22 *Egypt. J. Agron*. **Vol. 38**, No.3, pp.413-430(2016)

Additive Intercropping of Wheat, Barley, and Faba Bean with Sugar Beet: Impact on Yield, Quality and Land Use Efficiency

Heba S. A. Salama#, Dina El-S. El-Karamity* and A. I. Nawar
*Crop Science Department, Faculty of Agriculture, Alexandria University, Alexandria and *Ministry of Justice, Egypt.*

TWO FIELD experiments were conducted during the winter seasons of 2013 and 2014, at the Experimental Station of the Faculty of Agriculture, Alexandria University, Alexandria, Egypt. Main aim was to study the effect of intercropping sugar beet with wheat, barley, and faba bean on the yield and some quality attributes of sugar beet and the used companion crops. In addition, to examine the effectiveness of intercropping using the new index – dry matter equivalent ratio (DMER) - in comparison to the traditional land equivalent ratio (LER) that was also investigated. The field trials were laid out in a split plot design with three replications. The three companion crop (wheat, barley, and faba bean) percentages (50, 75, and 100%) were tested in the main plots, while the sub plots were assigned to testing the variations among the seven intercropping patterns. Results revealed that the leaf area (m^2), root yield (ton ha^{-1}), harvest index and sugar yield (ton ha^{-1}) of sugar beet were significantly affected by the interaction between the companion crop species and percentage in both seasons. Pure stands of sugar beet were superior in the four traits (leaf area, root yield, harvest index and sugar yield) followed by sugar beet intercropped with the lowest companion crops percentage. Intercropping with cereals (wheat and barley) resulted in slightly better values for these traits than intercropping with faba bean. Grain yields of wheat and barley and seed yield of faba bean reached the maximum in the pure stands and reduced by reducing the intercropping percentages of the three companion crops. On the contrary, number of pods and 100-seed weight of faba bean followed an opposite trend and reduced by increasing the intercropping percentages. Values of LER were greater than 1.00 in any intercropping system of sugar beet with wheat, barley, and faba bean, indicating an advantage of the intercropping patterns for land usage and yield gain. However, when determining the yield gain in terms of DMER, it was found that only in case of intercropping sugar beet with wheat there was a yield gain (DMER > 1). On the other hand, when intercropping sugar beet with barley and faba bean, there was loss in the overall produced yield (DMER < 1), indicating a severe competition between the sugar beet and the two companion crops. The DMER provided more realistic idea about the effect of intercropping, compared to the LER.

Keywords: Intercropping, Sugar beet, Wheat, Barley, Faba Bean.

#Corresponding author: heba1942001@yahoo.com

Due to growing human population in Egypt, the demand for the different food products is far beyond excess of supplies, which created food security gap. On the other hand, agricultural land for the production of different crops is becoming scarce day by day. Thus, there is an increasing need to maximize the land usage to accelerate productivity gains, which may encourage a rapid closure of the expected food security gap. In terms of land use, intercropping (growing crops in mixed stands) cultivation, as an element of sustainable agriculture is regarded as more productive crop raising system than growing them separately (Andrews & Kassam, 1976; Willey, 1979 and Kumar *et al.,* 2014). Common advantages of different forms of intercropping are intensification of crop production and exploiting more efficiently environments with limiting or potentially limiting growth resources (Papendick *et al.,* 1976 and Trenbath, 1982). In addition to the better use of growth resources (Willey, 1979), other advantages associated with intercropping are better weed management (Litsinger & Moody, 1975 and Rao & Shetty, 1977), and pest control (Pinchinat *et al*., 1975 and Raheja, 1977), assurance against failure of crop (Kumar *et al.,* 2014), reduced fertilizer requirement (Gao *et al.*, 2014) and better soil fertility and soil conservation (Li *et al*., 2001 , 2011 and Zhang & Li, 2003) than sole cropping.

The choice of the component crops in the intercropping cultivation is crucial. Under intercropping system, attention should be given to the crops that can grow together with minimal competition and maximum profit (Aboukhadra *et al*., 2013a and Abdel Motagally & Metwally, 2014). Among the important crops in the Egyptian agricultural system are the sugar crops. Area of sugar beet had increased significantly, by approximately 25.6%, during last 35 years in Egypt. Consequently, the contribution of sugar beet to sugar production in Egypt largely increased to reach 35.5 % of the total sugar production in 2012 (Abdel Motagally & Metwally, 2014). Increasing the sugar yield per unit area of sugar crops is, thus, a national demand and could be achieved by adopting suitable cultural practices and applying intercropping. An agronomic advantage had been demonstrated when sugar beet was intercropped with other winter crops like wheat (Attia *et al*., 2007 and Aboukhadra *et al*., 2013b), barley (Khedr & Nemeat-Alla, 2006), and faba bean (Farghally *et al*., 2003 and Gadallah *et al.,* 2006). All the previously mentioned studies used the land equivalent ratio (LER) developed by De Wit (1960) and De Wit & Van den Bergh (1965) to determine the effectiveness of intercropping relative to sole cropping. However, in explaining the competitive relationships in the intercropping systems, Willey (1979) stated that the LER is the best index used in case of the replacement intercropping series. This is a series of treatments which contains the pure stands of each species and some mixtures formed by replacing given proportions of one species with equivalent proportions of the other. On the other hand, using the LER as an indicator of the effectiveness of intercropping in an additive intercropping series, like the current study, would lead to overestimating the final gain. In the additive intercropping series, one main species is grown with its entire density and the other species is additionally intercropped with various densities, compared to the pure stands of each species. In this model, it is desired to attain a specific yield of the main species and yield of the other additional species is a bonus. The use of LER, with such a model, would result in a biased estimate of yield gain towards the intercropping treatments. Therefore, alternative indices were developed to fairly determine effectiveness of intercropping compared to pure stands on an unbiased basis, such as the effective land equivalent ratio (ELER) modified by Mead & Willey (1980), area time equivalent ratio (ATER) proposed by Hiebsch (1980) and McCollum (1982), land equivalent coefficient (LEC) suggested by Adetiloye & Ezedinma (1983), and the staple land equivalent ratio (SLER) developed by Reddy & Chetty (1984). Among the newly developed indices is the dry matter equivalent ratio (DMER), which utilizes the dry matter yield instead of the fresh yield per unit area to compare the expected gain from the intercropping approach to the gain obtained from the sole cropping (Shaalan *et al.,* 2015). This index would provide a realistic estimate to the yield gain of the additive intercropping system compared to the sole crops. Therefore, the present investigation was planned to study the impact of intercropping sugar beet with cereal crops, *viz.* wheat and barley, and legume crop *i.e.*, faba bean on the yield and quality attributes of sugar beet and companion crops, as well as to examine the effectiveness of intercropping using the new index (DMER) in comparison to the traditional land equivalent ratio (LER).

