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The Effects of Row Spacing on Yield and Yield Components of Full Season and Double-Cropped Soybean

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Abstract: Compared to full season soybean cropping systems, seed yield reduction is a major concern in double-cropped soybean production systems. This study was conducted at the Research Farm of Mustafa Kemal University, Hatay, Turkey, to determine if it is possible to enhance the yield of both full season and double-cropped soybean by narrowing row spacing. Two soybean cultivars, A3935 and S4240, were planted using row widths of 30, 50, and 70 cm, and twin row (50 25 50 cm) in 2004 and 2005. Seed yield and the other investigated plant parameters of double-cropped soybean were lower compared to full season soybean. Row spacing had a significant effect on plant height, number of nodes per plant, main-stem pod and seed number, branch pod and seed number, and seed yield in both cropping systems. The highest seed yield (4142.5 kg ha^{-1}) averaged over years was obtained from a 50-cm row width in full season soybean cropping, whereas a 30-cm row width had the highest seed yield (3241.5 kg ha^{-1}) in double-cropped soybean. In full season soybean production, a 23% yield increase was recorded when row width was shifted from 70 to 50 cm, and no yield increase was recorded by further narrowing the row width. In double-cropped soybean, 24.8%, 59.5%, and 35.6% yield increases were recorded when soybean was planted in 50 and 30 cm, and twin row width, respectively, instead of a 70-cm row width. Our results indicated that yield reductions in double-cropped soybean production could be alleviated by narrowing the row width in the eastern Mediterranean region.

Key Words: Soybean, *Glycine max*, planting date, row width, seed yield, yield decrease

Ana ve İkinci Ürün Soya Tarımında Sıra Arası Mesafelerinin Verim ve Verim Öğeleri Üzerine Etkileri

Özet: Ana ürün soya tarımına göre ikinci ürün soya tarımında verim düşüklüğü önemli bir kaygıdır. Bu çalışma, ana ürün ve ikinci ürün soya tarımında sıra arası mesafelerinin daraltılması ile olası verim artışını tespit etmek amacı ile Mustafa Kemal Üniversitesi Araştırma Çiftliğinde yürütülmüştür. 2004 ve 2005 yıllarında yürütülen çalışmada, iki soya çeşidi (A3935 ve S4240), 30, 50, 70 cm aralıklı ve çiftli (50 25 50 cm) sıralardan oluşan parsellere ekilmiştir. İkinci ürün soya tarımında tohum verimi ve incelenen diğer bitkisel özellikler ana ürüne göre daha düşük bulunmuştur. Sıra arası mesafesi ana ürün ve ikinci ürün soyalarda bitki boyu, ana dalda boğum sayısı, ana dalda bakla ve tohum sayısı, yan dalda bakla ve boğum sayısı ve tohum verimi üzerine önemli etkide bulunmuştur. Verim ve diğer tüm incelenen özellikler üzerine çeşit x sıra arası interaksiyonu önemli bulunmamıştır. İki yıllık ortalama verimlere göre ana ürün soyada en yüksek tohum verimi 4142.5 kg ha^{-1} ile 50 cm sıra arası mesafeden elde edilirken ikinci ürün soyada en yüksek tohum verimi 3241.5 kg ha^{-1} ile 30 cm sıra arası mesafeden elde edilmiştir. Ana ürün soya üretiminde sıra arası mesafesinin 70 cm den 50 cm ye düşürülmesi ile % 23 oranında verim artışı sağlanırken, sıra arası mesafesinin daha da azaltılması verim artışı sağlamamıştır. İkinci ürün soya üretiminde 70 cm sıra arası mesafesine kıyasla 50, 30 cm ve çift sıra ekimde sırası ile % 24.8 ve 59.5 ve 35.6 oranında verim artışı kaydedilmiştir. Çalışma sonucunda elde edilen bulgular, Doğu Akdeniz bölgesi koşullarında sıra aralığının daraltılması ile ikinci ürün soya tarımında yaşanan verim düşüklüğünün azaltılabileceğini göstermiştir.

