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Productivity, land equivalent ratios and water use efficiency of intercropping corn with soybean in Egypt.

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ABSTRACT

The present investigation was carried out at Giza Agricultural Experiments and Research Station, Faculty of Agriculture, Cairo University, Egypt during the two successive summer seasons 2015 and 2016 to determine yield, WUE and LERs of intercropping soybean with corn at beds 140 cm width as compared with solid plantings of traditional ridges 70 cm width. The experiment included eighteen treatments which were the combinations between three applied irrigation water (75, 100 and 125% of the recommended applied water) and six cropping systems (2 intercropping systems: 100% corn with 50 and 100% soybean plants) and 2 solid plants of corn and soybean which were grown on beds, compared to 2 solid plantings, as traditional on ridges. The experimental design was split plot design with four replications. The data indicated that soybean seed yields per plant and per ha were reduced significantly by intercropping with corn. Than solid plantings, increasing soybean plant density at intercropping unit area from 50 to 100% as that of solid culture achieved high seed yield without any significant reduction on corn grain yield. Also, corn yield was not affected significantly by cropping systems Each of applied level irrigation water and the interaction between applied irrigation water and cropping systems did not affect soybean seed yield; but the converse was true for corn. Corn yield was increased significantly by raising applied water from 75 to 125%. Corn yield was increased significantly with high level of applied irrigation water, but it was not affected with solid systems. Land equivalent ratios (LERs) were not affected significantly by applied levels of irrigation water but the converse were true for cropping systems and the interaction between previous factors. LERs of intercropping culture ranged between 1.39 and 1.52 as compared to solid plantings (1.0). Water use efficiency (WUE) was increased by decreasing applied irrigation water levels from 125 to 75% of recommended irrigation water level. High population densities of the intercrops with application 100% of applied irrigation water achieved the highest LER as well as WUE and could be recommended for Egyptian farmers.

Keywords: Intercropping, Soybean, Corn, WUE, LER.

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INTRODUCTION

Population growth always requires an increase in the use of available environmental resources around the world. It is considerable pressure on available environmental resources especially water that is one of the major factors in arid and semiarid regions **(Zadeh and Mousavi, 1996)**. Moreover; the limited water resources in Egypt are most pressing factors of water issues. However, increased cropping systems to meet world demands will require an increase of 40% in the area of harvest major crops by 2030, and that the amount of water allocated to irrigation must increase correspondingly by 14% **(UNESCO, 2006)**. Accordingly, the threat of insufficient food supply in the near future encourages intensification of the search for more productive agricultural techniques by increasing water use efficiency (WUE). The ratio of water used in plant metabolism to water lost by the plant through transpiration under different cropping systems should be considered. Although availability of water can limit crop production **(Genc *et al*., 2013)**, but improving WUE is necessary for securing environmental sustainability of food production in semiarid areas with respect to population growth **(Medrano *et al*., 2015).** The current population of Egypt is 94,779,988 based on the latest United Nations estimation. Hence, Egyptian population is equivalent to about 1.27% of the total world population **(Worldometers population, 2017)**.

Certainly, output improvement in cropping systems must be related to the better use of resources especially water and light. Several different cropping systems are followed in the Nile Valley and Delta areas of Egypt, depending on the soil type and crops; however, the low size of cultivated land per farmer is one of the most problems associated with the cropping systems. Consequently, the cropping system adopted by the farmer under these environments must be physically viable, sustainable, less exhaustive acceptable to farming community and most important thing is that it should be economical. In addition, Egyptian farmer is very responsive to technology transfer, extension activities and price incentives for a successful cropping system such as intercropping soybean (*Glycine max* L.) with corn (*Zea mays* L.). The intercropping is one of the agricultural strategies for increasing water productivity to make maximum use of soil moisture **(Alizadeh A, 2001)**. In this concern, intercropping soybean with corn was the successful example to save irrigation water **(Ouda *et al*., 2007 and Gaballah and Ouda, 2008)** and increase each of land and net equivalent ratios **(Metwally *et al*., 2008; Metwally *et al*., 2012; Abdel-Galil *et al*., 2014a and Abdel-Wahab and Abd El-Rahman, 2016)**.

In Egypt, there is a modern trend for growing crops on beds (100 – 140 cm width) according to population densities of field crops (wheat, corn, cotton, soybean, ----etc.) to save irrigation water by about 15% compared by traditional practice on ridges 60-70 cm in width **(Abouelenein *et al.*, 2009 and Ahmad *et al.*, 2009)**. So, it is important to address our efforts to this fundamental issue by increasing WUE with intercropping soybean with corn in the Nile Valley and Delta areas. Therefore, the objective of this investigation was to determine productivity, WUE and LERs of intercropping soybean with corn in beds as compared with solid plantings of traditional ridges.

MATERIAIS AND METHODS

A two-year study was carried out at Giza Agricultural Experiments and Research Station, Faculty of Agriculture, Cairo University, Giza, Egypt during two successive summer seasons (2015 and 2016). The main factors were three levels of applied irrigation water (6069, 8092 and 10115 m^3/ha) and six cropping systems of solid and intercropping corn and soybean. Eighteen treatments were the combinations of the previous factors (Figure 1) as follows:

Intercropping systems

a. Corn plants were grown in both sides of beds 140 cm width by growing two plants/hill distanced 50 cm apart, meanwhile two rows of soybean were grown in middle of the bed (2 plants/hill distanced 15 cm apart). This pattern was expressed as 50% soybean + 100% corn plants.
b. Corn plants were grown in both sides of beds 140 cm width by growing two plants/hill distanced at 50 cm apart, meanwhile four rows of soybean were grown in middle of the bed (2 plants/hill distanced 15 cm apart. This pattern was expressed as 100% soybean + 100% corn plants.

