African Journal of Agricultural Research Vol. 6(17), pp. 4116-4121, 5 September, 2011
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR11.643
ISSN 1991-637X ©2011 Academic Journals

Full Length Research Paper

Effects of broccoli-crispy salad intercropping on yield and quality under greenhouse conditions

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Accepted 12 August, 2011

This research was conducted to determine the effects of intercropping system of broccoli-crispy salad on the yield, quality characteristics, and land equivalent ratio (LER) by comparing alone broccoli and crispy salad cultivation under greenhouse conditions in the autumn of 2006 and 2007. According to results of this study, the highest values in investigated criteria were found in mono cropping. The highest total yield of broccoli was obtained with 1.67 and 2.46 kg m^{-2} in mono cropping, respectively in the autumn of 2006 and 2007. Similarly, the highest total yield of crispy salad was established with 5.93 and 3.36 kg m^{-2} in mono cropping, respectively in the autumn 2006 and 2007. LER was found to be greater than 1 in broccoli and crispy salad combination for both periods. The highest value of LER was determined to be 1.64% in autumn 2007 period.

Key words: Broccoli, crispy salad, greenhouse, yield, quality, intercropping, colour measurements.

INTRODUCTION

In order to supply fresh vegetable needs, producers should use high quality seeds, implement new techniques in production, and carry out timely cultural appropriate practices (Karatas et al., 2005). As in many other parts of the world, the main objective of agricultural research in Turkey is to increase the net income and quality obtained per unit area (Kizilsimsek and Erol, 2000). In order to increase the yield in vegetable production, the yield obtained per unit area should be increased.

Vegetables are grown in open fields, as well as in protected areas such as low and high tunnels and greenhouses. Greenhouse vegetable cultivation has developed in the coastal towns of the Mediterranean region of Turkey and in the other regions where producers can utilize natural energy resources such as solar energy and geothermal hot water, etc. in winter (Gunay, 2005). Vegetable production in Turkey is about 24 453 000 tons. Production of broccoli has reached 17 300 tons while lettuce, which has been seen observed to be increasing in demand with the increase in consumption habits, has reached 141 000 tons in year (Anonymous, 2009).

Intercropping is the practice of growing two or more crops together so that they interact agronomically (Vandermeer, 1989). In general, intercropping means growing at least two different crops at the same cultivation season and in the same area (Kizilsimsek and Erol, 2000). The increasing concern over agricultural sustainability favors the maintenance of intercropping systems due to its positive effect on soil conservation and improvement of soil fertility (Jarenyama et al., 2000). Additionally, more stable yields of intercropped systems use natural resources more effectively (Horwith, 1985).

There are many studies on intercropping. But the information is very scanty on intercropping with broccoli in vegetable production. In the province of Adana, Turkey, cauliflower and broccoli were used as the main crop and green pea, leek, garlic and onion were used as an intercrop for two years under field conditions. There was no adverse effect in the development and nutrition ratios of main crops and it was determined that the vegetables that were cultivated as the sole crop had greater uptake of nutrients from the soil (Unlu et al., 2008).

Yildirim and Guvenc (2005) reported that cauliflower

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Table 1. Physical and chemical characteristics of tested soil in greenhouse.

Soil properties	Unit	Values	Assessment
pH		7.4	Slightly alkali
Calcareous	%	17.1	Heavily calcareous
Salt	%	0.405	Medium/light salty
Texture	%		Clay loamy
Organic matter	%	1.7	Low/medium
Total N	%	0.241	Good
Available P	kg P_2O_5/ha	1349	Excessive
Exchangeable K	kg K_2O/ha	4127	Excessive
Exchangeable Ca	kg CaO/ha	25295	Excessive
Exchangeable Mg	kg MgO/ha	1432	Sufficient
Available Fe	ppm	5.25	Excessive/sufficient
Available Mn	ppm	37.58	Sufficient
Available Zn	ppm	17.22	Excessive
Available Cu	ppm	7.19	Sufficient

as a main crop was intercropped with cos lettuce, crispy salad, radish, onion and snap bean. Results of this study indicated that different intercropping systems compared to sole cropping did not affect growth characteristics and yield of cauliflower except for radish as the intercrop. Net income increased when cos lettuce, bean, crispy salad or onion was used as the intercrop. Land equivalent ratio (LER) values were always greater than 1 in intercropped systems. In an experiment carried out by Rezende et al. (2010), cucumber was intercropped with crispy salad. Salad seedlings were planted on different planting dates and the salad yield was affected by the planting dates while commercial lettuce quality was affected by the shadow formed by cucumber.

