J. Soils and Crops 29 (2) 218-226, December 2019

ISSN 0971-2836 (Print)
ISSN 2582-2756 (Online)
NAAS Rating - 4.46
Scientific Journal Impact Factor - 7.375

INTERCROPPING SYSTEMS FOR SUGAR BEET TO IMPROVE ITS LAND AND WATER PRODUCTIVITY

A. A. Zohry[1] and S. A. Ouda[2]

ABSTRACT

Intercropping is a technique of land utilization for maximizing production. Two field experiments were conducted in 2014/15 and 2015/16 seasons to investigate the effect of intercropping onion, faba bean or chickpea on sugar beet yield under ridge widths of 0.6, 0.8 and 1.20 m (raised beds), as well as on land and water equivalent ratios. The experimental design was split plots with four replicates, where ridge widths and intercropping systems were assigned to main and sub plots, respectively. The results indicated that there were significant differences between the yield of sole sugar beet and intercropped with any of the three crops. There was significant difference between 0.60, 0.80 m and raised beds on sugar beet yield. The results also showed that sugar beet yield was reduced under the three intercropping systems, compared to sole yield. The highest sugar beet yield was obtained under onion intercropped with sugar beet system on raised beds, where the highest values of land and water equivalent ratios were obtained. In conclusion, onion intercropping with sugar beet on raised beds can attain the highest yields for both the crops. Furthermore, this system required the lowest applied irrigation amount and attained the highest land and water equivalent ratios.

(Key words : Onion intercropped with sugar beet,faba bean intercropped with sugar beet, chickpea intercropped with sugar beet, land equivalent ratio, water equivalent ratio)

INTRODUCTION

Intercropping is one of the techniques of land utilization for optimum production (Bhattanagar *et al*., 2007). The efficiency of any intercropping system depends directly on the management involved(Cecílio Filho *et al*., 2011). The careful choice of the component crop in the system and its associated times of establishment is particularly important for efficiently exploiting the available resources, where the period of coexistence between the species influences its productivity (Cecílio Filho *et al.*, 2013). The spatial arrangement of the intercropped crops and its planting density can reduce the competition for resources and increase the efficiency of the intercropping system(Porto *et al.,*2011).The advantages of intercropping system are more apparent when the co-crops have different requirements of the available resources, in quantity, quality, and time of demand(Alfa and Musa, 2015).These factors, when properly managed, can bring ecological and economic benefits, as a result of the complementarity nature of the species involved, increasing production when compared to monoculture (Lima *et al.*,2010).

Sugar beet is one of the most important cultivated crops in Egypt. The crop was introduced to Egypt 15 years ago to contribute in the reduction of sugar production-consumption gap. Compared to sugarcane, sugar beet has lower growth season, and consequently lower water requirements. The recorded cultivated area of sugar beet in 2015 was 231,193 hectares as reported by the Egyptian Ministry of Agriculture and Land Reclamation. The cultivated area of sugar beet was steadily increased in the past 10 years. However, the spread of sugar beet cultivation was on behalf of other winter crops, such as legume crops as a result of limited arable lands in Egypt. To overcome this situation, implementing intercropping systems of sugar beet was considered. Sugar beet is a good candidate for implementing intercropping systems in Egypt due to its long growing season, namely 180-200 days (Abdel Motagally and Metwally, 2014) and its high water requirements, almost 508-604 mm (Ouda and Zohry, 2018).

The previous studies on the suitability of different companion crops for sugar beet intercropping systems concluded that onion, faba bean and chickpea are good nominees to be intercropped with it to maximize land and water productivity (Azad and Alam 2004 ; Marey, 2004 ;

1 Professor, Crop Intensification Research Department, Field Crops Research Institute, Agricultural Research Centre, Giza, Egypt.
2 Professor, Water Requirements and Field Irrigation Research Department,Soils, Water and Environment Research Institute, Agricultural Research Centre, Giza, Egypt. Corresponding author: samihaouda@yahoo.com

Salama *et al.*,2016). However, these studies were conducted using high planting density of companion crop was between 50-75% of its recommended planting density. Although planting density for the companion crop increased land equivalent ratio to be higher than 1, it highly reduced sugar beet yield (Salama *et al.,* 2016). That result was attributed to high competition between the companion crop grown with sugar beet (Aboukhadra *et al.,* 2013 ; Abdel Motagally and Metwally, 2014).Farghaly *et al.*(2003) intercropped onion with sugar beet using 50% planting density and obtained 8% reduction in sugar beet yield, compared to sole sugar beet planting. Toaima *et al.,* (2001) found that intercropping onion with sugar beet resulted in greater yield and improved quality of sugar beet, compared to sole planting of sugar beet. Salama *et al.* (2016) intercropped faba bean with sugar beet with 50, 75 and 100% of its planting density and found that increasing faba bean planting density highly reduced sugar beet yield. They attributed the reduction of sugar beet yield to shading effect of faba bean shoots on sugar beet shoot with increasing faba bean density. This effect resulted in high competition for light, which negatively affect the rate of photosynthesis and reduced sugar beet root yield. Marey (2004) reported that lower competition between sugar beet and chickpea intercropping system exist, compared to sugar beet and faba bean intercropping system, which resulted in higher sugar beet yield. Farghaly *et al.*(2003) indicated that percentage of sugar beet yield reduction under intercropping it with chickpea was 12%, whereas it was 15% under intercropping it with faba bean, when 33% of planting density was used for the either companion crops. Marey (2004) cultivated chickpea with planting density 100, 66 and 50% and found that reducing chickpea planting density resulted in an increase in sugar beet yield by 30%, compared to 100% of its planting density.

