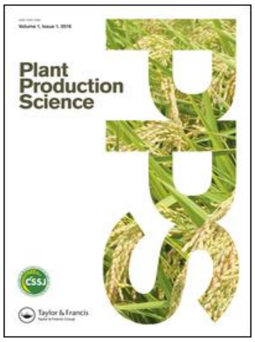

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Performance of double cropping and relay intercropping for black soybean production in small-scale farms

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ABSTRACT
We investigated the soybean productivity of double cropping and relay intercropping in farmer's fields for three years using two black soybean cultivars of Kurozukin and Tanbaguro, which are used for the first and second crop, respectively. Kurozukin is the early maturing cultivar for vegetable soybean harvest and Tanbaguro is the late-maturing cultivar for the harvest of vegetable soybean and seeds. The yield of the first crop (Kurozukin) was similar to the mono cropping regardless of cropping patterns. However, the yield of the second crop (Tanbaguro) was affected by cropping patterns. The yield of Tanbaguro in double cropping was prone to decrease by late sowing. The late sowing was induced by the late sowing and late harvesting of Kurozukin because of the low temperature in April and the large amount of precipitation in rainy season, respectively. In relay intercropping that Tanbaguro was sown between the rows of Kurozukin at about one month before the harvest of Kurozukin, the yield of Tanbaguro was similar to the mono cropping and the competition with Kurozukin was not observed. Thus, the land equivalent ratio value of double cropping was lower than that of relay intercropping. These results suggest that relay intercropping is more useful cultivation system than double cropping to increase the annual soybean production.

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Agricultural land in Japan gradually decreases year by year. According to the research by Ministry of Agriculture, Forestry and Fisheries in Japan (MAFF, 2012), total area of agricultural land of Japan in 2012 was 454.9 million ha, which was 36% lower than that of 50 years ago. In addition, the average land area of each farmer except for Hokkaido was less than 2.0 ha (MAFF, 2015). Thus, it is necessary to increase land use efficiency for the increment of yield and income of each farmer, leading to the enhancement of domestic productivity.

Since the productivity of soybean in Japan is lower than that of world average, the cropping system for increasing the production is necessary. Recently, the demand for soybean production increased compared to other grain legumes such as groundnut, cowpea and common bean in southern Africa (Mpepereki et al., 2000). In addition, small-scale soybean production is expanding rapidly in the region. For the increase in small-scale soybean production, the increase in land use efficiency would be one of the candidate strategies.

Double cropping and intercropping may be useful for the increase in soybean production. The intercropping of cereal and leguminous crops has been largely investigated in Asian (Homma et al., 2009; Li et al., 1999; Polthanee & Trelo-ges, 2003) and African regions (Agegnehu et al., 2006; Muoneke et al., 2007; Tsujimoto et al., 2015; Zegada-Lizarazu et al., 2006) because of the higher productivity than mono cropping. The benefits of the intercropping will be high resource use efficiency in agriculture, especially in terms of nutrients (Zhang & Li, 2003). Iijima et al. (2004) reported the other advantage through cassava-based intercropping trial that the intercropping is beneficial in terms of economy and risk dispersion; in addition, the intercropping reduces soil erosion compared with the cassava mono cropping in Sumatra Island.

Double cropping will be also beneficial for the increment of annual production. Double cropping with summer crops such as maize, soybean, or cotton, and a winter crop such as wheat has been widely studied in South America (Andrade & Satorre, 2015; Monzon et al., 2007) and Asia (Du et al., 2015). In double cropping, the cultivation system using same crop has been investigated. Duy and Yoshida (1999) investigated the double cropping of sorghum and reported the problems that sowing time are important factors affecting crop productivity and early mature varieties are desirable. Nishioka and Okumura (2003) investigated the double cropping using soybean: vegetable soybean and seeds were harvested as the first and second crop,

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respectively. The authors suggested that the yield of the second crop decreased because of the short growth duration as compared with the normal cultivation because of the late sowing. In the Argentinean Pampas, there is a field trial to investigate effectiveness of double cropping and relay intercropping using maize and soybean as first and second crop, respectively, for the enhancement of production in the limited length of the growing season (Monzon et al., 2014). In the relay intercropping, soybean was sown between the rows of maize at 40–60 days after maize sowing. In the report, soybean yield in double cropping was reduced compared with that of mono cropping due to late sowing. Also, soybean production in relay intercropping was reduced by the long-term overlap growth period with maize. The report leads to the hypothesis that relay intercropping by short-term overlap growth period would be effective to prevent the reduction in soybean production by late sowing and competition. However, there are few field trials to investigate the effectiveness of double cropping and relay intercropping, and thus it is worth to investigate whether these cultivation systems are effective for the increase in annual soybean production.

Recently, the cultivation of black soybean has been focused because the market price is higher than yellow soybean. In addition, since black soybean includes higher content of polyphenol than yellow soybean, it is recognized worldwide that the intake of black soybean would be useful for preventing low-density lipoprotein oxidation-related diseases such as atherosclerosis or various types of cancers (Takahashi et al., 2005). Thus, double cropping and relay intercropping using black soybean would be beneficial for small-scale farmers in terms of productivity and income. The objective of this study is to compare the productivity among mono cropping, double cropping, and relay intercropping using two black soybean cultivars. For this purpose, we investigated the growth and productivity of black soybean for three years in farmer's fields.

