Asian Journal of Crop Science

ISSN 1994-7879

science alert
http://www.scialert.net

ANSInet
an open access publisher
http://ansinet.com

Asian Journal of Crop Science 6 (3): 226-235, 2014
ISSN 1994-7879 / DOI: 10.3923/ajcs.2014.226.235

Maximizing Productivity by Intercropping Onion on Sugar Beet

[1]F.M.F. Abdel Motagally and [2]A.K. Metwally
[1]Department of Agronomy,
[2]Department of Horticulture, Faculty of Agriculture, Assiut University, Assiut, Egypt

Corresponding Author: F.M.F. Abdel Motagally, Department of Agronomy, Faculty of Agriculture, Assiut University, Assiut, Egypt

ABSTRACT

For studying the effect of intercropping system of onion plants on sugar beet plants, a field experiment was conducted at the Experimental Farm, Faculty of Agriculture, Assiut University which carried out during two winter growing seasons of 2011-2012 and 2012-2013. In the study, we focused on the relative advantage of intercropping systems of sugar beet with onion on the growth, yield and yield components of the two crops intercropping parameters which also considered. The effects of the associated cropping patterns of onion with sugar beet on yield and its components of onion crop were significantly decreased by intercropping. Nevertheless the yield of sugar grown in monoculture was slightly high than obtained from any intercrop combination under study. These results may be due to competition between sugar beet and onion plants for nutrient, water and solar radiation. The highest values of Land Equivalent Ratio (LER) and gross return were observed when sugar beet intercropping with onion as compared to mono crops of either species. This investigation showed that grown sugar beet intercropping with onion gave the highest economic return for the farmers.

Key words: Sugar beet, onion, intercropping, land equivalent ratio, aggressivity, economic return

INTRODUCTION

One of the main problems associated with the Egyptian Agricultural system is the low size of cultivated land per farmer. In average, 42.9% of the farmers own or work in field one feddan (4200 m^2) or less (Ahmed *et al*., 2009). This led to an increase need to maximize land usage to enhance farmer's income. The need to follow process such as intercropping is of great importance in this context. If the process of intercropping is adopted, attention should be given to the crops used that can grow together with minimal loses and maximum profit. Intercropping is an agricultural system that utilizes several crops to attain better final income. It is mostly associated with non mechanized farming system. Intercropping is the growing of two or more crop on the same time and position.

The intercropping system greatly contributes to crop production by its effective utilization of resources, as compared to the monoculture cropping system (Zhang and Li, 2003). Currently, this system was interestingly increasing in low-input crop production systems and was being extensively investigated (Li *et al*., 1999). The choice of the intercropped crops is critical. The selected crops must be complement each other rather than compete with each other.

Sugar beet is one of the most important crops not only in Egypt but also all over the world. However, production of sugar is not enough, so the agricultural policy has been given much attention to grow sugar beet to narrow the gap between consumption and production. Increasing

sugar yield per unit area had national interest and it can be achieved by adopting suitable cultural practices such as intercropping systems. The area that allocated to sugar beet in Egypt had increased mostly in the recent years (16900 fed in 1982 season to 450000 fed in 2012 season) also, the contribution of sugar beet to sugar production increased largely, as it reached 35.5% of the total sugar production in 2012 season. Since the cultivated area in Egypt is limited, the agriculture intensification had become urgent necessity to optimize the utilizing of unit area.

Onion is a valuable crop since ancient times and ranks second after tomato in the list of the worldwide cultivated vegetables. In 2010, about 74 million tones of onions were produced in 3.7 million hectares according to the FAOSTAT database (FAO, 2012).

Farghaly *et al.* (2003) reported that yield of sugar beet intercropped with onion, faba bean and chickpea were reduced by intercropping. The highest values for land equivalent ratio were observed when intercropping sugar beet with onion, while the lowest were done when sugar beet intercropping with faba bean. Besheit *et al.* (2002) showed that the highest sugar beet quality and productivity were obtained from beet planted on ridge (100 cm) width and intercropped with two onion rows, while intercropping onion on the other side of sugar beet ridge (50 cm) width was higher and negativity affected sugar beet quality and quantity.

Therefore, the present study aimed at finding out the effect of intercropping onion with sugar beet on yield and quality of sugar beet as well as on land equivalent ratio and the net income.