Cultivation on raised beds has many benefits for the growing plants. Ahmad *et al.* (2009) demonstrated that raised beds planting contributed significantly in improving water distribution and efficiency. Limon-Ortega *et al.*(2002) indicated that raised beds cultivation improves soil quality, which led to enhanced root growth. Furthermore, root length density in upper 45 cm of the raised beds was increased due to porous soil environment (Dey *et al.,* 2015).Raised beds cultivation significantly and substantially increased microbial functional groups and enzyme activities, compared to flat planting, thus it increasing availability of essential nutrients by stimulating microbial activity (Zhang *et al.,* 2012). Furthermore, increase in radiation use efficiency of sugar beet was observed under raised beds cultivation, which resulted in increasing water use efficiency and nutrients use efficiency, as well as increase final root yield (Ahmad *et al.*,2010).

Two indicators can be used to evaluate the usefulness of using intercropping systems on improving lands and water use, namely land equivalent ratio (LER) and water equivalent ratio (WER). LER refers to the ratio between the benefit from the mixed-cropping of two or more than two crops in the same field and the benefit from the monoculture of every crop (Fing *et al.,* 2016). It is an indication of the ratio value between the needed lands for the monoculture to acquire the same yield with intercropping and the lands needed for the intercropping (Mao *et al.,* 2012). WER is similar to LER, but it deals with water utilization efficiency of the intercropping population (Miao *et al.,* 2016). It quantifies the amount of water that would be needed in single crops to achieve the same yield as produced with one unit of water in intercrop (Mao *et al.,* 2012).

Thus, the objective of this investigation was to determine the effect of the interaction between three sugar beet intercropping systems (onion intercropped with sugar beet, faba bean intercropped with sugar beet and chickpea intercropped with sugar beet) and three ridge width (0.60, 0.80 and 1.20 m (raised beds) on sugar beet yield, land and water equivalent ratios.

MATERIALS AND METHODS

Two field experiments were carried out at El-Minia governorate, Middle Egypt during the two growing seasons of 2014/15 and 2015/16 to investigate the effect of intercropping of three crops, namely onion, faba bean and chickpea on sugar beet under three ridge widths, namely 0.6, 0.8 and 1.2 m (raised beds) on the yield of the four crops (sole and intercropped), as well as on land and water equivalent ratios. The experimental design was split plots with four replicates, where ridge widths were assigned to main plots and intercropping systems were assigned to sub plots. The soil of the experiment was silty clay loam (sand, 19%, silt 48% and clay, 33%), with soil pH equal to 7.66, EC was 1.6 dS m^{-1} and $CaCO_3$ was 3.88%. Furthermore, total N was 1.60% and organic matter was 1.68%.

Land preparation was done by ploughing the land twice and then the land was leveled. The plot area was 28.8 m^2 (4.8 X 6 m), where each plot included 8, 6 or 4 ridges in case of 0.60, 0.80 or 1.20 m width (raised beds), respectively. The preceding crop was maize in the two growing seasons. Fertilizer amounts were applied as recommended by the Egyptian Ministry of Agriculture and Land Reclamations. Super phosphate (72 kg P_2O_5 ha^{-1}) and potassium sulfate (57.6 kg K_2O ha^{-1}) were added once during land preparation. Planting method for either sole or intercropping sugar beet systems and plants population are presented in table 1.

Sugar beet variety sugar1 (sole or intercropped) was planted in the 18th of October and harvested in the 20th of May in first growing seasons and was planted in the 23rd of October and harvested in the 23rd of May in the second growing season. Sugar beet plants received 168 kg N ha^{-1} in the form of ammonium nitrate (33.5% N) in two equal doses. The first dose was 108 kg N ha^{-1} applied after thinning of sugar beet and the second dose (60 kg N ha^{-1}) was applied 75 days after sowing in both growing seasons.

Onion variety Giza 6 (sole or intercropped) was used. Seedlings were planted in the 8th of November and harvested in the 28th of April in the first growing season and in the second growing season was planted in the 12th

Table 1. Planting method for either sole or intercropped sugar beet, onion, faba bean and chickpea