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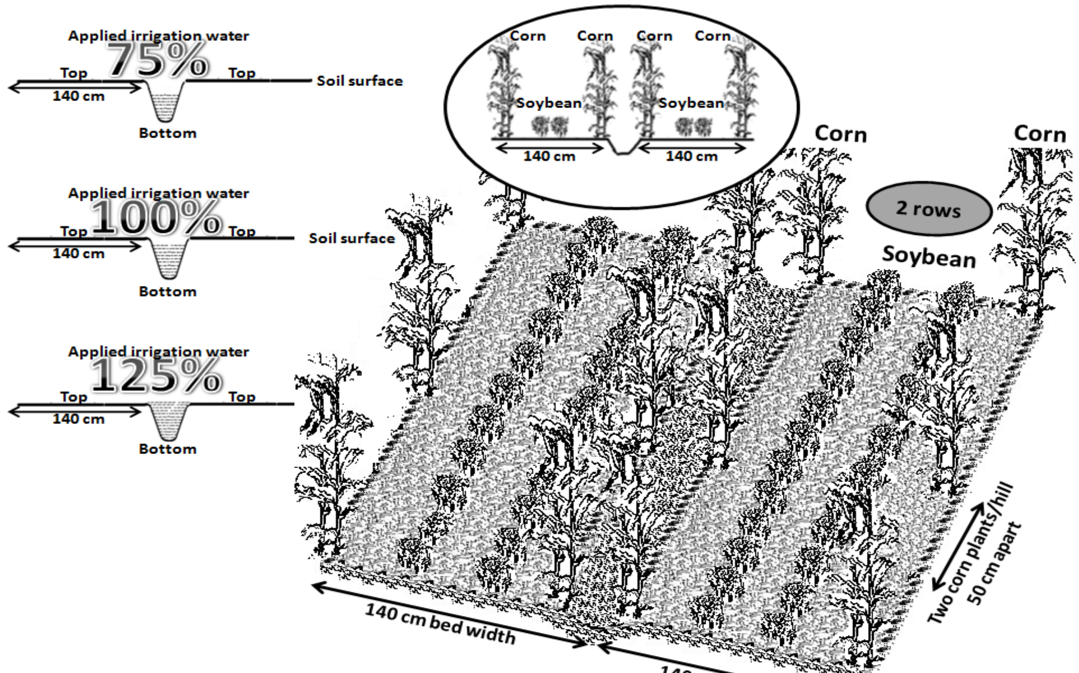
Traditional solid systems

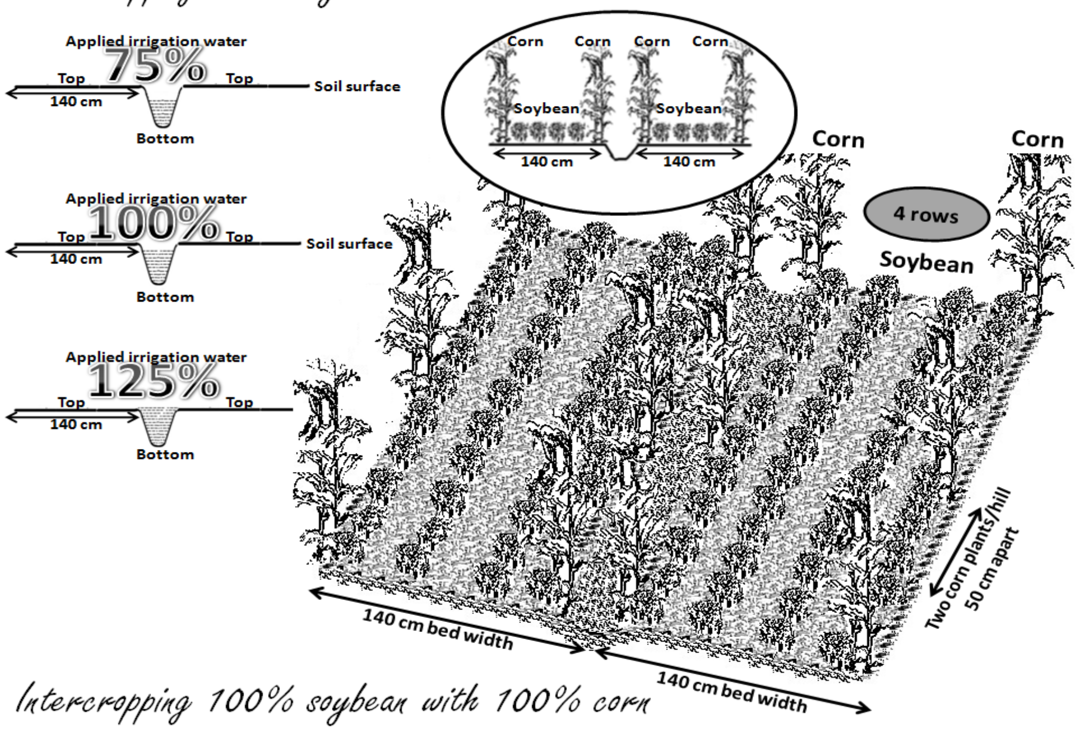
a. Traditional solid corn: Pure stand of corn on ridges was conducted by leaving one plant/hill with distance 25 cm apart resulted in 57120 plants/ha on ridges 70 cm width.
b. Traditional solid soybean: Pure stand of soybean on ridges was conducted by drilling 2 rows/ridge. Soybean was thinned to 2 plants distanced 15 cm between hills resulted in 380,800 plants/ha on ridges 70 cm width.

Modern solid systems

a. Solid corn as mixed system: Leaving two plant/hill with distance 50 cm apart resulted in 57,120 plants/ha on beds 140 cm width.



Intercropping 50% soybean with 100% corn



Intercropping 100% soybean with 100% corn

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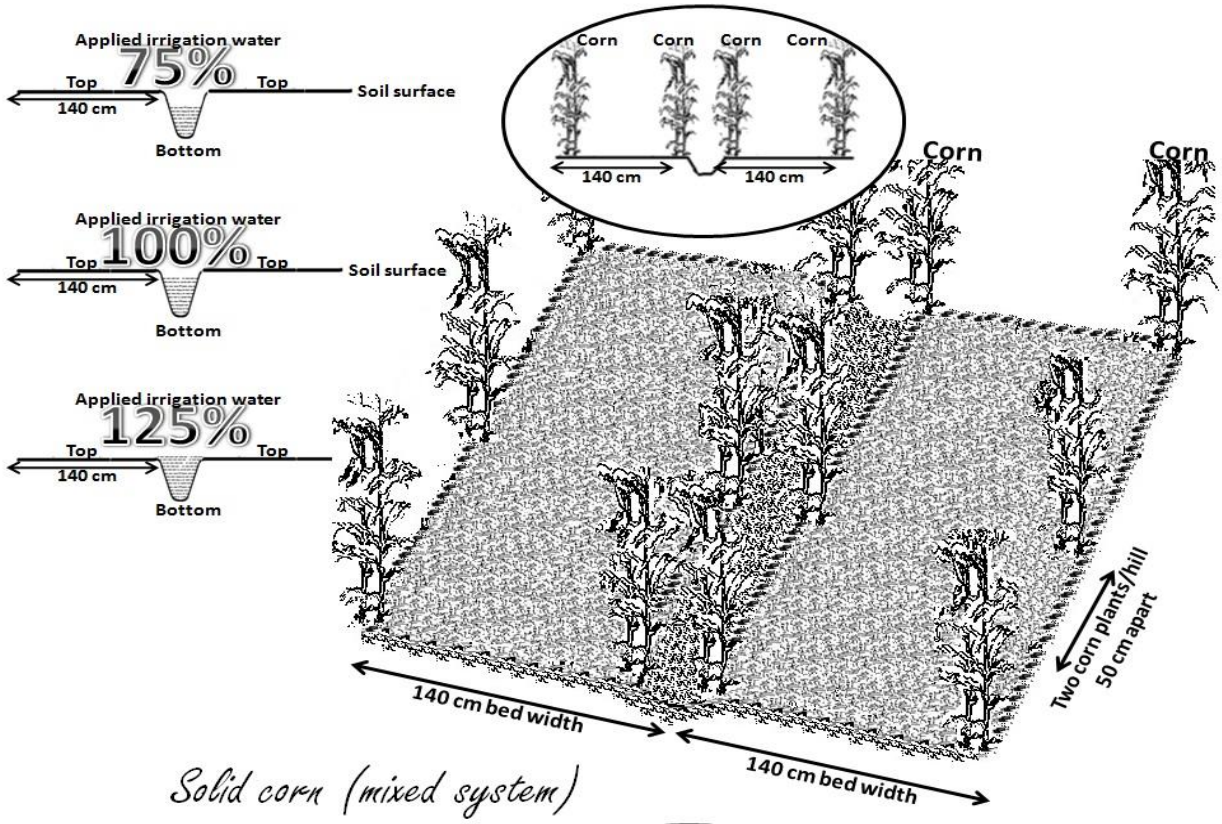
Figure 1: Intercropping soybean with corn and solid cultures of both crops.