In the organic farming system, the yield of marketable onion was reduced due to the presence of lettuce. Onion and lettuce were intercropped and lettuce development comparable to sole cropping. It has been determined that intercropping systems can be very advantageous to farmer income (de Paula et al., 2010). In a trial conducted by Zárate et al. (2008), LER value was found to be 1.49 when Arracacha was grown with Japanese spring onion and 0.97 when it was grown with parsley.

The objective of this study was to determine the effects of intercropping system of broccoli-crispy salad on the yield, quality characteristics, and land equivalent ratio by comparing alone broccoli and crispy salad cultivation under greenhouse conditions.

MATERIALS AND METHODS

This study was conducted under glasshouse conditions at University of Akdeniz, Faculty of Agriculture (36º 53'N, 30º 39'E), Turkey, during fall growing periods in 2006 and 2007. Broccoli (*Brassica oleracea italica* cv. Chief F1) as main crop was intercropped with crispy salad (*Lactuca sativa* L. var. *crispa* cv. Bohemia). Some soil physical and chemical characteristics of the experimental areas were analyzed in soil samples taken from a depth of 30 cm (Kacar, 1995; Kacar and Kovanci, 1982) (Table 1).

According to the results of the analysis, greenhouse soil is slightly alkaline, heavily calcareous, medium/light salty, clay loamy texture and classified as low/medium in respect of organic substance. Total N concentration of the soil is sufficient, available P, exchangeable K, Ca and available Zn contents excessive, exchangeable Mg, Mn and Cu concentrations are sufficient, available Fe content is excessive/sufficient.

Broccoli and crispy salad seedlings that were cultivated in the peat and pearlite mixture were planted at the same time in the trial field on November 10th in 2006 and 2007. The spacing between the broccoli seedlings (main crop) rows was 50 cm, within-row plant spacing 40 cm, while crispy salad seedlings (intercrop) were also planted as 50 × 40 cm space between the broccoli seedlings. There were 20 plants for each of two vegetables in each plot. On the other hand, crispy salad seedlings were transplanted as 50 × 30 cm spacing (26 plants/plot) while broccoli seedlings were planted as 50 × 40 cm spacing (20 plants/plot) in sole cropping. Each plot was 3.6 m^2 in mono and intercropping. The experiment was conducted with three replications as completely randomized design.

The total yield (kg m^{-2}) was determined by harvesting the main and side crowns in broccoli and the head diameter (cm) was measured in main crowns. For crispy salad, total yield (kg m^{-2}), marketable yield (kg m^{-2}), head height (cm), butt diameter (mm) and leaf number (per plant) were determined. Juices were obtained by squeezing the main crowns of broccoli and leaves of crispy salad using a solid fruit press machine and the vitamin C and citric acid amounts (mg 100 ml^{-1}) were measured. The total soluble solids in broccoli and crispy salad was established as percent by means of a hand refractometer (Model: FG 103/113) and pH values were measured by using a pH meter.

L*, a* and b* values were measured by means of Minolta CR 400 color chroma meter at the fifth leaf starting outwards to inwards in broccoli and crispy salad leaves. C (Chroma) and hue (°) angle values were calculated by the determined a* and b* (Siomas et al., 2002; Madeira et al., 2003). The productivity of intercropping systems was evaluated by the land equivalent ratio (LER). In the calculation of LER, which is defined as the total proportional values pertaining to the productivities of plants by themselves or together with other plants, the equation LER=LA+LB=AI/AS + BI/BS (Rao and Willey, 1983; Vandermeer, 1989) was utilized. Where LA and LB are the individual LERs of two crops A and B, LA is obtained by

Table 2. Effects of cropping systems on L, hue angle and Chroma colour values in the leaves of broccoli and crispy salad.

Cropping system	Broccoli			Crispy salad		
	L	hue°	C	L	hue°	C
2006 Autumn						
Intercropped	36.03	137.41	8.57[a]	65.54[b]	115.42	40.57
Sole Crop	36.12	135.87	9.59[b]	61.91[a]	115.58	40.26
LSD	NS	NS	0.936**	2.9995**	NS	NS
2007 Autumn						
Intercropped	36.10	137.04	8.63	61.27	116.43 a	44.55
Sole crop	36.13	135.17	9.50	60.15	117.12 b	43.85
LSD	NS	NS	NS	NS	0.593**	NS

NS: non significant.**Different letters within columns indicate statistical differences ($p < 0.05$).L = Lightness; C:$\sqrt{(a^2+b^2)}$; hue angle, h = arctg b/a; where 0^o = red-purple, 90^o = yellow, 180^o = bluish-green and 270^o = blue.