Crop	Ridge width		
	0.60 m	0.80 m	1.20 m (raised beds)
Sugar beet sole or intercropped	Seeds were sown on one side of the ridges with 20 cm distance (84,000 plants ha^{-1})	Seeds were sown on both sides of the ridges with 30 cm distance (84,000 plants ha$^{-1)}$	Seeds were sown on both sides of the with 20 cm distance (84,000 plants ha^{-1})
Onion sole	Seedlings were sown on three rows, two on both sides and one on top of the ridges with 10 cm distance (504,000 plants ha^{-1})	Seedlings were sown on four rows, two on both sides and two on top of the ridges with 10 cm distance (504,000 plants ha^{-1})	Seedlings were sown on six rows, two on both sides and four rows on top of the ridges with 10 cm distance (504,000 plants ha^{-1})
Onion intercropped	Seedlings were sown on one side of the ridges and sugar beet seeds were sown on the other side with 10 cm distance (168,000 plants ha^{-1})	Seedlings were sown in two rows on the top of the ridges (20 cm apart) with 15 cm distance (168,000 plants ha^{-1})	Seedlings were sown in two rows on the top of the ridges (20 cm apart) with 10 cm distance (168,000 plants ha^{-1})
Faba bean sole	Seeds were sown on both sides of the ridges, with 20 cm distances (336,000 plants ha^{-1})	Seeds were sown on both sides of the ridges, with 15 cm distances (336,000 plants ha^{-1})	Seeds were sown on both sides of the ridges and two rows on the top, with 15 cm distances (336,000 plants ha^{-1})
Faba bean intercropped	Seeds were sown on one side of the ridges and sugar beet seeds were planted on the other side, with 20 cm distance (84,000 plants ha^{-1})	Seeds were sown on two rows on top of the ridges (20 cm apart) with 15 cm distance (84,000 plants ha^{-1})	Seeds were sown on two rows on top of the ridges (20 cm apart) with 15 cm distance (84,000 plants ha^{-1})
Chickpea sole	Seeds were sown on both sides of the ridges, with 10 cm distances (336,000 plants ha^{-1})	Seeds were sown on both sides of the ridges, with 15 cm distances (336,000 plants ha^{-1})	Seeds were sown on both sides of the ridges and two rows on the top, with 10 cm distances (336,000 plants ha^{-1})
Chickpea intercropped	Seeds were sown on one side of the ridges and sugar beet seeds were planted on the other side, with 20 cm distance (84,000 plants ha^{-1})	Seeds were sown on two rows on top of the ridges (20 cm apart) with 15 cm distance (84,000 plants ha^{-1})	Seeds were sown on two rows on top of the ridges (20 cm apart) with 10 cm distance (84,000 plants ha^{-1})

of November and harvested in the 3rd of May. Plants received 288 kg N ha^{-1} in the form of ammonium nitrate (33.5% N) in three doses. The first dose was 72 kg N ha^{-1} applied during planting, the second dose was 108 kg N ha^{-1} applied one month after planting and the third dose was 108 kg N ha^{-1}applies one month later. Planting density was 100 and 30% of its recommended density for sole and intercropped onion, respectively.

Faba bean variety Giza 674 (sole or intercropped) was planted in the 18th of October and harvested in the 26th of April in the first growing season. In the second growing season, faba bean was planted in the 23rd of October and harvested in 30th of April. The plants received 36 kg N ha^{-1}in the form of ammonium nitrate (33.5% N) in one dose after planting. Planting density was 100 and 25% of its recommended density for sole and intercropped faba bean, respectively . In both seasons, faba bean seeds were inoculated by *Azotobacter* before sowing by mixing seeds with 1 g *Azotobacter* to100 g seeds (Zohry, 2005).

Chickpea variety Giza 3 (sole or intercropped) was planted in the 8th of November and harvested in the 25th of April in the first growing season. Furthermore, in the second growing season it was planted in the 12th of November and harvested in the 30th of April. The plants received 36 kg N ha^{-1} in the form of ammonium nitrate (33.5% N) in one dose after planting. Planting density was 100 and 25% of its recommended density for sole and intercropped chickpea, respectively. In both seasons, chickpea seeds were inoculated by *Azotobacter* before sowing using the procedure used in faba bean.

Weather data values were collected for the studied two growing seasons. Solar radiation was between14.8-26.0 MJ m^{-2}day^{-1}, maximum temperature was between 19.4-30.1°C, minimum temperature was between 5.5-13.0°C, dew point temperature was between -0.1-4.6°C and evapotranspiration was between 3.1-7.4 mm day^{-1} in the first growing season. In the second growing season, solar radiation was between 14.8-25.6 MJ m^{-2}day^{-1}, maximum temperature was between 18.7-34.8°C, minimum temperature was between 4.6-17.0°C, and dew point temperature was between -0.3-7.0°C. Reference evapotranspiration was calculated using Penman Montieth equation presented in BISm model (Snyder *et al.*, 2004). Evapotranspiration was between 3.1-7.6 mm day^{-1} in the second growing season. There was no rain in the experimental site in both the growing seasons.

Field capacity of the soil was 32.75%, wilting point was 16.91%, available water was 15.84% and bulk density was 1.26%. Surface irrigation was used and the applied irrigation amounts were calculated using 4 inch diameter tube according to Michael (1978) using the following equation:

$$Q= \frac{0.61 \text{ x A x} \sqrt{2x981xh}}{1000 \text{ x } 1000} x60 \quad (m^3t^{-1}) \qquad [1]$$

Q = water discharged (m^3t^{-1})

A = tube sectional area (cm^3)

h = water head over the centre of the tube (cm)

Gravity ground of speed = 981 cm s^{-2}

Crop water use was estimated by the method of soil moisture depletion according to Majumdar (2002), as follows:

$$CWU (cm) = (è_2 - è_1) * Bd * ERZ \qquad [2]$$

Where: CWU=the amount of water consumptive use (mm), $è_2$=soil moisture percentage after irrigation, $è_1$=soil moisture percentage before the following irrigation, Bd=bulk density in gcm^{-3}, ERZ= effective root zone. Soil moisture content from 0-20, 20-40 and 40-60 cm depths was measured by the gravimetric method for each plot before sowing, straight after harvest and just before and after each irrigation event.

For all the studied crops, seeds yield was recorded on the basis of experimental plot area by harvesting all plants, weighted it, and then all the plots were combined together. The biomass of all studied crops was removed from the field after harvest. In the second year, the experiment was implemented on the same area used for the first year experiment.

All the obtained data from the experiment of each season were subjected to the statistical analysis of split plot design with four replications according to Gomez and Gomez (1984). Revised Least Significant Differences (LSD') at 5 % levels of probability was used for comparing means according to Waller and Duncan, (1969).