Materials and Methods

Experimental site, design and treatments

Two field experiments were conducted during the winter season of two successive years (2013-2014) at the Experimental Station of the Faculty of Agriculture, Alexandria University, Alexandria, Egypt. A split plot design, with three replications, was used to evaluate seven intercropping patterns under three companion crop percentages. Main plots were assigned to test the three percentages *i.e.* 50, 75 and 100 % of the three companion crops; namely, wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and faba bean (*Vicia faba* L.), intercropped with sugar beet (*Beta vulgaris* L.) as a main crop. The seven intercropping patterns, assigned to the subplots, were: 1. sugar beet + wheat; 2. sugar beet + barley; 3. sugar beet + faba bean; 4. pure sugar beet; 5. pure wheat; 6. pure barley, and 7. pure faba bean.

Management and sampling

The sub plots area included two wide beds (1.20 x 3 m) for the intercropping treatments, and either four ridges (0.6 x 3 m) for pure stands of sugar beet and faba bean, or the equivalent flat area for pure wheat and barley stands.

The main crop, sugar beet, was planted at the recommended seeding rate (10 kg ha^{-1}) by the Egyptian Ministry of Agriculture, for both the intercropping treatments and pure stands. In the intercropping treatments it was sown in hills (20 cm apart) on both sides of the prepared seed bed, and later thinned to one plant per hill. However, in the pure stands it was sown also in hills (20 cm apart) but on only one side of the ridge. Sugar beet plots were sprayed with borax (11.3% Boron) one month before harvesting (1.2 kg ha^{-1}).

Concerning the monocot intercrops; wheat and barley, in the intercropping treatments, both were hand drilled in rows (30 cm apart) on top of the seed bed for the three tested plant densities. The used seeding rate was 120 and 100 kg ha^{-1} for wheat and barley, respectively. Similarly, the pure stands of both crops were also hand drilled in rows (30 apart) to obtain the full plant density (100%). On the other hand, the sole dicot intercrop (faba bean) was sown in rows in hills (20 cm apart) on top of the seed bed, and later thinned to two plants per hill. The three tested plant densities were obtained by manipulating the number of rows. In its pure stand, faba bean was sown in hills (20 cm apart) on both sides of the ridge and later thinned to two plants per hill.

All the tested crops were sown and harvested at the same date during the two growing seasons. All experimental plots were treated similarly, *i.e.* fertilized and irrigated at the same intervals in each growing season. Broadleaf and grass weeds were hand-removed from plots and 239 g Lannate® insecticide (S-methyl-N-[(methylcarbamoyl)oxy]thioacetimidate) was dissolved in 477 Liter water per hectare and sprayed with the knapsack twenty days after sowing to protect the crop against leaf worms. All plots were manually harvested.

Investigated parameters

Yield and quality analyses:

Sugar beet samples were randomly taken in a form of three guarded plants from each subplot to measure both the total leaf area (m^2) and the total soluble solids (TSS) which was measured using the refractometer. While, the biological and root yields (ton ha^{-1}) were determined for the whole plot. The harvest index, sucrose percentage, and sugar yield were later estimated using the following equations:

Sucrose (%) = TSS x 0.7 (Winner, 1982)

Sugar yield (ton ha^{-1}) = root yield (ton ha^{-1}) x sucrose %

Harvest index (%) = root yield / biological yield

Only grain yield (ton ha^{-1}) was investigated in case of wheat and barley intercrops and sole stands. In addition, for faba bean, seed yield (ton ha^{-1}), number of pods per plant and 100-seed weight (g) were, also, investigated.

Land use efficiency and yield advantages

Land equivalent ratio (LER): Determined after De Wit (1960), and De Wit & Van Den Bergh (1965), as the sum of the fractions of the yield (ton ha^{-1}) of intercrops relative to their sole crop yields.

$$LER = \frac{Yab}{Yaa} + \frac{Yba}{Ybb}$$

where, Yab = mixture yield of species "a" (in combination with species "b"), Yaa = pure stand yield of species "a", Yba = mixture yield of species "b" (in combination with species "a"), Ybb = pure stand yield of species "b".

