Control of Doubling and Early Bolting Bulbsof Onion Genotypes by Sizes of Sets and Irrigation Systems

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Abstract: A field experiment was conducted during two cropping seasons 2012 and 2013 at the Agriculture Research Station belonging to King Abdulaziz University to study the effects of set sizes (SS) and irrigation system (IS) on growth, yield, doubling and early bolting of three onion cultivars. Three sizes of sets, small (0.5-1.5cm), medium (1.5-2.5cm) and large (2.5-3.5cm) of onion cultivars 'Red Amposta', 'Giza 6' and 'Texas 502'werecultivated using surface and subsurface drip irrigation systems. All experiments were laid out in Randomized Complete Block Design (RCBD) using 3 replicates. The results showed that growth, yield and bulbs quality of the tested onions cultivars were significantly affected by the irrigation systems and sizes of sets and their interactions. The surface drip irrigation (IS1) produced the highest plant height and no. of leaves/plant, highest no. of doubling, split and early bolting bulbs/plot. The subsurface drip irrigation (IS2) produced the highest average weight and diameter of single marketable bulbs, no. of marketable bulbs/plot, total yield of marketable, doubling, split and early bolting bulbs (ton/ha). The sizes of sets 2.5-3.5cm (SS3) significantly increased plant height (cm), no. of leaves/plant, days to maturity, number (per plot) and total yield (ton/ha) of doubling, split and early bolting bulbs. Using the medium sizes of sets(1.5-2.5cm) increased number (per plot) and total yield (ton/ha) of marketable bulbs significantly, and average weight and diameter of single marketable bulbs. The onion cultivar 'Texas 502' produced the highest number (per plot) and total yield (ton/ha) of marketable bulbs, lowest number (per plot) and total yield (ton/ha) of doubling, split and early bolting bulbs (ton/ha). The onion cultivar 'Red Amposta' produced the highest plant height (cm), no. of leaves/plant, days to maturity, average weight and diameter of single marketable bulbs, highest number (per plot) and total yield (ton/ha) of doubling and early bolting bulbs. The onion cultivar 'Giza 6', the smallest sizes of sets(0.5-1.5cm) and surface drip irrigation produced the lowest number (per plot) and total yield (ton/ha) of marketable bulbs. Growing the onion cultivar 'Texas 502' using the medium/large sizes of sets (1.5-3.5cm) and subsurface drip irrigation system significantly increased yield and yield components of marketable bulbs.