Evaluation of the studied intercropping systems

Two indicators were used to evaluate the studied sugar beet intercropping systems. The first indicator is land equivalent ratio (LER): It is an evaluation of the land utilization efficiency of the intercropping (Rao and Willey, 1980):

$$LER= LER_A + LER_B = (Y_{int,A}/ Y_{mono,A}) + (Y_{int,B}/ Y_{mono,B}) \qquad [3]$$

Where: LER_A and LER_B are the partial land equivalent ratio of crop A (sugar beet) and crop B (onion, faba bean or chickpea), respectively. $Y_{int,A}$ and $Y_{int,B}$ are the intercropping yield of crop A and crop B. $Y_{mono,A}$ and $Y_{mono,B}$ are the monoculture yield of crop A and crop B, respectively. If LER is more than 1, it indicates that the land utilization efficiency of the intercropping is higher than that of monoculture.

Furthermore, water equivalent ratio (WER) quantifies the amount of water that would be needed in single crops to achieve the same yield as produced with one unit of water in intercrop and it is calculated according the formula of (Mao *et al* . , 2012) as followed:

$$WER=WER_A+WER_B=[(Y_{int,A}/WU_{int})/(Y_{mono,A}/WU_{mono,A})]+[(Y_{int,B}/WU_{int})/(Y_{mono,B}/WU_{mono,B})] \ [4]$$

Where: WU_{int}, $WU_{mono,A}$ and $WU_{mono,B}$ =water use efficiency of whole intercropping system, A and B in monocultures, respectively, Y_{int}, $Y_{mono,A}$ and $Y_{int,B}$= yield of whole intercropping system, A and B in monocultures, respectively. If the WER ÿ 1, it suggests that the water utilization of intercropping is higher than that of monoculture. If WER "ÿ 1, it shows that water utilization of intercropping is lower than that of monoculture.

RESULTS AND DISSCUSION

The yield of sole or intercropped sugar beet under different ridge widths

Table 2 presents sugar beet yield under sole planting and under three intercropping systems using three ridge widths. The table showed that there were significant differences (*P<0.05*) between sole sugar beet yield and sugar beet intercropped with onion or faba bean, however there was no significant difference (*P>0.05*) between sugar beet yield when faba bean or chickpea was intercropped with it. These results hold true in both growing seasons. Furthermore, there was no significant difference (*P>0.05*) between cultivation on 0.8 m or raised beds in the first growing season and there was a significant difference between 0.8 m and raised beds on sugar beet yield in the second growing season. The interaction between ridge width and cropping system was found insignificant.

The table also showed that sugar beet yield was reduced under the three intercropping systems, compared to its sole yield in both growing seasons. It was reduced by 5-9% when cultivation was implemented on 0.6 ridge width and by 2-7% under cultivation on raised beds under intercropping systems. Similar results were obtained by other researchers (Farghaly *et al.*,2003; Mohammed *et al.*, 2005 ; Gadallah *et al.*, 2006 ; Aboukhadra *et al.*,2013; Abdel Motagally and Metwally, 2014 ; Salama *et al.*, 2016), however, the yield of the companion crop compensate the loss in sugar beet yield. Furthermore, the loss in sugar beet yield depended on the type of the companion crop and its planting density. The results in table 2 indicated that intercropping onion with sugar beet on raised beds resulted in 2% reduction in sugar beet yield, compared to sugar beet sole planting. The table also indicated that sugar beet yield, either sole or intercropped were higher under 0.8 m ridge width and raised beds, compared to its value under 0.6 m ridge width in both growing seasons. Abouelenin *et al.* (2010) indicated that cultivation on raised beds increased crop productivity by 15%. Other benefits exist under raised beds cultivation, where microbial functional groups and enzyme activities were increased compared to flat planting (Zhang *et al.*, 2012), which can explain the rise in the productivity under raised beds cultivation. Hobbs *et al.* (2000) demonstrated that raised beds planting increased fertilizer use efficiency and reduced weed infestation, and seed rate without sacrificing yield.

The highest sugar beet yield was obtained from onion intercropped with sugar beet system in both growing seasons, followed by chickpea intercropped with sugar beet system. Chimonyo *et al.*(2015) indicated that improved the utilization of natural resources and differences in spatial and temporal distribution under intercropping, as well as morphology of component crops affect the yield of the main crop in the intercropping system. Moreover, Zhang *et al.* (2012) indicated that high yields are achieved with intercropping when inter-specific competition is lower than intra-specific competition. Thus, the nature and growth habit of onion shoots and roots reduces competition with sugar beet shoots for solar radiation and roots for nutrients in the rhizosphere (Abdel Motagally and Metwally, 2014). Furthermore, Badawy and Shalaby (2015) indicated that intercropping onion with sugar beet resulted in lowest infestation with cotton leaf worm, beet fly, tortoise beetle and beet moth, which improve the resulted sugar beet yield.

Additionally, intercropping chickpea with sugar beet attained higher yield than faba bean intercropping with sugar beet. This result can be attributed to higher shoot competition between sugar beet and faba been, compared to chickpea (Farghaly *et al.*, 2003; Mohammed *et al.*, 2005 ; Gadallah *et al.*, 2006).