Dry matter equivalent ratio (DMER): Determined as the sum of the dry yield of the main crop and the companion crops relative to the dry matter yield of the sole main crop.

$$DMER = \frac{DMYSB_C + DMYCC}{DMYSB_S}$$

where: $DMYSB_C$ = Dry matter yield of sugar beet at each companion crop percentage, $DMYSB_S$ = Dry matter yield of pure sugar beet, and DMYCC = Dry matter yield of the companion crop.

Statistical analysis

Data were tested for significance using Proc Mixed of SAS 9.1 (SAS Institute, Inc., 2000). Only replicates were considered random. The studied parameters (*P*) then were analysed according to the following model:

$$P_{ijk} = \mu + F_i + C_j + R_k + e_{ijk} + (F\ x\ C)_{ij} + s_{ijk}$$

where µis the overall mean, F_i is the forage treatment effect (i = 1,2,3,4,5,6,7), C_j is the companion crop percentage effect (j = 1,2,3), R_k is the replication (k = 1,2,3), e_{ijk} is the effect of main plot's error, $(F\ x\ D)_{ij}$ is the effect of the interaction between the forage treatment and plant density, and s_{ijk} is the effect of sub-plot's error.

Data of each growing season are separately presented and discussed. Significance was declared at $P< 0.05$ and means were compared with the least significant difference (L.S.D) procedure.

Results and Discussion

Yield and quality parameters

Sugar beet

Analysis of variance of yield and quality parameters for the main and companion crops revealed that the two way interaction between the companion crop species and percentage significantly affected the leaf area (m^2), root yield (ton ha^{-1}), harvest index, and sugar yield (ton ha^{-1}) of sugar beet, in both growing seasons. However, the sucrose percentage was significantly influenced by the companion crop percentage only in the 2^{nd} growing season.

Means presented in Table 1, showed that the sugar beet tended to have the highest significant leaf area (m^2) when intercropped with wheat under the three tested companion crop percentages in both growing seasons. Obviously, the leaf area of the pure sugar beet stands was significantly superior to that intercropped with the three companion crops, amounting to 1.66 and 2.16 m^2 for 2013 and 2014, respectively. However, with each companion crop species the leaf area of sugar beet significantly increased with decreasing the companion crop percentage in both growing seasons. Similar result was observed by Aboukhadra *et al*. (2013a) when sugar beet was intercropped with faba bean at variable row spacing.

The same trend was also obtained with the root yield (ton ha^{-1}) of the main crop (Table 1). The sugar beet produced the significantly higher root yield when intercropped with wheat under the 50 and 100 companion crop percentages, while under the 75 %, the root yield of sugar beet was significantly superior when grown with wheat and barley compared to that grown with faba bean, for both growing seasons. Similar to the leaf area, the highest significant sugar beet root yield was achieved from the pure stands, amounting to 49.90 and 50.98 ton ha^{-1} in 2013 and 2014, respectively. Meanwhile, the lowest percentage of the companion crops was accompanied by highest amount of sugar beet root yield. The difference between the sugar beet root yield produced from 50 and 100 companion crop percentages amounted in the first growing season to 11.5, 12.3, and 10.0 ton ha^{-1} for wheat, barley and faba bean, respectively. While in the second growing season the difference amounted to 11.9, 12.3, and 10.0 ton ha^{-1} for the three respective companion crops. The effect of intercropping on the root yield of sugar beet, mainly depends on the nature and growth habit of the companion crop. Abdel Motagally & Metwally (2014) concluded that root yield of sugar beet was not significantly affected when intercropped with onion. However, similar to the current study, it was reported that the maximum significant root yield of sugar beet was achieved for pure stands followed by the lowest intercropping density of the companion crop, when sugar beet was intercropped with wheat (Aboukhadra *et al.*, 2013b), barley (Khedr & NemeatAlla, 2006), and faba bean (Mohammed *et al*., 2005). Researchers attributed this effect to the even arrangement of sugar beet and companion crop plants which resulted in greater exposure of the plant canopy to the solar radiation. This better effect of the solar radiation was reflected on better root growth and higher root yield. On the other hand, the reduction of sugar beet root yield with increasing the companion crop's density may be due to the shading effect, in addition to the high competition for light which negatively affect the rate of photosynthesis and, thus, reduces the root yield.

Means of the sugar beet harvest index presented in Table 2 revealed that, sugar beet had the highest significant harvest index when planted with wheat and barley, under the three companion crop percentages in both seasons. Comparing the effect of the companion crops and the sugar beet pure stands on the harvest index of the main crop under each companion crop percentage revealed a different attitude than what was previously observed for the other tested parameters. This was clear in 2013 season, when sugar beet was accompanied with wheat, recording highest significant harvest index (75.71) under the highest companion crop percentage (100%). While, when accompanied with barley, the highest harvest index (76.30) was obtained under 75 companion crop percentage. Meanwhile, intercropping faba bean with sugar beet, the harvest index of sugar beet pure stands was the highest and significant (73.62) followed by that under the lowest companion crop percentage (71.30). Furthermore, in 2014, no significant variations in the harvest index were detected among the three tested companion crop percentages and sugar beet pure stands when sugar beet was intercropped with wheat and barley. However, similar to 2013, when planting faba bean as a companion crop to sugar beet, the sugar beet pure stands and the lowest companion crop percentage (50%) had the highest significant harvest index.

