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Full Length Research Paper

Influence of sowing date on phenological stages, seed growth and marketable yield of four vegetable soybean cultivars in North-eastern USA

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Sowing date effect on grain soybean has been well documented, while less research was done on vegetable soybean. The impact of sowing date on the duration of critical phonological stages, and the responses of seed growth and marketable yield of four vegetable soybean cultivars with different maturity planted at about 2-weeks intervals over a 6–weeks span in North-eastern USA was investigated. The difference in fresh pod harvest (R6) from the first to the last sowing date ranged from 15 to 30 days. Sowing after June 5th did not shorten the growing period for early maturity cultivar. The later the sowing date, the longer the duration from R6 to mature seed harvest. Seed dry matter accumulation period was extended for one or two more weeks by late sowing. The marketable yield ranged from 4069 to 8660 kg/ha, and the response to sowing date differed among cultivars. Marketable yield decline, per day of sowing delay was 34.4 - 54.9 kgha^{-1}day^{-1} for three cultivars, while an unexpected rank reversal occurred for brown seed cultivar. Yield decline associated with delayed sowing was primarily related to reduction in standard pod number, while increased fresh seed weight might compensate the yield loss at R6 stage. The insensitivity of yield response to sowing date from early maturity cultivar Dongdou 24, provides farmers flexibility to gain higher economic return.

Key words: Sowing date, growing period, fresh seed weight, standard pod number, vegetable soybean.

INTRODUCTION

Vegetable soybean or edamame is a specialty soybean harvested as a fresh vegetable before fully filled green pods turn yellow (Zhang et al., 2007). This stage corresponds to the R6 stage of soybean development (Fehr et al., 1971). The seeds of vegetable soybeans are larger, sweeter and tender than that of grain soybean. Because of its excellent nutrition and slightly sweet taste, mild flavor and nutty texture, with less objectionable beany taste, it is preferred over conventional grain soybeans as a fresh green bean (Lee and Hwang, 1998). Active public research with vegetable soybeans occurs in Japan, China, Korea, Sri Lanka, Taiwan, and Thailand. Although in the USA, vegetable soybean research has been conducted for many years, mostly in the west, it was only a dozen year ago that Americans began to learn about vegetable soybean varieties as a potential new cash crop with good fit to crop rotation, and good marketability. However, there has been little commercial production, with little or no resources being available for agronomic decisions on vegetable soybean production in New England.

Sowing date is the variable with the largest effect on crop yield (Calvino et al., 2003a, b). Fine-tune management of soybean by sowing date is a good approach to enhance both crop yield and economic benefit. Effects of planting date on soybean yield and other traits varied at locations (Hoeft et al., 2000; Naeve et al., 2004). Environmental conditions associated with late sowing affect crop features related to the capture of radiation and portioning of crop resources. These include less vegetative growth (Board et al., 1992), shorter stems (Boquet, 1990), lower reproductive nodes (Board et al., 1999), and

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shortening of the reproductive phases (Kantolic and Slafer, 2001).

In spring-sown single crops of soybean, yield is most susceptible to nutritional and water deficits during late flowering and grain filling, and grain number is the main yield component involved in this response (Andriani et al., 1991; Calvino and Sadras, 1999). Delayed sowing generally shifts reproductive growth into less favorable conditions with shorter days and lower radiation and temperature (Egli and Bruening, 2000). In a simulation study, Egli and Bruening (1992) found that reduced radiation and temperature accounted for most of the reduction in yield associated with late sowing in well-watered soybean crops reaching maturity in late October or early November. Unlike grain soybean, the taste of the grain and the pod traits of vegetable soybean at harvest are extremely important (Takao, 2004). If seeds are over matured then it will lose its marketability. Like many other vegetables, in order to increase the profitability of vegetable soybean production, sowing at different dates might be a good strategy for maximum profitability.

The yielding ability of green soybean may be affected by its sowing time due to adverse weather conditions and the number of pods set; the green soybean yield decreased with delay in the sowing time (Nishioka and Okumura, 2008; Zhang et al., 2008). Large pods containing many grains are considered to be of good quality. While variation in soybean planting date is expected to impact the pattern of soybean growth and development, very few reports have been examined in vegetable soybean.