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1.Introduction

Onion (*Allium cepa* L.) is considered to be one of the most important commercial vegetable crops worldwide due to its medicinal values and rich contents of carbohydrates and protein, vitamin A, thiamine, riboflavin, niacin and ascorbic acid (Baloch *et al.,* 1994; Mousa and Mohammed, 2009). Originally, onion was discoveredin different parts of Asia including Central Asiatic region (i.e. Pakistan and Afghanistan), West Asia (i.e. Palestine and India), and Middle and South-eastern Asia (i.e. China and Russia). Onion is one of the major vegetables in Asia since it produces about 65.4% from the world's total production (54192500 tons) followed by Europe with 11.8% (977864 tons), African 11.2% (9267545 tons), and Americans with 11.2% (9267170 tons) (Food and Agriculture Organization (FAO 2012). China is the leading country in onion production since it cultivates 575,820 ha of onion with total production of 12.03 million MT and productivity of 20.9 MT/ha, followed by Indiathat cultivates area of 480,600 ha with total production of 5.47 million MTand productivity of 11.37 MT/ha.The United States is cultivating 78,000 ha with total production of 3.44 million MT and productivity of 4.28 ton/ha (Food and Agriculture Organization (FAO 2012). The leading onion producing Arab countries is Egypt with 2.38 million MT (cultivated area of 85,000 ha and productivity of 22 MT/ha), followed by Algeria with 1.2 million MT produced from 60000ha (average productivity of 20 MT/ha), Morocco with 0.856 million MT (cultivated area 430000 ha and productivity of 19 MT/ha). Saudi Arabia is cultivating about 7000 ha with productivity of 22 MT/ha and total production of 105000 MT (Food and Agriculture Organization (FAO 2012).Onion is adjusted to growth and production under wide range of climatic conditions including temperature, light and moisture. Cool weather conditions and adequate moisture are recommended during the early growth stage while warm and dry conditions are required during maturity and curing (Jones and Mann 1963).Bulbs doubling (internal and external doubling) and early flowering (bulbs bolting) are themost important factors affecting onion production worldwide. Most of onion varieties in North Africa (i.e. Egypt) and North West Asia (i.e. Saudi Arabia) have the ability to produce floral stalks in the first year of cultivation which greatly contribute to yield losses of sensitive varieties (Sanders and Cure, 1996; Mousa and Mohammed, 2009). Early flowering (early bolting) was reported to be strongly associated with climatic factors particularly low temperatures (Brewster, 1994) and long-day photoperiod (Khokhar, 2008b), sowing dates (Sinclair; 1983) and set sizes (Khokhar *et al.,* 2002). It was reported that using large set sizes (2.6 – 2.9cm) increased total yield of double bulbs, splitted bulbs and early flowering bulbs (Khokhar *et al.,*2002). They found that the set sizes 2.6 and 2.9cm produced 55.8% and 69.4% double bulbs, 25.8% and 31.1% bolting bulbs and 18.8% and 17.5% of marketable yield. Brewster and Salter (1980) found that plant population did not significantly influence bolting of onion bulbs, while sowing date and cultivars significantly influenced bolting. They also reported that early flowering of onion bulbs can be minimized when sowing is delayed and when cultivars that are not prone to bolting are used. On the contrary, an increase in plant population (from 20 to 160 plants m^{-2}) caused significant increase in number of bolted bulbs/m^{-2} (BoschSerra and Domingo Olivé, 1999). However, Khokhar *et al*., 2007 observed that early flowering required cold temperature (6 to 15°C) and plants with a minimum of 7 to 10 leaves. Information is limited about the effects of irrigation systems (methods) on onions bulbs yield and quality as well as bulbs doubling and early bolting. Moreover, knowledge of the influence of drip irrigation systems (surface and subsurface) on bulbs yield and quality of onions mainly bulbs doubling and bolting is important for to maximize water use efficiency and onion yield and quality (Stern and Bresler, 1983). The present work demonstrates how irrigation systems and sizes of onion sets would affect growth, yield and bulbs quality particularly early bolting and doubling of three onion cultivars.

2.Materials and Methods

Experimental Site and climate:

A field experiment was carried out during the growing seasons 2012 and 2013 at the Agriculture Experimental Station of King Abdulaziz University (KAU) located at Hada Alsham village, 120 km north east of Jeddah, KSA. The experiment was conducted to investigate the effects of two drip irrigation systems and three sizes of sets on growth, yield and quality of three onion cultivars. The soil texture of the experimental sites was classified as sandy loam(Sand 84.21%: silt 14.05%: clay 1.74%). The physical properities of the soil were pH 7.8 unit, EC 1.79 dsm^{-1}, organic matter 0.453%, organic carbon 0.5% and available macro nutrients N (0.215%), K (0.781%) and P (0.07%). The dominant climate of the area is arid with high temperatures and long photoperiods during summer season.

Plant materials and experimental design:

Three commercial onion cultivars named 'Red Amposta', 'Giza 6' and 'Texas 502' obtained from the seed markets of the western regions of Saudi Arabia were used. The onion cultivars were cultivated using three different sizes of bulb sets 0.5-1.5cm, 1.5-2.5cm and 2.5-3.5cm. The onion sets were planted on 15thJanuary in each year with a distance of 0.3m between plants and 0.5 m between rows. The experiments were laid out in Randomized Complete Block design (RCBD) using three replicates.