2. Materials and methods

2.1. Study sites

The patterns of double cropping and relay intercropping of black soybean were tested at the farm field of Miki (34°79′ N, 135°04′ E) and Kyotanabe (36°46′ N, 135°45′ E). The experiment of 2009 was conducted at Miki (Hyogo prefecture) and the experiments of 2010 and 2011 were conducted at Kyotanabe (Kyoto prefecture). In Miki field, soybean had been cultivated for two years before this experiment and gramineous plants had not been cultivated during the period. Thus, the present experiment was the third season of continuous cropping of soybean. In Kyotanabe field, soybean had not been cultivated before this experiment. Thus, 2010 experiment was the first season of soybean cultivation. Gramineous plants had not been cultivated for two years. Figure 1 shows the temperature and rainfall during the experiment at Miki (upper), Kyotanabe (middle and lower) and 30 year average (long-term average (LTA), 1981–2011) at both experimental sites. Sources of the data are Local Meteorological Observatories of Miki and Kyotanabe. The total rainfall during the experimental period from April to December was 917 mm (69 mm below the long-term average, LTA), 1,312 (165 mm above LTA), and 1,363 mm (215 mm above LTA), respectively, in the 2009, 2010 and 2011. The average temperatures in the 2009, 2010, and 2011 were 18.1 °C (0.2 °C above LTA), 19.3 °C (1.2 °C above LTA), and 19.0 °C (0.9 °C above LTA), respectively. The data of total rainfall of Kyotanabe from late in July to early in September in 2010 were lost due to unknown reason. In addition, the data of average temperature of Kyotanabe from late in August to early in September in 2010 were lost as well. The topsoil in Miki field was sandy clay loam with pH of 6.6 (water extracted) and EC of 6.0 ms m^{-1}; total N, 1.60 g kg^{-1}; total C, 18.2 g kg^{-1}, and the topsoil in Kyotanabe field was light clay with pH of 5.7 (water extracted) and EC of 11.8 ms m^{-1}; total N, 1.9 g kg^{-1}; total C, 17.4 g kg^{-1}.

2.2. Cropping patterns and field management

Two patterns of double cropping and relay intercropping and mono cropping were tested with three replications in a randomized complete block design using two black soybean cultivars of Kurozukin and Tanbaguro to evaluate the competition and the productivity for three years. Kurozukin is an early-maturing cultivar (relative maturity of 80 days) for vegetable soybean harvest. Tanbaguro is one of the major commercial and late-maturing cultivars of black soybean cultivated mainly in Tanba-sasayama region (north Hyogo of Japan). The plant type of Tanbaguro is relatively large, and thus Tanbaguro is normally cultivated by larger row and hill space than other soybean cultivars. The large body and long cultivation period will lead to heavier seed weight than other soybean cultivars. Since the seeds of Tanbaguro are used for the festive foods for the New Year, the market price is higher than other black soybean cultivars. The cropping patterns tested in each year are shown in Table 1. In double cropping, Kurozukin for vegetable soybean harvest was grown as the first crop and Tanbaguro for the harvest of either vegetable soybean (D1) or seed (D2) was grown as the second crop. In relay intercropping, the second crop of Tanbaguro grown for the harvest of either vegetable soybean (R1) or seed (R2) was sown between the rows of the first crop of Kurozukin. Mono cropping (M) is the control for each cropping pattern. In R2 of 2009 and R1 and R2 of 2011, Tanbaguro was