Intercropping sugar beet with faba bean under each companion crop percentage resulted in producing the lowest significant sugar yield (ton ha^{-1}) in both growing seasons (Table 2) compared with wheat and barley as companion crops. However, with each companion crop the sugar beet pure stands produced the significantly higher sugar yield. Obviously, the sugar yield of sugar beet decreased with increasing the companion crop percentage in case of the three companion crops in both growing seasons. The sugar beet pure stands produced 7.34 and 7.41 ton sugar yield ha^{-1} in 2013 and 2014, respectively. This amount was around 1.5 to 2.9 tons higher than that produced with the lowest companion crop percentage. Amer *et al.* (1997), Abo Mostafa *et al.* (2012), and Aboukhadra *et al.* (2013a) also reported highest values for sugar beet root and sugar yields with decreased densities of different companion crops. They attributed this reduction in sugar beet traits to the increased intra- and inter-crop competition between the sugar beet, as a main crop, and the high densities of the companion crops. However, the sucrose % of the main crop, sugar beet, was significantly affected by the companion crop percentage only in the second growing season (2014). Table 3 revealed that the significantly higher sucrose percentage (14.55 %) was produced by sole sugar beet, as expected, while it significantly decreased with increasing the percentage of the companion crop. It reached the minimum value (11.46 %) when sugar beet was planted with a 100% companion crop. Similar results were obtained by Abdel Motagally & Metwally (2014), who found that in intercropping sugar beet with onion, the sugar % decreased by increasing the density of the companion crop. Moreover, Aboukhadra *et al.* (2013b) and Amer *et al.* (1997) reported an increase in sugar yield and sucrose % of sugar beet intercropped with low densities of wheat and faba bean, respectively. They attributed such increase, to the considerable increase in root yield and, thus the amount of sugar extracted from the roots. When studying the effect of intercropping wheat on sugar cane, Ahmed *et al.* (2013) reported a decrease in the sugar content of sugar cane with increasing the companion crop’s density. It is, thus, obvious that the sugar content of the different sugar crops decreases when intercropped with high densities of companion crops.

TABLE 1. Means of leaf area (m^2) and root yield (ton ha^{-1}) of sugar beet as affected by the interaction between the companion crop species and percentage in 2013 and 2014 growing seasons.

Companion crop (%)	Leaf area (m^2)						Root yield (ton ha^{-1})					
	Companion crop species						Companion crop species					
	2013			2014			2013			2014		
	Wheat	Barley	Faba bean	Wheat	Barley	Faba bean	Wheat	Barley	Faba bean	Wheat	Barley	Faba bean
50	1.28aB†	0.91 bB	0.83bB	1.84aB	1.69bB	1.42cB	39.92aB	37.43bB	32.42cB	41.19aB	38.37bB	33.38cB
75	1.03aBC	0.78bBC	0.75bBC	1.56aC	1.43bBC	1.33cB	31.03aC	29.94aC	24.95bC	32.22aC	31.12aC	26.07bC
100	0.79aC	0.63bC	0.64bC	1.31aD	1.15bC	1.11bB	28.45aD	25.12bD	22.46cD	29.26aD	26.08bD	23.37cD
Pure	1.66 A	1.66 A	1.66 A	2.16 A	2.16 A	2.16 A	49.90 A	49.90 A	49.90 A	50.98 A	50.98 A	50.98 A

†For each parameter and year, means followed by the same small letter(s) within the same row or the same capital letter(s) within the same column are not significantly different according to the LSD test at 0.05 level of probability.

TABLE 2. Means of harvest index and sugar yield (ton ha^{-1}) of sugar beet as affected by the interaction between the companion crop species and percentage in 2013 and 2014 growing seasons.

Companion crop (%)	Harvest index						Sugar yield (ton ha^{-1})					
	Companion crop species						Companion crop species					
	2013			2014			2013			2014		
	Wheat	Barley	Faba bean	Wheat	Barley	Faba bean	Wheat	Barley	Faba bean	Wheat	Barley	Faba bean
50	74.36aB†	74.61aB	71.30bB	74.05aA	74.37aA	71.19bAB	5.89aB	5.57aB	4.52bB	5.64aB	5.17bB	4.47cB
75	74.15bB	76.30aA	67.86cD	72.75aA	74.94aA	69.57bBC	4.29aC	4.19aC	3.43bC	4.14aC	3.90aC	3.35cC
100	75.71aA	75.20aB	69.16bC	74.28aA	73.66aA	68.12bC	4.03aC	3.39bD	3.16bC	3.36aD	3.02bD	2.66cD
Pure	73.62 B	73.62 C	73.62 A	72.68 A	72.68 A	72.68 A	7.34 A	7.34 A	7.34 A	7.41 A	7.41 A	7.41 A

†For each parameter and year, means followed by the same small letter(s) within the same row or the same capital letter(s) within the same column are not significantly different according to the LSD test at 0.05 level of probability.

TABLE 3. Means of sucrose (%) of sugar beet,grain yield (ton ha^{-1}) of wheat and barley intercrops, and seed yield (ton ha^{-1}), number of pods (plant), and 100-seed weight (g) of faba bean as affected by the companion crop percentage in 2013 and 2014 growing seasons.

