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Response of early maturity soybean cultivars to row spacing in full-season crop and double-crop systems

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Abstract: Cultivar selection and crop systems are important factors for maximising soybean seed yield. The effect of row spacing (RS1 = 75 cm, RS2 = 25 cm) on the performance of 10 early maturity soybean cultivars grown in full-season and double-crop system for two consecutive years was studied. The agronomic traits measured were seed yield (SY), plant height (PH), pods per plant (PP), first pod height (FPH), crude protein. RS had a significant effect on SY, PH, PP and FPH. Higher SY ($P < 0.01$) was recorded in RS2 regardless of the crop system. The double-crop system yield reduction index of the tested cultivars ranged from 30.0% to 56.4% and from 21.5% to 57.2% for RS1 and RS2, respectively. Cultivars differed ($P < 0.01$) for all traits in both RS and crop systems. Maturity Group I cultivars showed the highest productivity; the cultivars PR92B63 and Atlantic were better adapted to the full-season crop system (SY > 5.67 t/ha); cv. Sphera was the most productive in the double-crop system (4.66 t/ha); cv. PR92M22 showed good adaptability to both cropping systems. In conclusion, the significant effect of RS and crop system on SY was observed, whereas different high yielding cultivars were identified as suitable for full-season and double-crop system.

Keywords: *Glycine max* (L.) Merr.; cultivation system; non-genetically modified soybean; environmental condition; legume

Soybean (*Glycine max* [L.] Merr.) is one of the most important arable crops worldwide and is considered as the top-traded commodities due to its multiple uses such as food, feed, and biodiesel component (Hartman et al. 2011).

Since the production of genetically modified crops is banned in the European Union, European farmers can be benefited from the relatively higher premiums for the production of non-genetically modified (GM) soybean due to the increased global demand along with the extra monetary support for protein crops included in the current Common Agricultural Policy.

Seed yield is affected by numerous factors, including genotype, maturity group (MG), soil fertility, nodulation and cropping system (Salmerón et al. 2016, Jarecki 2020). Bastidas et al. (2008) and Acikgoz et al. (2009) have investigated the effect of cropping systems on soybean yield across different locations and environmental conditions; however, little is known about the response soybean yield to full *vs.* double cropping.

Double-crop soybeans can be beneficial for sustainable crop intensification (Ilker 2017). Double-cropping soybeans after cereals can increase the

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total crop yield and quality, reduce soil erosion, and intensify land and equipment use (Kyei-Boahen and Zhang 2006). Genotype and MG are critical for minimising the yield gap associated with the double-cropping (Ilker 2017). Previous studies showed that yield reduction due to double-cropping can be attributed to the shorter vegetative period and reproductive cycle, leading to reduced biomass, pods per plant, number of branches, plant height, and photosynthetic activity (Bhatia et al. 1999, De Bruin and Pedersen 2008). Thus, the use of early maturity genotypes for planting after wheat usually leads to relatively short plants and low yields, whereas late maturity genotypes are vulnerable to frost (Bastidas et al. 2008).

Soybean response to row spacing (RS) depends on multiple factors such as water availability, stem morphology, planting date and tillage management (Zhou et al. 2010, Sobko et al. 2019). Previous studies revealed that narrow RS (≤ 50 cm) increases yield compared with wide RS (> 50 cm) under different production systems (De Bruin and Pedersen 2008, Zhou et al. 2010), whereas other researchers reported no difference in yield between RS (Neugschwandtner et al. 2019).

Different soybean genotypes need to be routinely evaluated under different cropping systems to identify the optimum cultivation conditions. It is known that the optimum crop system and RS for a particular genotype results in yields close to the maximum crop potential under specific environmental conditions (Salmerón et al. 2016). Although the effects of crop system and RS on soybean yield have been assessed separately, information on the combined impact of these factors is still limited. The objectives of this study were to investigate the effect of RS and crop system (full-season crop *vs*. double-crop) on the agronomic performance and growth characteristics of 10 early maturity non-GM soybean cultivars.