Anahtar Sözcükler: Soya, *Glycine max*, ekim zamanı, sıra arası, verim, verim azalışı

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Introduction

Soybean (*Glycine max* L.) has been an important component of crop production in the Mediterranean region of Turkey since 1985, although total planting area has fallen over the years. Because of the long growing season in this region, soybean can be cultivated as a double crop after wheat. Double-cropped soybean production comprises over 90% of soybean production. Compared to full season soybean production, seed yield reduction is a major concern in double-cropped soybean production systems (Boerma and Ashley, 1982; Board and Hall, 1984; Kane et al., 1997; Arslan et al., 2006). Seed yield reduction in late planted soybean was attributed to shorter day length (Board and Hall, 1984; Board and Settimi, 1986), decreased length of time from emergence to R5 (stages according to Fehr and Caviness, 1977), little vegetative growth for optimum yield (Egli et al., 1987), reduced plant height, and reduced height of the lowest pod (Quattara and Weaver, 1995). In a wheat-soybean double-cropping system, seed yield could be increased by cultivar selection and suitable cultural practices.

Low seed yield limits the expansion of double-cropped soybean planting area across the Amik Plain, Hatay, Turkey. Optimization of plant density by narrowing row spacing is the easiest method to maximize double-cropped soybean yield (Boquet et al., 1990; Bowers et al., 2000). This can be achieved by modifying inter- and intra-row spacing. There is no optimum row spacing and plant density for all environmental factors. The effects of plant density and row spacing on achieving suitable vegetative growth and increasing yield have been investigated under many conditions and in many locations throughout the USA (Board and Harville, 1994; Board et al., 1990; Bullock et al., 1998; Egli, 1994). Beatty et al. (1982) reported that April plantings in 18-cm rows with 60 seeds m^{-2} and 48-cm rows with 46 seeds m^{-2} yielded more than May or June plantings at any row spacing. Boquet (1998) found that planting date and cultivar selection were the most important factors for increasing yield, while row spacing was less significant.

Row spacing and seeding recommendations may vary for each growing region and soybean cultivar; thus, many studies have sought to determine optimum row spacing and plant density for soybean under different environmental conditions. Seed yield increases with decreasing row spacing, up to a certain point (Ablett et al., 1984; Oplinger and Philbrook, 1992), and declines when plant density is further decreased (Board and Harville, 1992). Yield responses to narrow-row culture are influenced by geography, crop stress, and planting date (Carter and Boerma, 1979; Taylor, 1980; Boerma and Ashley, 1982; Boquet et al., 1982; Johnson, 1987; Heatherly, 1988); therefore, adjusting row spacing and plant density to increase light interception and reduce evaporation are the most feasible practices to increase seed yield of double-cropped soybean. Double-cropped soybeans reach about half of their normal height due to the delayed planting; therefore, seed yield could be higher in rows ≤ 50 cm apart for double cropping. In the eastern Mediterranean region, however, both full season and double-cropped soybeans are grown with wide row widths (≥ 65 cm) since row spacing is determined by tractor tire size due to required cultivation practices for soybean. Planting double-cropped soybean with the same row width used for full season results in significant yield reductions. Determining suitable row spacing for double cropping will provide for successful second crop soybean production.

This study was designed to determine the effects of row spacing on yield and yield components of full season and double-cropped soybean in the eastern Mediterranean region of Turkey.

Materials and Methods

The experiment was carried out at the Research Farm of Mustafa Kemal University, Hatay, (lat 36°15′N, long 36°30′E) in the eastern Mediterranean region of Turkey, in 2004 and 2005. The soil of the experimental site, which developed from alluvial deposits of river terraces, is typical for the eastern Mediterranean region of Turkey. It is classified as Chromoxerert by USDA Soil Taxonomy (1998) and as Vertisol by FAO/UNESCO (1974), and has relatively high clay content with the predominant clay minerals smectite and kaolinite. The soil of experimental plots was a clay silt loam with pH of 7.6, 1.7% organic matter, 0.13% total nitrogen content, and water holding capacity of 0.34 cm^3. Based on soil analysis and local recommendations, nitrogen and phosphorus fertilizer was applied prior to planting at a rate of 25 kg ha^{-1} each. Recommended practices were used for weed and insect control.