Onion cropping systems

The results in table (3) indicated that there were significant differences ($P<0.05$) between the sole onion yield or intercropped with sugar beet yield under the

Table 2. Sugar beet yield (ton ha^{-1}) under different cropping systems and ridge widths in both growing seasons

Crop / Ridge width	2014/15 growing season 0.6 (m)	0.8 (m)	1.2 (m)	Mean	2015/16 growing season 0.6 (m)	0.8 (m)	1.2 (m)	Mean
Sole sugar beet	67.90	68.40	69.20	68.50^{a}	68.60	69.00	70.00	69.20^{a}
Onion on sugar beet	63.90	64.47	68.40	65.59^{b}	66.20	66.20	67.83	66.74^{b}
Faba bean on sugar beet	61.50	63.60	64.80	63.30^{c}	63.03	63.47	66.20	64.23^{bc}
Chickpea on sugar beet	61.90	66.00	64.60	64.16^{bc}	62.53	64.27	64.93	63.91^{c}
Mean	63.92^{c}	65.49^{ab}	66.75^{a}		65.09^{b}	65.74^{b}	67.24^{a}	
$LSD_{0.05}$								
Ridge width (RW)		2.18				1.14		
Cropping system (CS)		1.52				0.89		
RW X CS		-				-		

Means with different letters indicated significant difference

Table 3. Onion yield (ton ha^{-1})under different cropping systems and ridge widths in both growing seasons

Crop / Ridge width	2014/15 growing season 0.6 (m)	0.8 (m)	1.2 (m)	Mean	2015/16 growing season 0.6 (m)	0.8 (m)	1.2 (m)	Mean
Sole onion	21.8	22.07	25.33	23.07a	22.13	21.63	24.03	22.60a
Intercropped onion	11.2	13.3	14.99	13.16b	11.53	13.27	14.7	13.17b
Mean	16.50c	17.69b	20.16a		16.83b	17.45b	19.37a	
		$LSD_{0.05}$	F test			$LSD_{0.05}$	F test	
Ridge width (RW)		0.49	—			0.74	—	
Cropping system (CS)	—	**			—	**		

Means with different letters indicated significant difference

three ridge widths in the first growing season. In the second growing seasons, similar trend was observed for sole or intercropped onion yield. However, there was no significant difference between onion yield under 0.6 and 0.8 m ridge width in the second growing season only, and there were significant differences between onion yield under 0.8 m ridge width and raised beds. Furthermore, the yield of sole onion was higher than its counterpart value under intercropping in both growing seasons as a result of being 100% of its planting density. In addition, the yield of onion was increased by increasing ridge width from 0.60 m to raised beds in both growing seasons.

Faba bean cropping systems

There were significant differences ($P<0.05$) between the yield of sole faba bean or intercropped with sugar beet under the three ridge width in both growing seasons. The yield of faba bean was increased by increasing ridge width from 0.60 m to raised beds in both growing seasons.

In addition, the yield of sole faba bean was higher than its counterpart value under intercropping in both growing seasons as a result of being 100% of its planting density (Table 4).

Table 4. Faba bean yield (ton ha^{-1}) under different ridge widths and cropping systems in both growing seasons

Crop / Ridge width	2014/15 growing season				2015/16 growing season			
	0.6 (m)	0.8 (m)	1.2 (m)	Mean	0.6 (m)	0.8 (m)	1.2 (m)	Mean
Sole faba bean	3.30	3.47	3.67	3.48a	3.38	3.49	3.88	3.58a
Intercropped faba bean	1.10	1.28	1.40	1.26b	1.06	1.22	1.40	1.23b
Mean	2.20c	2.38b	2.54a		2.22c	2.36b	2.64a	
		LSD	F test			LSD	F test	
Ridge width (RW)	0.08	—			0.11	—		
Cropping system (CS)	—	**			—	**		
RW X CS	ns	—			0.06	—		

Means with different letters indicated significant difference

Chickpea cropping system

Regarding chickpea, sole or intercropped with sugar beet, there were significant differences ($P<0.05$) between its yield under the two cropping systems under the three ridge widths in both growing seasons. Furthermore, the interaction between ridge width and cropping systems was significant in the first growing season and insignificant in the second growing season (Table 5).

Table 5. Chickpea yield (ton ha^{-1}) under different cropping systems and ridge widths in both growing seasons

Crop / Ridge width	2014/15 growing season				2015/16 growing season			
	0.6 (m)	0.8 (m)	1.2 (m)	Mean	0.6 (m)	0.8 (m)	1.2 (m)	Mean
Sole chickpea	2.01	2.07	2.2	2.09a	2.06	2.23	2.28	2.19a
Intercropped chickpea	0.65	0.79	0.98	0.81b	0.71	0.83	0.95	0.83b
Mean	1.33c	1.43b	1.59a		1.39c	1.53b	1.62a	
		LSD	F test			LSD	F test	
Ridge width (RW)	0.07	—			0.08	—		
Cropping system (CS)	—	**			—	**		
RW X CS	0.03	—			ns	—		

Means with different letters indicated significant difference

Water consumptive use and applied irrigation water

Table 6 indicated that water consumptive use for intercropped sugar beet in the three intercropping systems was slightly higher than its counterpart values of sole sugar beet in both growing seasons. Furthermore, cultivation on 1.2 m ridge width (raised beds) resulted in lower value of water consumptive use of sugar beet under the three intercropping systems in both growing seasons. Water consumptive use was reduces by 19-20% averaged on the two growing seasons for sole and intercropped sugar beet under cultivation on raised beds, compared to 0.6 m ridge width.

Sing *et al.* (2010) found lower water consumption by crops on raised beds planting than under conventional flat beds planting due to decrease in irrigation amount and water use.