MATERIAL AND METHODS

Experimental conditions. Field experiments were conducted in the growing seasons of 2013 and 2014 at the Institute of Industrial and Forage Crops (IIFC) in Larissa (22°25'E, 39°36'N). Basic soil physicochemical analyses were provided by the accredited under international Quality standards (ELOT EN ISO/IEC 17025, 2017) Soil, Water and Plant Analysis lab of IIFC. Both experiments were carried out on a Vertisol (Soil Taxonomy 1999) clayey soil (37% sand, 21% silt, 42% clay in 2013 and 27% sand, 24% silt, 49% clay in 2014; Bouyoucos hydrometer method) with poor organic carbon content (0.36–0.75%, Walkley and Black method) down to 30 cm. At the same depth, the soil was medium (18 mg P/kg in 2013) or medium to low (10 mg P/kg in 2014) in phosphorous (Olsen and Sommers 1982) and high in exchangeable potassium content (Ammonium acetate method; Thomas 1982; 1.1–1.4 cmol K^+/kg). The soil pH was slightly alkaline (pH = 7.4; 1:1 soil-H_2O suspension; McLean 1982).

The climate in the region of Larissa is semi-arid in the cool version (Köppen: BSk), but it is close to a hot summer Mediterranean climate and is classified as Csa (temperate climate with a hot-dry summer) by the Köppen-Geiger system (Peel et al. 2007). Mean, minimum, and maximum air temperature followed similar patterns and August was the hottest month in both growing seasons with max temperatures ≥ 40 °C. The wettest months were June in 2013 (51.0 mm) and September in 2014 (59.6 mm). Data on air temperature and precipitation were acquired from a nearby (0.5 km) automatic weather station (Figure 1).

Planting for the full-season crop system was carried out on May 5, 2013, and May 9, 2014, whereas for the double-crop system on June 25, 2013, and July 1, 2014. Previous cultivation was wheat (*Triticum durum* L.). Each experimental plot was 4 m long with three rows, and the seeding rate was 450 000 seeds/ha.

In each cropping system (full-season crop or double cropping) and year, the experiments were laid out in a split-plot design with three replications. RS was selected to be in the main plots and cultivars (C) in the subplots. Two RS treatments were used: (*i*) RS1: 75 cm between rows, 30–35 seeds/m (~135 seeds/row), and plant-to-plant spacing of 3.5 cm, and (*ii*) RS2: 25 cm between rows, 9–12 seeds/m (~45 seeds/row), and plant-to-plant spacing of 9 cm. Ten non-GM soybean cultivars were used (Table 1).

Soybean seeds were not inoculated with rhizobia, and no nodulation was observed after visual evaluation. Based on soil analysis and plant needs, a total of 210 units N/ha was supplied during the growth period. Fertilisation was split into 3 doses: balanced basal fertilisation with 330 kg/ha (15N-15P_2O_5-15K_2O) was pre-plant incorporated, and another 230 kg/ha as ammonium nitrate (NH_4NO_3) at full flowering and at the beginning of pod filling were top dressed. Sprinkler irrigation was used throughout the growing season to sustain plant development. The total water amount was adjusted to precipitation levels to a total of 350–370 mm over the growing