The objectives of our study were to quantify the impact of sowing date on the duration of critical phonological stages, and to examine the responses of seed growth and yield of four vegetable soybean cultivars with varied maturity planted at about 2-weeks intervals over a 6–weeks span in Massachusetts, North-eastern USA.

MATERIALS AND METHODS

Field experiment was conducted at the University of Massachusetts Agronomy farm in 2007. The previous crop was corn (*Zea mays* L.). The soil is a Hadley fine sandy loam (Typic Udifluvent). A split-plot randomized complete block design was used with four replications. Main plots were five planting dates at about 2-weeks intervals on May 22, June 5 and June 20, July 5 and July 17. Subplots were four vegetable soybean cultivars with different maturity and seed coat color, and they were Dongdou 26 (late maturity), Dongdou 24 (early maturity), Zhongmei 52 (early-medium maturity) and Zhongke 57 (medium maturity). The four cultivars were selected from the highest entries in 2-years performance trials conducted in 2004 and 2005 in Massachusetts and North-east China (Zhang et al., 2008). The five-row subplots row length was 7.0 m, with an interrow spacing of 0.65 m. The viable seeding rate was 280,000 seeds ha^{-1} and sowing depth was 3 cm. Plots were planted with a grain drill. Manual weeding was applied during the growing season. The number of days from sowing to emergence, emergence to R1, R1 to R6, and R6 to harvest was recorded. Data on yield and yield components were collected and agronomic characters were examined. Fresh pods from 10 plants per plot were randomly collected every 8 days beginning at R4 stage to determine fresh and dry seed weight. At R6 stage, 10 plants per plot were randomly selected from the center two rows to determine pod number, fresh pod weight, and hundred seed fresh weight. Pods in 2 m^2 from each treatment plot were weighed for the marketable yield. The pods having two and three seeds were considered standard pod or marketable, while pods with one or, without seeds, and those with pod discoloration, small seeds, insect damaged and abnormal pods were classified as cull types or unmarketable pods. Experimental data were analyzed by using PROC ANOVA (analysis of variance), and Duncan's multiple range tests were used for mean comparison (SAS Institute, Inc. 1996).

RESULTS

Phenological stages and seed growth

Strong downward trend in plant maturity relative to sowing date delay was observed. The later the sowing date, the shorter the days needed from sowing to fresh pod harvest (R6). Late maturity cultivar, Dongdou 26 was most sensitive to sowing date. The days required from sowing to R6 for May 22, June 5, June 20, July 5 and July 17 was 98, 89, 82, 79, and 74 days (Table 1). For cultivar Zhongmei 52, the corresponding days was 93, 72, 71, 68, and 63 days. While for early maturity cultivar Dongdou 24, the duration required was 88, 75, 76, 76, and 73 days. This means that for this early maturity cultivar, sowing after June 5 did not shorten the growing period. Although the days required from sowing to R6 for cultivar Zhongke 57 was significantly reduced from 93 days planted on May 22 to 66 days planted on June 20, the duration was 71 and 68 days planted on July 5 and 17 respectively, which was 2 - 5 days more than that of June 20. For all cultivars, the days from sowing to emergence was 7 days at sowing date of May 22, June 5 and June 20, and was 5 days at the other two sowing dates. Compared with sowing date of May 22, later sowing in all cultivars extended the days from R6 to mature seed harvest except cultivar Zhongke 57 planted on June 5 (Table 1). The later the sowing date, the longer the duration from R6 to mature seed harvest. The duration from R6 to mature seed harvest planted on July 17 was still 5 - 19 days longer than early planting on May 22.

Seed growth started around August 2 for sowing date of May 22 and late August for the sowing dates of June 5 and June 20. While for sowing date of July 5, seed, growth started around September 11. However, seed growth started around August 10 for sowing date of July 17 (Figure 1). For early maturity cultivar Dongdou 24, the seed dry matter accumulation was 4-weeks for the sowing date of May 22, and was extended to 5- weeks for the sowing date of June 5, and July 17. While for sowing date of June 20 and July 5, the seed dry matter accumulation was extended to 6- weeks. All other cultivars, compared with sowing date of May 22, late sowing extended dry matter accumulation period for one or two more weeks except cultivar Zhongmei 52 at sowing date of July 17 (Figure 1).

Table 1. Effects of sowing dates on the number of days from different phenological stages.