Companion crop (%)	Main crop		Companion crop species									
	Sugar beat		Wheat		Barley		Faba bean					
	sucrose		Grain yield		Grain yield		Seed yield		Number of pods		100-seed weight	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
50	14.53 A†	13.52 B	3.31 D	2.49 D	1.83 D	1.87 D	1.97 C	1.77 D	24.73 A	22.59 A	127.07 A	129.47 AB
75	13.87 A	12.75 B	4.97 C	3.74 C	2.74 C	2.80 C	2.95 C	2.64 C	19.13 BC	17.04 BC	124.77 A	125.53 BC
100	13.92 A	11.46 C	6.62 B	4.98 B	3.66 B	3.73 B	3.39 B	3.53 B	18.00 C	15.67 C	123.27 A	123.07 C
Pure	14.70 A	14.55 A	7.10 A	6.44 A	4.63 A	4.45 A	4.34 A	4.01 A	20.29 B	18.18 B	128.80 A	131.00 A

†Means followed by the same letter(s) within the same column are not significantly different according to the LSD test at 0.05 level of probability.

Companion crops

Grain yield (ton ha^{-1}) of wheat and barley, in addition to seed yield (ton ha^{-1}), number of pods per plant and 100-seed weight (g) of faba bean were tested for significance using the analysis of variance. Results revealed that, for both growing seasons, the previous parameters where significantly variable among the tested companion crop percentages, except for faba bean 100-seed weight that was significantly variable only in 2014. Means in Table 3 demonstrate that wheat and barley produced the highest significant grain yields in their pure stands amounting to 6.8 and 4.5 ton ha^{-1} as an average of both growing seasons for wheat and barley, respectively. In the intercropping system with sugar beet, the grain yield of both cereal crops increased by increasing their percentages, thus, the lowest grain yield was achieved in case of 50 companion crop percentage that reached 2.90 and 1.85 ton ha^{-1} as an average of both growing seasons for the two respective crops. Similar trend was observed for faba bean seed yield (ton ha^{-1}) in 2013 and 2014. Furthermore, the number of pods per faba bean plant was the maximum when intercropping 50 % faba bean with sugar beet. In this case the number of pods reached 24.73 and 22.59 pods plant^{-1} in 2013 and 2014, respectively. The lowest significant number of pods plant^{-1} was recorded in case of 100 companion crop percentage, which reached 18.00 and 15.67 pods plant^{-1} for the two respective seasons. Similar to the number of pods per plant, the maximum faba bean 100-seed weight was obtained for the faba bean pure stands (131.00 g) and when intercropped with the lowest percentage (129.47 g) in 2014. On the other hand, the lowest 100-seed weight (123.07 g) was achieved from the 100 companion crop percentage. Higher grain/seed yields of mono cropped wheat, barley and faba bean relative to intercropping treatments may be due to the less disturbance in the habitat in homogeneous environment of mono cropping systems (Grime, 1977). Similar findings to the current study were also reported by other researchers (Farghally *et al.,* 2003; Mohammed *et al.,* 2005 and Abo Mostafa *et al.,* 2012), who reported that some faba bean yield components like seed yield per plant, number of seeds per pod and 100-seed weight were decreased with increasing the percentage of faba bean intercropped with sugar beet. They attributed this result to the increased above and below ground competition in the intercropping system, where the dense sowing would lead to severe competition among plants for water, light and nutrients, resulting in the production of less vigorous plants (Aboukhadra *et al.,* 2013a). On the other hand, similar to the current results, the seed yield of faba bean (ton ha^{-1}) followed an opposite trend to the yield components and increased with increasing the percentage of faba bean in the intercropping system. Moreover, when intercropping sugar beet with wheat, Aboukhadra *et al.* (2013b) found that wheat grain yield significantly increased with increasing the companion crop's density. They explained the increase in wheat grain yield with dense sowing to the increase in some yield components like number of spikes per m^2 and 100-grain weight. Similar observations were reported by Khedr & NemeatAlla (2006) in barley-sugar beet intercropping system.

Means of the sugar beet root dry matter yield as affected by the companion crop species and percentages, presented in Table 4, followed the same trend as like fresh root yield (Table 1). Similarly, the variations of the dry matter yields of wheat and barley grains, as well as faba bean seeds under varying companion crop percentages (Table 4) were similar to the variations in the grain and seed yields presented in Table 3. The dry matter yields in Table 4 were mainly determined to be used in calculating the dry matter equivalent ratio (DMER).

Land use efficiency and yield advantage

Data of LER, presented in Table 5, indicated that the interaction between the companion crop species and percentage had a positive impact on the land usage, in both growing seasons. Generally intercropping sugar beet accompanied with any of the three tested companion crops under the three percentages tended to in increase the land usage. The highest LER was achieved with the highest companion crop percentage (100 %) for both years. In 2013, the LER values reached 1.50, 1.29, and 1.36 with 100 % wheat, barley and faba bean companion crop, respectively. In 2014, the values of the three respective companion crops were 1.34, 1.35, and 1.34. In line with the results of the current study, Abdel Motagally & Metwally (2014), and Aboukhadra *et al.* (2013b) also espoused that LER values were greater than 1.00 in any intercropping system of sugar beet, with onion and wheat, respectively. These results were, also, in agreement with those reported by Abou Mostafa *et al.* (2012) and Abd El-All (2002) when intercropping sugar beet with faba bean, and Ahmed *et al.* (2013) when intercropping sugar cane with wheat. Moreover, intercropping of sugar beet with barley, Khedr & Nemeat-Alla (2006) reported that the LER increased with the dense sowing of barley over the monocultures of both crops.Moreover, in their investigation on intercropping sugar beet with onion, faba bean, and chickpea, Farghaly *et al.* (2003) found that the lowest values of LER were achieved in case of intercropping sugar beet with faba bean, compared to the other two companion crops, as observed in the current study. This might be partially attributed to the deep root system that characterizes sugar beet and faba bean, which increase the under-ground competition between the two crops on soil moisture and nutrients. Unlike the different root systems of sugar beet and cereal crops (wheat and barley), which allow the crops in the intercropping system to use the soil moisture and nutrients at different depths and, thus, reduce the under-ground competition between them and, consequently, reflect on better yield advantage (Vandermeer, 1992).