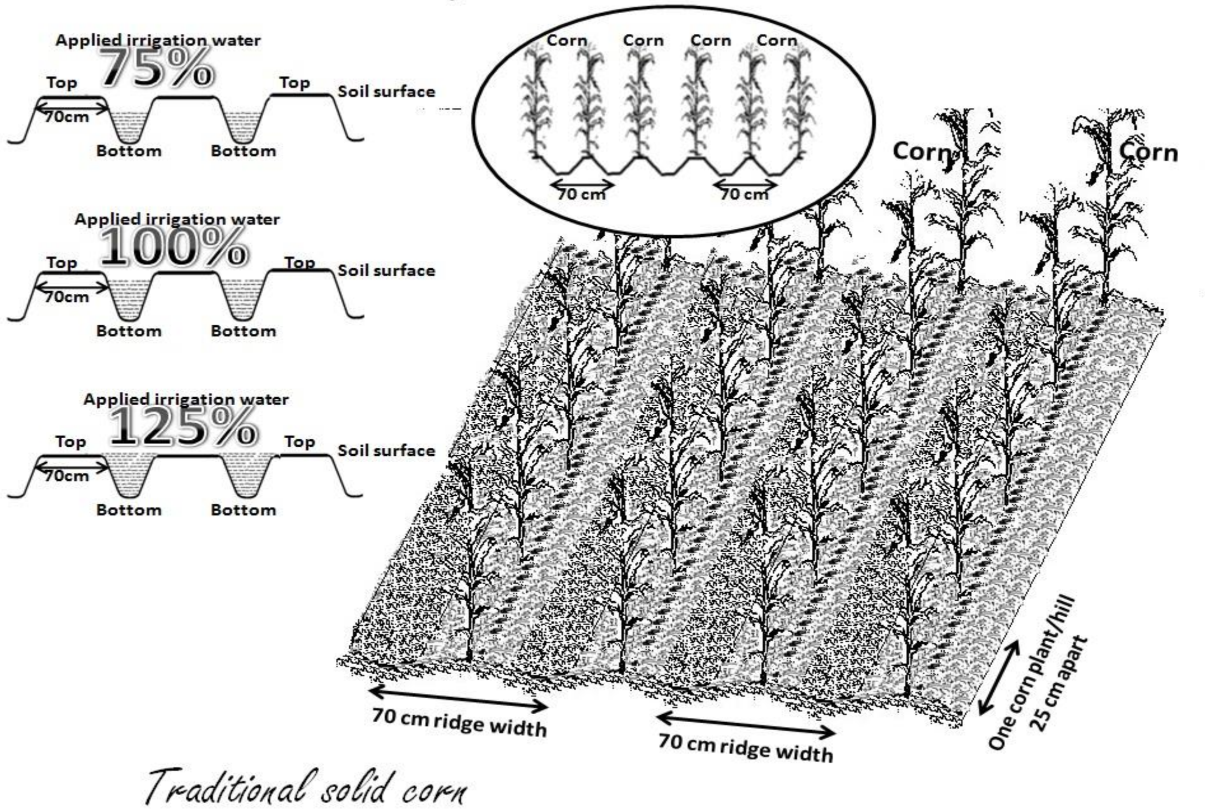


Figure 1: Continued

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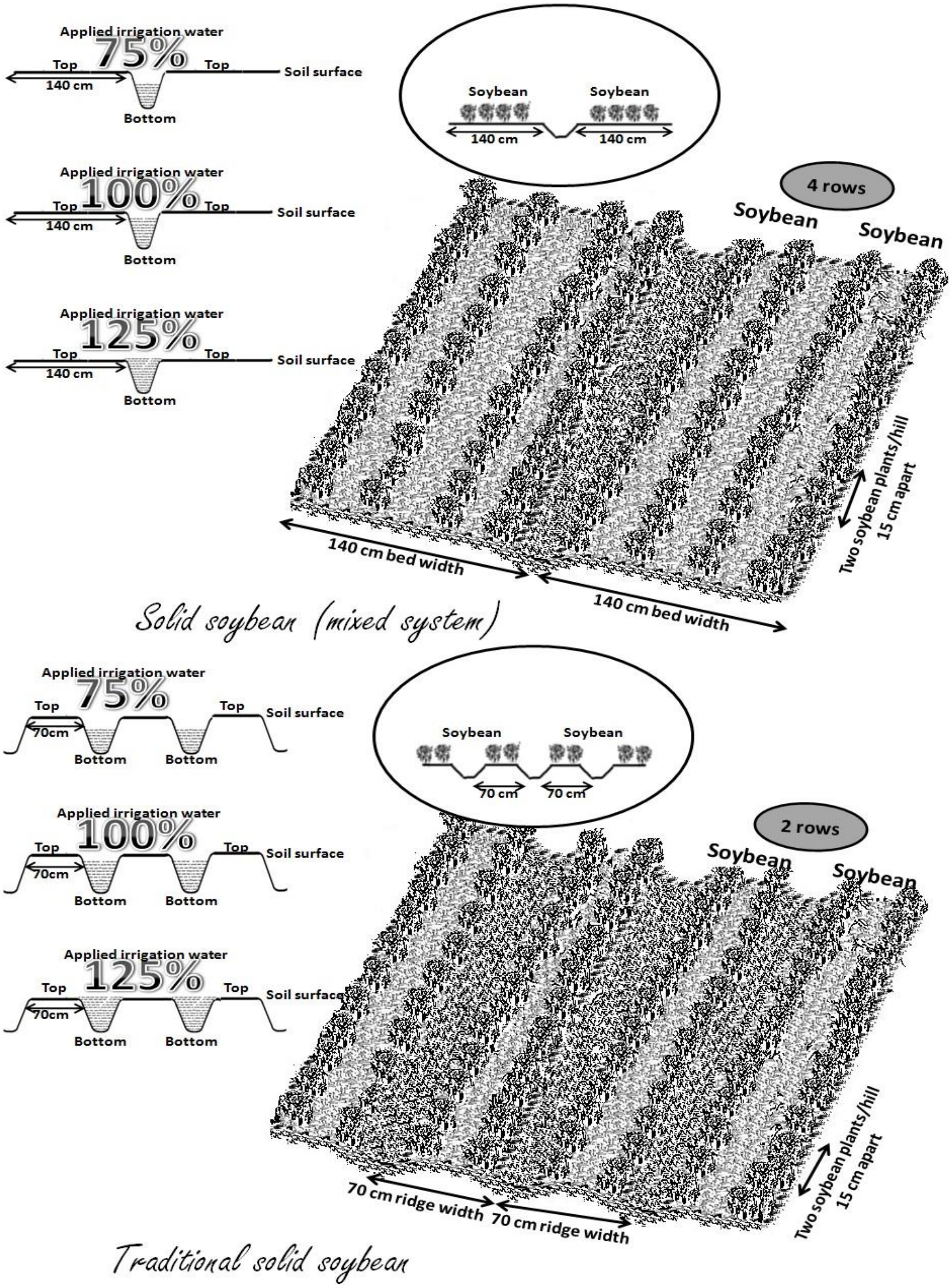