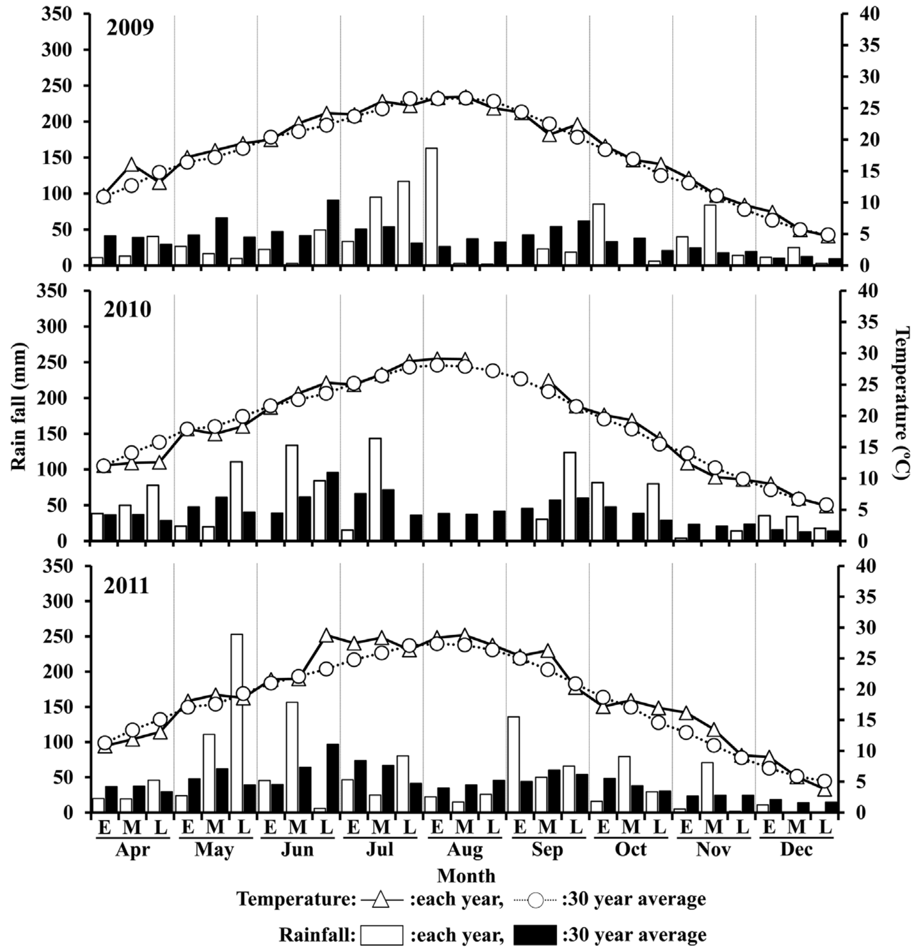

Figure 1. Monthly average temperature and total rainfall during the period of 2009, 2010, 2011 and 30 year average E, M and L indicate early, middle and late in each month, respectively.

sown between the rows of Kurozukin at one month before the harvest (Figure 2 (C) and (D)). There was space between the rows of Kurozukin, and Tanbaguro could receive light (Figure 2 (D)). In R1 and R2 of 2010, Tanbaguro was sown on 20 June between the rows of Kurozukin. However, the germinated seeds of Tanbaguro wilted due to heavy rainfall in mid-June (Figure 1 middle). Thus, Tanbaguro was sown between the rows of Kurozukin on 8 July again, whereas the large amount of rainfall in mid-July (Figure 1 middle) spoiled the germinated seeds. As a result of the large amount of rainfall in rainy season, the relay intercropping failed in 2010. In the relay intercropping fields, Kurozukin and Tanbaguro were sown on the same day as the second crop, and mixed intercropping was conducted (data not shown). In the present report, therefore, we showed only the results of double cropping.

Before sowing, the land was prepared and leveled with rotary plough to a depth of 15 cm in both Miki and Kyotanabe fields. Basal fertilizer was applied to each field at 30, 100, and 100 kg ha^{-1} each of N, P_2O_5 and K_2O every year. Basal fertilizer was not applied before the sowing of the second crop in double cropping. Two black soybean cultivars were planted as shown in Table 1. The row spacing × hill spacing of Kurozukin and Tanbaguro in all cropping patterns were 0.6 m × 0.2 m (83,333 plants per ha) and 1.2 m × 0.3 m (27,777 plants per ha), respectively (Figure 2). In relay intercropping fields, Tanbaguro was sown between the rows of Kurozukin as shown in Figure 2. The size of each plot in Miki and Kyotanabe was 15 m^2 (5 m × 3 m) and 6.48 m^2 (3.6 m × 1.8 m), respectively. The germinated seeds of Kurozukin and Tanbaguro were thinned to two plants and one plant per a hill around three weeks after sowing, respectively. The top dressing in the field of mono cropping was applied once, and the application rate was at 30, 30, and 30 kg ha^{-1} for N, P_2O_5, and K_2O, respectively. In the double and relay intercropping fields, top dressing was applied separately in the first and second crop and each application rate was at 15, 15, and 15 kg ha^{-1} for N, P_2O_5, and K_2O, respectively. In 2009 experiment, top dressing was applied to the first and second crop on 25 May and 10 September, respectively. In 2010, top dressing was applied to the first and second crop on 11 June and 17 September,

Table 1. Cropping patterns tested and the data of sowing and harvesting in each year.

Year (Location)	Cropping pattern		Sowing ○	Harvest △ (total growth duration)
2009 (Miki)	M	K. (D2, R2)	16	7 (82)
		T. (R2)	16	14 (181)
	D2		16	7 (82)
			10	14 (157)
	R2		16	7 (82)
			16	14 (181)
2010 (Kyotanabe)	M	K. (D1, D2)	26	21 (86)
		T. (D1)	23	23 (92)
		T. (D2)	23	10 (140)
	D1		26	21 (86)
			23	23 (92)
	D2		26	21 (86)
			23	10 (140)
2011 (Kyotanabe)	M	K. (D1, D2, R1, R2)	2	20 (79)
		T. (R1)	19	18 (121)
		T. (R2)	19	12 (176)
	D1		2	20 (79)
			27	18 (83)
	D2		2	20 (79)
			27	12 (138)
	R1		2	20 (79)
			19	18 (121)
	R2		2	20 (79)
			19	12 (176)

Month: Apr. May Jun. Jul. Aug Sep. Oct. Nov. Dec.