Furthermore, under the three companion crop percentages, sugar beet produced higher yields (La) when intercropped with wheat followed by barley then faba bean, in both seasons (Table 5). Obviously, the sugar beet yield increased with decreasing the companion crop percentage.

TABLE 4. Mans of root dry matter yield (ton ha^{-1}) of sugar beet as affected by the interaction between the companion crop species and percentage, and means of the grain/seed dry matter yield (ton ha^{-1}) of wheat, barley, and faba bean companion crops as affected by the companion crop percentage in 2013 and 2014 growing seasons.

Companion crop (%)	Root dry matter yield (ton ha^{-1})						Grain/seed dry matter yield (ton ha^{-1})					
	Companion crop species						Companion crop species					
	2013			2014			2013			2014		
	Wheat	Barley	Faba bean	Wheat	Barley	Faba bean	Wheat	Barley	Faba bean	Wheat	Barley	Faba bean
50	7.98aB†	7.49bB	6.48cB	8.24aB	7.67bB	6.68cB	2.81 D	1.56 D	1.67 C	2.52 D	1.59 D	1.50 D
75	6.00aC	5.69aC	4.74bC	6.62aC	5.91aC	4.95bC	4.52 C	2.33 C	2.51 C	3.88 C	2.38 C	2.24 C
100	5.12aD	4.52bD	4.04cD	5.77aD	4.69bD	4.21cD	5.63 B	3.11 B	2.88 B	4.73B	3.17 B	3.00 B
Pure	10.45 A	10.45 A	10.45 A	10.51 A	10.51 A	10.51 A	6.04 A	3.94 A	3.69 A	5.47 A	3.78 A	3.41 A

†For each parameter and year, means followed by the same small letter(s) within the same row or the same capital letter(s) within the same column are not significantly different according to the LSD test at 0.05 level of probability.

TABLE 5.Rlative yield of sugar beet (La), companion crop (Lb), land equivalent ratio (LER), and dry matter equivalent ratio (DMER) at different companion crop percentages in 2013 and 2014 growing seasons.

Companion crop (%)	Companion crop species											
	Wheat				Barley				Faba bean			
	La	Lb	LER	DMER	La	Lb	LER	DMER	La	Lb	LER	DMER
Growing season 2013												
50	0.80	0.47	**1.27**	**1.03**	0.75	0.40	**1.15**	**0.87**	0.65	0.45	**1.10**	**0.78**
75	0.62	0.70	**1.32**	**1.01**	0.60	0.59	**1.19**	**0.77**	0.50	0.68	**1.18**	**0.69**
100	0.57	0.93	**1.50**	**1.02**	0.50	0.79	**1.29**	**0.73**	0.45	0.91	**1.36**	**0.66**
Growing season 2014												
50	0.81	0.39	**1.20**	**1.01**	0.75	0.42	**1.17**	**0.88**	0.65	0.44	**1.09**	**0.78**
75	0.63	0.58	**1.21**	**1.01**	0.61	0.63	**1.24**	**0.79**	0.51	0.66	**1.17**	**0.68**
100	0.57	0.77	**1.34**	**1.01**	0.51	0.84	**1.35**	**0.75**	0.46	0.88	**1.34**	**0.69**

However, when determining the yield gain in terms of DMER (Table 5), it was found that only in case of intercropping sugar beet with wheat there was a slight yield gain (DMER > 1). On the other hand, when intercropping sugar beet with barley and faba bean, there was loss in the overall produced yield (DMER < 1), indicating a severe competition between the sugar beet and the two companion crops. Noticeably, the loss in the overall gain was more in case of faba bean than barley. As previously mentioned, this might be because the faba bean root system severely competes with the sugar beet root system for soil moisture, nutrients and space, than the cereal crops' root systems do.

Comparing the values of the LER to those of the DMER, reveals that all the values of DMER were lower than the LER. This confirms the assumption that the LER was not the most accurate index to be used to determine the expected gain in case of an additive intercropping model. It resulted in overestimating the gain (all LER values were greater than 1). However, the DMER provided a more realistic idea about the effect of intercropping compared to the grown sole crops.

*Acknowledgement:*The authors are grateful to Prof. Abdel-Aziz A.Shalaby, Department of Crop Science, Faculty of Agriculture, Alexandria University, for revising the written manuscript and for his valuable comments and suggestions.

References

Abdel Motagally, F.M.F. and Metwally, A.K. (2014) Maximizing productivity by intercropping onion on sugar beet. *Asian Journal of Crop Science,* **6**, 226-235.

Abd El-All, A.M. (2002) Weed control treatments for different intercropped systems of sugar beet and faba bean. *Journal of Agricultural Sciences. Mansoura Univ.* **27**, 8081-8092.

Aboukhadra, S.H., Badawy, S.A., Toaima, S.E.A. and El-Shireef, D.E.E. (2013a) Effect of intercropping system of faba bean with sugar beet on their productivity and land use. *Minufiya Journal of Agricultural Research,* **38**,1501-1518.

Aboukhadra, S.H., Badawy, S.A., Salah, E.A.T. and El-Shireef, D.E.E. (2013b) Effect of intercropping system of wheat with sugar beet on their productivity and land use. *Journal of Agricultural Research, Kafr El-Sheikh Univ.* **39**, 37-54.