Figure 1: Continued

b. Solid soybean as mixed system: Soybean was planted by drilling 4 rows on beds 140 cm width. Soybean was thinned to 2 plants at 15 cm between hills resulted in 380800 plants/ha.

The previous cropping systems were received three levels of applied irrigation water (6069, 8092 and 10115 m^3/ha).

Corn variety (S.C.130) and soybean variety (Giza 111) were used in this study. Recommended solid cultures of soybean and corn were used to estimate the competitive relationships.

Furrow irrigation is the traditional irrigation system in the area with growing corn in ridges 70 cm width. Corn grains of this experiment were sown at 18th and 19th May in 2015 and 2016, respectively, and soybean seeds were sown at 25th and 26th May in 2015 and 2016 seasons, respectively. The treatments were laid out in split plot design with four replicates. Applied irrigation water was randomly assigned to the main plots and cropping systems were allocated in sub-plots. The area of each sub plot was 16.8 m^2, each plot consisted of 6 ridges for traditional system and 3 beds (140 cm) for intercropping system and solid plantings in modern systems and 4.0 m in length. All cultural practices of experimental crops were applied as recommended in the region.

The studied characters

Corn characters

1. Ten guarded corn plants were taken at random from each sub plot at 90 days from sowing corn to estimate LAI through determine leaf area by leaf length x leaf width x 0.75 according to **Francis *et al.* (1969)**. LAI = total leaf area per plant in cm^2 / land area per plant in cm^2.
2. Ten plants at harvest were taken at random from each sub plot to determine corn grain yield per plant (g).
3. Corn grain yield per ha (ton) were determined from grain weight of each sub plot and converted to ton per ha.

Soybean characters

1. Ten soybean plants were taken randomly from each sub plot at 90 days from sowing soybean to estimate leaf area index (LAI) through determine leaf area by the disc method of **Johnson (1967)**. LAI = leaf area per plant in cm^2 / land area per plant in cm^2.
2. Ten guarded plants at harvest were chosen at random from each sub plot to determine soybean seed yield per plant (g).
3. Soybean seed yield per ha (ton) were determined from seed weight of each sub plot and converted to ton per ha.

Land equivalent ratio (LER)

Land equivalent ratio (LER): It defines as the ratio of area needed under sole cropping to one of intercropping at the same management level to produce an equivalent yield **(Mead and Willey, 1980)**. It is calculated as follows: LER = $(Y_{ab} / Y_{aa}) + (Y_{ba}/ Y_{bb})$; where Y_{aa} = Pure stand yield of crop a (corn), Y_{bb} = Pure stand yield of crop b (soybean), Y_{ab} = Intercrop yield of crop a (corn) and Y_{ba} = Intercrop yield of crop b (soybean).

Water relations

Irrigation water use efficiency (IWUE) values were calculated according to **Bhattarai *et al*. (2006)** as follow: IWUE = (Ey/ Ir). Where IWUE is irrigation water use efficiency (kg/m^3), Ey is the economical yield (kg/ha) and Ir is the amount of applied irrigation water (m^3).

Statistical analysis

Analysis of variance of the obtained results of each season was performed. The homogeneity test was conducted of error mean squares and accordingly, the combined analysis of the two experimental seasons was carried out. The measured variables were analyzed by ANOVA using MSTATC statistical package **(Freed, 1991)**. Mean comparisons were done using least significant differences (L.S.D) method at 5 per cent level of probability to compare differences between the means **(Gomez and Gomez, 1984)**.

RESULTS AND DISCUSSIONS

Soybean growth

Effect of applied irrigation water

Soybean LAI was affected significantly by levels of applied irrigation water in the combined data across the two seasons (Table 1). The improvement of soil water conditions by using the highest applied irrigation water achieved higher (*$P \leq 0.05$*) LAI than the lowest applied irrigation water. It is important to mention that there were no significant differences either between 75 and 100% of recommended applied irrigation water or between 100 and 125% (Table 1) These findings may be attributed to the genetic bases of soybean variety under different irrigation water treatments. The highest applied irrigation water integrated positively with soybean to have more leaf area and covered unit ground surface area more than those of the other treatment (75% of recommended applied irrigation water).

Table 1: Effect of applied irrigation water, cropping systems and their interaction on LAI, combined data across 2015 and 2016.

Cropping systems	Applied irrigation water(m^3/ha)	LAI		
		Corn	soybean	Total (systems)
Intercropping systems (Inter 1) 1. 50% soybean + 100% corn	75% (6069)	6.20	4.57	10.77
	100% (8092)	6.34	5.34	11.68
	125% (10115)	7.45	5.21	12.66
Mean		**6.66**	**5.04**	**11.70**
2. 100% soybean + 100% corn (Inter 2)	75% (6069)	6.06	6.64	12.70
	100% (8092)	6.66	8.20	14.86
	125% (10115)	7.60	9.31	16.91
Mean		**6.77**	**8.05**	**14.82**
Average of intercropping	75% (6069)	**6.13**	**5.61**	**11.74**
	100% (8092)	**6.51**	**6.77**	**13.28**
	125% (10115)	**7.53**	**7.26**	**14.79**
Mean		**6.72**	**6.55**	**13.27**
Solid systems (as mixed)	75% (6069)	6.40	4.33	5.32*
	100% (8092)	6.43	6.13	6.28*
	125% (10115)	6.88	6.86	6.87*
Mean		**6.57**	**5.80**	**6.19***
Traditional solid systems	75% (6069)	6.50	6.71	6.61*
	100% (8092)	6.50	6.10	6.30*
	125% (10115)	6.71	7.53	7.12*
Mean		**6.05**	**6.80**	**6.43***
Average of applied irrigation water	75% (6069)	**6.29**	**5.56**	**5.93***
	100% (8092)	**6.47**	**6.44**	**6.46***
	125% (10115)	**7.16**	**7.23**	**7.20***
L.S.D.0.05 Applied irrigation water		**0.71**	**1.25**	**1.26**
L.S.D.0.05 Cropping systems		**N.S.**	**1.57**	**2.74**
L.S.D.0.05 Interaction		**0.85**	**1.66**	**3.66**