Full season and double-cropped soybean production system experiments were separately conducted and analyzed to eliminate the complication of interpretation of cropping system × row width interactions. Soybean cultivars A3935 (MG III) and S4240 (MG IV), selected for their widespread cultivation in both main and double cropping systems in Turkey, were planted by hand with row widths of 30, 50, and 70 cm, and twin row (50, 25, and 50 cm) in the 2004 and 2005 growing seasons. Seeds were planted with 5-cm intra-row spacing on May 10 and May 8 for full season, and June 13 and June 11 for double-cropped, in 2004 and 2005, respectively. The average plant densities were 66, 40, 28, and 50 plants m^{-2} for 30-, 50-, 70-cm, and twin row width, respectively. The choice of row width depends on such factors as equipment suitability, weed problems, experience, soil conditions, insect pressure, and planting date. Consequently, twin row width was chosen for its suitability for mid- and late season cultivation used for weed and pest control. In both years, seed germination and plant emergence were aided by light sprinkler irrigation. Flood irrigation was applied every 15 days after emergence. Trifluralin was applied at the rate of 1200 g ha^{-1} pre-sowing to control annual weeds. Later, the emergence of weeds was controlled with hoe or rotovator in each year.

Canopy cover (%) was determined with the light stick method described by Adams and Arkin (1977) in which light interception was estimated by the amount of light falling on a white 1-m stick placed diagonally between rows at soil level. For example, if light appeared on 20% of the stick, canopy cover was 80%. Measurements were made within 1 h of solar noon. Ten plants were harvested at maturity from the first and fourth rows of each plot for measuring plant height, lowest pod height, number of branches per plant, number of nodes per plant, number of pods per plant, number of seeds per plant, and seed yield. Measured plant parameters were determined as follows:

1. Branch number $plant^{-1}$ was determined from a 10-plant sample. Pod bearing branches were counted and then divided by 10.
2. The lowest pod height (cm) was determined from a 10-plant sample. The distances between soil surface and the first pods on the plants were measured and then divided by 10.
3. Branch pod number $plant^{-1}$ was determined from a 10-plant sample. The numbers of pod on branches were counted and then divided by 10.
4. Main stem seed number $plant^{-1}$ was determined from the same 10-plant sample. Seeds in the pods of the main stem were counted and then divided by 10.
5. Branch seed number $plant^{-1}$ was determined from the same 10-plant sample used to determine branch pod number. The number of seeds in the pods of branches was counted and then divided by 10.
6. Seed weight (g per 100 seeds) was determined by counting 300 seeds from each yield sample, drying the seeds at 60 ºC in a forced air dryer, weighing the sample, and then dividing the weight by 3.
7. Seed yield (kg ha^{-1}) was determined by harvesting 5 m of 2 central rows at maturity.

The obtained data from each soybean production system were subjected to analysis of variance as a split plot design, using the general linear models procedure in the Statistical Analysis System (SAS Institute, 1996). The factors evaluated were cultivar (main plot) and row width (split-plot). Each treatment was replicated 3 times. Means of measured plant parameters were compared using Fisher's protected least significance difference (LSD) at $P < 0.05$.

Results and Discussion

Total annual precipitation at the study site was 610 mm in 2004, and 680 mm in 2005. No rainfall occurred during the growing period (June-August) in 2004 and 2005. Mean air temperature was about 26 °C during the cropping period (June-October) in both years, while the mean relative humidity was about 51% and 52% during the growing periods in 2004 and 2005, respectively.

Cultivar and row width had significant effects ($P < 0.05$) on all investigated plant parameters in both full season and double-cropped soybean production systems (Table 1). Mean values are presented in the paper for both years combined since year × cultivar × row width interactions were not significant for the evaluated traits.

