Genotypic Adaptation of Soybean to Late Sowing in Southwestern Japan

Fatichin\textsuperscript{1,2}, Shao-Hui Zheng\textsuperscript{3}, Kosuke Narasaki\textsuperscript{3} and Susumu Arima\textsuperscript{3}

\textsuperscript{1}The United Graduate School of Agricultural Sciences, Kagoshima University, Kagoshima 890-0065, Japan; \textsuperscript{2}Faculty of Agriculture, Jenderal Soedirman University, Purwokerto 53122, Indonesia; \textsuperscript{3}Faculty of Agriculture, Saga University, Saga 840-8502, Japan

Abstract: In southwestern Japan, late sowing of soybean is an option that may avoid the damage caused by excessive soil moisture during the rainy season. We investigated the adaptability to late sowing using 17 genotypes from 5 countries. The seeds were sown on 15–20 July, and 2–5 August in the normal and late sowing seasons, respectively, in an upland field in Karatsu, southwestern Japan in 2009, 2010 and 2011. Late sowing reduced the seed yield by 28.1% and 21.8% on average in the 2009 and 2011 experiments, respectively, whereas it had almost no effect in 2010, in which the temperature was high from sowing to flowering. Seed yield was not improved by increasing the growth period with a longer juvenile growth stage in the genotypes that originated in tropical areas. In the late sowing, seed yield was significantly correlated with the reproductive period from flowering to maturity and pod number, but not with the vegetative period from sowing to the end of leaf expansion or seed size. Soybean cultivars Caviness (USA), Parana and IAS-5 (Brazil), and Akisengoku and Akiyoshi (Japan) showed higher productivity in both types of sowing season, and their seed yields were less reduced by late sowing. These genotypes generally have larger pod number and seed number or longer seed filling periods, but they have medium-size seeds. Our results indicate that the seed yield in late sowing could be improved by the selection of adaptive genotypes that have larger seed number and / or longer seed filling periods.

Key words: Genotypic difference, Late sowing, Seed yield, Soybean.

Soybean cultivation is becoming more common in converted rice fields in southwestern Japan. The optimum sowing time for soybean in this region is thought to be early to mid July. However, because this optimum sowing time is also the rainy season in this area, the germination and seedling standing are often damaged by excessive soil moisture from flooding (Zheng and Watabe, 2000; Nakayama et al., 2004; Hamada et al., 2007; Yamashita et al., 2008). Early or delayed sowing is an option to avoid the damage from flooding in the rainy-season; however, in early sowing, excessive vegetative growth causes lodging (Ohga et al., 1985), and in late sowing, poor vegetative growth caused by the shorter day length results in decreased yields (Asanuma and Okumura, 1991).

With delayed sowing of soybean, the growth period is shortened due to earlier flowering time. This reduces the vegetative mass that would contribute to yield production (Egli et al., 1987) and eventually lowers seed yield (Boerma and Ashley, 1982). Earlier flowering is caused mainly by a shorter day length (Board and Settimi, 1986; Zhang, 2006) or by a combination of short day length and high temperature (Board and Hall, 1984) during the vegetative and early reproductive periods.

However, previous research conducted near Baton Rouge, Louisiana, USA (30º N), which is similar in latitude to Kyushu Island in southwestern Japan, demonstrated that a 29% – 276% increase in soybean seed yield through proper genotype selection for late sowing depended on lateness of sowing (Board, 2002). This indicates that soybean yield reduction by late sowing could be minimized by genotype selection. A better understanding is needed regarding yield-limiting factors, such as yield components and morphological factors, which are affected by late sowing.

To avoid sowing soybean during the rainy season in southwestern Japan, several practices for late sowing are reported. In northern Kyushu, Japan, there was no yield reduction when the sowing time was delayed to the end of July (Uchikawa et al., 2009). Umezaki et al. (1996) also reported that some late-maturing cultivars produced high seed yields even when they were sown in early or mid August in Miyazaki, in southern Kyushu. However, no
studies on the yield performance of cultivars with a wide genetic background have been published, to our knowledge.