Cultivars	May 22				June 5				June 20				July 5				July 17			
	P-E	E-R1	R1-R6	R6-H	P-E	E-R1	R1-R6	R6-H	P-E	E-R1	R1-R6	R6-H	P-E	E-R1	R1-R6	R6-H	P-E	E-R1	R1-R6	R6-H
Black seed	7 a	41a	50a	29 a	7 a	41 a	41 a	32a	7 a	32 a	43 a	36 b	5 a	32 a	42 a	41 a	5 a	31 a	38 a	34b
Brown seed	7 a	40 a	41 b	21 c	7 a	34 c	34 b	22 b	7 a	32 a	37 b	42 a	5 a	32 a	39 b	32 c	5 a	29b	38a	32 c
Yellow seed	7 a	37b	49 a	20c	7 a	33 c	32 b	23 b	7 a	30 b	34 b	36 b	5 a	27 b	36c	38 b	5 a	27b	31 c	39 a
Green seed	7 a	38 b	48 a	23 b	7 a	37 b	41 a	17 c	7 a	30 b	29 c	42 a	5 a	23 c	43 a	34 c	5 a	28b	35 b	35b

P: planting; E: emergence; R1: initial flowering; R6: fresh pod harvest; H: mature seed harvest Values followed by the same letter within the column for different cultivars are not significantly different ($P \leq 0.05$).

Marketable yield and yield components

Sowing date had a significant impact on marketable yield. However, the magnitude of response differed among cultivars (Figure 2). The highest marketable yield of 7688, 6572 and 8661 kg/ha was obtained on May 22 for cultivars Zhongke 57, Zhongmei 52 and Dongdou 26, respectively. While the highest marketable yield of 6349 kg/ha was obtained at sowing date of July 5 for cultivar Dongdou 24. Lowest yield was found for cultivar Zhongke 57 at sowing date of July 5, for cultivar Zhongmei 52 at sowing date of July 17, and for cultivar Dongdou 26 around June 20 to July 5. However, the lowest yield for cultivar Dongdou 24 was at the sowing date of May 22. For cultivar Zhongke 57, no yield differences were found among sowing date of June 5, June 20, and July 17, while their yields were significantly different with sowing date of July 5. While for Zhongmei 52 and Dongdou 26 cultivars, yield by sowing date of July 17 was significantly lower than that of sowing date from June 5, June 20 and July 5. An unexpected rank reversal occurred for cultivar Dongdou 24, the yield of late sowing on June 5, July 5 and July 17 was greater than that of May 22.

The sowing date effect on fresh seed weight at R6 stage differed among cultivars (Table 2). For cultivars Dongdou 26 and Dongdou 24, fresh seed weight increased as planting was delayed from 22 May to July 5, but the June 20 planting generated a somewhat larger increase than expected, and declined at sowing date of July 17. In opposite, fresh seed weight was reduced by late sowing for cultivar Zhongke 57. However, for cultivar Zhongmei 52, compared with sowing date of May 22, fresh seed weight was only reduced at sowing date of June 5, but increased at sowing date of June 20, and July 5. Lowest fresh seed weight was observed for all cultivars at sowing date of July 17. The trend of later sowing date leading to fewer standard pods until July 5 was observed for every cultivar. Except cultivar Dongdou 26, standard pod number at sowing date of July 17 was greater than that of May 22.

DISCUSSION

Seedling emergence in earlier (cooler) plantings is frequently slower than that in later plantings (Oplinger and Philbrook, 1992). Our data fit this scenario. The difference in R6 plant maturity from the first to the last sowing date was 24 days for cultivar Dongdou 26, 30 days for cultivar Zhongmei 52, 15 days for cultivar Dongdou 24, and 25 days for cultivar Zhongke 57. This is mostly due to the shortening of both emergence to R1 and R1 to R6. Calvino et al. (2003a) found that delayed sowing shortened season length mostly by reducing the duration of late reproductive phase. Surprisingly, our data observed that late sowing extended the duration from R6 to mature seed harvest. This extension contributed to the extended seed dry matter accumulation period in the present study. Pedersen and Lauer (2004a, b) studied the effects of early (3 - 6 May) vs. late (23 - 27 May) planting dates on soybean growth, development, and yield in Wisconsin, and observed that the start of each reproductive stage-from R1 (begin flower) to R5 (begin seed) was delayed by the 3-weeks delay in planting date, except for stage R6 (full stage), which occurred coincidently in both planting dates at 105 days after emergence.