Note: * Average of solid corn and soybean

According to **Santos and Carlesso (1998)**, the most prominent responses of plants to water deficits in terms of morphological processes are decreases in leaf area and acceleration of the senescence and abscission of leaves. Consequently, the most prominent response of this treatments were translated into similar alteration of leaf area growth rate for helping the plant to overcome 25% of water deficit between 75 and 100%, as well as, 100 and 125% of recommended applied irrigation water, especially **Muller (2011)** found that water is one of the strongest factors that controls leaf area through the leaf cell expansion.

Effect of cropping systems

LAI was affected significantly by cropping systems in the combined data across the two seasons (Table 1). Intercropping soybean with corn increased *($P \leq 0.05$)* LAI by 12.93% as compared with solid culture (mixed system). On the other hand, there were no significant differences between soybean of traditional solid culture and soybean of the intercropping systems. These results could be due to spatial arrangement of solid culture (mixed system) and intercropping cultures was similar; and this effect was increased by increasing intercropped soybean plant density per unit area from 50 to 100% of solid culture.

Thus, increasing soybean plant density per unit area from 50 to 100% under intercropping conditions increased inter-specific complementary between the intercrops; thereby high rate of translocation of photosynthates metabolites to the leaf area of intercropped soybean was occurred. Also, soybean plants of intercropping system that have high density (100% soybean) achieved higher LAI than those of intercropping system 50% soybean +100% corn. These results could be attributed to higher plant density of the legume component formed larger leaf area to cover unit ground surface area more than those of the other treatment (50% soybean + 100% corn) under intercropping conditions. It is likely that there was little inter or intra – specific competition either between the intercrops or between soybean plants, respectively, for the available environmental resources at the earlier soybean growth stages and this competition was increased by increasing the plant age towards harvest date.

Obviously, intercropping culture caused shading and unfavorable conditions for soybean growth and development as compared with that of solid cultures. These results are in the same context of those obtained by **Camara (1997)** who reported that the LAI of the culture can vary even for plants in the same plant phenology stage depending on the genotype x environment interaction.

Effect of the interaction between applied irrigation water and cropping systems:

Applied irrigation water x cropping systems affected significantly LAI in the combined data across the two seasons (Table 1). Intercropping soybean with corn under high densities (100% soybean + 100% corn) and high application of water (125%) produced *($P \leq 0.05$)* the highest LAI as compared with the other treatments. The lowest applied irrigation water integrated negatively with soybean solid culture (mixed system) or with intercropping. However, LAI of intercropped soybean (Inter 1) was not differed among applied irrigation water treatments under intercropping system which have low density (50% soybean). These data revealed that there was an effect of cropping systems x applied irrigation water on soybean LAI. In this concern, **Wright *et al*. (1988)** showed that soybean is considered as an ideal crop for intercropping with corn owing to its comparative tolerance for shade and drought, efficient light utilization and utilizes soil moisture efficiently. Also, **Flexas *et al.* (2006)** reported that the effects of water stress on the initial activity of Rubisco may be reproduced by induction of stomatal closure, independent of the reduction in the relative water content in the leaves of soybean plants. These data showed that each of these two factors act dependently *($P \leq 0.05$)* on LAI.

Corn growth

Effect of applied irrigation water

LAI was affected significantly by applied irrigation water in the combined data across the two seasons (Table 1). The highest applied irrigation water (125%) caused significant increment *($P \leq 0.05$)* in LAI as compared to those of the other treatments. It is important to mention that there were no significant differences between 75 and 100% of recommended applied irrigation water. It seems that the corn plants interacted positively with water shortages from 100 to 75% of recommended applied irrigation water by reducing transpiration and cell expansion of the plant leaf which indicating some degree of resource complimentarily.

On the other hand, increasing applied irrigation water per unit area from 100 to 125% of recommended applied irrigation water did not enhance ability of corn plant to cover unit ground surface area probably due to raise canopy temperature and retain moisture shorter. These results are in the same context of those obtained by **Matusso *et al*. (2014)** who showed that higher LAI when intercropped with soybean during 2013 could have been attributed to sufficient rainfall at the beginning of the season that stimulated corn leaf growth.

Effect of cropping systems

LAI was not affected significantly by cropping systems in the combined data across the two seasons (Table 1). However, there was a trend to increase LAI of corn plant under intercropping systems than traditional corn planting. These results reveal that growth and development of different parts of corn plant under cropping systems were similar ($P > 0.05$) during growth stages of corn plant.

Effect of the interaction between applied irrigation water and cropping systems

The interaction of applied levels of irrigation water and cropping systems affected significantly LAI of corn plant in the combined data across the two seasons (Table 1). Intercropping soybean with corn that received high application of water (125%) produced ($P \leq 0.05$) the highest LAI as compared with solid corn systems. These data could be due to more shading around corn plants of traditional solid plantings which might be caused death, senescence and dropping of the lower leaves of the plant by decreasing applied irrigation water from 125 to 75% of the recommended irrigation water. It is known that LAI is required to manage crop growth and to serve as a basis for plant growth analysis **(Dammer *et al*., 2008)**. However, LAI of intercropped corn was not differing among applied irrigation water treatments under intercropping system 50% soybean + 100% corn. These data reveal that there was an effect of cropping systems x applied irrigation levels of water on LAI.

Total leaf area index of intercropping and solid systems

Effect of applied irrigation water

Total LAI was affected significantly by levels of applied irrigation water in the combined data across the two seasons (Table 2). The highest total LAI was obtained ($P \leq 0.05$) by increasing irrigation water from 75 to 125% of the recommended irrigation water. It seems that leaf elongation and fractions altered to levels of applied irrigation water. Consequently, total leaf size became smaller with the lowest application of applied irrigation water compared to the others through lowered cellular turgor pressure **(Kramer and Boyer, 1995)**. Accordingly, it is expected that the evaporation from soil surface increased but canopy transpiration decreased as a result of increasing irrigation water from 75 to 125%. Therefore, space-time distribution of vegetation is a key factor for a correct evaluation of evapotranspiration **(Gigante *et al*., 2009)**.