Table 3. The effects of cropping systems on total yield, head diameter, vitamin C, citric acid, soluble solids and pH values in broccoli.

Cropping system	Total yield (kg m^{-2})	Head diameter (mm)	Vitamin C (mg 100 ml^{-1})	Citric acid (mg 100 ml^{-1})	Soluble solid (%)	pH
2006 Autumn						
Intercropped	1.33[a]	9.28	89.74[a]	0.50	9.13	6.47[a]
Sole crop	1.67[b]	9.59	99.10[b]	0.50	9.00	6.39[b]
LSD	0.1208*	NS	7.3217*	NS	NS	0.0641**
2007 Autumn						
Intercropped	2.13[a]	15.04	89.32[a]	0.40[a]	5.60[a]	6.18[a]
Sole crop	2.46[b]	15.53	97.65[b]	0.52[b]	6.07[b]	6.29[b]
LSD	0.2387*	NS	6.1376**	0.0217*	0.3069*	0.101**

NS: non significant; *, **different letters within columns indicate statistical differences ($p < 0.01$), ($p < 0.05$), respectively.

dividing the yield of crop A in intercropping (AI) by the yield of the same crop in sole cropping (AS). LB is calculated in the same way. When the LER value is greater than 1, the intercropping is more effective in respect of productivity and land utilization compared to sole cropping. However LER value is less than 1, intercropping is less effective compared to sole cropping (Vandermeer, 1989).

Statistical analysis

GLM of SAS (SAS 2009) was used to determine statistical differences among the treatments, and the least significant test (LSD) at $P \leq 0.05$ and $P \leq 0.01$ was used for comparisons.

RESULTS AND DISCUSSION

The effects of cropping systems for the leaves of broccoli and crispy salad on the L, hue angle and Chroma color values are given in the Table 2.

In the autumn 2006 period, there was no significant difference between L and hue angle values on intercropped and the sole crop broccoli leaves. However, there was a difference for Chroma values, by cropping systems and that the highest Chroma value (9.59) was obtained from broccoli plants that were grown solely. Denoting the brightness or opacity of the color of the leaves, Chroma level was found to be brighter at the ratio of 11.9% for broccoli leaves that were grown solely. It was determined that cropping systems didn't affect L, hue angle and Chroma levels in 2007 autumn period.

When color values were examined for crispy salad in the 2006 autumn period, there was a difference only in L value and the highest value (65.54) was obtained from intercropped. Denoting the darkness or lightness of leaf color numerically, L value was found to be lighter colored (5.86%) in the intercropped. In the following 2007 autumn period, there was only a difference in hue angle and the highest value (117.12) was obtained from sole cropped plants. Hue angle value that shows the leaf color denotes that the crispy salad that was sole cropped was greener by 0.6%.

The effects of cropping systems in broccoli on total yield (kg m^{-2}), head diameter (cm), vitamin C (mg 100 ml^{-1}), citric acid (mg 100 ml^{-1}), soluble solids (%) and pH values are given in Table 3.

Table 4. The effects of cropping systems on vitamin C, citric acid, soluble solids and pH values in crispy salad.

Cropping system	Vitamin C (mg 100 ml^{-1})	Citric acid (mg 100 ml^{-1})	Soluble solid (%)	pH
2006 Autumn				
Intercropped	6.41	0.15	3.40	6.01
Sole Crop	6.96	0.14	3.27	6.03
LSD	NS	NS	NS	NS
2007 Autumn				
Intercropped	5.56^{a}	0.15^{a}	2.27^{a}	5.95
Sole Crop	7.05^{b}	0.18^{b}	2.87^{b}	5.90
LSD	1.2034**	0.0262**	0.4341*	NS

NS: non significant;*, **different letters within columns indicate statistical differences ($p < 0.01$), ($p < 0.05$), respectively.