M, Mono cropping; D, Double cropping; R, Relay intercropping. 'K.' and 'T.' represent Kurozukin and Tanbagoro, respectively. Sowing and harvesting are represented by the symbols of ○ and △, respectively. The number of the left side of ○ represents the sowing day, and the number of the right side of △ represents the harvest day. The values in parenthesis indicate the total growth duration. The cropping seasons of Kurozukin and Tanbaguro are shown by thin and thick lines, respectively. The cultivation for the harvesting of vegetable soybean and seed are shown by dotted and solid lines, respectively.

respectively. In 2011 experiment, top dressing was applied to the first and second crop on 15 June and 16 September, respectively.

In all fields, the midterm tillage was conducted once when top dressing was applied. No irrigation was applied during the experiment. For bird control and seed disinfection, thiuram (wetter powder) was coated around soybean seeds. Weed control was done by broadcasting benthiocarb, pendimethalin, and linuron (granule) at the rate of 50 kg ha^{-1}. Insect control was done by spraying Etofenprox (Emulsifiable Concentrate) against stink bug.

2.3. Data collection and statistical analysis

At the harvest in 2009 experiment, 10 hills of Kurozukin and Tanbaguro were selected from each plot (in total, 30 hills (10 hills per plot × 3 replications) were harvested). At the harvest in 2010 and 2011 experiments, 5 hills of Kurozukin and Tanbaguro were selected from each plot (in total, 15 hills (5 hills per plot × 3 replications) were harvested). The moderate growth of Kurozukin and Tanbaguro plants were selected to measure the growth and yield. The length and number of main node and branch number were measured for the determination of soybean growth in 2010 and 2011 experiments, whereas only yield was measured in 2009 experiment. After removing pods, number and weight of pods were measured for the determination of vegetable soybean yield of Kurozukin and Tanbaguro. Only well-developed and green color pods (R6; soybean stages are according to Fehr et al. (1971)) were selected for the measurement. For the determination of seed yield of Tanbaguro, ripened pod number, seed number, and seed weight were measured. Land equivalent ratio (LER) was calculated as the sum of relative yields of Kurozukin (RY_{Kuro}) and Tanbaguro (RY_{Tanba}) using the following equation to evaluate and compare the productivity of double cropping, relay intercropping, and mono cropping (Monzon et al., 2014).

$$LER = RY_{Kuro} + RY_{Tanba}$$

$$RY_{kuro} = Y_{int\text{-}Kuro}/Y_{mono\text{-}Kuro} \text{ or } Y_{double\text{-}Kuro}/Y_{mono\text{-}Kuro}$$

$$RY_{Tanba} = Y_{int\text{-}Tanba}/Y_{mono\text{-}Tanba} \text{ or } Y_{double\text{-}Tanba}/Y_{mono\text{-}Tanba}$$

where $Y_{double\text{-}Kuro}$, $Y_{int\text{-}Kuro}$, and $Y_{mono\text{-}Kuro}$ are the pod weight (g $plant^{-1}$) of vegetable soybean of Kurozukin from double cropping, relay intercropping, and mono cropping, respectively, and $Y_{double\text{-}Tanba}$, $Y_{int\text{-}tanba}$, and $Y_{mono\text{-}Tanba}$ are the pod weight of vegetable soybean and the seed weight (g $plant^{-1}$) of Tanbaguro from double cropping, relay intercropping, and mono cropping, respectively. For the calculation of LER, only the yield of mono cropping at

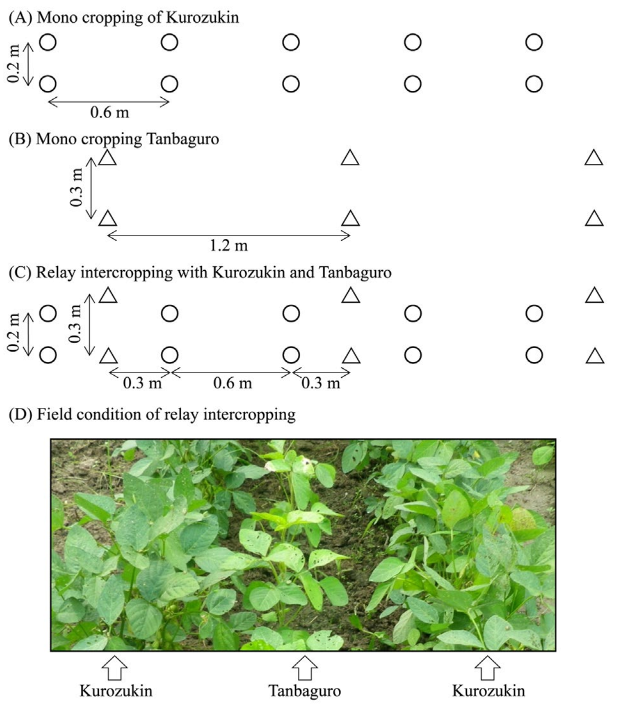

Figure 2. Row arrangement of Kurozukin, Tanbaguro and their relay intercropping. The symbols of ○ and △ represent Kurozukin and Tanbaguro, respectively. (A) Mono cropping of Kurozukin, (B) Mono cropping of Tanbaguro. (C) Relay intercropping with Kurozukin and Tanbaguro. In relay intercropping fields, Tanbaguro was sown between the rows of Kurozukin, leading to the row arrangement as shown by (C). (D) A photograph of the field condition of relay intercropping. The photograph was taken on 20 July of 2011 (just before the harvest of Kurozukin).