MATERIALS AND METHODS

Two field experiments were conducted in the Experimental Farm, Faculty of Agriculture, Assiut University, during two winter growing seasons of 2011-2012 and 2012-2013, to study the relative advantage of intercropping systems of sugar beet (*Beta vulgaris* L.) with onion (*Allium cepa* L.) on the growth, yield and yield components of the two crops intercropping parameters are also considered. Some physical and chemical properties of a representative soil sample used in the experimental soil were determined before preparation according to Jackson, 1973 and presented in Table 1.

The recommended dose of phosphorus fertilization was applied at a level 100 kg calcium superphosphate fed^{-1} (15.5% P_2O_5) during preparation. The experimental design was a randomized complete block with five treatments replicated thrice. The area of each plot was

Table 1: Some physical and chemical properties of a representative soil samples in the experimental site before sowing (0-30 cm depth) in 2011-2012 and 2012-2013 seasons

Character	2011-2012	2012-2013
Particle size distribution		
Silt (%)	27.7	26.8
Sand (%)	25.7	24.4
Clay (%)	48.4	48.8
Texture	Clay silty	Clay silty
Organic matter (%)	1.84	1.82
Field capacity (%)	42.60	43.6
EC (1:1 extract) (dS m^{-1})	0.88	0.85
pH (1:1 suspension)	7.60	7.82
Total nitrogen (%)	0.78	0.74
CaCO (%)	3.46	3.68
Extractable P (ppm)	8.50	8.72
Extractable K (ppm)	122	123

*Each value represents the mean of three replications

10.5 m^2 (3 m length×3.5 m width), with 4 ridges 85 cm width, 3 m in length. Sowing took place on 2nd and 5th October 2011-2012 and 2012-2013, respectively. Seed halls of multigerm cultivar (Gloria cv.) were sown in hills 20 cm apart at using 3-4 seed halls $hill^{-1}$. In the two growing seasons, seeds of sugar beet crop were planted in one side of the ridge and after 25 days onion seedlings (Giza-6 cv.) were transplanted into other side of ridge as the following.

Intercropping systems:

- Pure stand of onion (on both sides of ridges, 10 cm between hills)
- Intercropping onion on the other sides of one sugar beet ridge and leaving ridge three without intercropping (O+B, 1:4 ridges)
- Intercropping onion on the other sides of two sugar beet ridges and leaving two ridges without intercropping (O+B, 2:4 ridges)
- Intercropping onion on the other sides of three sugar beet ridges and leaving one ridges without intercropping (O+B, 3:4 ridges)
- Intercropping onion on the other sides of all sugar beet ridges (O+B, 4:4 ridges)
- Pure stand of sugar beet. (solids culture)

Sugar beet plants were thinned to one plant per hill after 25 days from planting. Nitrogen fertilizer was added at a level 100 kg N fed^{-1} in the form of urea (46.5% N) were added in two equal doses. The first one was applied after thinning and the other one 21 days later. Potassium fertilizer in the form of potassium sulphate (48% K_2O) was applied in one dose after thinning. The preceding crop was sorghum in the two seasons. The other cultural practices were carried out as recommended (feddan = 4200 m^2).

At harvest (200 days from sowing), plants of each plot were harvest to determine roots and foliage yield (ton fed^{-1}). A sample of 25 kg of roots were taken at random from each plot and sent to the Beet Laboratory at Abo-Korkas Sugar Factory, to determine root quality.

Sugar beet growth and quality:

- Top fresh weight $plant^{-1}$(g)
- Root fresh weight $plant^{-1}$(g)
- Root length (cm)
- Root diameter (cm)
- Root yield ton fed^{-1}: was taken from one ridge and repeated 3 times for each treatment
- Sucrose% (Pol%) was estimated in fresh samples of sugar beet root using Saccharometer according to the method described by AOAC (1995)
- Purity%
- Sugar yield ton fed^{-1}
- Gross sugar yield (ton fed^{-1}) = root yield (ton fed^{-1}) X sucrose%

Onion growth: At 90 days from transplanting the onion traits were determined, i.e. plant height (cm), number of leaves, bulb diameter (cm), neck diameter (cm) bulbing ratio and bulb yield (g).