In both autumn 2006 and 2007 periods, total yield of broccoli was determined to be different at the level of $p < 0.01$ and the highest yield was obtained in sole cropping. In some studies conducted on this subject, similar and different results were obtained. In broccoli: green pea intercropping, broccoli yield did not vary significantly compared to sole cropping, but there was a reduction in yield when intercropped with cauliflower (Santos et al., 2002). In field conditions, the main crops of cauliflower, broccoli and lettuce were intercropped with lettuce, green pea, leek, garlic, onion, green beans and radish, and there was no adverse affect in the development of main crops (Unlu et al., 2008).

In another study that was investigated in field conditions, main crop cabbage was intercropped with cos lettuce, crispy salad, radish, onion and bean. The cabbage that was grown with inter crops, except for radish, was not adversely affected in respect of growth features and yield compared to sole cropping. When cabbage was intercropped with radish, some growth features such as leaf number, head diameter, head height and yield of cabbage were adversely affected (Guvenc and Yildirim, 2006). In another study, it was determined that radish and turnip adversely affected plant growth and reduced yield in cabbage and increased yield in peas and faba beans (Sharma et al., 1988).

In the diameter measurement of main crowns of broccoli, there was no difference between both cropping systems in either period. In another investigation, the best results in head diameters for cauliflower that was intercropped with cos lettuce, crispy salad, radish, onion and dwarf bean were obtained from intercropping with crispy salad while the worst results were with radish (Guvenc and Yildirim, 2005). In the first and third years of the study, when the same vegetables were intercropped with head cabbage, the smallest heads were obtained from the radish combination, while there was no significant difference in the second year (Guvenc and Yildirim, 2006).

From the analysis of vitamin C in the juices of main crowns of broccoli, there were differences between cropping systems both in 2006 ($p < 0.01$) and 2007 ($p < 0.05$). The highest values were obtained from sole cropping higher than 10.43 and 9.33% in the first and second year, respectively. In the analyses of citric acid, there was no difference in 2006 between cropping systems while there was a difference in 2007 ($p < 0.01$) and the highest value was obtained in sole cropping with 0.52 mg 100 ml^{-1}.

There was no difference of soluble solids in the 2006, while there was a difference at $p < 0.01$ level in 2007 and the Brix value was lower in 2007. For Vitamin C and citric acid, the highest Brix value was measured in sole cropping with 6.07%. The most acidic (6.39) juice was tested in sole cropping in 2006 and intercropped in 2007 (6.18) ($p < 0.05$).

The effects of cropping systems in crispy salad on vitamin C (mg 100 ml^{-1}), citric acid (mg 100 ml^{-1}), soluble solid (%) and pH are given in Table 4. In 2006, there was no difference between cropping systems for vitamin C, citric acid, soluble solids and pH quality parameters. In 2007, however, differences couldn't be established between pH measurements. There were differences at $p < 0.01$ for soluble solids and at $p < 0.05$ for vitamin C and citric acid. The highest vitamin C content (7.05 mg 100 ml^{-1}) was obtained from sole cropping of crispy salad and more 26.80% higher than intercropping. The highest citric acid (0.18 mg 100 ml^{-1}) and Brix (2.87%) values were found in sole cropping of crispy salad.

The effects of cropping systems in crispy salad on total (kg m^{-2}) and marketable yield (kg m^{-2}), head height (cm), butt diameter (mm) and number of leaves (per plant) are given in Table 5.

When cropping systems were compared for total and marketable yield in 2006 and 2007 growing periods, differences were significant ($p < 0.01$). In both periods, sole crispy salad cropping had a higher total yield the intercropping of 48.25% (5.93 kg m^{-2}) and 30.2% (3.36 kg m^{-2}) for 2006 and 2007. Similarly, higher marketable yield was achieved for sole crispy salad of 49.3% (5.60 kg m^{-2})

Table 5. The effects of cropping systems on total and marketable yield, head height, butt diameter and number of leaf in crispy salad.

Cropping system	Total yield (kg m^{-2})	Marketable yield (kg m^{-2})	Head height (cm)	Butt diameter (mm)	Leaf number (per plant)
2006 Autumn					
Intercropped	4.00[a]	3.75[a]	29.58	17.96	38.53
Sole crop	5.93[b]	5.60[b]	29.64	18.02	38.47
LSD	0.3421*	0.4482*	NS	NS	NS
2007 Autumn					
Intercropped	2.58 a	1.90[a]	27.67	16.84[a]	62.80
Sole crop	3.36 b	2.47[b]	27.87	20.34[b]	61.22
LSD	0.2663*	0.2475*	NS	1.12*	NS

NS: Non significant; *different letters within columns indicate statistical differences ($p < 0.01$).