The present study was conducted to evaluate the adaptability of various soybean genotypes to the late sowing season in southwestern Japan, and to investigate how yield components and morphological factors affect the seed yield in the late sowing season.

**Materials and Methods**

1. **Plant materials**

   The experiments were conducted in 2009, 2010 and 2011 in an upland field at the Coastal Bioenvironment Center, Saga University, Karatsu, Japan (33°27′N and 129°58′E). The soybean genotypes were collected from Japan, USA, Brazil, Vietnam, and Indonesia, with wide variation in origin, maturity group, seed size, and growth type (Table 1). The seeds used in each experiment were harvested in the year before the experiment (i.e., 2008, 2009 and 2010).

2. **Treatments and experimental design**

   The experiments were arranged in a split-plot design with ‘sowing season’ as the main plot (normal and late sowing) and ‘genotype’ as a sub-plot. The sub-plot was arranged in a random completely blocked design with three replications in each year-experiment. In the normal sowing, the seeds were sown on 20 July in 2009, 20 July in 2010, and 15 July in 2011. For the late sowing, the seeds were sown on 5 August in 2009, 5 August in 2010 and 2 August in 2011. Each plot’s design consisted of four rows with 70 cm spacing and ten hills with 20 cm intervals (2.8 m × 2 m). The soil was sandy loam. Chemical fertilizer at the rate of 3 : 10 : 10 g m⁻² of N : P₂O₅ : K₂O and agricultural lime (100 g m⁻²) were applied before the plowing. Weeding was conducted with a hand tractor, and pesticide was used when necessary. No irrigation was provided during the field experiments. The day length at the sowing time in the normal and late sowing seasons was about 14.1 and 13.2 hours, respectively. Seedlings were thinned to achieve a density of 14 plants m⁻² (two plants per hill).

### Table 1. Soybean genotypes used in the experiments in 2009, 2010 and 2011.

| No. | Origin | Genotype | Maturity group* | Seed size** | Growth type | Experiment year |
|-----|--------|----------|-----------------|-------------|-------------|----------------|
| 1.  | Japan  | Koganedaizu IIa / 0 | medium | Determinate | 2009 |
| 2.  | Japan  | Enrei IIc / III | large | Determinate | 2010 |
| 3.  | Japan  | Sachiyutaka IIIc / VI | large | Determinate | 2009, 2010, 2011 |
| 4.  | Japan  | Tamahomare IIIc / VI | large | Determinate | 2009, 2010, 2011 |
| 5.  | Japan  | Fukuyutaka IVc / VII | large | Determinate | 2009, 2010, 2011 |
| 6.  | Japan  | Hyuga IVc / VIII | large | Determinate | 2009 |
| 7.  | Japan  | Akiyoshi IVc / VIII | large | Determinate | 2009, 2010 |
| 8.  | Japan  | Hogyoku Vc / IX | medium | Determinate | 2009 |
| 9.  | Japan  | Akisengoku Vc / IX | medium | Determinate | 2009, 2010, 2011 |
| 10. | USA    | Stressland − / IV | medium | Indeterminate | 2010 |
| 11. | USA    | Caviness − / V | medium | Determinate | 2009, 2010, 2011 |
| 12. | Brazil | Pêrola − | medium | Determinate | 2009 |
| 13. | Brazil | Parana − | medium | Determinate | 2009, 2010 |
| 14. | Brazil | IAS - 5 − | medium | Determinate | 2009, 2010, 2011 |
| 15. | Vietnam|M TD 455-3 − | medium | Semi-determinate | 2009 |
| 16. | Vietnam|M TD 176 − | medium | Semi-determinate | 2009 |
| 17. | Indonesia | AGM 01 − | medium | Semi-determinate | 2009 |

* The maturity groups are based on the Japan / USA classification (Zhou et al., 2002).