Effect of cropping systems

Intercropping soybean with corn increased ($P \leq 0.05$) total LAI as compared to traditional solid cultures of corn and soybean, respectively. Increasing soybean population density under intercropping caused significant increase by about 26.3% over than lower population density (Inter 2). Also, intercropping system of corn and soybean had significant increases of LAI than solid systems by about 114% and 105% over than solid as mixed and traditional systems, respectively (Table 1). Certainly, evapo-transpiration is affected by meteorological, biological, and soil factors **(Todorović, 2006)**.

Effect of the interaction between applied irrigation water and cropping systems

Increasing irrigation water to 125% caused significant increase of LAI under intercropping with high density of soybean than those of other systems.

Soybean seed yield

Effect of applied irrigation water

Seed yields per plant and per ha were not affected significantly by levels of applied irrigation water in the combined data across the two seasons (Table 2). These results could be attributed to canopy structure of soybean variety Giza 111 acclimated with the lowest applied irrigation water to prevent more solar radiation penetration among the other leaves of the plant **(Metwally *et al*., 2012 and Abdel-Galil *et al*., 2014a)** which reflected positively on each of leaf transpiration and soil moisture. In other words, shortage in applied irrigation water by 25% of recommended applied irrigation water did not reduce accumulation of dry matter in different organs of the plant during the early vegetative and development growth stages and consequently yield of the crop. These results are in accordance with those obtained by **Aiken and Lamm (2012)** who reported that the crop canopy shades soil and reduces evaporative water losses.

Also, soybean tap roots and torrent to drought than corn. Increasing applied irrigation water to 25% over that of recommended applied irrigation water did not increase soybean yield. The highest applied irrigation water may have cooler canopy temperatures and retain moisture longer which increased the probability of foliage disease problems compared to others. Excessive irrigation water during the vegetative stage stimulates vegetative growth and dry matter and increase potentiality for lodging and may be increasing fungal diseases without an increase in yield **(Kranz and Benham, 2003)**.

Table 2: Effect of applied irrigation water, cropping systems and their interaction on soybean seed yield, combined data across 2015 and 2016.

Cropping systems	Applied irrigation water(m^3/ha)	Soybean seed yield/plant (g)	Soybean seed yield/ha (ton)
Intercropping systems (Inter 1) **1. 50% soybean + 100% corn**	**75% (6069)**	7.6	1.14
	100% (8092)	9.1	1.41
	125% (10115)	10.4	1.36
Mean		**9.0**	**1.30**
2. 100% soybean + 100% corn (Inter 2)	**75% (6069)**	5.4	1.34
	100% (8092)	6.8	1.64
	125% (10115)	6.3	1.64
Mean		**6.2**	**1.54**
Average of intercropping	**75% (6069)**	**6.5**	**1.24**
	100% (8092)	**8.0**	**1.53**
	125% (10115)	**8.4**	**1.50**
Mean		**7.6**	**1.42**
Solid soybean (mixed system)	**75% (6069)**	14.4	2.99
	100% (8092)	15.4	3.07
	125% (10115)	15.1	3.07
Mean		**15.0**	**3.04**
Traditional solid soybean	**75% (6069)**	15.1	3.16
	100% (8092)	14.4	3.23
	125% (10115)	14.4	3.23
Mean		**14.6**	**3.21**
Average of applied irrigation water	**75% (6069)**	**10.6**	**2.16**
	100% (8092)	**11.4**	**2.34**
	125% (10115)	**11.6**	**2.33**
L.S.D.0.05 Applied irrigation water		**N.S.**	**N.S.**
L.S.D.0.05 Cropping systems		**2.5**	**0.16**
L.S.D.0.05 Interaction		**N.S.**	**N.S.**

Effect of cropping systems

Seed yields per plant and per ha were affected significantly by cropping systems in the combined data across the two seasons (Table 2). These differences depending on number of soybean plants per plot and shading effects by adjacent corn plants in intercropping systems. Traditional soybean solid culture had the highest values (*$P \leq 0.05$*) for seed yields per plant and per ha as compared to those of intercropping systems. In general, intercropping soybean with corn decreased *($P \leq 0.05$)* seed yields per plant and per ha by about 47.94% and 55.76%, respectively, as compared with those of traditional solid system (Table 2). These results could be due to the adverse shading effects of adjacent corn plants which increase inter and intra-specific competition between plants as compared with those of traditional solid cultures, especially, during reproductive and seed filling stages **(Metwally *et al*., 2012 and Nagasuga *et al.*, 2014)**

Also, soybean plants of intercropping system which have low density (50% soybean) achieved higher seed yield per plant than that of intercropping system which have 100% soybean. Conversely, increasing soybean plant density per unit area from 50 to 100% increased significantly seed yield per ha under intercropping conditions. It is obvious that yield potential /ha of soybean was increased by increasing soybean plant density per unit area from 50 to 100% under intercropping systems. The converse was true for decreasing plant density of soybean where it gave more space to increase solar radiation penetration between soybean plants and more yield for individual plants. These results are in the same context of those obtained by **Metwally *et al.* (2012)**, **Abdel-Galil *et al.* (2014a) and Abdel-Wahab and Abd El-Rahman (2016)** who showed that soybean solid planting had the highest seed yields per plant and per ha as compared to those of intercropping.

Effect of the interaction between applied irrigation water and cropping systems

The interaction between applied irrigation water levels and cropping systems did not affect significantly seed yields per plant and per ha in the combined data across the two seasons (Table 2). These data showed that each of the two factors act independently ($P > 0.05$) on seed yields per plant and per ha, as well as, cropping systems had higher effects on soybean productivity than other factors.

Corn grain yield

Effect of applied irrigation water

Grain yields per plant and per ha were affected significantly by applied irrigation water in the combined data across the two seasons (Table 3). The highest applied irrigation water caused significant increments ($P \leq 0.05$) in grain yields per plant and per ha as compared to those of the other treatments. The highest applied irrigation water increased grain yields per plant and per ha by 11.82% and 14.26 %, respectively, as compared to those of the lowest applied irrigation water. It is known that the oxygen created by plants comes from the water it uses rather than from the CO_2 **(Wittwer, 1992)**. Accordingly, it is expected that the excess irrigation water treatment (125%) enhanced efficiency of photosynthetic process of the plant especially corn which has high water requirements **(Igbadun *et al*., 2008)** and thereby more dry matter accumulation in the different organs of the plant.

Table 3: Effect of applied irrigation water, cropping systems and their interaction on corn grain yield, combined data across 2015 and 2016.