Table 6. Water consumptive use (mm) of sugar beet under sole and intercropping systems

Crop / Ridge width	2014/15 growing season			2015/16 growing season		
	0.6 (m)	0.8 (m)	1.2 (m)	0.6 (m)	0.8 (m)	1.2 (m)
Sole sugar beet	675	608	547	661	602	542
Onion on sugar beet	682	621	546	667	614	540
Faba bean on sugar beet	687	632	563	672	605	538
Chickpea on sugar beet	691	622	553	677	616	548

Water consumptive use of the companion crop under sole planting with 100% of its planting density is presented in table 7. The results indicated that water consumptive use was increase under low ridge width (0.6 m) and reduced under raised beds. This result was true for all the studied crops under both growing seasons. Water consumptive use was reduced by 18-20% averaged on the two growing seasons for three studied crops under cultivation on raised beds, compared to 0.6 m ridge width.

Table 7. Water consumptive use (mm) for sole companion crops under 100% of its planting density

Crop / Ridge width	2014/15 growing season			2015/16 growing season		
	0.6 (m)	0.8 (m)	1.2 (m)	0.6 (m)	0.8 (m)	1.2 (m)
Onion	565	512	462	550	499	450
Faba bean	473	427	387	486	439	402
Chickpea	439	391	351	435	387	352

Similar trend was observed in the applied water to sole or intercropped sugar beet, where the applied water was lowest under raised beds and was the highest under 0.60 m ridge width. This result was true in both growing seasons. Furthermore, the highest amount of applied water was obtained when onion was intercropped with sugar beet in both growing seasons. The applied irrigation water was reduced by 19- 20% averaged on the two growing seasons for three studied sugar beet intercropping systems under cultivation on raised beds, compared to 0.6 m ridge width (Table 8).

Abouelenin *et al.*(2010) indicated that cultivation on raised beds save 20% of the applied water. Furthermore, Ahmad *et al.* (2009) reported that an improvement in water distribution and efficiency under raised beds can be attained.

Table 8. Applied irrigation water for sugar beet ($m^3 ha^{-1}$) under sole and intercropping systems

Crop / Ridge width	2014/15 growing season			2015/16 growing season		
	0.6 (m)	0.8 (m)	1.2 (m)	0.6 (m)	0.8 (m)	1.2 (m)
Sole sugar beet	10887	9798	8819	10661	9712	8741
Onion on sugar beet	10895	9882	8913	10672	9680	8731
Faba bean on sugar beet	10862	9808	8877	10663	9629	8830
Chickpea on sugar beet	10851	9657	8682	10651	9480	8626

The applied irrigation water for sole onion, faba bean and chickpea are presented in table (9). The results in the table indicated that the highest amount of applied water was found under 0.6 ridge width and the lowest value was found under raised beds cultivation.

Table 9. Applied irrigation water (m^3 ha^{-1}) for sole companion crops under 100% of its planting density

Crop	2014/15 growing season			2015/16 growing season		
Sole sugar beet	10887	9798	8819	10661	9712	8741
	0.6 (m)	0.8 (m)	1.2 (m)	0.6 (m)	0.8 (m)	1.2 (m)
Onion	3870	3993	3795	3787	3254	3067
Faba bean	3204	3325	3134	3292	2875	2700
Chickpea	2927	2798	2627	2900	2573	2407

Land equivalent ratio

Land equivalent ratio is often used as an indicator to determine the efficacy of intercropping (Brintha and Seran, 2009). Table 10 presented the value of land equivalent ratio (LER) for sugar beet intercropping systems. The table showed that the value of land equivalent ratio was higher than 1, which indicated better use of land and higher land productivity (Chimonyo *et al.,*2015). The highest values of LER were obtained when sugar beet intercropping systems cultivated on raised beds. In general, the highest value of land equivalent ratio was obtained when onion was intercropped with sugar beet on raised beds, followed by the same intercropping system on 0.8 ridge width. Thus, land productivity was increased by 58, 32 and 36% for onion intercropped with sugar beet, faba bean intercropped with sugar beet and chickpea intercropped with sugar beet, respectively averaged over both growing seasons. Similar results were obtained by Farghaly *et al.,* (2003), where high land equivalent ratio for onion intercropped with sugar beet was obtained.

Water equivalent ratio

Water equivalent ratio reflects water use advantage of intercropping systems (Kour *et al.,* 2013). The results in table 11 indicated that water equivalent ratios for sugar beet intercropping systems had similar trend as land equivalent ratio. Furthermore, the value of water equivalent ratio of intercropping systems were all greater than 1, which indicated that higher water utilization efficiency of the intercropped crops than that of monoculture (Feng *et al.,* 2016). Furthermore, the value of water equivalent ratio for sugar beet intercropping systems was the highest for onion intercropped with sugar beet on raised beds. Moreover, onion intercropped with sugar beet system on 0.8 ridge width had lower value than its counterpart value under raised beds. Thus, water equivalent ratio was increased by 52, 31 and 29% for onion intercropped with sugar beet, faba bean intercropped with sugar beet and chickpea intercropped with sugar beet, respectively averaged over both growing seasons. Yang *et al.* (2011) reported that intercropping has been observed to improve productivity unit^{-1} area through efficient and complementary use of water. Coll *et al.* (2012) indicated that the great yields attained by the intercrops are only as a consequence of low water losses. Furthermore, Miao *et al.* (2016) found that actual evapotranspiration, irrigation water use, crop transpiration, and groundwater contribution of intercropping systems were larger than those of the sole crops, which led to significantly higher land and water equivalent ratios of intercropping than those of single crops.