** Medium: 15 − 25 g per 100 seeds; Large: over 25 g per 100 seeds.
4. Statistical analysis

Tukey’s test was used for the mean comparisons of the parameters measured. A correlation analysis was used to estimate the relationships among growth, yield components, and yield.

Results

The daily average temperatures during August in 2010 were higher than those in 2009 and 2011 (Fig. 1). This resulted in high-temperature conditions for the period of R1 to R5 in the normal sowing, whereas for the vegetative growth (sowing to R1) in the late sowing. The distribution and volume of precipitation during seedling growth and R1 to R5 stages in the late sowing experiment in 2011 were lower than in 2009 and 2010. The seed sowing was easy in the late sowing experiments because the continuous rainfall had already ended (Fig. 1).

Late sowing shortened the period from sowing to R1 by 3 to 5 days, the leaf expansion period (sowing to R5) by 6 to 7 days, and the whole life period (sowing to R7) by 6 to 7 days; however, late sowing did not affect the seed filling period (R5 to R7) on the average over the three years (Table 2). There were genotypic differences in the response of reproductive growth to the late sowing. Late maturing genotypes such as Akiyoshi, Akisengoku and IAS-5 showed longer period of sowing to R1, R5 to R7, and whole life periods (Tables 1 and 2). The exception was that some genotypes from tropical area showed longer period of sowing to R1, but no change in the whole life period.

The seed yields were reduced by 28.1% and 21.8% on the average by late sowing in the 2009 and 2011 experiments but not in 2010 (Table 3). In the 2009 experiment, genotypes with a high seed yield in late sowing were Akiyoshi (290.4 g m⁻²), Caviness (281.1 g m⁻²), and Parana (277.2 g m⁻²). Pérola, Parana, and Akiyoshi also showed less reduction of seed yield (< 20%) by late sowing. In the 2010 experiment, Akiyoshi (361.9 g m⁻²) and Caviness (353.9 g m⁻²) also showed the highest seed yield in late sowing. In the 2011 experiment, Akisengoku (258.2 g m⁻²), Caviness (256.5 g m⁻²), and IAS-5 (250.7 g m⁻²) showed higher seed yield in late sowing compared to the other genotypes. Thus, Caviness, Parana, Akiyoshi, and Akisengoku showed stable high seed yields in late sowing in all years. These cultivars are from USA (Caviness), Brazil (Parana), and Japan (Akiyoshi and Akisengoku) and have middle-size seeds (except Akiyoshi with large seeds). However, the cultivars that originated from tropical area, such as MTD 455-3 and MTD 176 (Vietnam), and AGM 01 (Indonesia), showed relatively low seed yields in both normal and late sowing in 2009. Therefore, these cultivars were not sown in later experiments.

Fig. 2 shows the relationship between seed yield and yield components in all three years. The seed yield was not associated with 100-seed weight (Fig. 2A), but was closely and significantly associated with seed number (Fig. 2B) and fertile pod number (Fig. 2C) in both the normal and late sowing seasons. The seed number showed a significant negative correlation with seed size (Fig. 2D).

In the normal sowing experiments, the seed yield was significantly correlated with the duration including the vegetative growth such as the period of sowing to R5 and sowing to R7 stages, whereas in the late sowing experiments, the seed yield tended to correlate with the duration including the reproductive growth such as the period of sowing to R7, R1 to R7 and R5 to R7 (Fig. 3A-D). In particular, very high positive correlations were observed between the yield and the period of R1 to R7 ($r = 0.673$, $p < 0.001$), and R5 to R7 ($r = 0.541$, $p < 0.01$) in late sowing.

There were positive but non-significant correlations
Late sowing reduced the seed yield by an average of 28.1% and 21.8% in the 2009 and 2011 experiments, respectively, but did not in 2010 (Table 3). We suspect that the different tendency in the 2010 experiment was because between seed yield and shoot biomass at the R5 stage in the normal and late sowing ($r = 0.48$ and 0.42, respectively; Fig. 4A). However, neither the crop growth rate during the R1 to R5 stage (Fig. 4B) nor the leaf area index at the R5 stage (Fig. 4C) was correlated with seed yield.