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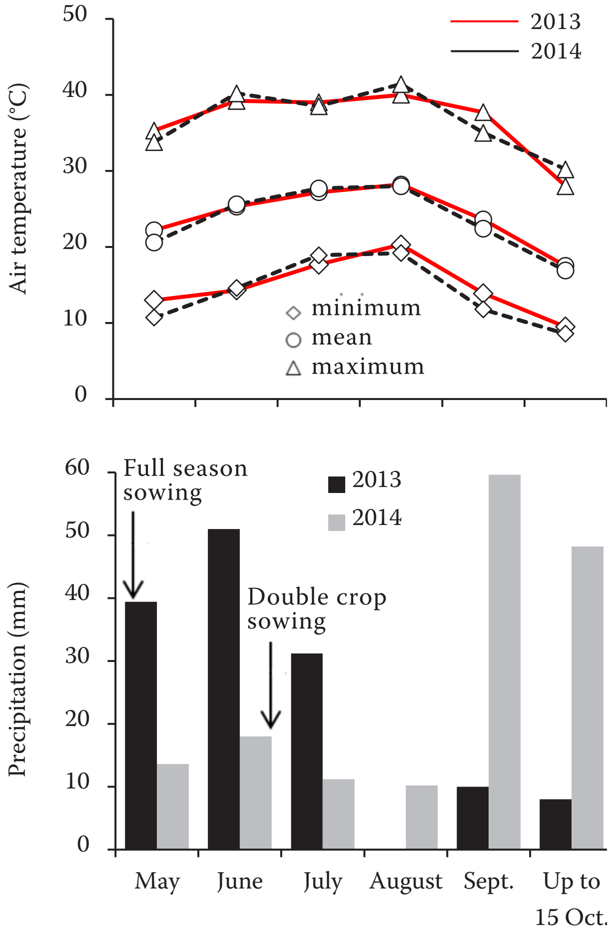

Figure 1. Monthly temperature and precipitation throughout the growing seasons

season. Phytosanitary actions were taken to keep the experiments free of pests and diseases. Weeds were controlled using pendimethalin (1.65 kg/ha) before planting and by hand weeding throughout the growing season.

Data collection. The plant height (PH) of 10 randomly selected plants from the central row in each plot was measured at the end of the flowering period, whereas several agronomic parameters (number of pods per plant (PP), first pod height (FPH), percentage of lost pods (LP)) were measured at maturity. Seed yield (SY) was assessed at the harvest maturity stage of each cultivar and expressed in t/ha after adjusting to 13% moisture content. Cultivars were harvested by hand and threshed with a Wintersteiger LD 350 laboratory thresher. Seed crude protein percentage (CP) was obtained using the Kjeldahl method. The yield reduction index (YRI) between full-season crop and double-crop systems was estimated as follows:

YRI = (yield of the top-yielding cultivar in full-season cropping – yield of each cultivar in double-cropping)/ yield of the top-yielding cultivar in full-season cropping

Statistical analysis. Analysis of variance (ANOVA) in conjunction with Fisher's least significant difference (*LSD*) was used to identify significant differences. C and RS were considered as fixed effects, whereas year (Y) as a random effect. Data analysis was performed using the statistical software JMP 8 (SAS Institute 2009, Cary, USA).

RESULTS AND DISCUSSION

Full season cropping. Significant differences ($P < 0.01$) were found for all measured traits (SY, PH, PP, FPH, LP, CP) among soybean cultivars grown as a full-season crop (Table 2). The effect of Y was

Table 1. Characteristics of ten soybean cultivars

Cultivar	Origin	Maturity group	Growth type	Days to maturity	
				full season	double-crop
Fortuna	Serbia	00	IND	106	90
Zora	Serbia	0	D	113	100
PR92B63	US	I+	D	122	104
PR91M10	US	0	D	114	99
Sphera	France	I-	IND	116	104
Shama	France	I-	SD	122	103
Atlantic	Italy	I+	D	123	107
Kondor	Serbia	II	D	130	117
PR92M22	US	I	SD –IND	116	104
Mercury	Serbia	00	D	109	93

Growth type: IND – indeterminate; D – determinate; SD – semi-determinate. Days to maturity are means across years

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Table 2. Partitioning of treatment sum of squares (SS_{TRMT}), treatment effects, mean comparisons for seed yield (SY), plant height (PH), pods per plant (PP), first pod height (FPH), lost pods (LP) and seed crude protein (CP) of 10 soybean cultivars sown as a full-season crop for two years under two row spacing (RS)