Competitive relationships and yield advantages: The following parameters were calculated:

- **Land equivalent ratio (LER):** This was determined according to Willey (1979):

$$LER = \frac{yab}{yaa} + \frac{yba}{ybb}$$

Where:
yab = Mixture yield of a (when combined with b)
yaa = Pure stand yield of crop (a)
yba = Mixture yield of b (when combined with a)
ybb = Pure stand yield of crop (b)

- **Aggressivity (A):** Aggressivity values were determined according to McGilchrist (1965):

$$Aga = \frac{yab}{yaa \times zab} - \frac{yba}{ybb \times zba}$$

$$Agb = \frac{yba}{ybb \times zba} - \frac{yab}{yaa \times zab}$$

Where:
Aga = Aggressivity value for sugar beet
Agb = Aggressivity value for onion
zab = Sown proportion of sugar beet (in mixture with onion)
zba = Sown proportion of onion (in mixture with sugar beet)

- **Economic evaluation**
  - **Gross return (L.E. fed^{-1}):** Gross return from each treatment was calculated in Egyptian pounds (L.E.)/ton of sugar beet and (L.E.)/ton of onion in both seasons as follows:

Ton of sugar beet = 350 L.E and Ton of onion = 1500 L.E for both seasons

Price of sugar beet was obtained by Egyptian Sugar and Integrated Industries Company and price of onion was obtained by market search.

Statistical analysis: Statistical analysis of the collected data was carried out using the computer program MSTAT-C package by Freed *et al*. (1988) according to Gomez and Gomez (1984). Barlett test was used to assess the variance of experimental error of both seasons. Least significant difference (LSD 5%) was used for comparison among the means.

RESULTS AND DISCUSSION

Effect of intercropping patterns on yield components of sugar beet: Data presented in (Table 2) indicated that sugar beet yield and its components were not significantly decreased by intercropping with onion comparing with pure stand. Nevertheless the yield of sugar grown in monoculture was slightly high than obtained from any intercrop combination under study.

Sugar beet characters i.e., top fresh weight plant^{-1}, root fresh weight plant^{-1}, root diameter (cm) and sugar yield (ton fed^{-1}) were highly significantly affected by intercropping sugar beet with onion in both seasons, while root length (cm), root yield ton fed^{-1} and purity% were not significantly affected by intercropping sugar beet with onion in both seasons. Also results indicate that

Table 2: Effect of intercropping sugar beet with onion on some sugar beet characters grown in 2011-2012 and 2012-2013 seasons

Intercropping systems	Top fresh weight plant^{-1} (g)		Root fresh weight plant^{-1} (g)		Root length (cm)		Root diameter (cm)		Root yield ton fed^{-1}	
	2011-2012	2012-2013	2011-2012	2012-2013	2011-2012	2012-2013	2011-2012	2012-2013	2011-2012	2012-2013
T_1	235.0	213.3	1070.0	1066.7	24.87	24.47	9.23	8.43	29.42	27.71
T_2	210.0	206.7	1010.0	930.0	25.47	25.53	8.17	7.43	28.55	26.98
T_3	195.0	201.7	991.7	880.0	25.87	25.60	7.60	6.83	28.27	26.74
T_4	186.7	186.7	885.0	816.7	26.17	26.10	6.43	5.73	28.28	26.41
T_5	175.0	168.3	815.0	773.3	26.67	26.37	5.67	5.10	27.45	25.9
LSD 5%	17.27	21.67	70.81	89.15	ns	ns	0.77	0.86	ns	ns

ns: Not Significant

Table 3: Effect of intercropping sugar beet with onion on the sugar beet quality grown in 2011-2012 and 2012-2013 seasons

Intercropping systems	Sugar yield ton fed^{-1}		Sucrose (%)		Purity (%)		Gross sugar yield (ton fed^{-1})	
	2011-2012	2012-2013	2011-2012	2012-2013	2011-2012	2012-2013	2011-2012	2012-2013
T_1	4.33	4.17	18.77	19.20	88.27	88.03	5.69	5.32
T_2	4.10	3.93	18.37	18.87	86.63	87.43	5.35	5.09
T_3	3.91	3.84	18.70	18.77	86.43	87.07	5.29	5.02
T_4	3.83	3.76	18.40	18.20	86.73	86.80	5.20	4.81
T_5	3.73	3.68	18.37	18.17	86.70	86.73	5.04	4.70
LSD 5%	0.185	0.15	ns	0.73	ns	ns	0.38	0.44

ns: Not significant

sucrose% of sugar beet was not significantly affected by intercropping sugar beet with onion in the first season, while it was highly significantly in the second season (Table 3).