Cropping systems	Applied irrigation water(m^3/ha)	Corn grain yield/plant (g)	Corn grain yield/ha (ton)
Intercropping systems (Inter 1) **1. 50% soybean + 100% corn**	**75% (6069)**	205	6.83
	100% (8092)	215	7.36
	125% (10115)	241	7.76
Mean		**220**	**7.33**
2. 100% soybean + 100% corn (Inter 2)	**75% (6069)**	202	6.66
	100% (8092)	210	7.16
	125% (10115)	230	7.56
Mean		**214**	**7.13**
Average of intercropping	**75% (6069)**	**204**	**6.76**
	100% (8092)	**213**	**7.26**
	125% (10115)	**236**	**7.66**
Mean		**217**	**7.22**
Solid corn (mixed system)	**75% (6069)**	195	6.66
	100% (8092)	208	7.49
	125% (10115)	216	7.66
Mean		**206**	**7.26**

Tradition solid corn	**75% (6069)**	209	6.79
	100% (8092)	220	7.59
	125% (10115)	221	7.73
Mean		**217**	**7.36**
Average of applied irrigation water	**75% (6069)**	**203**	**6.73**
	100% (8092)	**213**	**7.39**
	125% (10115)	**227**	**7.69**
L.S.D.0.05 Applied irrigation water		**10.1**	**0.76**
L.S.D.0.05 Cropping systems		**N.S.**	**N.S.**
L.S.D.0.05 Interaction		**12.0**	**0.69**

Effect of cropping systems

Grain yields per plant and per ha were not affected significantly by cropping systems in the combined data across the two seasons (Table 3). Obviously, the yielding ability of corn crop was not ($P> 0.05$) likely to be much affected by cropping systems. These results could be attributed to corn crop had high ability for acclimation to different light environments of the studied cropping systems **(Abdel-Galil *et al*., 2014b)**. These data suggest that corn plant had the same ability for convert more solar energy to chemical energy and more translocation of photosynthates metabolites to the ears under the studied cropping systems. These results are in agreement with those obtained by **(Metwally, 1999 and Undie *et al*. 2012)** who indicated that intercropping soybean with corn had no significant reduction in grain yield of corn.

Effect of the interaction between applied irrigation water and cropping systems

Applied irrigation water x cropping systems affected significantly grain yields per plant in the combined data across the two seasons (Table 3). Intercropping soybean with corn under application high level of water (125%) produced higher grain yield of corn per plant as compared with solid corn plantings. this may be attributed to wide spacings between corn plants in beds than those on traditional solid planting on ridges (70cm). It is obvious that efficiency of photosynthetic process of the intercropped corn plant was enhanced with increasing applied irrigation water up to 125% of the recommended applied irrigation water. These results could be attributed to increase in LAI of the intercropped corn plant (Table 1) which increased surface absorbing sunlight and decreased evaporation rate from soil surface compared with the others **(Andrade *et al*., 2002)**. Increasing irrigation water level from 6069 to 10115 m^3/ha had significant increments on grain yield per plant under intercropping systems more than that of traditional solid planting. This may be due to wide spaces of beds furnished more light penetration between corn plants under intercropping (140 cm per bed) than that of traditional solid system (70 cm per ridge). Also, there were positive effects between corn plant and adjacent soybean plants due to beneficial effects of soybean residues under intercropping culture **(Metwally *et al.*, 2008 and El-Shamy *et al*., 2015)**. Accordingly, intercropping soybean with corn increased light intensity and CO_2 concentrations around corn canopy and thereby this biological situation reflected on the developing ears. Cobs may be considered as temporary sink and the stored photosynthates were translocated to grains during their development. These data reveal that there was an effect of cropping systems x applied irrigation water on grain yields per plant.

Land equivalent ratio (LER)

Effect of applied irrigation water

LER was not affected by applied irrigation water in the combined data across the two seasons (Figure 2). These data show that yielding ability of the intercropping was not ($P> 0.05$) likely to be much affected by applied irrigation water (Tables 2 and 3) that contributed mainly in stability of relative yield of the intercrop under the studied applied irrigation water.

Effect of cropping systems

LER was affected significantly by cropping systems in the combined data across the two seasons (Figure 2). Intercropping soybean with corn increased *($P \leq 0.05$)* LERs as compared to traditional solid cultures of both crops in the combined data across 2015 and 2016 seasons. The results showed that corn was superior in the intercrop pattern where relative yield increased; meanwhile, soybean was inferior companion crop where the relative yield was decreased in the combined analysis. The advantage of the highest LER by intercropping soybean with corn over solid cultures of both crops could be due to their effects on intra-specific competition between plants of the same species for basic growth resources than those of traditional solid culture. These results are in accordance with those obtained by **(Metwally, 1999 and Metwally *et al*. 2003, 2005, 2007 and 2009a and b)** who found that intercropping patterns increased LERs as compared to solid cultures of both crops.

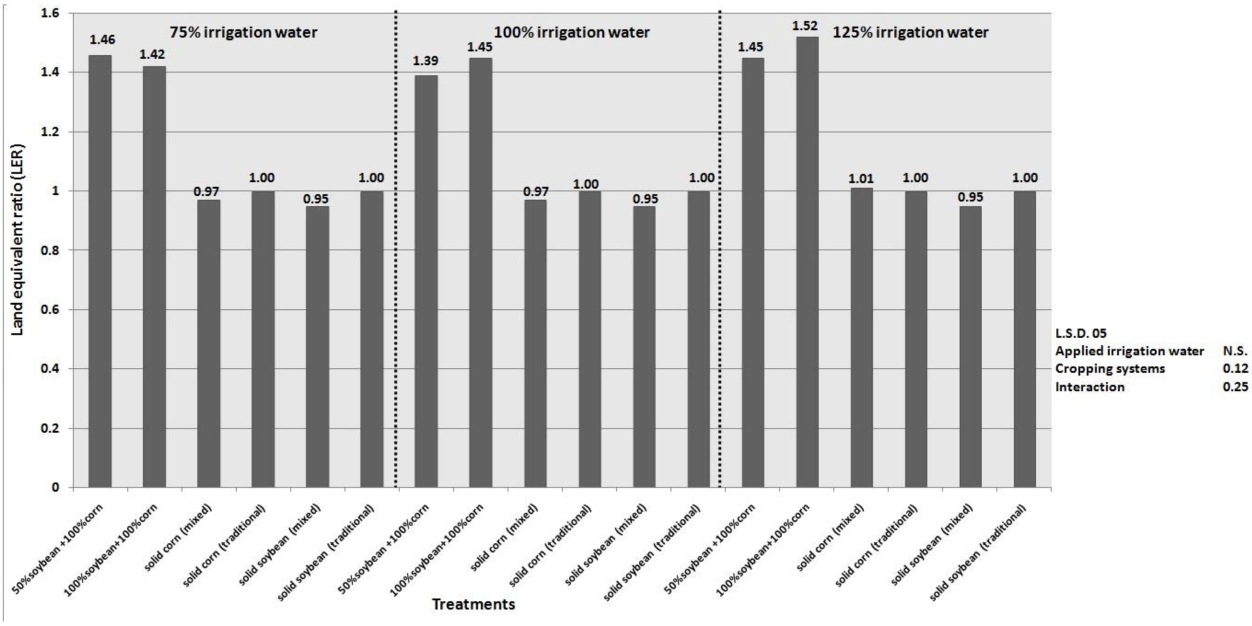

Figure 2: Effect of applied irrigation water, cropping systems and their interaction on LER, combined data across 2015 and 2016.