Table 10 . Land equivalent ration (LER) for sugar beet intercropping systems

Crop /	2014/15 growing season			2015/16 growing season		
Ridge width	0.6 (m)	0.8 (m)	1.2 (m)	0.6 (m)	0.8 (m)	1.2 (m)
Onion on sugar beet	1.45	1.55	1.58	1.49	1.57	1.58
Faba bean on sugar beet	1.23	1.31	1.32	1.23	1.27	1.31
Chickpea on sugar beet	1.23	1.35	1.38	1.26	1.30	1.34

Table 11. Water equivalent ration (WER) for sugar beet intercropping systems

Crop /	2014/15 growing season			2015/16 growing season		
Ridge width	0.6 (m)	0.8 (m)	1.2 (m)	0.6 (m)	0.8 (m)	1.2 (m)
Onion on sugar beet	1.32	1.44	1.54	1.31	1.42	1.50
Faba bean on sugar beet	1.27	1.30	1.31	1.29	1.30	1.32
Chickpea on sugar beet	1.26	1.27	1.28	1.27	1.29	1.30

We evaluated three intercropping systems, namely onion intercropped with sugar beet, faba bean intercropped with sugar beet and chickpea intercropped with sugar beet. These intercropping systems were grown on three ridge widths, namely 0.60, 0.80 and raised beds. It could be concluded that onion (30% of its recommended planting density) intercropping with sugar beet system (100% of its recommended planting density) implemented on raised beds (1.20 m ridge width) can attain the highest sugar beet and onion yields. Furthermore, this system required the lowest applied amount of irrigation water and achieved the highest land and water equivalent ratios. Thus, sugar beet is considered as a good candidate for intercropping in Egypt.

REFERENCES

Abdel Motagally, F.M.F. and A.K. Metwally,2014. Maximizing productivity by intercropping onion on sugar beet. Asian. J. Crop. Sci.**6**(3):226-235.

Abouelenein, R., T.Oweis,M. El Sherif,H.Awad, F. Foaad,S. Abd El Hafez,A. Hammam, F. Karajeh, M.Karo and A. Linda,2009. Improving wheat water productivity under different methods of irrigation management and nitrogen fertilizer rates. Egypt. J. Appl. Sci.**24**(12A). 417-431.

Aboukhadra, S.H., S.A. Badawy,S.E. Toaima and D.E.E. El-Shireef,2013. Effect of intercropping system of faba bean with sugar beet on their productivity and land use. Minuf. J. Agric. Res.**38**:1501-1518.

Ahmad, I.M., B. Qubal, G. Ahmad and N.H. Shah, 2009. Maize yield, plant tissue and residual soil N as affected by nitrogen management and tillage system. J. Agric . Biol. Sci. **1**(1):19-29.

Ahmad, Z., P. Shah, K.M. Kakar,H. El-Sharkawi,P.B.S. Gama,E.A. Khan,T. Honna and S. Yamamoto, 2010. Sugar beet (*Beta vulgaris* L.) response to different planting methods and row geometries II: Effect on plant growth and quality. J. Food Agric. Environ.**8** (2):785-791.

Alfa, A.J. and U.T. Musa, 2015. Assessing the land equivalent ratio (LER) and stability of yield of two cultivars of sorghum (*Sorghum bicolor* L. Moench)-soybean (*Glycine max* L. Merr) to row intercropping system. J. Bio.Agric.Healthcare Tehran.**5**(18):144-149.

Azad, M.A.K. and M.J. Alam, 2004. Popularizing of sugarcane based intercropping systems in Non Millzone. J.Agron.**3**(3):159-161.

Badawy, S.A.E. and G.A. Shalaby, 2015. Effect of intercropping sugar beet with onion and garlic on insect infestation, sugar beet yield and economics. J. Plant Prod. **6**(6):903–914.

Bhatnagar, P., M.K. Kaul and J. Singh, 2007.Effect of intercropping in Kinnow based production system. Indian J. Arid Hort. **2**:15-17.

Brintha, I. and T. H. Seran, 2009. Effect of paired row planting of radish (*Raphanus sativus* L.) intercropped with vegetable amaranths (*Amaranths tricolor* L.) on yield components in sandy regosol. J. Agric.Sci. **4**:19-28.

Cecílio Filho, A.B., F. Bezerra Neto, B.L.A. Rezende,L.C. Grangeiro and J.S.S. Lima, 2013. Indices of competition and bioagro economic efficiency of lettuce and tomato intercrops in greenhouses. Aust. J. Crop Sci.**7**:809-819.

Cecílio Filho, A.B., B.L.A. Rezende, J.C. Barbosa and L.C. Grangeiro, 2011. Agronomic efficiency of intercropping tomato and lettuce. Anal.Acad. Bras.Cienc. **83** : 1109-1119.

Chimonyo, V.G.P., A.T. Modi and T. Mabhaudhi, 2016. Water use and productivity of a sorghum–cowpea–bottle gourd intercrop system. Agri. Wat.Manag.**165**:82-96.

Coll, L., A. Cerrudo,R. Rizzalli,J.P. and Monzon,F.H. Andrade,2012. Capture and use of water and radiation in summer intercrops in the south-east Pampas of Argentina. Fld. Crop. Res. **134**:105–113.

Dey, D., D. Nath and P.B.Jamatia, 2015. Effect of raised bed planting method of maize under sandy loam soil of West Tripura. Inter. J. App. Res.**1**(7):561-563.