Besheit *et al.* (2002) revealed that intercropping onion at various densities on both ridge widths (50 and 100 cm) had insignificant effect on most quality and productivity traits in both seasons except pol% (in the first season), extractable sugar, extractability % and sugar yield ton fed^{-1} (in both seasons). The highest sugar beet quality and productivity were obtained from beet planted on 100 cm ridge width and intercropped with two onion rows, while intercropping onion on the other side of beet ridge 50 cm width was high and negatively affected beet quality and productivity. Abou Khadra *et al.* (2013) found that a significant difference among intercropping systems in top, root and sugar yields and their attributes as well as root quality in the two seasons. Decreasing density of wheat increased root length, root diameter, root yield, top yield, total sugar%, white sugar% and juice purity%, while it decreased concentration of impurities, alkalinity coefficient and losses sugar%. Root and sugar yields fed^{-1} produced by solid beet plants and its intercropped with wheat at hills 80 cm apart were practically the same and significantly surpassed those intercropped with wheat at hills 20 cm apart in both seasons.

Similar results were recorded by Abd-El-All (2002), Farghaly *et al.* (2003), El-Shaikh and Bekheet (2004), Gadallah *et al.* (2006) and Hussein and Yousrya (2012).

Effect of intercropping systems on yield components of onion: Data presented in (Fig. 1-6) show that the associated cropping patterns of onion with sugar beet on yield and its components of onion crop, plant height, number of leaves, bulb diameter, neck diameter and weight of bulb, were significant decreased by intercropping. These results may be due to competition between sugar beet and onion plants for nutrient, carbon dioxide, moisture and solar radiation. Plant height of onion was more affected at the T_4 and T_5 treatments of intercropping as compared with solid (Fig. 1).

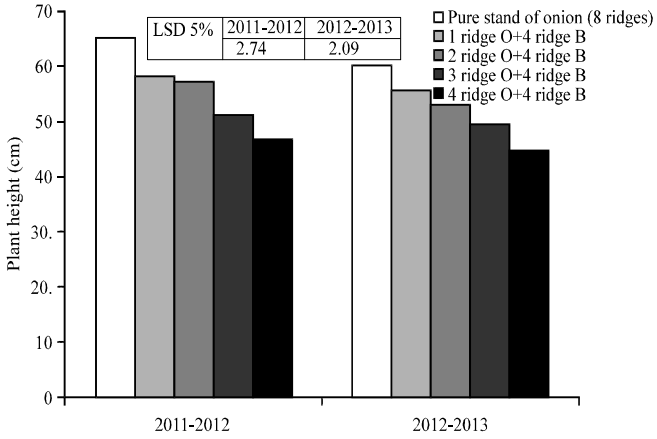

Fig. 1: Plant height (cm) of onion as affected by intercropping with sugar beet

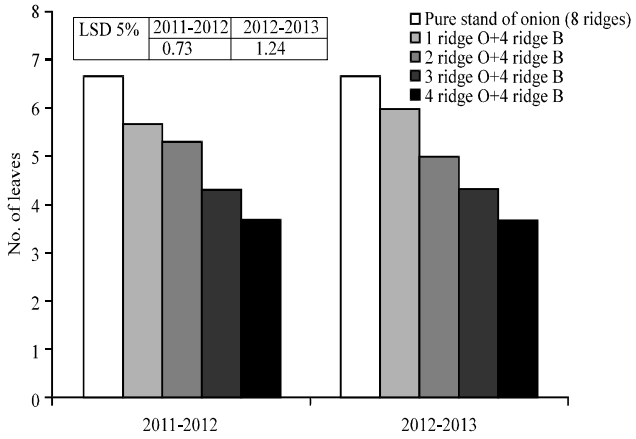

Fig. 2: No. of leaves of onion as affected by intercropping with sugar beet

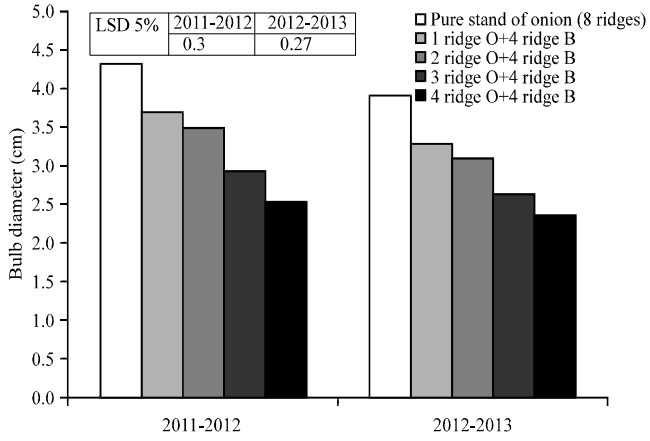

Fig. 3: Bulb diameter (cm) of onion as affected by intercropping with sugar beet

Concerning bulb yield of onion, the results indicated that, significant reduction was observed by intercropping sugar beet with onion, compared to onion pure stand. The highest values of the