Applied drip irrigation Systems

The onion plants were grown using surface and subsurface drip irrigation systems. For installing both surface and subsurface drip irrigation systems, the experimental site was precisely leveled then the dripper lines were installed on soil surface for drip irrigation and at 10 cm depth from soil surface for subsurface drip irrigation. The distance between the dripper lines (rows spacing) was 50 cm and the distance between drippers (distance between each two sets in the same line) was 30 cm. The type of the dripper lineswas*RAIN BIRD LD- 06- 12-1000 Landscape drip 0.9 G/h @18"*(obtained from the irrigation accessories market in Jeddah, Saudi Arabia). The downstream end of each dripper line was connected to a manifold for convenient flushing. Inlet pressure on each tap was about 1.5 bars. The system uses 125 micron disk filter. The water source was from two containers always full of water via main irrigation network installed in the location.

Planting of onion Sets and cultural practices

The onion sets with sizes of 0.5-1.5cm, 1.5-2.5cm and 2.5-3.5cm were planted in 10th and 15th January2012 and 2013, respectively. Two sets were planted per dripper (on both sites of the dripper) with a distance of 30cm between two sets in the same row and 50cm between rows. The plant water requirements were added to the plants and controlled automatically through PSM timer. The timer was programmed to supply irrigation water for a period of 10 minutes twice a day starting at 7:00 am and 6:00 pm for a period of 2 weeks. The supplied irrigation water was extended gradually along the growing season to cover the required amount of water for onion. The quality of applied irrigation water was as recommended for onion including water EC (1.5 dsm^{-1}), Na (0.39 $meql^{-}$

^{1}), Mg (0.22 meql^{-1}) and Ca (5.15 meql^{-1}). The plants were fertigated by the recommended dose of 20:20:20 N-P-K combined fertilizer, which divided into 6 equal doses and injected with irrigation water. The other culture practices required for onion cultivation were applied as recommended (Mousa and fouad, 2009).

Measurements

The following parameters were assessed during and at the end of each cropping season: plant height (cm), number of leaves/plant, days to maturity, c) no. of marketable bulbs/plot, no. of internal doubling bulbs/plot, no. of external doubling bulbs/plot, no. of early bolting bulbs/plot, total yield of marketable bulbs (ton/ha), total yield of internal doubling bulbs (ton/ha), total yield of external doubling bulbs (ton/ha) and total yield of early bolting bulbs (ton/ha).

Data Analysis

Analysis of variance related to RCBD experiments as described by Gomez and Gomez, (1984), was conducted. The treatment means were compared by F-test and the Least Significant Differences test (LSD) at 5% probability level.