### Table 2. The period of each growth stage in normal and late sowing.

| Sowing – R1 (days) | Sowing – R5 (days) | Sowing – R7 (days) | R5 – R7 (days) |
|--------------------|--------------------|--------------------|----------------|
| Normal  | Late  | Normal  | Late  | Normal  | Late  | Normal  | Late  |
| 2009 |
| Koganedaizu | 36 | 33 | 56 | 50 | 86 | 80 | 30 | 30 |
| Sachiyutaka | 36 | 32 | 56 | 50 | 94 | 82 | 38 | 32 |
| Tamahomare | 33 | 29 | 57 | 50 | 94 | 86 | 37 | 36 |
| Fukuyutaka | 41 | 34 | 65 | 55 | 99 | 94 | 34 | 39 |
| Hyuga | 40 | 33 | 62 | 56 | 102 | 87 | 40 | 31 |
| Akiyoshi | 42 | 36 | 64 | 58 | 112 | 99 | 48 | 41 |
| Hogyoku | 44 | 35 | 64 | 57 | 105 | 96 | 41 | 39 |
| Akisengoku | 46 | 36 | 67 | 61 | 110 | 96 | 43 | 35 |
| Caviness | 37 | 34 | 57 | 56 | 98 | 94 | 41 | 38 |
| Pérola | 44 | 39 | 74 | 58 | 102 | 96 | 28 | 38 |
| Parana | 40 | 36 | 62 | 58 | 96 | 88 | 34 | 30 |
| IAS - 5 | 44 | 40 | 64 | 59 | 101 | 98 | 37 | 39 |
| MTD 455-3 | 41 | 39 | 63 | 64 | 93 | 95 | 30 | 31 |
| MTD 176 | 49 | 44 | 68 | 68 | 99 | 97 | 31 | 29 |
| AGM 01 | 50 | 44 | 72 | 64 | 98 | 96 | 26 | 32 |
| **Average** | **41.5** | **36.3** | **63.4** | **57.6** | **99.3** | **92.3** | **35.9** | **34.7** |
| 2010 |
| Enrei | 30 | 29 | 47 | 43 | 91 | 88 | 44 | 45 |
| Sachiyutaka | 33 | 31 | 49 | 45 | 100 | 90 | 51 | 45 |
| Tamahomare | 28 | 27 | 50 | 45 | 100 | 90 | 50 | 45 |
| Fukuyutaka | 36 | 33 | 57 | 50 | 105 | 98 | 48 | 48 |
| Akiyoshi | 37 | 33 | 63 | 54 | 115 | 102 | 52 | 48 |
| Akisengoku | 40 | 36 | 66 | 57 | 116 | 103 | 50 | 46 |
| Stressland | 30 | 26 | 52 | 50 | 94 | 92 | 42 | 42 |
| Caviness | 36 | 32 | 55 | 49 | 102 | 99 | 47 | 50 |
| Parana | 37 | 32 | 55 | 49 | 97 | 90 | 42 | 41 |
| IAS - 5 | 40 | 35 | 63 | 55 | 102 | 101 | 39 | 46 |
| **Average** | **34.7** | **31.4** | **55.7** | **47.7** | **102.2** | **95.3** | **46.5** | **45.6** |
| 2011 |
| Sachiyutaka | 35 | 32 | 55 | 46 | 93 | 85 | 38 | 39 |
| Tamahomare | 32 | 29 | 54 | 45 | 99 | 86 | 45 | 41 |
| Fukuyutaka | 37 | 37 | 60 | 51 | 100 | 96 | 40 | 45 |
| Akisengoku | 43 | 39 | 71 | – | 110 | 103 | 39 | – |
| Caviness | 35 | 33 | 59 | 51 | 100 | 94 | 41 | 43 |
| IAS - 5 | 41 | 35 | 64 | – | 96 | 95 | 32 | – |
| **Average** | **37.2** | **34.2** | **60.5** | **48.3** | **99.7** | **93.2** | **39.2** | **42.0** |