Source of variation	SS_{TRMT} (%)					
	SY (t/ha)	PH (cm)	PP (N°)	FPH (cm)	LP (%)	CP (%)
Year (Y)	1.7	11.0*	0.3	0.3	4.2	
Row spacing	41.4**	9.2*	5.7**	2.5	1.0	0.1
Y × RS	0.1	1.7	2.1	0.0	0.0	
Cultivar (C)	23.7**	44.8**	64.6**	74.2**	67.8**	98.7**
C × Y	15.6**	13.7	13.4	14.1	9.5	
C × RS	7.1	13.4	10.1	3.9	1.8	1.1
C × Y × RS	10.3	6.2	3.8	5.0	15.4	
Cultivar						
Fortuna	4.72[de]	80.6[bc]	43.1[e]	11.7[a]	0.2[c]	26.5[a]
Zora	4.93[cde]	79.7[bc]	73.1[ab]	7.3[c]	3.7[a]	22.7[ef]
PR92B63	6.23[a]	88.8[ab]	74.4[a]	11.8[a]	0.3[c]	22.1[f]
PR91M10	5.19[bcde]	83.1[bc]	69.5[abc]	10.6[ab]	1.1[bc]	24.0[bcd]
Sphera	5.51[bc]	87.3[ab]	54.1[de]	11.6[a]	0.2[c]	27.1[a]
Shama	5.40[bcd]	82.0[bc]	59.4[bcd]	11.6[a]	0.2[c]	24.9[b]
Atlantic	5.67[ab]	81.8[bc]	81.6[a]	10.6[ab]	0.2[c]	23.0[def]
Kondor	5.42[bc]	93.4[a]	69.6[abc]	9.9[ab]	1.2[bc]	24.5[bc]
PR92M22	5.79[ab]	76.3[c]	57.4[cde]	9.8[ab]	2.3[b]	23.6[cde]
Mercury	4.58[e]	76.1[c]	76.7[a]	8.6[bc]	2.2[b]	26.3[a]
Row spacing						
RS1 (75 cm)	4.71[b]	85.3[a]	62.5[b]	10.6	1.0	24.5
RS2 (25 cm)	5.98[a]	80.5[b]	69.3[a]	10.1	1.3	24.4
$P_{(C)}$	**	**	**	**	**	**
$P_{(RS)}$	**	*	*	ns	ns	ns
CV (%)	15.8	13.4	27.6	25.7	28.5	4.14

*$P < 0.05$; **$P < 0.01$; ns – non-significant. Within columns means with the same letter are not significantly different at $P \leq 0.05$; *CV* – coefficient of variation

significant only for PH, whereas PH variation was predominately explained by the effect of C, which in turn was also the main source of variation for PP, FPH, LP and CP. SY was mainly affected by RS followed by C, whereas the significant C × Y indicated that C effects on SY were modified yearly, probably due to multiple environmental effects such as different amount and distribution of precipitation (Chen and Wiatrak 2010). Cv. PR92B63 showed the highest SY (6.23 t/ha) and PP (74.4) and the lowest CP (22.1%) (Table 2), while the lower SY (4.58 t/ha) was observed in cv. Mercury. Similarly, the cv. Fortuna showed very low SY (4.72 t/ha) and PP (43.1), probably because it had the shortest growth period (106 days to maturity, Table 1). Previous studies reported that prolonged vegetative and reproductive growth stages lead to higher pod numbers and seeds per area unit and, thus, to increased yield gains (Wilcox and Frankenberger 1987). The high-yielding cvs. PR92B63 and Atlantic had common growth type (D), MG (I) and growth cycle (122–123 days to maturity) and ranked in the top for PH and PP. In addition, they showed the best values for the traits FPH and LP, which are very important for mechanical harvesting. All these traits consist of an interesting cultivar profile that should be considered for future breeding programs. Moreover, it should be underlined that these two cultivars had the lower CP values, whereas the least productive cultivars, Fortuna and Mercury, showed the highest CP following the generally negative correlation between SY and CP that was observed in full-season crop (data not shown).