3.Results and Discussion

Growth and maturity parameters

Plant height (cm), no. of leaves/plant and days to maturity were significant affected by the applied irrigation systems. The subsurface drip irrigation enhanced onion plant heights in both seasons, whereas the surface drip irrigation (IS1) significantly increased no. of leaves/plants and days to maturity (Table 1). The tallest onion plants were produced using subsurface drip irrigation with 70.79cm and 70.83cm in 2012 and 2013, respectively. A significant increase in no. of leaves/plant and no. of days to bulbs maturity (cropping season 2013) were observed under the effects of surface irrigation system as compared to subsurface drip irrigation system (IS2) in both cropping seasons. Regarding the bulb set sizes, the bulbs set 0.5-1.5cm (SS2) produced the highest length of onion plants with no significant differences from the bulb set size 2.5-3.5cm (SS3) in both seasons. The no. of leaves/plant and days required to onion bulbs maturity were significantly increased when plants cultivated using bulbs of the SS3 (2.5-3.5cm). Using bulbs belongs to the SS1 (0.5-1.5cm) significantly restricted the height and leaves number of onions plant, however the SS1 significantly reduced the number of days required by bulbs to reach maturity (Table 1).The onion cultivar 'Red Amposta' significantly produced the tallest plants, no. of leaves/plant and the greatest number of days to bulb maturity. The shortest plants and least number of leaves/plant were produced by the onion cultivar 'Giza 6' in 2012 and 2013 cropping seasons (Table 1). The earliest matured bulbs were produced by plants of the onion cultivar 'Texas 502'. The interactions between irrigation systems (IS), set sizes (SS) and onion cultivars (Cvs) were significantly affected the growth parameters and days to bulb maturity of onion except plant height (cm) (cropping season 2012) and days to bulbs maturity (cropping season 2013) (Fig 1A- D). The onion cultivar 'Red Amposta' produced the tallest plants when cultivated with set size 1.5-2.5cm (SS2) using surface and subseries drip irrigation with no significant differences (Fig 1A). The shortest plants were recorded for the onion cultivar which cultivated using bulbs set 0.5-1.5cm and surface drip irrigation (53.67cm). Cultivating plants of the onion cultivar 'Red Amposta' using bulbs set of 2.5-3.5cm (SS3) and surface drip irrigation system result the highest number of leaves/plant with 20.42 and 19.82 leaves for 2012 and 2013 cropping season (Fig 1B&C). Surface irrigation and the sizes of sets 2.5-3.5cm (SS1), 1.5-2.5cm (SS2) and 0.5-1.5cm (SS1) significantly delayed the maturity of the bulbs of the onion cultivar 'Red Amposta' (for cropping season 2012). The days required by bulbs to reach maturity were 161.67, 151.00 and 138.67 days for surface irrigation and bulb sets 2.5-3.5cm, 1.5-2.5cm and 0.5 and 1.5cm, respectively. Plants of the onion cultivar 'Texas 502' were the earliest to mature when cultivating by size of sets 1.5-2.5cm under surface and subsurface drip irrigation systems (Fig 1D). The onion growth, yield and quality are highly dependent on the interaction of genetic makeup and environment (including climate conditions, soil types, appropriate and methods of water supply, etc...). It was reported that the methods of watering onion plants (irrigation systems) significantly affected the performance of onion cultivars (Shoke *et al.,* 2000). Drip irrigation provides the plants with their water requirements through the application of uniform and frequent dosages of water at the plant root zone which leads to an increase of yield and saving water (Bozkurt *et al.*, 2006; Sezen *et al.*, 2008). However, the high level of evaporation resulting from thr application of drip irrigation system increased the accumulation of salts at the soil surface (Ayers and Westcot, 1985; Hachicha *et al.,*2006).Subsurface drip irrigation system was designed to directly provide the plants with small amounts of water at their root zone and preservation of high soil moisture in this area due to no evaporation evidence (Enciso *et al.*, 2007). Also, subsurface drip irrigation decreases the accumulation of salts at the plant root zone, reduction of evaporation, increases leaves transpiration which improves the stomata opening and photosynthetic activity. Thus, improves the plant growth, yield and quality of tomato (Ayars *et al.*, 2001; Hanson *et al.*, 2004), onion (Enciso *et al.*, 2007), bean (Gençoglan *et al.*, 2006) and potato (Patel and Rajput, 2008). The results of effects of sizes of sets on onion growth and maturity were in agreement with that observed by Khokhar *et al.* (2002a). They found that the small and medium sizes of sets significantly decreased days to maturity as compared to large sizes of sets. However, the results of the present work were in contrast with that observed by Khokhar *et al.*(2002) and Jones and Mann (1963). They observed significant increase in number of days to bulbs maturity with increasing bulbs set size from 1.4cm – 2.4cm. They attributed their findings to larger number of shoots/plant produced by using larger sizes of sets which increased competition on assimilates and decrease number of days to maturity. Also they observed that the small and medium sizes of sets delay the bulbs maturity because of its ability to form single shoots/plant results no competition between shoots on assimilates. These contrasts may attributed to the larger sizes of sets, genotypes and cropping seasons used in Khokhar *et al.*(2002) and Jones and Mann (1963) study as compared to the present work.