optimum sowing period (mid-June) was used. Since the seed of Tanbaguro was not sown at optimum period in 2010 experiment, the LER in 2010 was not calculated.

In addition, competitive ratio (CR) was calculated using the following equation to evaluate the competition in relay intercropping (Snaydon, 1991; Willey & Rao, 1980):

$$CR_{Kuro} = \left(Y_{int\text{-}Kuro} / Y_{mono\text{-}Kuro}\right) / \left(Y_{int\text{-}Tanba} / Y_{mono\text{-}Tanba}\right)$$

$$CR_{Tanba} = \left(Y_{int\text{-}Tanba} / Y_{mono\text{-}Tanba}\right) / \left(Y_{int\text{-}Kuro} / Y_{mono\text{-}Kuro}\right)$$

F values, probability levels, and standard error of means were indicated in all the parameters. One-way analysis of variance (ANOVA) was first applied for statistical evaluation using Excel 2012 for Windows (SSRI Japan, Co. Ltd). If ANOVA was significant, *post hoc* analyses were conducted using Tukey's multiple comparison test, with the level of statistical significance taken as $p < 0.05$. One-way ANOVA was also applied to compare the difference of growth and yield among the experimental period for two or three years. Only the data of mono cropping were used for the comparison.

3. Results

3.1. Growth and vegetable soybean yield of Kurozukin

Table 2 shows the growth and yield of Kurozukin for three years. The growth and yield of Kurozukin in each year were not statistically different between cropping patterns. In relay intercropping of R2 in 2009 and R1 and R2 in 2011, Tanbaguro was sown between the rows of Kurozukin at about one month before the harvest. However, the growth and yield of Kurozukin were similar to the mono cropping (Table 2 upper and lower). The yield of Kurozukin of mono cropping was statistically different among the experimental period for three years. The yield of Kurozukin in 2009 experiment was higher than those in 2010 and 2011 (Table 2 upper). On the other hand, the yield of Kurozukin in 2010 was the lowest among the cropping seasons tested (Table 2 middle).

3.2. Growth and yields of Tanbaguro

Table 3 shows the growth and yield of Tanbaguro for the harvest of vegetable soybean. In 2010 (Table 3 upper), the length and node number of main stem were similar level among the cropping patterns. The branch number of D1 tended to decrease compared with that of the mono cropping. The vegetable soybean yield of D1 was similar to the mono cropping. In 2011 (Table 3 lower), the length and node number of main stem of D1 tended to decrease compared with those of mono cropping and R1. The vegetable soybean yields of R1 were similar to mono cropping. However, the yield of D1 was statistically lower than that of mono cropping. The yield and growth of Tanbaguro for the harvest of vegetable soybean were not statistically different among the experimental period for two years (2010 and 2011).

Table 4 shows the growth and yield of Tanbaguro for the harvest of seeds. In 2009 (Table 4 upper), statistical differences were not observed between the cropping patterns. In 2010 (Table 4 middle), the length and node number of main stem were similar level among the cropping patterns. The branch numbers of D2 tended to decrease compared with that of mono cropping. The yield components such as ripened pod number, seed number, and seed weight in D2 were similar to the mono cropping. In 2011 (Table 4 lower), the growth and yield of R2 were similar to those of mono cropping. However, the growth and yield of D2 were lower than mono cropping and R2. The length of main stem of D2 showed statistical decrease compared with that of mono cropping and R2. The statistical decreases in main stem node number were observed by one-way ANOVA, whereas the statistical decrease was not observed by Tukey's multiple comparison test. The branch number

Table 2. Effects of cropping patterns on the growth and yields of vegetable soybean of Kurozukin for three years.