**Discussion**

Late sowing reduced the seed yield by an average of 28.1% and 21.8% in the 2009 and 2011 experiments, respectively, but did not in 2010 (Table 3). We suspect that the different tendency in the 2010 experiment was because...
the high average temperature in August stimulated the vegetative growth in late sowing but was disadvantageous for pollen setting in normal sowing (Fig. 1). This is supported by the finding by Spaeth et al. (1987) that high temperature and solar radiation contribute to soybean productivity.

The late-maturing cultivars originating in Japan such as Akiyoshi (2009, 2010) and Aksengoku (2010, 2011) showed higher seed yields in both sowing seasons compared to the standard cultivar Fukuyutaka in this region, and they showed little seed yield reduction by late

### Table 3. Yield and yield components in normal and late sowing.

| Genotype    | Seed weight (g m²⁻¹) | Seed number plant⁻¹ | 100-seed weight (g) |
|-------------|----------------------|----------------------|---------------------|
|             | Normal (N) | Late (L) | L/N | Normal (N) | Late (L) | L/N | Normal (N) | Late (L) | L/N |
| **2009**    |            |          |     |            |          |     |            |          |     |
| Koganedaizu | 253.9        | 180.2     | 0.71 | 109.3      | 80.1      | 0.73 | 18.7        | 15.7      | 0.84 |
| Sachiyutaka | 341.4        | 236.7     | 0.69 | 90.4       | 58.4      | 0.65 | 33.0        | 29.4      | 0.89 |
| Tamahomare  | 282.8        | 188.5     | 0.67 | 76.3       | 52.3      | 0.69 | 31.1        | 26.5      | 0.85 |
| Fukuyutaka  | 307.3        | 244.2     | 0.79 | 86.0       | 66.0      | 0.78 | 28.6        | 27.7      | 0.97 |
| Hyuga       | 329.6        | 257.5     | 0.80 | 110.0      | 75.1      | 0.68 | 24.2        | 25.3      | 1.05 |
| Akiyoshi    | 360.0        | 290.4     | 0.81 | 96.4       | 78.1      | 0.81 | 25.2        | 27.1      | 1.08 |
| Hogyoku     | 331.9        | 234.6     | 0.71 | 114.6      | 83.1      | 0.73 | 23.5        | 22.4      | 0.95 |
| Aksengoku   | 299.9        | 232.2     | 0.78 | 120.0      | 87.9      | 0.73 | 22.8        | 19.9      | 0.87 |
| Caviness    | 356.5        | 281.1     | 0.73 | 167.6      | 130.8     | 0.78 | 18.3        | 18.9      | 1.03 |
| Pérola      | 302.7        | 255.5     | 0.84 | 144.1      | 119.8     | 0.83 | 17.6        | 17.2      | 0.98 |
| Parana      | 338.3        | 277.2     | 0.82 | 142.6      | 127.7     | 0.90 | 16.5        | 18.0      | 1.09 |
| IAS-5       | 323.3        | 210.5     | 0.65 | 145.1      | 120.8     | 0.71 | 20.0        | 16.4      | 0.82 |