Yield was significantly affected by sowing date, which arose because the general yield decline per day of sowing delay was 40.8 $kgha^{-1}day^{-1}$ for cultivar Zhongke 57, 34.4 $kgha^{-1}day^{-1}$ for cultivar Zhongmei 52, 54.9 $kgha^{-1}day^{-1}$ for cultivar Dongdou 26. Thus, cultivar Dongdou 26 with a genetic predisposition for greater pod numbers displayed a larger difference over planting date. These observed declines were much greater than the grain soybean yield decline of 22 $k\ ha^{-1}day^{-1}$ from May 1 to June 10 observed by

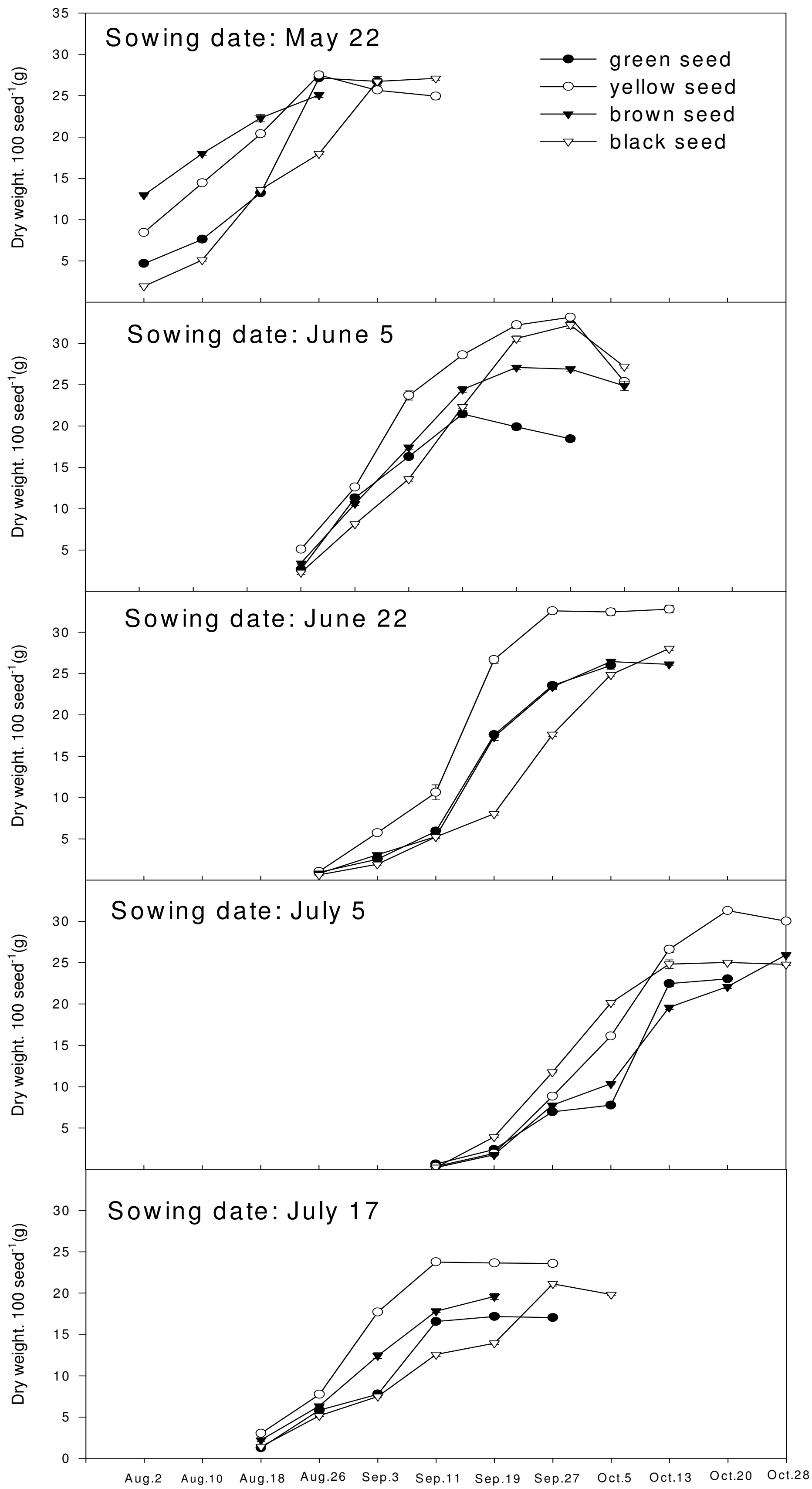

Figure 1. Sowing date effect on seed dry weight accumulation to different cultivars.