Yield and yield component of unmarketable onion bulbs

No. of doubling, split and early bolting bulbs/plot

The applied drip irrigation systems significantly affected the number of doubling, split and early bolting bulbs/plot. Surface drip irrigation increased significantly number of doubling, split and early bolting bulbs/plot as compared to subsurface drip irrigation in both cropping seasons (Table 2). The numbers of doubling bulbs/plot and split bulbs/plot were significantly increased with the increase of sizes of sets from 0.5-1.5cm to 2.5-3.5cm in both cropping seasons. The largest sizes of sets (SS3, 2.5-3.5cm) produced total number of 15.8 (cropping season 2012) and 13.35 (cropping season 2013) doubling bulbs/plot, and 16.94 (cropping season 2012) and 20.28 (cropping season 2013) split bulbs/plot (Table 2). The sizes of sets were not significantly affected the numbers of early bolting bulbs/plot, however the largest sizes of sets produced higher number of early bolting bulbs/plot with compared to the medium and small sizes of sets. High numbers of doubling and early bolting bulbs were registered for plants belong to the cultivar ‘Red Amposta’ in 2012 and 2013. The ‘red Amposta’ plants produced a total of 20.96 and 19.06 doubling bulbs/plot and 16.09 and 16.68 early bolting bulbs/ plot in 2012 and 2013 respectively. Plants of the cultivar ‘Giza 6’ registered the highest number of split bulbs/plot with 29.90 and 27.93 in 2012 and 2013, respectively. As compared to other cultivars, ‘Texas 502’ significantly reduced numbers of doubling, split and early bolting bulbs/plot in both cropping seasons. Significant interactions were observed between IS and SS about no. of doubling bulbs/plot and no. of split bulbs/plot (cropping season 2012). Surface drip irrigation inspired the small sizes of sets (0.5-1.5cm) and the medium sizes of sets (1.5-2.5cm) to produce the highest no. of doubling bulbs/plot with 26.05 and 18.24 in cropping season 2012 and 2013, respectively. However, significant reduction in no. of doubling bulbs/plot observed when the small and medium sizes of sets were cultivating with subsurface drip irrigation (Fig 2D). The tested sizes of sets produced higher number of split bulbs/plot when were cultivating with surface drip irrigation than subsurface drip irrigation (Fig 3A) in both cropping seasons (the differences were not significant in 2013). The sizes of sets 0.5-1.5cm, 1.5-2.5cm and 2.5-3.5cm produced 20.86, 24.72 and 21.60 split bulbs/plot with surface drip irrigation in 2012 as compared to 8.30, 8.85 and 12.27 split bulbs/plot with subsurface drip irrigation, respectively. Also, consistent significant interaction about no. of doubling and split bulbs/plot between IS and cvs. was observed (Figures 3B and 4A). Grown onion cultivars ‘Red Amposta’ and ‘Giza 6’ in the first season and ‘Giza 6’ in second season using surface drip irrigation produced the highest no. of doubling bulbs/plot (Fig 3B). Superior number of split bulbs/plot was registered for the onion cultivar ‘Giza 6’ with surface drip irrigation (Fig 4A). Plants of the onion cultivar ‘Texas 502’ were significantly inhibited to produce split bulbs/plot under the effects of subsurface drip irrigation (Fig 4A). Inconsistent interaction was observed between SS and cvs. concerning no. of doubling and split bulbs/plot (Fig 3A&D). The sizes of sets 0.5-1.5cm, 1.5-2.5cm and 2.5-3.5cm of the onion cultivar ‘Giza 6’ produced the greatest number of split bulbs/plot with 25.53, 34.36 and 29.82 in 2012 and 24.9, 24.08 and 34.8 in 2013 respectively (Fig 3D). The cultivar ‘Red Amposta’ produced the greatest number of doubling bulbs/plot when were cultivating with sets of 2.5-3.5cm in 2012 (26.30) and 2013 (22.82) (Fig 3A). The no. of early bolting bulbs/plot was not significantly affected by the second and triple interactions between irrigation system (IS), sizes of sets (SS) and cultivars (cvs.) in both cropping seasons.

Total yield of doubling, split and early bolting bulbs (ton/ha)

The total yield (ton/ha) of doubling, split and early bolting bulbs of three onion cultivars grown under two drip irrigation systems using sizes of bulbs were presented in Table (4). The trend of the obtained results was not comparable with that found above for the number of doubling, split and early bolting bulbs/plot. Higher total yield of doubling, split and early bolting bulbs (ton/ha) were observed under subsurface drip irrigation system as compared with surface drip irrigation. The size of sets 2.5-3.5cm (SS3) produced the greatest total yield of doubling

