cultivars (Fig. 2).

Radiation-use efficiencies based on total insolation for the control plots were generally higher in 1989 (0.63 to 0.84 g MJ^{-1}) than in 1990 (0.57 to 0.66 g MJ^{-1}) (Table 2). Radiation-use efficiencies in 1989 were similar for all cultivars except Hardin, which was lower. McCall and Hardin had higher radiation-use efficiencies (approximately 15%) than Harper and Essex in 1990.

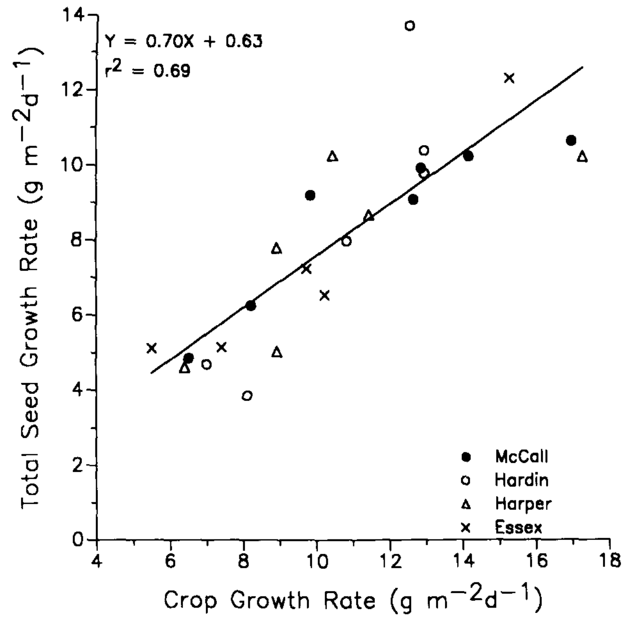

Fig. 2. The relationship between total seed growth rate (g m^{-2} and area day^{-1}) and crop growth rate across cultivars, 1989–1990. The linear regression equation was significant at $\alpha = 0.01$. The quadratic term did not significantly ($\alpha = 0.05$) improve the goodness of fit. Total seed growth rate was the product of individual seed growth rate (Table 2) and seeds m^{-2} (Table 1).

DISCUSSION

The cultivars used in the experiments reported here exhibited a range of 54 days in the average length of the total growth cycle (planting to growth stage R7) from McCall (MG 00) to Essex (MG V). The vegetative growth period (planting to growth stage R5) also increased, resulting in larger plants as shown by nodes and maximum vegetative mass per plant. The MG 00 and I cultivars had twice as many plants per unit area and thus the number of nodes per unit area was slightly higher than Harper (MG III) and less than Essex (MG V). However, vegetative mass per unit area at R5 was less for the MG 00 and I cultivars. Similar relationships have been reported for other cultivars (Zeiher et al., 1982; Kane and Grabau, 1992).

Comparisons of CGR among cultivars must take into consideration potential differences in insolation or insolation interception, especially when comparing cultivars of different maturities. All cultivars had 95% PAR interception soon after R1, so differences in PAR interception did not influence CGR. Essex had approximately 10% less insolation during growth stage R1 to R5 than the other three cultivars. Maximum CGR were similar for McCall and Harper, but were slightly lower for Hardin and Essex. Lower insolation could be related to the lower CGR for Essex; however, Hardin also had a slightly lower CGR, but insolation levels similar to McCall and Harper. Radiation-use efficiency for the early cultivars, except for Hardin in 1989, was equal to or greater than the later cultivars. These data suggest that the larger plants produced by the later-maturing cultivars did not provide any advantage for the accumulation of dry matter by the plant community. Apparently, under similar environmental conditions, crop canopies of different-sized plants or leaf area indices (LAI) produce similar CGR, providing the lowest LAI is adequate to maximize insolation interception (Shibles and Weber, 1965; Wells, 1991).

The primary yield component, seeds m^{-2}, is influenced by canopy photosynthesis during flowering and pod set and by the assimilate requirement per seed, estimated by SGR (Charles-Edwards, 1984; Egli and Yu, 1991). Seeds m^{-2} could therefore vary among cultivars because of environmental effects on photosynthesis or genetic differences in SGR, neither of which relate to cultivar yield potential.

Shade treatments were used to create a range in CGR within each cultivar to facilitate comparison of the relationship between CGR and seeds m^{-2} among cultivars. Individual SGR was used to adjust for cultivar differences in the assimilate requirement per seed (Charles-Edwards, 1984; Egli and Yu, 1991).

As expected, there was a linear increase in seeds m^{-2} with increasing CGR for each cultivar (Herbert and Litchfield, 1984; Ramseur et al., 1985; Charles-Edwards et al., 1986; Egli and Yu, 1991) and seeds m^{-2} was inversely related to cultivar differences in SGR as reported previously (Egli and Yu, 1991). Total seed growth rate (seeds $m^{-2} \times$SGR from equation 1) was linearly related to CGR and there was no evidence of any cultivar differences in this relationship.