Year	Cropping pattern	Main Stem length (cm)	Main stem node number	Branch number	Pod number ($hill^{-1}$)	Pod weight (g $hill^{-1}$)
2009	Mono	–	–	–	51.3 (1.79)	94.3 (3.84)
	D2	–	–	–	49.4 (2.81)	100 (5.74)
	R2	–	–	–	57.0 (2.10)	109 (4.60)
One-way ANOVA	*F* value	–	–	–	3.035	2.229
	Probability				0.123	0.189
2010	Mono	33.7 (2.45)	8.43 (0.29)	3.71 (0.14)	27.1 (4.12)	51.4 (5.61)
	D1	35.2 (3.54)	8.24 (0.36)	3.31 (0.28)	35.8 (5.80)	70.6 (13.2)
	D2	32.4 (1.09)	8.24 (0.19)	3.83 (0.41)	30.8 (5.11)	60.1 (9.45)
One-way ANOVA	*F* value	0.302	0.146	0.854	0.748	0.942
	Probability	0.750	0.867	0.472	0.513	0.441
2011	Mono	25.7 (2.55)	7.679 (0.55)	3.73 (0.29)	45.5 (5.31)	79.8 (8.86)
	D1	28.4 (0.87)	8.17 (0.25)	4.00 (0.25)	51.7 (4.67)	88.9 (14.6)
	D2	24.3 (2.01)	8.17 (0.08)	4.15 (0.10)	46.2 (3.49)	79.2 (5.85)
	R1	25.8 (1.13)	7.67 (0.12)	4.10 (0.31)	45.2 (6.86)	82.7 (13.3)
	R2	27.0 (2.58)	8.20 (0.26)	3.50 (0.12)	43.1 (6.78)	76.5 (12.6)
One-way ANOVA	*F* value	0.615	0.681	1.437	0.327	0.167
	Probability	0.662	0.621	0.292	0.854	0.950
One-way ANOVA Year	*F* value	5.166	1.051	0.001	9.92	11.48
	Probability	0.085	0.363	0.975	1.25×10^{-2}**	8.90×10^{-3}**

The data are means of three replicated plots. The values in parenthesis indicate standard error of mean. The effects of cropping patterns on growth and yield in each year were analyzed by ANOVA. In addition, the difference of yield between each year was analyzed by ANOVA.

of D2 was statistically lower than that of mono cropping and R2. The ripened pod number, seed number, and seed weight of D2 were statistically lower than those of mono cropping and R2. The main stem nod number was statistically different between the experimental period for two years (2010 and 2011). However, other growth and yield parameters were not statistically different among the experimental period for two and three years, respectively.

3.3. LER and CR analysis

Table 5 shows RY, LER, and CR. In the present study, RY and LER of both of double cropping and relay intercropping were calculated to compare the productivity (Monzon et al., 2014). In 2009 and 2011, the RY values of Kurozukin in all cropping patterns were around 1.0. In 2009, the RY value of Tanbaguro in D2 was 0.80, whereas the seeds were sown at one month later than optimal sowing. In 2009, therefore, the LER values of both of double cropping (D2) and relay intercropping (R2) were around 2.0. On the other hand, the RY values of Tanbaguro in D1 and D2 in 2011 were 0.44 and 0.46, respectively. The low RY values induced the lower LER values compared with those of relay intercropping (R1 and R2). The LER values of R1 and R2 in 2011 were 1.99 and 1.84, respectively.

The CR value of Kurozukin and Tanbaguro of R2 in 2009 was 1.18 and 0.85, respectively. The CR value of Kurozukin and Tanbaguro of R1 in 2011 was 1.09 and 0.92, respectively. The CR values of Kurozukin and Tanbaguro of R2 in 2011 were 1.09 and 0.92, respectively. The growth period of Tanbaguro overlapped with Kurozukin in 2009 and 2011 were 21 and 31 days, respectively. Thus, the growth period overlapped about one month did not induce the significant competition between cultivars and did not reduce RY and LER.

4. Discussion

The yield of Kurozukin was statistically different among three cropping seasons. The difference would be due to the weather condition, especially precipitation pattern. The yield of Kurozukin in 2009 was higher than those in other cropping season (Table 2 upper). On the other hand, the yield of Kurozukin in 2010 was the lowest among the cropping seasons (Table 2 middle). In 2009, the precipitation during the growth period was less than that of 30 year average (Figure 1 upper). In 2010, the precipitation in mid-June and mid-July was about twice compared with that of 30 year average (Figure 1 middle). Since Kurozukin would be harvested from 35 to 40 days after flowering, mid-June, and mid-July in 2010 would correspond to reproductive stage. Although there was the large amount of precipitation in late May of 2011 (Figure 1 lower), the yield of Kurozukin in 2011 (Table 2 lower) was higher than that in 2010 (Table 2 middle). Since Kurozukin was sown on 2 May in 2011 experiment, late in May would correspond to vegetative stage. Although there was the large amount of precipitation in mid-June 2011, the total amount of precipitation in June and July of 2011 was less than that of 2010 (Figure 1 middle and lower). Thus, the yield of Kurozukin in 2011 could be not affected by excess moisture conditions. There are some reports that soybean was more sensitive to excess moisture conditions at reproductive stage than that at the vegetative stage (Griffin & Saxton, 1988; Linkemer et al., 1998; Scott et al., 1989). These results suggest that the large amount of precipitation around one month

Table 3. Effects of cropping patterns on the growth and yield of vegetable soybean of Tanbaguro.