| MTD 455-3*  | 257.6        | 181.7     | 0.71 | 88.3       | 78.3      | 0.89 | 22.5        | 19.5      | 0.87 |
| MTD 176     | 273.7        | 145.5     | 0.53 | 132.0      | 77.6      | 0.59 | 17.9        | 16.1      | 0.90 |
| AGM 01      | 241.0        | 135.2     | 0.56 | 135.8      | 77.0      | 0.57 | 16.2        | 13.9      | 0.85 |
| **2010**    |            |          |     |            |          |     |            |          |     |
| Enrei       | 125.2        | 145.0     | 1.16 | 37.7       | 43.3      | 1.15 | 22.9        | 28.4      | 1.24 |
| Sachiyutaka | 230.5        | 296.0     | 1.34 | 59.1       | 67.1      | 1.14 | 30.5        | 31.6      | 1.04 |
| Tamahomare  | 234.5        | 234.4     | 1.00 | 63.8       | 61.4      | 0.97 | 28.8        | 29.2      | 1.01 |
| Fukuyutaka  | 276.7        | 300.8     | 1.09 | 77.9       | 71.6      | 0.92 | 29.3        | 29.0      | 0.99 |
| Akiyoshi    | 335.8        | 361.9     | 1.08 | 100.2      | 96.2      | 0.96 | 29.0        | 27.3      | 0.94 |
| Aksengoku   | 292.8        | 310.8     | 1.06 | 92.7       | 95.6      | 1.03 | 23.6        | 24.6      | 1.04 |
| Stressland  | 283.4        | 274.3     | 0.97 | 106.9      | 116.1     | 1.09 | 17.7        | 17.3      | 0.97 |
| Caviness    | 315.9        | 353.9     | 1.12 | 115.9      | 141.4     | 1.22 | 21.4        | 19.7      | 0.92 |
| Parana      | 298.1        | 289.0     | 0.97 | 131.7      | 116.3     | 0.88 | 19.7        | 17.9      | 0.91 |
| IAS5        | 326.0        | 279.0     | 0.86 | 116.8      | 104.3     | 0.89 | 22.7        | 18.2      | 0.80 |
| **2011**    |            |          |     |            |          |     |            |          |     |
| Sachiyutaka | 241.0        | 166.5     | 0.69 | 67.2       | 48.3      | 0.72 | 30.0        | 28.9      | 0.96 |
| Tamahomare  | 151.6        | 155.9     | 1.03 | 47.9       | 51.9      | 1.08 | 27.3        | 24.9      | 0.91 |
| Fukuyutaka  | 291.9        | 203.5     | 0.70 | 101.2      | 63.7      | 0.63 | 27.2        | 27.4      | 1.01 |
| Aksengoku   | 338.9        | 258.2     | 0.76 | 142.8      | 80.3      | 0.63 | 21.4        | 23.7      | 1.11 |
| Caviness    | 332.5        | 256.5     | 0.77 | 137.9      | 125.9     | 0.91 | 21.0        | 17.3      | 0.82 |
| IAS-5       | 324.1        | 250.7     | 0.77 | 136.1      | 117.2     | 0.86 | 19.9        | 18.6      | 0.94 |
| **Average** |            |          |     |            |          |     |            |          |     |
|             | 280.0       | 215.2     | 0.79 | 105.3      | 82.7      | 0.81 | 24.5        | 23.4      | 0.96 |