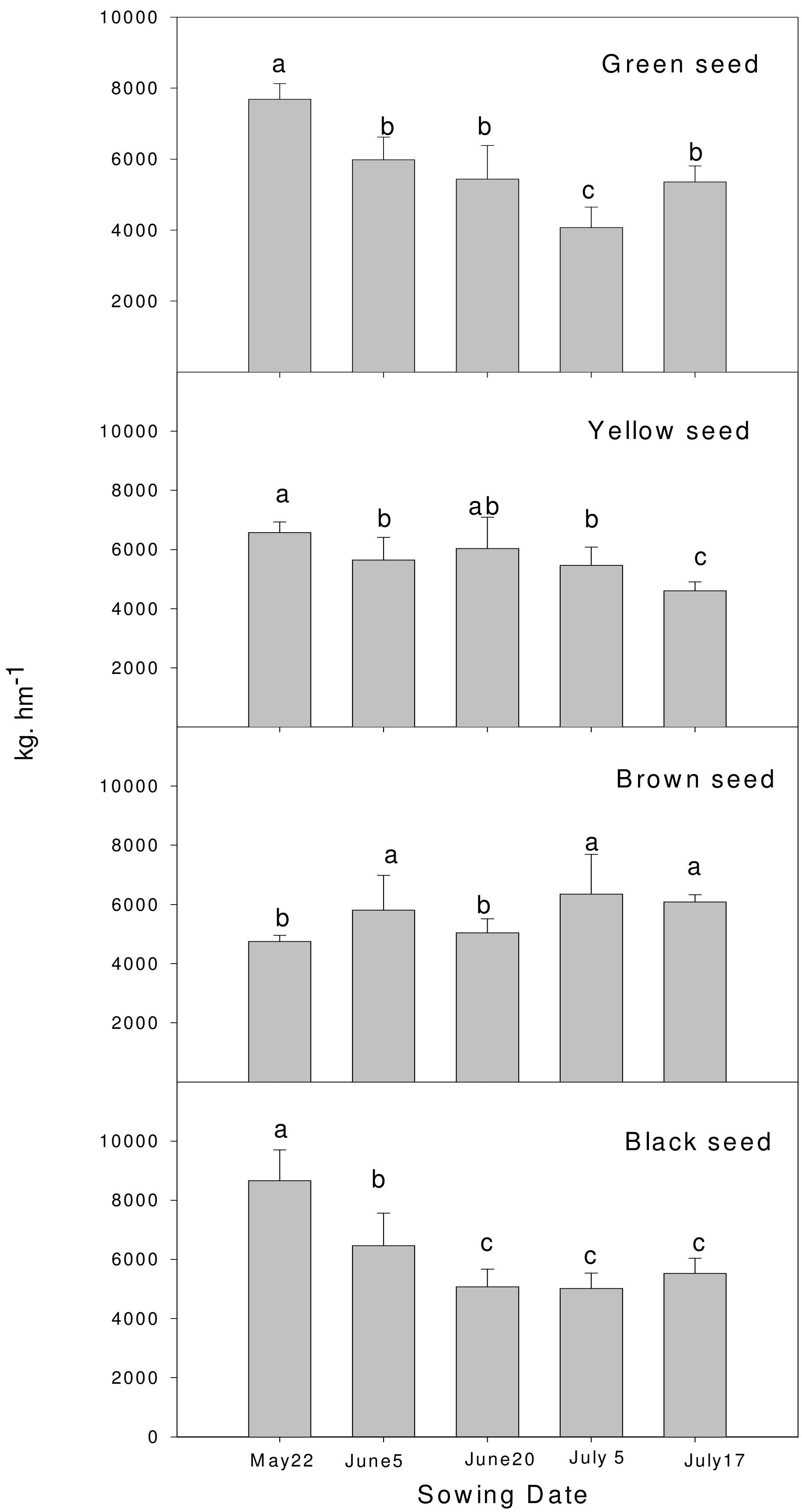

Figure 2. Sowing date effect on marketable yield to different cultivars.