Year		Cropping pattern	Main stem length (cm)		Main stem node number		Branch number		Pod number ($plant^{-1}$)		Pod weight (g $plant^{-1}$)	
2010		Mono	43.7	(4.51)	12.5	(0.74)	11.1	(2.58)	55.9	(6.30)	225	(27.6)
		D1	42.0	(2.84)	12.3	(0.41)	9.40	(1.29)	57.7	(2.07)	232	(13.8)
One-way ANOVA		*F* value	0.100		0.010		0.334		0.074		0.043	
		Probability	0.768		0.768		0.594		0.799		0.847	
2011		Mono	43.0	(3.58)	12.1	(0.47)	–		69.1^a	(7.11)	229^a	(27.1)
		D1	36.0	(4.03)	11.2	(1.01)	–		30.1^b	(4.03)	99.9^b	(13.1)
		R1	50.8	(2.82)	14.0	(0.88)	–		69.2^a	(9.38)	217^a	(32.8)
One-way ANOVA		*F* value	4.423		3.118		–		9.031		7.662	
		Probability	0.066		0.118		–		0.016*		0.022*	
One-way ANOVA	Year	*F* value	0.015		0.283		–		1.911		0.007	
		Probability	0.910		0.622		–		0.239		0.938	

The data are means of three replicated plots. The values in parenthesis indicate standard error of mean. The effects of cropping patterns on growth and yield in each year were analyzed by ANOVA. In addition, the difference of yield between each year was analyzed by ANOVA. When ANOVA of cropping patterns in each year was significant, *post hoc* analyses were conducted using Tukey's multiple comparison test, with the level of statistical significance taken as $p < 0.05$.
The symbols of * and ** indicate significant differences at $p < 0.05$ and $p < 0.01$ by ANOVA, respectively. The same letters adjacent to the value indicate no significant difference at $p < 0.05$ according to Tukey's multiple comparison test.

Table 4. Effects of cropping patterns on the growth and seed yield of Tanbaguro.

Year		Cropping pattern	Main Stem length (cm)		Main stem node number		Branch number		Ripened pod number		Seed number ($plant^{-1}$)		Seed weight (g $plant^{-1}$)	
2009		Mono	–		–		–		–		67.5	(8.22)	50.0^b	(5.03)
		D2	–		–		–		–		53.0	(7.98)	40.2	(4.34)
		R2	–		–		–		–		58.3	(9.71)	48.8^b	(12.6)
One-way ANOVA		*F* value	–		–		–		–		0.719		0.425	
		Probability	–		–		–		–		0.525		0.672	
2010		Mono	42.7	(3.06)	11.9	(0.44)	9.13	(0.74)	69.7	(5.46)	81.7	(10.9)	52.6	(7.79)
		D2	42.7	(1.45)	11.8	(0.12)	8.13	(0.29)	69.1	(5.07)	87.7	(9.29)	56.6	(7.69)
One-way ANOVA		*F* value	3.87×10^{-4}		8.70×10^{-2}		1.573		5.78×10^{-3}		0.175		0.132	
		Probability	0.985		0.783		0.278		0.943		0.698		0.735	
2011		Mono	47.9^a	(2.34)	14.3^a	(0.47)	10.9^a	(0.82)	77.9^a	(1.54)	101^a	(2.77)	70.5^a	(0.91)
		D2	34.5^b	(4.21)	11.4^a	(0.90)	5.40^b	(1.14)	33.4^b	(7.45)	49.8^b	(12.8)	32.3^b	(8.13)
		R2	48.0^a	(1.77)	14.4^a	(0.74)	13.8^a	(0.88)	73.0^a	(8.84)	86.9^a	(6.68)	62.0^a	(6.68)
One-way ANOVA		*F* value	6.943		5.471		19.69		13.14		9.645		10.80	
		Probability	0.027*		0.044*		2.31×10^{-4}**		6.42×10^{-4}**		0.013*		0.010*	
One-way ANOVA	Year	*F* value	1.824		13.32		2.458		2.105		4.302		4.282	
		Probability	0.830		0.022*		0.192		0.221		0.069		0.070	

The data are means of three replicated plots. The values in parenthesis indicate standard error of mean. The effects of cropping patterns on growth and yield in each year were analyzed by ANOVA. In addition, the difference of yield between each year was analyzed by ANOVA. When ANOVA of cropping patterns in each year was significant, *post hoc* analyses were conducted using Tukey's multiple comparison test, with the level of statistical significance taken as $p < 0.05$.
The symbols of * and ** indicate significant differences at $p < 0.05$ and $p < 0.01$ by ANOVA, respectively. The same letters adjacent to the value indicate no significant difference at $p < 0.05$ according to Tukey's multiple comparison test.

before the harvest of Kurozukin would affect the vegetable soybean production.

In the present study, 2009 experiment was the third cropping season and 2011 experiment was the second cropping season of soybean production. However, the yield decrease due to the continuous cropping was not observed. Matsumoto and Yoshikawa (2010) investigated the yield decrease using the black soybean cultivar of Shin-tanbaguro in the upland field converted from paddy for five years. The authors reported that the seed yield increased until the third year after the conversion, whereas the yield gradually decreased after the fourth year. Although the yield decrease due to the continuous cropping was not observed in the present study, further studies will be needed for preventing the yield decrease. Since crop rotation system (Matsuzaki, 2013) and the application of green manure (Yoshida, 1979) would be effective to suppress the decrease in soybean yield by continuous cropping, the cultivation system for the suppression of the yield loss by continuous cropping should be developed.