Effect of the interaction between applied irrigation water and cropping systems

Applied irrigation water x cropping systems affected significantly LER in the combined data across the two seasons (Figure 2). Intercropping soybean with corn (50% soybean + 100% corn or 100% soybean + 100% corn) produced the highest LER with regardless to the applied irrigation water as compared with the other treatments. Therefore, there was potential for higher productivity of intercrops when intra-specific competition is less than inter-specific competition for a limiting resource of water. These data showed that each of these two factors act dependently *($P \leq 0.05$)* on LER.

Water use efficiency (WUE)

Effect of applied irrigation water

WUE of economic yield was affected significantly by applied irrigation water in the combined data across the two seasons, meanwhile WUE of biological yield was not affected (Figure 3). The lowest applied irrigation water caused significant increments *($P \leq 0.05$)* in WUE of economic yield as compared to those of the other treatments. However, there were no significant differences between 100 and 125% applied irrigation water treatments. The highest applied irrigation water decreased WUE of economic yield by about 50.00% as compared to the lowest applied irrigation water.

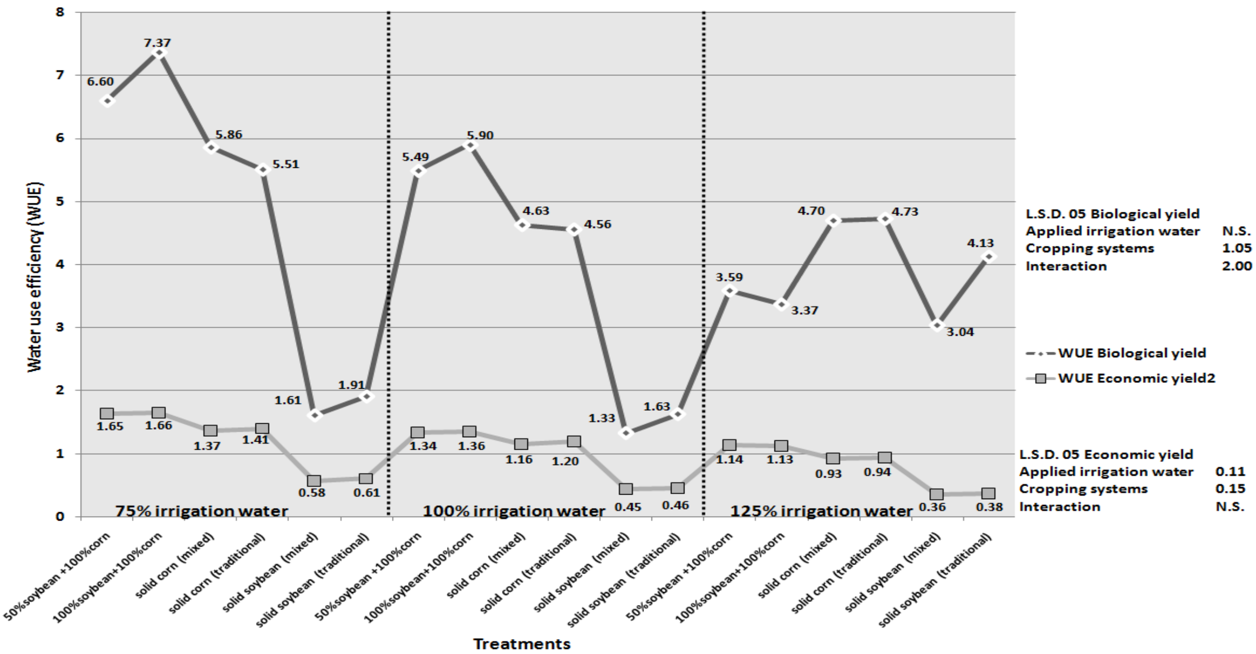

Figure 3: Effect of applied irrigation water, cropping systems and their interaction on water use efficiency (WUE), combined data across 2015 and 2016.

These finding imply that economic yield per unit water was increased by decreasing applied irrigation water from 125 to 75% of the recommended applied irrigation water.

Effect of cropping systems

WUE of economic and biological yields were affected significantly by applied irrigation water in the combined data across the two seasons (Figure 3). Intercropping soybean with corn increased WUE of economic yield by 16.94% as compared to traditional solid plantings of corn in the combined data across 2015 and 2016 seasons. Also, intercropping soybean with corn increased WUE of biological yield by 9.33% as compared to traditional solid plantings of corn in the combined data across 2015 and 2016 seasons. With respect to intercropping patterns, increasing soybean plant density from 50 to 100% did not affect negatively WUE of economic yield (Figure 3). These results indicate that corn plants may grow larger and they may use more water as CO_2 concentration increases as a result of intercropping with the C_3 plants where rising CO_2 concentrations could be decreased leaf stomatal conductance to water vapor. The efficiency of WUE is the ratio of net CO_2 assimilation to water used **(Bacon, 2004)**. Despite WUE of C_4 crops often being higher than that of C_3 crops **(Gowik and Westhoff, 2011)**, water availability still dictates the maximum yields achievable by the C_4 crop **(Ings *et al.*, 2013)**. Accordingly, it is expected that this effect reduced leaf transpiration especially **Allen (2017)** revealed that rising CO_2 concentrations and rising global temperatures changed WUE.

Effect of the interaction between applied irrigation water and cropping systems

WUE of biological yield was affected significantly by the interaction between applied irrigation water and cropping systems in the combined data across the two seasons, meanwhile WUE of economic yield was not affected (Figure 3). Intercropping soybean with corn (50% soybean + 100% corn or 100% soybean + 100% corn) with the application of 75% of recommended applied irrigation water achieved the highest WUE of biological yield which is likely related to a more effective reduction in soil evaporation by intercropping compared the other treatments. Moreover, the economic yield did not increase more intensely as water utilization increased in the unit area resulting in WUE stability under different cropping systems.

CONCLUSION

Productivity, land equivalent ratio (LER) and water use efficiency (WUE) were increased more under intercropping systems than those of solid ones. Also, the production of economic and biological yields, as well as, LER were increased more by increasing irrigation level of water from 75 to 125%, while the converse was true with WUE. It be concluded that applied irrigation water of 6069 to 8092 m^3/ha was suitable for economic yield under solid and intercropping cultures in beds 140 cm.

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