Table 1. Combined analysis of variance for evaluated traits in full season and double-cropped soybean.

Production system	Source of variation	Plant height	Lowest pod height	Node no.	Branch no.	Main-stem pod no.	Main-stem seed no.	Branch pod no.	Branch seed no.	Seed yield	Seed weight
Full season	Year (Y)	NS	*	**	NS	NS	NS	*	*	NS	NS
	Cultivar (C)	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
	Y X C	NS	*	NS	NS	*	NS	*	*	NS	NS
	Row width (R)	***	***	NS	***	**	***	***	***	***	NS
	Y X R	*	NS	NS	NS	NS	NS	***	***	*	NS
	C X R	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Y X C X R	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Double-cropped	Y	*	NS	NS	NS	*	NS	NS	NS	NS	NS
	C	NS	NS	NS	NS	NS	NS	NS	**	NS	NS
	Y X C	*	NS	NS	*	NS	NS	NS	NS	NS	NS
	R	*	***	*	***	***	***	***	***	***	NS
	Y X R	*	*	NS	***	***	***	NS	NS	NS	NS
	C X R	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Y X C X R	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; NS: Not significant.

Row width significantly affected plant height of both full season and double-cropped soybean. In full season soybean production, the greatest plant height was obtained with a 30-cm row width, while the lowest was obtained with a 50-cm width (Table 2). However, in the double-cropping soybean system, the greatest plant height was obtained in a 30-cm row width, while the lowest was obtained in a 70-cm row width. Regardless of row width, double-cropping reduced plant height. Reduced plant height mainly resulted from shorter day lengths and lower levels of insolation during vegetative and reproductive periods. Higher temperature after planting of double-cropped soybean also contributed to reduced plant height. The combined effects of increased temperature and shortened day length shortened the length of time from emergence to R5; consequently, plants had little vegetative growth for optimum growth. Our results are in good agreement with those reported by Boerma and Ashley (1982), Egli et al. (1987), Egli and Bruening (1992), and Calvino et al. (2002). Possible environmental factors explaining increased plant heights in higher plant densities due to reduced row spacing are light quantity and quality. The stem sections of plants that receive more light usually tend to have slower elongation rates (Garrison and Briggs, 1972). The level of light, as well as the ratio of red/far red light, plays an important role in stem elongation (Holmes and Smith, 1977) and, consequently, on final plant height.

The lowest pod height is an important plant parameter to reduce harvest loss, especially in wheat-soybean double cropping systems. Pods too close to the soil surface increase harvest losses since some combine harvester heads are unable to pick up the lowest pods. Double-cropped soybean is subject to greater harvest losses due to lower pod height (Grabau and Pfeiffer, 1989). In the current study, 2-year averaged lowest pod height values varied between 15.5 and 21.6 cm for full season, and between 8.8 and 16.1 cm for double-cropped soybean (Table 2). Delayed planting shortened the vegetative growth period and reduced the bottom pod set. Therefore, double-cropped soybeans grown in wider row widths have a high potential to have a lower level of pod replacement. Cultivar selection is another factor affecting the lowest pod height. Increasing plant density seems to be a feasible approach to increasing the lowest pod height in double-cropping systems. In the present study, as row spacing decreased from 70 to 30 cm, the lowest pod height increased from 8.8 to 16.1 cm in double-cropped soybean. Our findings showed that the lowest pod height could be increased by narrowing the row width in double-cropped soybean. Palmer and Privette (1992) reported the lowest pod height increases with the use of narrow row width.

Table 2. Effects of row width on canopy cover, plant height, lowest pod height, number of main stem nodes, and seed weight of full season and double-cropped soybean, averaged over cultivars and years.