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Table 3. Partitioning of treatment sum of squares (SS_{TRMT}), treatment effects, mean comparisons for seed yield (SY), plant height (PH), pods per plant (PP), first pod height (FPH), lost pods (LP), seed crude protein (CP) of 10 soybean cultivars sown as double-crop under two row spacing (RS)

Source of variation	SS_{TRMT} (%)					
	SY (t/ha)	PH (cm)	PP (N°)	FPH (cm)	LP (%)	CP (%)
Year (Y)	3.4*	79.1**	0.1	50.0**	61.9**	
Row spacing	31.4**	0.7*	7.7**	3.7**	1.6	0.0
Y × RS	0.4	0.2	0.1	0.1	0.6	
Cultivar (C)	42.7**	14.4**	53.9**	30.6**	14.4	97.4**
C × Y	11.4	1.6	26.7**	7.3	9.1	
C × RS	8.9	2.7	6.7	3.4	6.0	2.6
C × Y × RS	1.7	1.2	4.8	5.0	6.3	
Cultivar						
Fortuna	3.67^{cde}	77.3^{ab}	41.0^{d}	12.3^{a}	1.4	28.6^{a}
Zora	3.76^{cde}	65.2^{d}	69.7^{ab}	8.5^{cd}	3.6	26.3^{d}
PR92B63	3.83^{bcd}	77.7^{ab}	70.6^{a}	9.9^{bc}	2.7	26.8^{d}
PR91M10	4.17^{abc}	72.4^{bc}	53.0^{c}	9.8^{bc}	1.7	28.5^{ab}
Sphera	4.66^{a}	82.5^{a}	58.4^{bc}	12.9^{a}	0.4	27.8^{bc}
Shama	3.55^{de}	68.9^{cd}	39.5^{d}	10.1^{b}	1.6	28.5^{ab}
Atlantic	3.15^{ef}	66.0^{d}	73.8^{a}	9.5^{bcd}	2.6	27.6^{c}
Kondor	3.85^{bcd}	75.9^{b}	64.6^{ab}	8.8^{bcd}	2.6	26.8^{d}
PR92M22	4.39^{ab}	65.8^{d}	52.7^{c}	9.4^{bcd}	3.0	28.7^{a}
Mercury	2.77^{f}	76.9^{ab}	62.3^{abc}	7.9^{d}	3.3	28.1^{abc}
Row spacing						
RS1 (75 cm)	3.33^{b}	74.2^{a}	54.3^{b}	10.4^{a}	2.0	27.8
RS2 (25 cm)	4.23^{a}	71.6^{b}	62.9^{a}	9.4^{b}	2.6	27.8
$P_{(C)}$	**	**	**	**	ns	**
$P_{(RS)}$	**	*	**	**	ns	ns
CV (%)	19.8	9.5	23.9	20.5	24.1	0.01

*$P < 0.05$; **$P < 0.01$; ns – non-significant. Within columns means with the same letter are not significantly different at $P \leq 0.05$; *CV* – coefficient of variation

Double-season cropping. Significant C effects ($P < 0.01$) were found for all studied traits, except for LP (Table 3). In addition, C was the main source of variation for SY, PP and CP, whereas Y explained most of the variation in PH, FPH, and LP. Seed yield ranged from 2.77 to 4.66 t/ha. Regardless of RS, Sphera was the most productive cultivar, whereas cv. Mercury the least productive (Figure 2B). With regards to plant traits, it is interesting that the two high yielding cultivars in the full-season crop system (cvs. PR92B63, Atlantic) showed the highest values for PP in double cropping but finally ranked in the middle and lower for SY (Table 3). It is obvious that the aforementioned cultivars could not complete the pod-filling stage with success (Bhatia et al. 1999). On the contrary, cv. Sphera indicated high adaptability to double-cropping as it had a moderate value for PP but ranked in the top for SY differing 0.83 t/ha form cv. PR92B63 and 1.51 t/ha from cv. Atlantic. Also, cv. Sphera indicated excellent traits (FPH, LP) for mechanical harvesting. Moreover, cv. PR92M22, when grown under RS2, yielded high in both crop systems, indicating wide adaptation capacity across cropping systems (Tables 2 and 3, Figure 2).