(3.12 ton/ha in 2012 and 3.14 ton/ha in 2013) and split bulbs (3.18 ton/ha in 2012 and 3.76 ton/ha in 2013). Moreover, the sizes of sets 2.5-3.5cm (SS3) and 0.5-1.5cm (SS1) produced the highest early bolting bulbs with no significant differences in both cropping seasons. The SS1 (0.5-1.5cm) significantly reduced the total yields of split and doubling bulbs (ton/ha) as compared to sizes of sets SS3 and SS2 in both cropping seasons. Regarding performance of onion cultivars, 'Red Amposta' produced the highest yield of doubling bulbs (4.52 ton/ha in 2012 and 4.38 ton/ha in 2013) and early bolting bulbs (3.92 ton/ha in 2012 and 4.47 ton/ha in 2013).The highest yield of split bulbs (4.59 ton/ha in 2012 and 4.54 ton/ha in 2013) was produced by 'Giza 6'. The least yields of doubling split and early bolting bulbs were produced by the onion cv. 'Texas 502' in both cropping seasons (Table 4). Significant differences due to the interactions between sizes of sets (SS), irrigation system (IS) and onion cultivars (cvs.) were observed in both cropping seasons except the interactions between IS x SS (on total yield of early bolting bulbs), SS x cvs. (total yield of split and early bolting bulbs) and IS x SS x cvs. (total yield of early bolting bulbs) in the cropping season 2012(Table 4).The subsurface drip irrigation inspired the sizes of sets 2.5-3.5cm (SS3) to produce the highest total yield of doubling, spilt and early bolting bulbs with 4.36 and 4.40, 3.94 and 4.03, and 3.70 and 6.22 ton/ha in 2012 and 2013, respectively (Figures4D, 5C and 6B). Cultivating the onion cultivar 'Red Amposta' using sizes of sets 2.5-3.5cm resulted the highest yield of doubling (6.02 ton/ha in 2012 and 5.78 ton/ha in 2013) and early bolting bulbs (4.19 ton/ha in 2012 and 4.49 ton/ha in 2013 with no differences from size of sets 0.5-1.5cm) (Figures 5A and 6C). The sizes of sets 1.5-2.5cm and 2.5-3.5cm and the onion cultivar 'Red Amposta' produced the greatest yield of split bulbs with no significant differences in both cropping seasons (Fig 5D). Concerning interaction between irrigation system and onion cultivars, the onion cv. 'Red Amposta' produced the highest yield of doubling and early bolting bulbs with 5.25 and 5.23 ton/ha for doubling bulbs and 5.16 and 6.22 ton/ha for early bolting bulbs in 2012 and 2013, respectively (Figures 5B and 6D). Planting the onion cv 'Giza 6' using subsurface drip irrigation system resulted the highest yield of split bulbs with 5.36 and 5.79 ton/ha in 2012 and 2013, respectively (Fig 6A). In the present study watering onion plants using drip irrigation system increased the number of doubling, split early bolting bulbs due to the high evaporation and lackedthe uniformed distribution of water as compared to subsurface drip irrigation. Thus, onion plants can be challenged water deficit at any of the growth stages which affected the bulbs quality including bulbs size, shape, doubling, split and early bolting. The efficient irrigation system should reduce water losses and maximize distribution uniformity. The growth and yield of several crops including onion were affected by the heterogeneity of water application (Ruelle *et al.*, 2003; Dechmi *et al.,* 2004). Drip irrigation is considered to be the most efficient irrigation system for crops growth and yield, however high water losses through the high level of evaporation can affect crops performance (Ayers and Westcot, 1985; Hachicha *et al.,* 2006). Onion growth, bulbs yield and quality was reported to be highly sensitive to water deficiency at all growth stages. Chung (1989) reported that water stress during critical growth period causes reduction in bulbs quality including size and weight of single bulb and protein and TSS% contents. Mohammedi*et al.* (2010) reported that the percentage of single–centre bulbs (not doubling or split or bolting bulbs) reduced by 29.58; 21.71 and 10.98% as compared with the (C), when the soil-water stress treatments were imposed at initial growth stage treatment, development growth stage treatment and mid-season growth stage treatment. In the present study watering the onion plants through drip irrigation system increased the number of doubling, split early bolting bulbs due to the high evaporation and lack of uniform distribution of water. Regarding genotypic effects on doubling/split and early bolting of bulbs, the results of the present study were partially in agreement with that observed by Jilani and Abdul Ghaffoor (2003). They observed no significant variation between the tested onion varieties regarding percentage of early bolting bulbs. Also, they reported that the onion varieties varied significantly in number of split/double bulbs. The large size sets increased number of doubling, split and early bolting bulbs. These results may be attributed to the high level of vernalization caused by large size sets. Khokhar *et al.*(2002) reported that using of large size sets increasing the early bolting bulbs by 40% as compared to small and medium size sets. Also, the authors found that large size sets produced 69.4% doubling bulbs as compared to 6.1% for the small size sets.