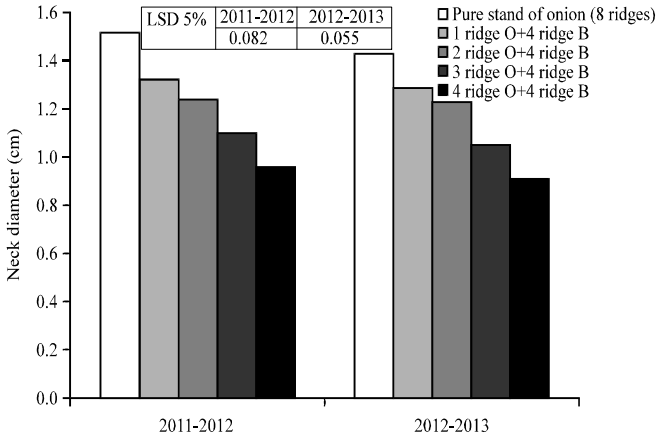

Fig. 4: Neck diameter (cm) of onion as affected by intercropping with sugar beet

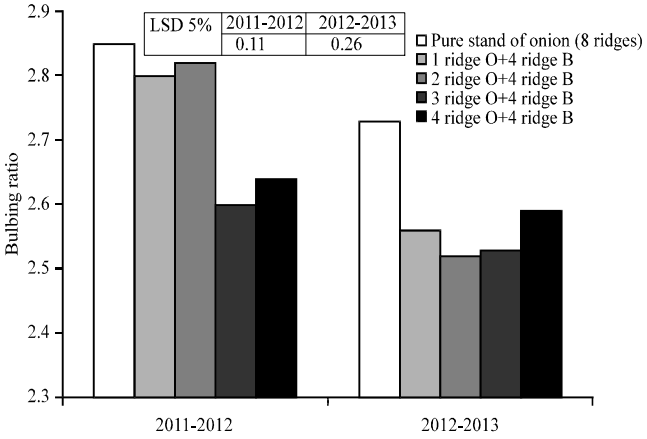

Fig. 5: Bulbing ratio of onion as affected by intercropping with sugar beet

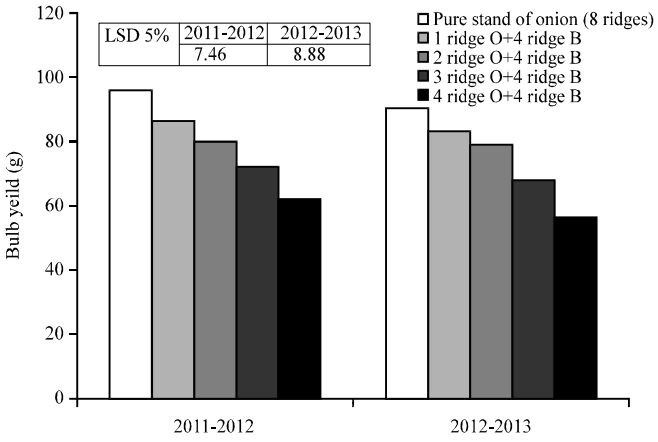

Fig. 6: Bulb yield (g) of onion as affected by intercropping with sugar beet

bulbs diameter (Fig. 3) were 4.29 cm and 3.91 cm while the lowest values were 2.54 cm and 2.37 cm first and second seasons, respectively. The highest values of bulb weight (Fig. 6) were

96.0 and 90.67 g, while the lowest values were 62.67 and 57.0 g first and second seasons, respectively. These results may be due to inter and intra- competition between plants of sugar beet and onion for light. The reduction in yield of intercropping onion with sugar beet was mainly due to shading effect of sugar beet. This reduction in intercropping treatment may be due to inter specific competition between onion and sugar beet and intra competition between onion plants. Similar results were recorded by El-Kafoury *et al.* (1993) and Marey (2003) who found that the intercropping resulted in a significant decrease in number of leaves plant^{-1}, top weight plant^{-1}, root length, root diameter, root weight and yield of top or root fad^{-1}.