Farghaly, B. S., A.A. Zohry and S.A.A. Bassal, 2003. Crops management by intercropping sugar beet with some essential crops to maximize productivity of unit area. J. Agric. Sci.**28**(7):5183-5199.

Feng, L., Z.Sun, M. Zheng, M.Muchoki, J. Zheng, N. Yang, W. Bai, C. Feng, Z. Zhang, Q. Cai and D. Zhang, 2016. Productivity enhancement and water use efficiency of peanut-millet intercropping. Pak . J. Bot .**48**(4):1459-1466.

Gadallah, R.E., A.M. Abdel-Galil and F.R.Nawar, 2006. Maximizing productivity by intercropping of some winter crops on sugar beet. J. Agric. Sci.**31**:4957-4968.

Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. 2nded. John Wiley and Sons, Inc. New York.

Hobbs, P.R., Y. Singh, G.S.Giri,J.G. Lauren and J.M. Duxbury,2000. Direct seeding and reduced tillage options in the rice-wheat systems of the Indo-Gangetic plains of South Asia. IRRI workshop, Bangkok, Thailand, pp. 25-26.

Kour, R., B.C. Sharma, A. Kumar and P. Kour,2013. Nutrient uptake by chickpea + mustard intercropping system as influenced by weed management. India. J. Weed Sci.**45**:83–188.

Lima, J.S.S., F. Bezerra–Neto,M. Zuleide- de Negreiro,C. Cardoso–Ribeiro and A. Barros–Júnior,2010. Productive performance of carrot and rocket cultivars in strip-intercropping system and sole crops. Agro. Cien. Montecillo.**44**(7):561-574.

Limon-Ortega, A., K.D.Sayre, R.A. Drijber and C.A. Francis,2002. Soil attributes in a furrow-irrigated bed planting system in northwest Mexico. Soil Till. Res.**63**:123–132.

Majumdar, D.K. 2002. Irrigation Water Management Principles and Practice. 2nded. Prentice- Hall of India. New Delhi-110001.

Mao, L.L., L.Z. Zhang,W.W. Li,W.V.D. Werf,J.H. Sun,H. Spiertz and L. Li, 2012. Yield advantage and water saving in maize/pea intercrop. Fld. Crop Res.**138**:11-20.

Marey, R.A. 2004. Effect of intercropping faba bean and chickpea on sugar beet. Unpublished Ph.D. Thesis, Assuit University, Egypt.

Miao, Q., R.D. Rosa, H. Shi, P. Paredes, L. Zhu, J, Dai, J. M. Gonçalves, and L.S. Pereira,2016. Modeling water use, transpiration and soil evaporation of spring wheat–maize and spring wheat–sunflower relay intercropping using the dual crop coefficient approach. Agri. Wat.Manag.**165**:211-229.

Michael, A.M. 1978. Irrigation theory and practice. Vikas publishing house PVT LTD New Delhi, Bombay.

Mohammed, W.Kh., E.A. El-Metwally,and S.A. Saleh, 2005. Intercropping faba bean at different plant densities with sugar beet. Egypt. J. Agric. Res. **83**:649-662.

Ouda, S. and A. Zohry, 2018. Water requirements for prevailing cropping pattern. *In*: Cropping Pattern to Overcome Abiotic Stresses: Water, Salinity and Climate. Springer Publishing House.

Porto, V.C.N., F.B. Neto,J.S.S.de Lima, A.P. Barros Júnior and J.N. Moreira, 2011. Combination of lettuce and rocket cultivars in two cultures intercropped with carrots. Horti.Bras, Bras.**29**(3):404-411.

Rao, M.R and R.W. Willey, 1980. Evaluation of yield stability in intercropping: studies on sorghum/pigeonpea. Exp.Agri. **16**(2):105-116.

Salama, H.S.A., D.S. El-Karamity and A.I. Nawar, 2016. Additive intercropping of wheat, barley, and fababean with sugar beet: Impact on yield, quality and land use efficiency. Egypt. J.Agron.**38**(3):413-430.

Sing, V.K., B.S.Dwivedi, A.K. Shukla and R.P. Mishra,2010. Permanent raised bed planting of the pigeonpea-wheat system on a TypicUstoochrept: Effects on soil fertility, yield and water and nutrient use efficiencies. Fld. Crop Res.**116**:127-139.

Snyder, R.L., M. Orang,K. Bali and S. Eching, 2004. Basic irrigation scheduling BIS. http://www.waterplan.water.ca.gov/landwateruse/wateruse/Ag/CUP/Californi/Climate_Data_010804.xls.

Toaima, S.E.A, K.A El-Douby and A.I. Nafei, 2001. Effect of different intercropping systems of onion and garlic on sugar beet yield, yield components and chemical analysis. Egypt. J. Agric. Res. **79**:983-1003.

Waller, R.A.D.B.and Duncan, 1969. A Bays Rule for the Symmetric Multiple Comparison Problem. American State Association. USA.

Yang, C, G. Huang, Q. Chai and Z. Luo, 2011. Water use and yield of wheat/maize intercropping under alternate irrigation in the oasis field of northwest China. Fld. Crop. Res. **124**:426–432.

Zhang, G.,Z. Yang and S. Dong, 2011. Interspecific competitiveness affects the total biomass yield in an alfalfa and corn intercropping system.Fld Crop Res.doi:10.1016/j.fcr.2011.06.006.

Rec. on 15.07.2019 & Acc. on 30.07.2019