These data suggest that all cultivars were equally efficient at producing seeds per unit of canopy photosynthesis after adjustment for differences in SGR. There was no evidence in these data that plant size affected the partitioning of assimilate to the seed. This is consistent with previous results (Egli et al., 1985) suggesting that partitioning in soybean was stable across planting dates, growth habits, and moisture stress levels. Previous suggestions (Egli et al., 1987) that an R5 vegetative mass of 500 g m^{-2} was required to maximize seeds m^{-2} was not supported by the data in this experiment. Seeds m^{-2} was a function of CGR, not plant size; however, insolation interception is related to plant size and this may have influenced our previous results (Egli et al., 1987).

The duration of seed fill is also an important determinant of yield (Gay et al., 1980; Smith and Nelson, 1986a). McCall tended to have a shorter seed-fill duration (by 0 to 31%) than Hardin and Harper for both methods of estimating it. There was little difference between Hardin and Harper and the EFP of Essex was longer in one of two years. These data suggest that the duration of seed fill does not always increase in direct proportion to the total growth cycle as cultivar maturity is delayed. Others have reported similar results (Egli et al., 1978, 1981; Beaver and Cooper, 1982; Zeiher et al., 1982; Lin, 1990). Considering only seed-fill duration, the yield potential of McCall would be less than the other cultivars. Hardin, however, should have similar yield potential as Harper, with a 15-day longer growth cycle and possibly equal to Essex with 45-day longer growth cycle.

These data suggest that the potential yield of soybean does not necessarily increase as the total length of the growth cycle increases. The longer vegetative growth period associated with lengthening the total growth cycle increased vegetative plant size but this did not necessarily translate into higher CGR, more seeds m^{-2}, or a longer seed-fill duration. Schweitzer and Harper (1985) reached a similar conclusion when they shortened the vegetative period by manipulating photoperiod without affecting yield in some cultivars.

It is well known that maximum yield requires complete insolation interception during reproductive growth (Hawkins, 1982) which is facilitated by large plants, but can also be attained with small plants by increasing the number of plants per unit area. Shibles (1980) described a crop that was well adapted to its environment as one that efficiently balances the time available for growth between producing an adequate vegetative structure and maximum partitioning of assimilate to yield. However, if adequate vegetative structure is defined as providing complete insolation interception, it can be manipulated by changing row spacing and plant population and is not necessarily dependent upon the length of the vegetative growth period (Shibles and Green, 1969). Bunting (1971) eloquently discussed the question “is your vegetative phase really necessary?” and concluded “that it was necessary but not as necessary as you might think”. The data reported here for soybean are in agreement with this conclusion.

Time is an important resource in any environment. If yields do not increase in direct proportion to the total growth cycle, grain crops cannot effectively utilize the longer growing seasons at lower latitudes. This weakness can be compensated for by multiple cropping. If similar yields can be obtained from cultivars with shorter growth cycles by appropriate management, multiple cropping opportunities may be improved (Bunting, 1971) and extended to higher latitudes. The use of short-season cultivars would have other advantages including reduced total water use in irrigated agriculture, possible reductions in disease or insect problems, and increased flexibility in rotations. Soybean is usually considered to be tolerant of stress during vegetative growth, possibly because of large plants with excess LAI. Thus, use of early-maturing cultivars with short vegetative growth periods may result in increased susceptibility to stress during vegetative growth.

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REFERENCES

Beaver, J.S. and Cooper, R.L., 1982. Dry matter accumulation patterns and seed yield components of two indeterminate soybean cultivars. Agron. J., 74: 380–383.

Bunting, A.H., 1971. Productivity and profit or is your vegetative phase really necessary? Ann. Appl. Biol., 67: 265–285.

Charles-Edwards, D.A., 1982. Physiological Determinants of Crop Growth. Academic Press, New York, NY, 161 pp.

Charles-Edwards, D.A., 1984. On the ordered development of plants 1. An hypothesis. Ann. Bot., 53: 699–707.

Charles-Edwards, D.A., Doley, D. and Rimmington, G.M., 1986. Modeling Plant Growth and Development. Academic Press Australia, North Ryde, N.S.W., 235 pp.

Cooper, J.P., 1975. Control of photosynthetic production in terrestrial systems. In: J.P. Cooper (Editor), Photosynthesis and Productivity in Different Environments. Cambridge Univ. Press, pp. 593–621.

Daynard, T.B., Tanner, J.W. and Duncan, W.G., 1971. Duration of the grain filling period and its' relation to grain yield in corn, *Zea mays* L. Crop Sci., 11: 45–48.

de Wit, C.T., 1967. Photosynthesis: its relationship to overpopulation. In: A. San Pietro, F.A. Green and T.J. Army (Editors), Harvesting the Sun. Academic Press, New York, NY, pp. 315–320.