Effect of intercropping systems on competitive relationships and yield advantages

Aggressivity (Ag): The results in Table 4 showed that, aggressivity sugar beet was dominant crop under interaction treatments whereas onion was the dominated one in the both seasons. The highest Ag values were from the intercropping in one ridge of onion with all sugar beet ridges whereas the lowest Ag values obtained from all onion and sugar beet ridges intercropping in the both seasons. The present results indicate clearly that onion has lower competitive abilities than sugar beet. These results agree with these obtained by El-Kafoury *et al.* (1993), Farghaly *et al.* (2003) and Abou-Elela and Gadallah (2012).

Land equivalent ratio (LER): Results in Table 4 indicated that intercropping onion with sugar beet increased land equivalent ratio in all intercropping patterns. Highest land equivalent ratio value (1.85) was recorded due to (T_2) treatment in the first season, while the lowest land equivalent ratio value (1.35) was found by in the (T_5) treatment in the second season. Generally, LER value was greater than 1.0 for all intercropping patterns. This showed that the actual productivity was higher than the expected productivity when sugar beet with onion. Farghaly *et al.* (2003), found that yield of sugar beet intercropped with onion, faba bean and chickpea were reduced by intercropping. The highest values for LER were observed when intercropping sugar beet with onion, while the lowest values were done when intercropping sugar beet with faba bean. Abou Khadra *et al.* (2013) showed that land equivalent ratio (LER) values were greater than one at any intercropping systems. Intercropping sugar beet and wheat increased land usage by 37, 35, 31 and

Table 4: Effects of intercropping sugar beet with onion on land equivalent ratio (LER), aggressivity (Ag) and gross return (L.E. fed^{-1}) in 2011-2012 and 2012-2013 seasons

	Land equivalent ratio		Gross return (L.E. fed^{-1})	
	2011-2012	2012-2013	2011-2012	2012-2013
T_2	1.85	1.80	26137	24659
T_3	1.76	1.70	24293	23303
T_4	1.58	1.52	23149	22448
T_5	1.41	1.35	21832	20574
	2011-2012		2012-2013	
	Ag (S)	Ag (O)	Ag (S)	Ag (O)
T_2	0.667	-0.667	0.708	-0.708
T_3	0.218	-0.218	0.236	-0.236
T_4	0.077	-0.077	0.057	-0.057
T_5	0.014	-0.014	0.029	-0.029

33% over monocultures of both crops at wheat hill spacing of 20, 40, 60 and 80 cm. Similar results were recorded by Khedr and Nemeat Alla (2006), Attia *et al.* (2007) and Abou-Elela and Gadallah (2012).

Economic evaluation

Gross return (L.E. fed^{-1}): Data presented in Table 4 showed that, the highest value of gross return (26137 L.E. fed^{-1}) was recorded due to (T_2) treatment in the first season, while the lowest gross return (20574 L.E. fed^{-1}) was found by in the (T_5) treatment in the second season. Hussein and El-Deeb (1999) showed that intercropping faba bean at a density of 4 plant m^2 with sugar beet increased profitability by L.E 12.5% than solid sugar beet. Toaima *et al.* (2001) recorded that higher yield was observed when intercropping system was 120 cm width ridges higher LER were (1.56, 1.51) for onion, (1.53, 1.52) for garlic and total income (3174, 3154 L.E) for onion and (4103, 4120 L.E) for garlic in both seasons, respectively.

These results are in accordance with those obtained by Besheit *et al.* (2002) reported that all intercropping treatments increased markedly farmer net return and profitability per unit capital input (one Egyptian pound), but intercropping two or three rows of onion on wide ridge of beet maximized those traits.

CONCLUSION

Root yield of sugar beet was not significantly decreased by intercropping with onion comparing with pure stand. Effect the associated cropping patterns of onion with sugar beet on yield and its components of onion crop were significant decreased by intercropping. The highest values of land equivalent ratio and gross return were observed when sugar beet intercropping with onion as compared to mono crops of either species. These findings suggest that intercropping sugar beet and onion increase total productivity per unit area improve land equivalent ratio.

This investigation showed that grown sugar beet intercropping with onion gave the highest economic return for the farmers.

REFERENCES

AOAC, 1995. Official Methods of Analysis. 16th Edn., Association of Official Analytical Chemists, Washington, DC., USA.