Row with (cm)	Canopy cover at R3*		Plant height (cm)		Lowest pod height (cm)		Main-stem node number		Seed weight (g)	
	Full season	Double-cropped	Full season	Double-cropped	Full season	Double-cropped	Full season	Double-cropped	Full season	Double-cropped
30	100	80	89.9	68.6	21.6	16.1	17.7	13.1	14.6	11.8
50	75	40	84.0	64.2	17.3	13.9	17.2	13.0	13.2	12.2
70	30	30	87.4	62.9	15.5	8.8	17.3	14.1	13.7	11.9
Twin row (50 25 50)	85	35	89.0	65.9	18.8	13.4	16.9	14.4	14.5	12.0
LSD (0.05)			5.7	3.7	1.4	1.0	0.8	1.1	NS	NS

*Growth stage determined using the scales of Fehr and Caviness (1977), and Egli and Yu (1991)
NS: Not significant

The number of pod bearing nodes (fertile node) is one of the yield-determining factors for soybean production. Mean number of nodes per plant in double-cropped soybean at all row widths was lower than in full season soybean. Fewer fertile nodes per plant appeared to limit yield potential of double-cropped soybean. The average number of main-stem nodes in full season soybean varied between 17.7 and 16.9 nodes plant^{-1}. The highest and the lowest numbers were obtained from 30-cm and twin row spacing, respectively (Table 2). Row spacing also significantly affected node numbers in double-cropped soybean. The lowest number of nodes was obtained from a 50-cm row width (13.0 nodes plant^{-1}), while the highest was obtained from twin row width (14.4 nodes plant^{-1}).

Although the 2-year average seed weight ranged between 14.6 and 13.2 g for full season and between 11.8 and 12.2 g for double-cropped soybean, row spacing did not significantly affect seed weight (Table 2). Mean seed weight values of full season soybean were higher than those of double-cropped soybean. Average mass of an individual seed contributes to final seed yield; however, seed number per plant is the main component determining final yield.

Branch number per plant significantly varied among the row widths. This significant variation resulted from density differences among row widths. Plants grown in low plant density conditions received higher solar radiation compared to denser populations, which caused a greater portion of vegetative dry matter to be allocated into the branches. The average plant density in 70-cm row width was 57.6%, 42.8%, and 44.0% less than 30-, 50-cm, and twin width rows, respectively. Therefore, plants in wider rows were capable of partitioning more resources to increase branch number in response to plant density. Consequently, the ability of soybean to branch was greater in wide rows. Year × row width interaction for branch number was significant in double-cropped soybean. The significant interaction resulted from a 50-cm row width (Figure 1A).

Main-stem pod number significantly varied among row widths in both cropping systems. Main stem pod number was highest in the 70-cm row width and was lowest in the 30-cm row width (Table 3). Main-stem pod number determines the yield potential of soybean. Branch pod number showed a similar response to row width since the highest branch pod number was obtained from 70-cm row width, both in full season and double cropping systems. The yield contributions of branch pods were lower than those of the main-stem pods. Both main stem and branch stem seed number were highly dependent on row width. Increased plant number due to reduced row spacing decreased the mentioned yield components in full season and double-cropped soybean. Year × row width interaction for branch seed number was significant in full season soybean. The significant interaction was observed in 70- and 50-cm row widths. The highest