Egli, D.B. and Yu, Z.-w., 1991. Crop growth rate and seeds per unit area in soybean. Crop Sci., 31: 439–442.

Egli, D.B., Leggett, J.E. and Wood, J.M., 1978. Influence of soybean seed size and position on the rate and duration of filling. Agron. J., 70: 127–130.

Egli, D.B., Fraser, J., Leggett, J.E. and Poneleit, C.G., 1981. Control of seed growth in soya beans (*Glycine max*(L.) Merrill). Ann. Bot., 48: 171–176.

Egli, D.B., Guffy, R.D. and Leggett, J.E., 1985. Partitioning of assimilate between vegetative and reproductive growth in soybean. Agron. J., 77: 917–922.

Egli, D.B., Guffy, R.D. and Heitholt, J.J., 1987. Factors associated with reduced yields of delayed plantings of soybean. J. Agron. Crop Sci., 159: 176–185.

Fehr, W.R. and Caviness, C.E., 1977. Stages of soybean development. Coop. Ext. Service, Agric. and Home Econ. Exp. Stn. Iowa State Univ., Ames, IA, Spec. Rep. 80, 11 pp.

Gay, S., Egli, D.B. and Reicosky, D.A., 1980. Physiological basis of yield improvement in soybeans. Agron. J., 72: 387–391.

Hawkins, A.F., 1982. Light interception, photosynthesis and crop productivity. Outlook Agric., 11: 104–113.

Herbert, S.J. and Litchfield, G.V., 1984. Growth response of short season soybean to variations in row spacing and density. Field Crops Res., 9: 163–171.

Johnson, R.R., 1987. Crop Management. In: J.R. Wilcox (Editor), Soybeans: Improvement, Production, and Uses, 2nd edn. Agronomy, 16: 355–390.

Kane, M.V. and Grabau, L.J., 1992. Early planted, early maturing soybean cropping system: Growth, development and yield. Agron. J., 84: (in press).

Lin, H., 1990. A planting pattern study of early maturing soybean cultivars in Kentucky. M.S. Thesis, University of Kentucky, Lexington, KY, 83 pp.

Loomis, R.S., Williams, W.A. and Hall, A.E., 1971. Agricultural productivity. Ann. Rev. Plant Physiol., 22: 431–468.

Metz, G.L., Green, D.E. and Shibles, R.M., 1985. Reproductive duration and date of maturity in populations of three wide soybean crosses. Crop Sci., 25: 171–176.

Pendleton, J.W. and Hartwig, E.E., 1973. Management. In: B.E. Caldwell (Editor), Soybeans: Improvement, Production, and Uses, 1st edn. Agronomy, 16: 211–237.

Pfeiffer, T.W. and Egli, D.B., 1988. Heritability of seed filling period estimates in soybean. Crop Sci., 28: 921–925.

Ramseur, E.L., Wallace, S.U. and Quisenberry, V.L., 1985. Growth of 'Braxton' soybeans as influenced by irrigation and intra row spacing. Agron. J., 77: 163–168.

Schweitzer, L.E. and Harper, J.E., 1985. Effect of hastened flowering on seed yield and dry matter partitioning in diverse soybean genotypes. Crop Sci., 25: 995–998.

Shibles, R., 1980. Adaptation of soybeans to different seasonal durations. In: R.J. Summerfield and A.H. Bunting (Editors), Advances in Legume Science. Royal Botanic Gardens, Kew, England, pp. 279–286.

Shibles, R.M. and Green, D.E., 1969. Morphological considerations in breeding soybeans for narrow rows. In: W.R. Fehr (Editor), Proc. of the Soybean Breeding Conf. Iowa State Univ., Ames, IA, pp. 1–12.

Shibles, R.M. and Weber, C.R., 1965. Leaf area, solar radiation interception and dry matter accumulation by soybeans. Crop Sci., 5: 575–577.

Shibles, R.M., Anderson, I.C. and Gibson, A.H., 1975. Soybean. In: L.T. Evans (Editor), Crop Physiology. Cambridge Univ. Press, London, pp. 151–190.

Smith, J.R. and Nelson, R.L., 1986a. Relationship between seed filling period and yield among soybean breeding lines. Crop Sci., 26: 469–472.

Smith, J.R. and Nelson, R.L., 1986b. Selection for seed-filling period in soybean. Crop Sci., 26: 466–469.

Smith, J.R. and Nelson, R.L., 1987. Predicting yield from early generation estimates of reproductive growth periods in soybean. Crop Sci., 27: 471–474.

Wells, R., 1991. Soybean growth response to plant density: relationships among canopy photosynthesis, leaf area and light interception. Crop Sci., 31: 755–761.

Zeiher, C., Egli, D.B., Leggett, J.E. and Reicosky, D.A., 1982. Cultivar differences in N redistribution in soybeans. Agron. J., 74: 375–379.