Abd-El-All, A.M., 2002. Weed control treatments for different intercropping systems of sugar beet and faba bean. J. Agric. Sci. Mansoura Univ., 27: 8081-8092.

Abou Khadra, S.H., A.E.B. Shaimaa, E.A.T. Salah and E.E.E. Dina, 2013. Effect of intercropping wheat with sugar beet on their productivity and land use. J. Agric. Res. Kafr El-Sheikh Univ., 39: 37-53.

Abou-Elela, A.E.A.M. and R.A. Gadallah, 2012. Effect of transplanted seedling age of intercropped fodder beet with faba bean and nitrogen fertilizer levels on, yield and it's component of fodder beet and faba bean. Zagazig J. Agric. Res., 39: 1057-1067.

Ahmed, S.E., A.M. Abou-Salama, G.R. El-Naggar and F.M.F. Abdel-Motagally, 2009. Studies on legume-black cumin intercropping. Egypt. J. Appl. Sci., 24: 553-563.

Attia, A.N.E., E.M. Said, M.H. Ghonima and M.E.M. Ibrahim, 2007. Impact of nitrogen levels on growth and yield of sugar beet intercropping with faba bean and wheat. J. Agric. Sci. Mansoura Univ., 32: 779-792.

Besheit, S.Y., A.M. Abo Elwafa, A.S. Abo El- Hamd and M.A. Bekheet, 2002. Quality and productivity of sugar beet as affected by intercropping onion in various densities. Al-Azhar J. Agric. Res., 36: 87-101.

El-Kafoury, A.K., F.M. Seif El-Nasr and A.M. Hegazy, 1993. An agritechnique for intercropping onion with cotton. Minufiya J. Agric. Res., 18: 981-996.

El-Shaikh, K.A.A. and K.A.A. Bekheet, 2004. Effect of intercropping faba bean and garlic on sugar beet in the newly reclaimed soils. Assiut. J. Agric. Sci., 35: 187-204.

FAO, 2012. C.F. Computer research. Food and Agricultural Organization. http://faostat.fao.org.

Farghaly, B.S., A.A. Zohry and S.A.A. Bssaly, 2003. Crop management for intercropping sugar beet with some essential crops to maximize area unit productivity. J. Agric. Sci. Mansoura Univ., 28: 5183-5199.

Freed, M., S. Eisensmith, S. Goetz, D. Reicosky, V. Smail and P. Wolberg, 1988. User's Guide to MSTAT-C: A Software Program for the Design Management and Analysis of Agronomic Research Experiments. Department of Crop and Soil Sciences and Department of Agriculrural Economics, Michigan State University, USA., Pages: 152.

Gadallah, R.E., A.M. Abdel-Galil and F.R. Nawar, 2006. Maximizing productivity by intercropping some winter crops on sugar J. Agric. Sci. Mansoura Univ., 31: 2601-2614.

Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agriculture Research. 2nd Edn., John Wiley and Sons, New York, USA., ISBN-13: 9780471870920, Pages: 680.

Hussein, A.H.A. and M.A. El-Deeb, 1999. Evaluation of intercropping faba bean, chickpea and lentil with sugar beet in Middle Egypt. Arab Univ. J. Agric. Sci. Ain-Shams, Univ., 7: 475-482.

Hussein, M.M.M. and S.A.M. Yousrya, 2012. Effect of intercropping flax in different seeding rates in fields of sugar beet under nitrogen fertilization levels on yield, quality and land use efficiency attributes. Zagazig J. Agric. Res., 39: 9-29.

Jackson, M.L., 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi, India.

Khedr, A.H. and E.A.E. Nemeat Alla, 2006. Response of barley to intercropping with sugar beet under different nitrogen fertilization levels. J. Agric. Sci. Mansoura Univ., 31: 4957-4968.

Li, L., S.C. Yang, X.L. Li, F.S. Zhang and P. Christie, 1999. Interspecific complementary and competitive interactions between intercropped maize and faba bean. Plant Soil, 212: 105-114.

Marey, R.A., 2003. Effect of intercropping of faba bean of chickpea on sugar beet. Ph.D. Thesis, Faculty of Agriculture-Assuit University, Egypt.

McGilchrist, I.A., 1965. Analysis of competition experiments. Biometrics, 21: 975-985.

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.

Willey, R.W., 1979. Intercropping its importance and research needs. Part I. Competition and yield advantages. Field Crop Abst., 32: 1-10.

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