Yield components and total yield of marketable bulbs (ton/ha)

Weight and diameter of single marketable bulbs

Significant increase in no. of marketable bulbs due to the application of subsurface drip irrigation system as compared to surface drip irrigation was observed. The medium sizes of sets (1.5-2.5cm) produced the greatest no. of marketable bulbs (44.94 for 2012 and 48.63 for 2013) followed by small sizes sets (0.5-1.5cm) (44.48 for 2012 and 44.29 for 2013), while the large sizes of sets significantly reduced the no. of marketable bulbs/plot (39.03 in 2012 and 43.34 in 2013). Higher no. of marketable bulbs was produced by the onion cultivar 'Texas 502' (55.88 and 59.6 bulbs/plot for 2012 and 2013, respectively) followed by 'Red Amposta' (40.01 for 2012 and 43.34 for 2013), while the least no. of marketable bulbs was recorded for 'Giza6' (Table 2). Non-significant interactions were observed between IS, SS and cv. with regard tono. of marketable bulbs/plot except IS x SS in 2012 and IS x cvs. in 2012 and 2013 (Fig 4B&C). Concerning weight and diameter of single marketable bulbs, significant differences were observed due to the effects of applied irrigation system, onion cultivars and sizes of sets. However, no significant interactions between these factors were observed except the interactions IS x cvs. in both seasons, IS x SS in 2012 and IS x SS x cvs. in 2012 (Fig 2A,B&C). The greatest weight and diameter of marketable bulbs were produced under subsurface drip irrigation. Also, the sizes of sets 2.5-3.5cm increased weight and diameter of marketable bulbs, while the small size sets (0.5-1.5cm) significantly reduced weight and diameter of marketable bulbs. The onion cultivar 'Red Amposta' produced bulbs with highest weights and diameters, whereas 'Giza6' recorded the smallest weight and diameter bulbs in both seasons (Table 3). The results of the present study were partially in line with that observed by Patel and Rajput (2013). They investigated the effects of water deficit on onions growth, yield and quality under subsurface drip irrigation system. The authors recorded variation in size of onion bulbs under the different applied water deficit treatments. Full water application (1005 field capacity) produced the highest yield of grads A and B (5-6cm), while water deficit by 20% and 40% at any growth stages significantly reduced bulb sizes. Chung (1989) found that sizes and weight of onion bulbs were significantly affected by the water stress during the critical growth period. Also, the results of the present work were comparable with that observed by Karim *et al.*(999). They found that larger mother bulbs significantly increased bulb diameter, bulb volume and bulb weight (g). UD-Deen (2008) reported that the maximum bulb diameter (5.38 cm), bulb volume (32.82 cc) and bulb weight (47.96 g) were obtained from large mother bulb.