Abou Mostafa, R.A.I., El-Abbas, El., Rabie, E.M. and Aboshady, Kh.A. (2012) Agronomic and economic evaluation for some patterns of intercropping faba bean with sugar beet under two sowing dates. *Journal of Agricultural Research, Kafrelsheikh Univ.* **38**, 443-457.

Adetiloye, P.O., and Ezedinma, F.O.C. (1983) A land equivalent coefficient (LEC) concept for the evaluation of competitive and productive interactions in simple to complex crop mixtures. *Ecological Modelling,* **19**, 27-39.

Ahmed, A.M., Ahmed, N.R. and Khalil, S.R.A. (2013) Effect of intercropping wheat on productivity and quality of some promising sugar cane cultivars (Autumn plant). *Minia Journal of Agricultural Research and Development,* **33**, 597-623.

Amer, M.I., Radi, M.M., Ali, K.A. and Zalat, S.S. (1997) Intercropping faba bean (*Vicia faba* L.) cultivars to three sowing dates under different plant densities in North Delta. *Journal of Agricultural Research, Tanta Univ.* **18**, 591-599.

Andrews, D.J. and Kassam, A.H. (1976) *"In Multiple Cropping"* (R.I. Papendick, P.A. Sanchez, and G.B. Triplett, Ed.)pp. 1-10. Spec. Pub. No. 27 American Society of Agronomy. Madison, Wisconsin.

Attia, A.N.E., Said, E.M., Ghonima, M.H. and Ibrahim, M.E.M. (2007) Impact of nitrogen levels on growth and yield of sugar beet intercropped with faba bean and wheat. *Journal of Agricultural Sciences. Mansoura Univ.* **32**, 779-792.

De Wit, C.T. (1960) On Competition. VerslagLandbouwkundigeOnderzoek No. 66:1-82.

De Wit, C.T. and Van Den Bergh, J.P. (1965) Competition among herbage plants. *Netherlands Journal of Agricultural Science*, **13**, 212-221.

Farghaly, B.S., Zohry, A.A. and Bassal, A.A. (2003) Crops management for intercropping sugar beet with some essential crops to maximize area unit productivity. *Journal of Agricultural Sciences. Mansoura Univ.* **28**, 5183-5199.

Gadallah, R.E., Abdel-Galil, A.M. and Nawar, F.R. (2006) Maximizing productivity by intercropping some winter crops on sugar beet. *Journal of Agricultural Sciences. Mansoura Univ.* **31**, 4957-4968.

Gao, Y., Wu, P.T., Zhao, X.N. and Wang, Z.K. (2014) Growth, yield, and nitrogen use in the wheat/maize intercropping system in an arid region in north western China. *Field Crop Research*, **167**, 19-30.

Grime, J.P.L. (1977) Evidence for the existence of three primary strategies plants and its relevance to ecological and evolutionary theory. *The American Naturalist,* **111**, 1169-1174.

Hiebsch, C.K. (1980) Principles of intercropping: Effects of nitrogen fertilization, plant population and crop duration on equivalency ratios in intercrop versus monoculture comparisons. *PhD Thesis,* North Carolina State Univ. Raleigh.

Khedr, A.H. and Nemeat-Alla, E.A.E. (2006) Response of barley to intercropping with sugar beet under different nitrogen fertilization levels. *Journal of Agricultural Sciences*. *Mansoura Univ.* **31**, 4957-4968.

Kumar, B., Tiwana, U.S., Singh, A. and Ram, H. (2014) Productivity and quality of intercropped maize (*Zea mays* L.) + cowpea [*Vigna unguiculata* (L.) Walp.] fodder as influenced by nitrogen and phosphorus levels. *Range Management and Agroforestry* , **35**, 263-267.

Li, C.J., Li, Y.Y., Yu, C.B., Sun, J.H., Peter, C., An, M., Zhang, F.U. and Li, L. (2011) Crop nitrogen use and soil mineral nitrogen accumulation under different crop combinations and patterns of strip intercropping in North China. *Plant and Soil* , **342**, 221-231.

Li, I., Sun, J.H., Zhang, F.S., Li, X.L., Yang, S.C. and Rengel, Z. (2001) Wheat/maize or wheat/soybean strip intercropping 1. Yield advantage and interspecific interaction on nutrients. *Field Crop Research,* **71**,123-137.

Litsinger, J.A. and Moody, K. (1975) Integrated pest management in multiple cropping systems. In: *Multiple Cropping Symposium (Proceedings),* American Society of Agronomy, Annual Meeting, Knoxville, Tennessee, 24th-29th August.

Mead, R. and Willey, R.W. (1980) The concept of a 'Land equivalent ratio' and advantages in yield from intercropping. *Experimental Agriculture,* **16**, 217-228.

McCollum, R.E. (1982) Expert consult. Fertilizer Use Multiple Crop. Syst. FAO, 1-6 Feb., New Delhi.

Mohammed, W.KH., El-Metwally, E.A. and Saleh, S.A. (2005) Intercropping faba bean at different plant densities with sugar beet. *Egyptian Journal of Agricultural Research,* **83**, 649-662.

Papendick, R.I., Sanchez, P.A. and Trplett, G.B. (1976) *"Multiple Cropping. Special Publication"* No. 27. American Society of Agronomy, Madison, Wisconsin.