All studied cultivars showed lower SY in the double-crop compared with that in the full-season (Figure 2), probably because of their decreased size and PP (Bhatia et al. 1999). It is well known that the reduced soybean performance leads to lower net returns in the double-crop system compared with the full-season crop system (Pfeifer 2000, Bajaj et al. 2008). Kyei-Boahen and Zhang (2006) reported a 10–40% yield

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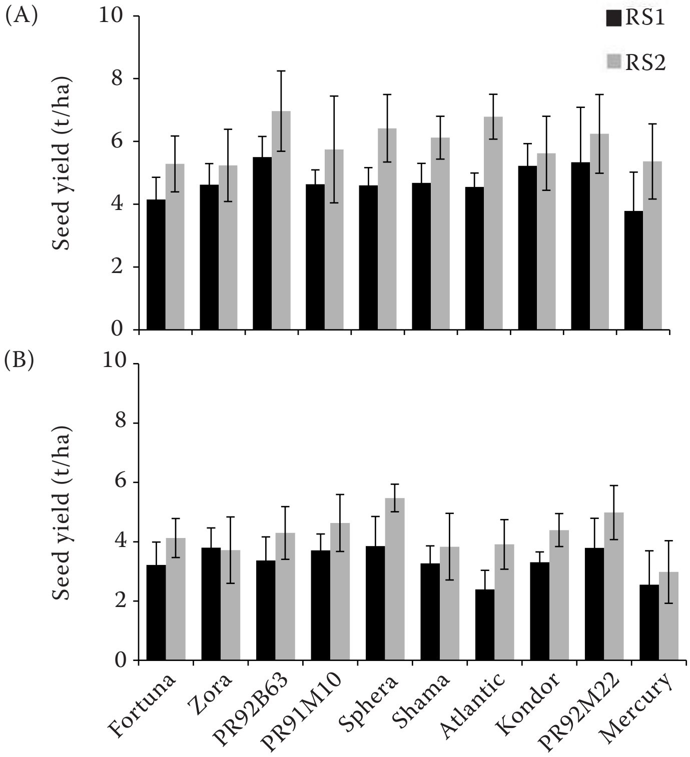

Figure 2. Seed yield of 10 soybean cultivars grown (A) as full-season crop and (B) double-crop across two years. RS1: 75 cm; RS2: 25 cm. Error bars represent standard error of the mean (n = 6)

reduction when soybean cultivars were cultivated in a double-crop system after wheat; however, the wheat-soybean double-crop system is more profitable in total than the full-season soybean system when the appropriate genotypes are used (Vlachostergios 2015). Here, YRI ranged from 25.7% to 55.4% in the double-crop system. Cv. Sphera followed by cv. PR92M22 showed high yield (4.66 and 4.39 t/ha, respectively) and low YRI values (25.7% and 29.8%, respectively), suggesting high adaptability to the wheat-soybean crop system. On the contrary, the increased YRI values of cvs. PR92B63 and Atlantic (38.6% and 50.2%, respectively) in the double-crop system and their maximal seed yield in the full-season crop system indicated that they require a prolonged growing season.