The yield of the first crop of Kurozukin would not be disturbed by cropping pattern. In R2 in 2009 and R1 and R2 in 2011, Tanbaguro was sown between the rows of Kurozukin at about one month before the harvest. However, the growth and yield of Kurozukin were similar to the mono cropping (Table 2 upper and lower) and the values of CR were around one (Table 5). Thus, the production of Kurozukin would not be affected by the relay intercropping with Tanbaguro for about one month.

Table 5. Relative yield (RY), land equivalent ratio (LER) and competitive ratio (CR) of Kurozukin and Tanbaguro in double cropping and relay intercropping.

Year	Cropping pattern	RY (Kurozukin)	RY (Tanbaguro) (Vegetable soybean)	RY (Tanbaguro) (Seed)	LER	CR (Kurozukin)	CR (Tanbaguro) (Vegetable soybean)	CR (Tanbaguro) (Seed)
2009	D2	1.06	–	0.80	1.87	–	–	–
	R2	1.15	–	0.98	2.13	1.18	–	0.85
2011	D1	1.11	0.44	–	1.55	–	–	–
	D2	0.99	–	0.46	1.45	–	–	–
	R1	1.04	0.95	–	1.99	1.09	0.92	–
	R2	0.96	–	0.88	1.84	1.09	–	0.92

The values of RY and LER in double cropping were calculated using the yield data of mono cropping at optimal sowing period.

On the other hand, the yield of the second crop of Tanbaguro was affected by cropping patterns. In double cropping, there is a possibility that the yield of the second crop would be reduced by the late sowing as observed in 2011 (Table 4 lower). The lower yields would be due to the short growth period of Tanbaguro by the late sowing of Kurozukin and the delay of land preparation for Tanbaguro. In 2011, since the temperature in April was lower than 30-year average (Figure 1 lower, the symbol of △), the first crop of Kurozukin in the double cropping was sown at early in May and harvested at late in July (Table 1 lower). In addition, the land preparation for Tanbaguro delayed because there was the large amount of rainfall in Kyotanabe at late in July (Figure 1 lower). These environmental conditions shortened the growth period of Tanbaguro of D1 and D2. Nishioka and Okumura (2003) reported using soybean that the sowing of the second crop in double cropping was prone to be late and the yield decreased. It is well known that the late sowing (from late in July to early in August) of soybean induces the decrease in yield (Fatichin et al., 2013). Thus, the double cropping using soybean cultivars would not be suitable because of the risk of yield decrease of the second crop by late sowing. Dense sowing would be effective for preventing from the yield decrease by late sowing. Thus, further studies are needed to confirm the effectiveness of dense sowing for recovering the yield decrease. Another problem would be hard labor. Since the harvest of the first crop and the preparation of the second crop in the double cropping should be done at the same time, the labor shortage would be problem for small-scale farmers.

Relay intercropping would be suitable for soybean cultivation because farmers can prevent from late sowing and hard labor. In addition, intercropping within one month would not disturb the growth and yield of both of the first and second crop. LER values of R2 in 2009 and of R1 and R2 in 2011 were near 2.0, which values are higher than those of double cropping (Table 5). The values of CR in both cultivars were near 1.0 (Table 5). Thus, the relay intercropping that the second crop is sown between the rows of the first crop at one month before the harvesting of the first crop would be proposed to increase soybean yield for small-scale farmers. In 2010 experiment, however, large amount of rainfall just after sowing spoiled soybean seedlings. Thus, the risk of late sowing of the second crop will not be completely prevented by this relay intercropping. The strategy for overwhelming waterlogging would be necessary for preventing the risk of late sowing.

Top dressing in double cropping and relay intercropping for seed harvest should be improved. The seed yield of Tanbaguro of R2 in 2009 and 2011 were lower than mono cropping, though statistical differences were not observed (Table 4 upper and lower). The lower yield could be due to the nutrient deficiency. In 2009 and 2011, the rates of top dressing in R2 during the growth period of Tanbaguro were half of the mono cropping because another half of top dressing was applied at the growth period of the first crop of Kurozukin. In the present study, the total amount of top dressing applied to each field was same rate at 30, 30, and 30 kg ha^{-1} for N, P_2O_5, and K_2O. Top dressing was applied to Tanbaguro at three months before the harvest (mid-Sep). The growth period of Tanbaguro is relatively longer than other soybean cultivars. Thus, further studies are needed to confirm the timing, the rate, and the frequency of the top dressing to Tanbaguro.

In summary, the relay intercropping tested was superior to double cropping for increase in annual yield. In addition, the relay intercropping would be useful for small-scale farmers because they can prevent from hard labor. A few problems such as possible yield decrease by continuous cropping and the application rate or timing of chemical fertilizer should be solved before we introduce the relay intercropping to farmers. However, the relay intercropping would be one of the cropping systems for increasing annual soybean yield.

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Disclosure statement

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