Pinchinat, A.M., Soria, J. and Bazan, R. (1975) Multiple cropping in tropical America. In: *Multiple Cropping Symposium (Proceedings),* American Society of Agronomy, Annual Meeting, Knoxville, Tennessee, 24th-29th August

Rao, M.R. and Shetty, S.V.R. (1977) Some biological aspects of intercropping systems on crop-weed balance. *In Weed Science Conference/Workshop in India (Proceedings),* Andhra Pradesh Agricultural University, Hyderabad, India, 17th-20th January.

Raheja, A.K. (1977) Pest and disease relationships within various crop mixtures. Research Program 1977-78. H. Cropping Systems. Institute for Agricultural Research, Samaru, Nigeria 4.

Reddy, M.N. and Chetty, C.K.R. (1984) Staple land equivalent ratio for assessing yield advantage from intercropping. *Experimental Agriculture,* **20**,171-177.

SAS Institute, Inc. (2000) SAS/STAT User's Guide, Version 9.1 SAS Institute, Cary, NC.

Shaalan, A.M., Khalil, H.E., Nawar, A.I. and El-Salamouni, M.M. (2015) Intercropping of grain and fodder maize crops under different nitrogen levels and cutting dates. *Alexandria Science Exchange Journal ,* **36**, 373-380.

Trenbath, B.R. (1982) Proc. Front. Res. Agric. Indian Statist. Inst. Golden Jubilee Int. Conf. Calcutta, pp. 265-286.

Vandermeer, J.H. (1992) *"The Ecology of Intercropping".* Cambridge Univ. Press.

Willey, R.W. (1979) Intercropping – Its importance and research needs. Part 1. Competition and yield advantages. *Field Crop Abstracts,* **32**,1-85.

Winner, C. (1982) Zuckerrubenbau. DLG-Verlags-GmbH, Rusterstrasse 13, D-6000 Frankfurt am Main Germany. pp. 29.

Zhang, F.S. and Li, L. (2003) Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient use efficiency. *Plant and Soil*, **248**, 305-312.

(*Received* 2/10/2016;
accepted 8/12/2016)

التحميل الاضافى للقمح، الشعير و الفول البلدى مع بنجر السكر: التاثير على المحصول، الجودة و كفاءة استخدام الارض

هبـه صبرى عطيه سلامه، دينا السيد القراميطى* و على عيسى نوار
قسم علوم المحاصيل – كلية الزراعة – جامعه الاسكندرية – الاسكندرية
و*وزارة العدل – كفر الشيخ – مصر.

تم اجراء التجارب الحقلية خلال الموسم الشتوى لعامى ٢٠١٣ و ٢٠١٤ فى محطة البحوث الزراعية بابيس، التابعة لكلية الزراعة، جامعة الاسكندرية. كان الهدف الرئيسى هو دراسة تاثير تحميل بنجر السكر مع القمح، الشعيراو الفول البلدى على المحصول و بعض صفات الجودة لبنجر السكر و المحاصيل المصاحبة له. بالاضافة الى ذلك، هدفت الدراسة إلى تقييم كفاءة التحميل باستخدام نسبة مكافئ المادة الجافة كمقياس جديد (Dry Matter Equivalent Ratio – DMER) مقارنة بالمقياس التقليدى و هو نسبة المكافئ الارضى (Land Equivalent Ratio – LER). تم استخدام تصميم القطع المنشقة فى ثلاث مكررات لدراسة ثلاث نسب لتحميل المحاصيل المصاحبة لبنجر السكر (٥٠، ٧٥ و ١٠٠٪) فى القطع الرئيسية، و دراسة معاملات التحميل فى القطع المنشقة. اظهرت النتائج ان صفات المساحة الورقية (م٢)، محصول الجذور (طن/هكتار)، معامل الحصاد و محصول السكر (طن/هكتار) لبنجر السكر تأثرت معنويا بالتفاعل بين نوع المحصول المصاحب (قمح، شعيرأو فول بلدى) و نسبتة (٥٠، ٧٥ أو ١٠٠٪) خلال موسمى الدراسة. بصفة عامة تفوقت الزراعات المنفردة لبنجر السكر فى الصفات الاربعة السابقة تلاها بنجر السكرفى معاملات التحميل باستخدام اقل نسبة محصول مصاحب.التحميل مع محاصيل الحبوب (القمح و الشعير) أظهر زيادة طفيفة فى تلك الصفات عن التحميل مع الفول البلدى. انتجت الزراعات المنفردة من الثلاث محاصيل المصاحبة اعلى محصول حبوب للقمح و الشعير و بذورللفول البلدى، بينما انخفض محصول الحبوب/البذورمع انخفاض نسبة تحميل المحاصيل الثلاثة على بنجر السكر. على عكس ذلك، انخفض عدد القرون للنبات، وزن ١٠٠ بذرة للفول البلدى مع زيادة نسبة التحميل. انتجت كل معاملات التحميل المدروسة LER اكثر من ١، مما يشير الى التاثير الايجابى للتحميل على كفاءة استخدام الارض والاضافة المحصولية. اما عند استخدام المقياس الجديد DMER لقياس كفاءة استخدام الارض والاضافة المحصولية، وجد انه كانت هناك اضافة فقط فى حالة تحميل بنجر السكر مع القمح (DMER>١). اما فى حالة تحميل بنجر السكر مع الشعير و الفول البلدى، كان هناك فقد فى المحصول الكلى النهائى (DMER<١)، مما يشير الى التنافس الشديد بين بنجر السكر وكل من الشعير و الفول البلدى. ثبت من هذه الدراسة ان DMER يعطى فكرة اكثر واقعية و دقة عن تاثير التحميل مقارنة بمقياس LER.