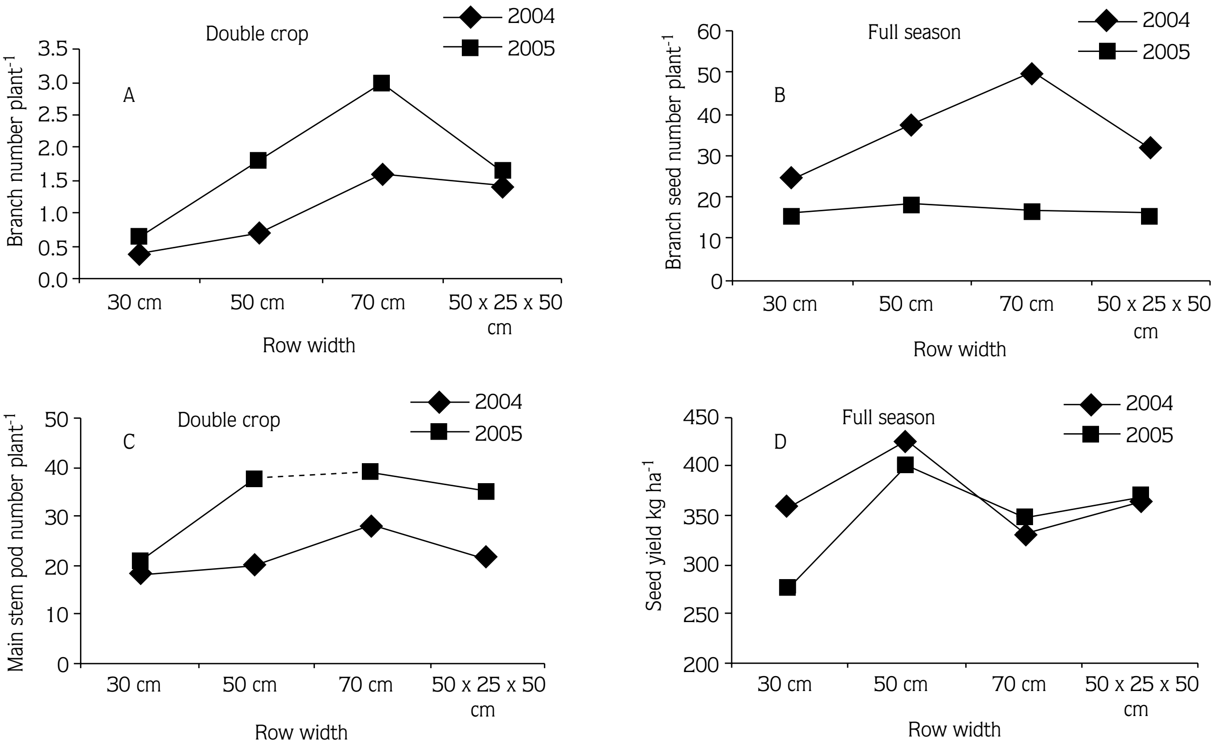

Figure 1. Year × row spacing interactions. A) Branch number per plant in double-cropped soybean. B) Branch seed number per plant in full season soybean. C) Main stem pod number per plant in double-cropped soybean. D) Seed yield in full season soybean.

Table 3. Effects of row width on branch number, number of main stem pods, number of branch pods, number of main stem seeds, and number of branch seeds of full season and double-cropped soybean, averaged over cultivars and years.

Row with (cm)	Branch number plant^{-1}		Main-stem pod number plant^{-1}		Branch pod number plant^{-1}		Mains-stem seed number plant^{-1}		Branch seed number plant^{-1}	
	Full season	Double-cropped	Full season	Double-cropped	Full season	Double-cropped	Full season	Double-cropped	Full season	Double-cropped
30	1.2	0.5	30.8	19.6	8.6	0.7	83.2	39.2	21.5	1.4
50	2.0	1.3	36.7	29.1	10.7	1.3	95.9	61.3	26.8	2.7
70	3.0	2.3	41.7	33.8	13.3	5.2	110.2	77.2	33.2	11.6
Twin row (50 25 50)	2.0	1.5	37.2	28.4	9.5	2.1	96.7	62.4	23.7	4.5
LSD (0.05)	0.4	0.3	4.8	2.8	1.8	1.3	11.6	8.2	4.5	2.9

*Growth stage determined using the scales of Fehr and Caviness (1977), and Egli and Yu (1991), NS: Not significant

branch seed number was obtained with a 70-cm row width in 2004; however, a 50-cm row width had the highest seed number in 2005 (Figure 1B). Branch seed number was much lower in the second year of the study. Year × row width interaction for main stem pod number was significant in double-cropped soybean. The significant interaction was observed in the 50-cm row width since it had the lowest main stem pod number in 2004, while it had a higher main stem pod number in 2005 (Figure 1C).