*For MTD 455-3, the 3rd replication was lodged and harvested failure. The value of the 3rd replication was calculated by the iteration method.

In a column, means followed by the same letter in each year are not significantly different at p < 0.05 by Tukey’s test.
Fig. 2. Relationships among seed yield, seed number, 100-seed weight and fertile pod number in normal (closed circles) and late (open circles) sowing in 2009, 2010 and 2011.

*p < 0.05; **p < 0.01; ***p < 0.001

Fig. 3. Relationships between seed yields and days from (A) sowing to R5 stage, (B) sowing to R7 stage, (C) R1 to R7 stage, and (D) R5 to R7 stage in normal (closed circles) and late (open circles) sowing in 2009, 2010 and 2011.

*p < 0.05; **p < 0.01; ***p < 0.001
sowing (Table 3). A similar tendency was also observed in Caviness (2009, 2010 and 2011), a middle maturing cultivar from USA, and Parana (2009, 2010) and IAS-5 (2010, 2011) from Brazil, which showed nearly identical maturity with Fukuyutaka at the experimental location.

In contrast, the soybean genotypes originating in tropical areas (e.g., Indonesia, Vietnam) which have a long juvenile growth stage, mostly resulted in lodging because of their long stems (data not shown), and therefore they had lower seed yields in both normal and late sowing (Table 3). These cultivars showed vigorous vegetative growth, but not a long whole life period at the experimental location, resulting in no effect on the seed yield. In contrast, some genotypes from Brazil (Parana, IAS-5) and USA (Caviness), which belong to the early or the same maturity group as the Japanese cultivar Fukuyutaka seem to be adaptive to southwestern Japan. Moreover, in the 2010 experiment, the cultivar with indeterminate growth habit (Stressland, MG IV) had a constantly higher seed yield than the determinate cultivars (Sachiyutaka and Tamahomare), which belong to the later maturity group (MG VI).

A long vegetative growth period does not always raise the seed yield potential of soybean, although it enlarges the vegetative biomass (Egli, 1993). Our results showed that assimilate availability (such as shoot biomass and leaf area at R5 stage and crop growth rate during R1 to R5 stages), although showing a positive tendency, was not significantly correlated with seed yield (Fig 4A-C). These results indicate that the determination of soybean seed yield may be more complex than the previous concept that seed yield depends on the assimilate supply during seed filling (Kokubun, 1988; Egli and Yu, 1991; Egli, 1998; Shiraiwa et al., 2004).

Because the long seed-filling period is positively correlated with seed yield (Hanway and Weber, 1971; Gay et al., 1980; Smith and Nelson, 1986), attempts to increase the seed-filling period are being made by several research groups. In the present study, the reproductive period (R1 to R7) and especially the seed-filling period (R5 to R7) showed highly significant correlations with the seed yield (Fig. 3C, D) in late sowing, consistent with previous reports. In fact, the high seed yields of most cultivars in the late sowing in 2010 showed longer seed-filling periods compared to those in 2009 and 2011, and even the period from sowing to flowering was shortened by the high air temperature (Table 2). Although the whole life period was shorter than in normal sowing, the seed-filling period was not shortened in late sowing. The cultivars Akiyoshi (Japan) and Caviness (USA) with constantly high seed yields in late sowing showed the longer seed-filling period in the experimental years. The main conclusion could be drawn from our results is that reproductive period (R1 to R7), especially seed filling period (R5 to R7) are the yield-limiting factors rather than leaf expansion period (sowing to R5) in late sowing in southwestern Japan.

Seed yield is affected more by seed number than by seed size (Egli, 1998). However, the environmental conditions during seed filling affect the seed yield through seed size rather than seed number (Zheng et al., 2012). The main factor determining seed yield is seed number, which is associated with the pod set before seed filling: the seed size is a compensative factor that is easily affected by environmental conditions during seed filling. In our study, compared to the 2009 and 2011 experiments, the seed filling period was clearly longer and the seed size was not reduced by late sowing in 2010 (Tables 2, 3). This may have contributed to the high yield in the 2010 late sowing because the long seed filling period could increase the seed size (Egli, 1993). It is also supported by the high correlation coefficients between the seed yield and the period of R1 to R7 and R5 to R7 in late sowing (Fig. 3C, D).

Matsumoto and Umezaki (1987) pointed out that the
soybean cultivars with a large seed number but relatively small seed size are more adaptive to late sowing because they easily produce adequate number of seeds. The determination of seed number may play an important role in the response to late sowing (Egli et al., 1987; Steel and Grabau, 1997; Egli and Bruening, 2000). Therefore, genetic improvements for late-sowing soybean seed yields may depend on selection for seed or pod numbers with longer seed-filling periods. This is supported by the present findings that the highest seed yields were produced by the soybean cultivars with medium-size seeds and larger number of pods (e.g., Caviness, IAS-5, Parana, Akisengoku) and longer seed-filling periods (e.g., Akiyoshi, Caviness, and Akisengoku) in southwestern Japan.

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