Row spacing. RS explained the 41.4% of the variation for SY in full-season cropping and the 31.4% in double-season. SY and PP were significantly higher in RS2 than in RS1 regardless of the cropping system. RS2 significantly increased SY by the same percentage (27%) in both cropping systems, while PP was significantly increased by 11% in the full-season crop system and by 16% in double-crop. A possible explanation is that narrow rows favor the relatively earlier ground coverage, minimising soil moisture loss, suppressing late weed emerging and increasing light interception (Board and Harville 1992, Zhou et al. 2010). In accordance, Cooper (1977) also obtained the largest yield at a very narrow-row spacing (20 cm); Bullock et al. (1998) showed that seed yield was linearly decreased with the increasing row width, and Kratochvil et al. (2004) indicated that the 19-cm RS significantly increased yield compared with the 38-cm RS in multi-year full-season cropping. In addition, previous studies in double-crop with narrow RS showed that later flowering dates, longer internodes and shorter reproductive periods were associated with increased yield (De Bruin and Pedersen 2008).

PR92B63 was the most productive cultivar, whereas Fortuna and Mercury the least productive cultivars in the full-season crop system, regardless of RS (Figure 2A) while, cv. Sphera had the highest SY and cv. Mercury the lowest in the double-crop, regardless of RS (Figure 2B). In the double-crop system, all cultivars showed a trend of higher values in RS2, except of cv. Zora. The most productive cv. Sphera showed an increased SY by 42% (1.62 t/ha, significant at $P < 0.05$) in RS2 compared with that in RS1. All cultivars showed lower SY in the double-crop compared with that in the full-season crop, regardless of RS.

YRI ranged from 30.0 to 56.4 (1.65–3.10 t/ha) in RS1 and from 21.5 to 57.2 (1.50–3.99 t/ha) in RS2 (Figure 3). The mean YRI across RS was 39.4 ± 8.4 (mean ± standard deviation). Regardless of RS,

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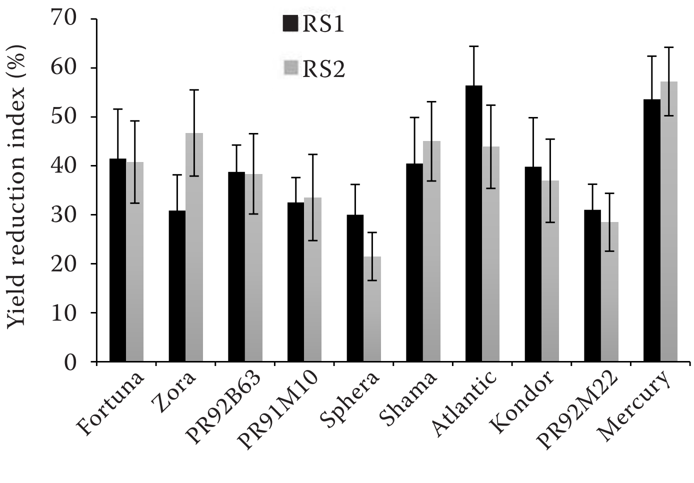

Figure 3. Yield reduction index between full-season and double crop of 10 soybean cultivars across two years. RS1: 75 cm; RS2: 25 cm. Error bars represent standard error of the mean (n = 6)

cvs. Sphera and PR92M22 had the lowest YRI, whereas cvs. Atlantic and Mercury the highest (Figure 3).

RS did not significantly affect CP. Previous reports are contradictory; Acikgoz et al. (2009) reported that RS and seeding rate have no significant effect on CP and seed oil content, whereas Bellaloui et al. (2015) demonstrated that the same factors alter CP, oil, fatty acid and sugar profile.

In conclusion, this study demonstrated significant effects of RS and crop system on soybean seed yield and other important agronomic traits in early maturity soybean cultivars. RS had a profound effect on SY, PH, PP and FPH, resulting in a higher SY in RS2. In the double-crop system, YRI ranged from 30 to 56.4 in RS1 and from 21.5 to 57.2 in RS2. The most productive cultivars were PR92B63 in the full-season crop system and cv. Sphera in the double-crop system regardless of RS. Besides, cv. PR92M22 indicated wide adaptability regardless of the crop system and RS.

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