Of the 2 cultivars used in the study, cultivar A3935 had better yield compared to S4240, at each row width and in both cropping systems. Row spacing significantly affected seed yield of both full season and double-cropped soybean. In the full season cropping system, the highest seed yield was obtained from a 50-cm row width (4142.5 kg ha^{-1}), while the lowest was obtained from a 30-cm row width (3181.7 kg ha^{-1}) (Table 4). Mutual shading caused by high plant density, a large number of leaves per land area, increased lodging due to extensive elongation of the stems, and plant competition appeared to reduce yield in the 30-cm row width. Weber and Fehr (1966), and Devlin et al. (1995) reported similar results. Row width below and above this spacing caused significant yield reduction in full season cropping; however, in double-cropped soybean, the highest seed yield was obtained from the 30-cm row width (3241.5 kg ha^{-1}). No lodging occurred in the 30-cm row width in double-cropped soybean, since mean plant height was 23.7% less than full season soybean. The yield increase associated with the 30-cm row width was attributed to greater light interception and earlier establishment of canopy closure. Our findings were similar to the findings of Cooper (1977), Taylor et al. (1982), Boerma and Ashley (1982), Boquet et al. (1982), Parks et al. (1982), and Board and Harville (1992). Yield increase recorded in narrow row widths for late planted soybeans were also reported (Taylor, 1980; Boerma and Ashley, 1982; Boquet et al., 1982; Johnson, 1987; Heatherly, 1988). Due to ease of cultivation, soybean has been grown in 65- or 70-cm row widths, both in full season and double cropping systems in the Amik Plain and in most other soybean production areas of the eastern Mediterranean region. Our results showed 40.2% and 38.8% yield reductions when double-cropped soybean was grown in 70- and 50-cm row widths, respectively; however, the yield potential of double-cropped soybean in a 30-cm row width was slightly higher (1.9%) than the full season soybean grown with a 70-cm row width. In narrow rows main stem yield is the primary contributor to total yield; therefore, cultivars that have higher main stem yield potential are best suited for narrow row spacing double cropping. Year × row width interaction was significant for seed yield in full season soybean. The significant interaction was the result of a 70-cm row width since the lowest seed yield was obtained from a 70-cm row width in 2004, while the lowest seed yield was obtained from a 30-cm row width in 2005 (Figure 1D).

Table 4. Effects of row width on seed yield of full season and double-cropped soybean averaged over cultivars and years.

Row with (cm)	Seed yield (kg ha^{-1})		Percent yield reduction
	Full season	Double-cropped	
30	318.2	324.2	+1.9
50	414.3	253.7	38.8
70	340.1	203.3	40.2
Twin row (50 25 50)	366.4	275.6	43.9
LSD (0.05)	29.9	13.6	

One of the benefits of higher plant density associated with the use of narrow row width in double-cropped soybean is its contribution to earlier canopy closure, which makes weed control easier by increasing competition between the crop and weeds. Although narrow row spacing gave the best yield results in double-cropped soybean, its application is very limited due to the preclusion of mid- and late season herbicide or insecticide application without damaging some of the crop with tractor tires. Therefore, twin row width is more acceptable to farmers for double cropping, without any additional equipment requirements.

This study illustrated substantial yield increase by decreasing row width from 70 to 50 cm, and no increase on seed yield by further decreasing the row width in full season soybeans. In double cropping, however, yield increased significantly by decreasing the row width from 70 to 50 cm and from 50 to 30 cm. Yield increase in narrow rows was mainly due to increased number of seeds per area rather than increased yield per plant (data not given). This led us to surmise that row spacing of double-cropped soybean is of prime importance for increasing soybean yield in the eastern Mediterranean region. Therefore, optimizing plant density by adjusting row spacing to increase light interception is the most feasible practice for double-cropped soybean. Narrow row soybean production may be a profitable practice with herbicide- and lodging-resistant cultivars. Narrowing the row width for maximum yield makes mid- and late season herbicide or insecticide application difficult without damaging some of the crop with tractor tires. Twin row planting can facilitate the use of required cultivation practices after emergence.

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