Table 2. Sowing date effect on yield components at R6 stages.

Cultivars	May 22		June 5		June 20		July 5		July 17	
	Standard pod number	Fresh seed weight (mg)	Standard pod number	Fresh seed weight (mg)	Standard pod number	Fresh seed weight (mg)	Standard pod number	Fresh seed weight (mg)	Standard pod number	Fresh seed weight (mg)
Black seed	46.0a	501c	33.0a	614b	25.0a	643d	19.0a	681b	27.5b	496b
Brown seed	19.0c	592c	23.0b	679a	18.0b	703c	15.0b	624b	22.0c	526b
Yellow seed	25.0c	782b	21.0b	713a	17.0b	844a	13.5b	852a	28.5b	608a
Green seed	35.0b	826a	29.0a	664ab	25.0a	772b	19.0a	807a	39.0a	497b

Values followed by the same letter within the column for different cultivars are not significantly different (P ≤ 0.05).

Beuerlein (1988). In a double-crop system in the south-eastern USA, grain soybean yield is reduced in late-planted systems primarily because of a shortened period of vegetative growth and earlier flowering caused by a combination of warm temperatures and shortened time to photoperiod-induced flowering (Board and Hall, 1984). In late-sown crops, stresses during late vegetative and early reproductive stages could be detrimental for yield (Board and Harville, 1998). Saitoh et al. (1999) reported that delayed flowering at the flowering stage resulted in reduced pod setting due to the competition for assimilates between the vegetative and reproductive stages of growth. Our data showed that yield decline associated with delayed sowing was primarily related to reduction in standard pod number, as found previously (Egli and Yu, 1991). Nishioka and Okumura (2008) showed that total number of nodes per plant was higher with early sowing than late sowing, and the number of pods set per plant and green soybean yield were also higher in the former than in the later. They also found a positive correlation among the RGR from R1 to R6, the number of pods, and the proportion of the number of 3-seeded pods to the total number of pods. This indicates that the soybean yield can be increased by controlling the growth of the plant up to the flowering stage and accelerating the growth thereafter.

Surprisingly, in this study the fresh seed weight generated in late sowing date before July 5 did not decrease as might be expected, and instead increased by 5 - 35% for three out of four cultivars. The declined standard pod number but increased fresh seed weight for three cultivars in present study with delayed sowing indicated that a compensatory mechanism existed in vegetable soybean yield formation. Most important phonological change was a longer duration of R6 - R8 which contributed to heavier fresh seed weight. While the increased pod number except cultivar Dongdou 26 at sowing date of July 17 also indicated that plants in late plantings can catch up with plants in early plantings in traits like pod number. Compensatory mechanisms leading to negative relationship between individual seed weight and seed number (Evans, 1996) account for the stability of seed weight commonly reported for late-sown soybean (Egli and Bruening, 2001; Kane et al., 1997). Much research on late-sown soybean has been done in relatively warm environments (Board and Harville, 1996; Board and Harville, 1998; Board et al., 1999; Weaver et al., 1991), individual seed mass has been found to be rather stable in response to low temperature (Saliba et al., 1982). Despite substantial research, no reports have been found of significant contribution of individual seed mass to yield reduction in late-sown soybean. It is therefore proposed that individual seed mass and duration of late crop stages (R6 - R8) are important variables in the response of vegetable soybean to late sowing in cooler sites. The decline in marketable yield of vegetable soybean with delayed sowing can be attributed to the following reasons: (1) a shorter season length leading to overall reduction in growth; (2) short days associated with low radiation and low temperature contributing to slower growth rates and lower pod set, and (3) a dramatic reduction on the relative duration of key phenostages which mostly resulted from reduced photoperiod (Purcell et al., 1987; Kantolic and Slafer, 2001; Calvino et al., 2003a, b). The decline in marketable yield, three out of four cultivars observed as sowing was delayed in this study highlights the importance of early planting for maximizing the yield potential of vegetable soybean in the North-eastern USA. Sowing date that maximize soybean yield as a single crop per year in this area ranges from late May to early June.

The insensitivity of yield response to sowing date from early maturity cultivar ensures farmers to gain higher economic return, since market prices will be higher either in the early August or late October. Additional research will be required to determine if late sowing will produce the similar quality seed as the early sowing.

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