Table 6. The effects of cropping systems on land equivalent ratio for total and marketable yield of crispy salad.

Cropping systems	Total yield	Marketable yield
2006 Autumn		
Sole Crop	1.00	1.00
Intercropped	1.48	1.47
2007 Autumn		
Sole Crop	1.00	1.00
Intercropped	1.64	1.64

and 30% (2.47 kg m^{-2}). In a similar study, main crop cauliflower was grown with intercropped crispy salad, radish, onion and dwarf bean in field conditions and it was determined that the yield and developmental features of the cauliflower were not affected by other vegetables except for the radish (Yildirim and Guvenc, 2005). Similarly, main crop eggplant was intercropped with bean, cos lettuce and crispy salad in greenhouse conditions and early and total yield was not different in intercropping compared to mono cropping (Guvenc and Yildirim, 2005). In an experiment that was conducted by Sharaiha and Gliessman (1992), lettuce: faba bean and lettuce: green pea combinations were compared to sole cropping and it was found that yield in lettuce did not vary significantly while it increased in faba bean. In lettuce: green pea combination, however, the yield of pea did not vary compared to sole cropping.

In crispy salad, it was found that there is no difference between cropping systems for head height. In a similar trial, when a lettuce: tomato combination was compared to sole lettuce cropping, it was found that the difference of head height was not significant (Karatas et al., 2005). When cropping systems were compared for lettuce butt diameter, there was no difference in 2006 while the difference in 2007 was significant ($p < 0.01$). The greatest value for lettuce butt diameter was in sole cropping and was 20.78% (30.34 mm) greater than intercropping. In both periods of the study, the number of leaves per plant did not vary according to cropping systems.

The land equivalent ratio of cropping systems (LER) is given in Table 6.

Land equivalent ratio was greater than 1 in the intercropped for both periods. LER for total yield was calculated as 1.48 in 2006 and as 1.47 for marketable yield. LER was higher in 2007 compared to 2006 and reached 1.64 for total and marketable yield. In other words, LER increased by 48% for total yield and by 47% for marketable yield in 2006 while there was a yield increase of 64% for total and marketable yield in 2007.

Similar results were reported in many studies that were conducted on intercropping. Main crops of tomato, cucumber and pepper were grown with crispy salad and lettuce and LER value was found to be greater than 1 and the obtained income was found to be higher than sole cropping (Erdogan and Karatas, 2000). Main crop tomato was intercropped with lettuce, onion, garlic and radish and the highest LER was obtained from a tomato: lettuce combination (1.36) and tomato: onion (1.13) combination. This was followed by a tomato: garlic (1.04) combination (Karatas et al., 2005). In a study where

cauliflower was intercropped with lettuce, crispy salad, radish, onion and dwarf bean. LER value was always found to be greater than 1 in intercropped systems (Yildirim and Guvenc, 2005). In another study, where basil and lettuce were intercropped with tomato under high tunnel conditions, LER value was found to be 1.40 to 1.83. In order to reach the obtained values from intercropping, it was calculated that 40-83% more field is needed when the same crops are monocropped (Jett et al., 2005). Similarly, LER value was always found to be greater than 1 in conducted intercropping research by Sharma et al. (1988), Varghese (2000), Baumann et al. (2001), and Zárate et al. (2008).

Conclusions

When the findings were evaluated, it was seen that intercropping could positively affect both broccoli and lettuce. The highest values in the parameters examined, except for color, were obtained from sole cropping. One of the reasons for this outcome is that the plants that are cropped on the same field at the same time share water and nutrients. Another factor is that solely cropped plants benefit from sunlight more compared to intercropped plants. It was especially observed that broccoli leaves partially shadowed the lettuce.

However, land equivalent ratio can be increased with intercropping applications. The results of this study have shown that LER value in broccoli: lettuce combination was greater than 1 in both periods. LER was determined to be 1.48 for total yield and 1.47 for marketable yield in the 2006 period and 1.64 in both total and marketable yield in the 2007 period.

ACKNOWLEDGEMENTS

The authors are grateful to the Scientific Projects Administration Unit of Akdeniz University for supplying financial support and to Dr. Abram J. Bicksler reviewer from ISDSI (Thailand) for her invaluable comments and suggestions.

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