Total yield of marketable bulbs (ton/ha)

Applied irrigation systems, sizes of sets and onion cultivars and their interactions resulted in significant changes in the total yield of marketable bulbs (ton/ha) during both cropping seasons.Higher yield of marketable bulbs was attained using subsurface drip irrigation system (16.53 ton/ha in 2012 and 17.16 ton/ha in 2013) compared to 14.88 and 12.16 ton/ha for surface drip irrigation in 2012 and 2013, respectively. The medium sizes of sets (1.5-2.5cm) significantly increased yield of marketable bulbs, while the smallest sizes of sets significantly reduced the yield of marketable bulbs in both cropping seasons (Table 4). The greatest yield of marketable bulbs were 17.63 and 15.92 ton/ha in 2012 and 2013 and were produced by the medium sizes of sets (1.5-2.5cm) followed by 15.65 ton/ha in 2012 and 14.79 in 2013 for the large sizes of set (2.5-3.5cm). The small sizes of sets (0.5-1.5cm) produced a total of 13.85 and 13.25 ton/ha of marketable bulbs in 2012 and 2013, respectively. The onion cultivar 'Texas 502' produced the highest marketable yield of bulbs with 20.58 ton/ha (2012) and 19.45 ton/ha (2013), whereas 'Giza 6' recorded the least yield with 8.75 and 7.98 ton/ha in 2012 and 2013, respectively. Significant interactions were observed between the irrigation systems, sizes of sets and onion cultivars in both cropping seasons. Cultivating onion plants using the medium sizes of sets (1.5-2.5cm) and subsurface drip irrigation system resulted the highest yield of marketable bulbs (19.79 and 18.87 ton/ha in 2012 and 2013 respectively). Planting the smallest sizes of sets (0.5-1.5cm) using surface drip irrigation system caused significant reduction in yield of marketable bulbs in both cropping seasons (Fig 7A). Using the medium sizes of bulbs (1.5-2.5cm) to produce the onion cultivar 'Texas 502' significantly increased the yield of marketable bulbs in both cropping seasons (Fig7B). Moreover, the onion cultivar 'Giza6' produced the least yield of marketable bulbs when was cultivating with the large, medium and small sizes of sets in 2012 and 2013 cropping seasons this was observed regardless from the sizes of sets (Fig 7B). As presented in Fig (7C), growing the onion cultivar 'Texas 502' using subsurface drip irrigation system resulted the highest yield of marketable bulbs (21.54 ton/ha in 2012 and 22.81 ton/ha in 2013), while 'Giza 6' produced the least yield of marketable bulbs under surface drip irrigation system with average yield of 6.97 ton/ha in 2012 and 5.72 ton/ha in 2013 (Fig 7C). There were a strong positive correlations between the yield component parameters (i.e. no. of bulbs/plot, weight of single bulb and diameter of single bulb) and the total yield of onion bulbs. Therefore, higher yield of marketable bulbs observedunder subsurface drip irrigation is attributed to the higher number, weight and diameter of marketable bulbs compared to the surface drip irrigation. Simultaneously, the onion cultivar 'Texas 502' and the medium sizes of sets (1.5-2.5cm) recorded the highest no. of marketable bulbs and second highest weight and diameter of marketable bulbs, which explained the higher yield of marketable bulbs (ton/ha). These results were in agreement with that reported by Khokhar et al. (2000). They found that the medium sizes of set (1.7cm) produced the maximum yield of marketable bulbs (26 ton/ha) followed by the large sizes of sets 2.0cm and 2.4cm with 22.9 and 20 ton/ha, respectively. Karim *et* *al.* (1999) found that the combination of larger sizes of bulb sets (2.1cm -2.5cm) and closer planting density (15cm x 10cm) produced the highest yield of marketable bulbs. UD-Deen, (2008) reported that the large sizes of sets significantly increased yield of marketable bulbs (14.68 ton/ha), while the smallest sizes of sets significantly reduced the yield of marketable bulbs (7.47 ton/ha).

Table (1): Growth parameters and days to maturity of three onion cultivars as affected by sets sizes and two irrigation systems.

Treatments	Plant height(cm)		No. of leaves/plant		No. of days to bulbs maturity	
	2012	2013	2012	2013	2012	2013
Irrigations system (IS)						
IS1[1]	65.28	64.94	11.90	10.71	130.00	128.44
IS2[2]	70.79	70.83	9.92	9.08	126.56	122.00
F test	*NS*	***	*	**	*	*NS*
Sets Sizes (SS)						
SS1[3]	64.24b	62.91b	8.46c	9.12c	115.33c	114.50c
SS2[4]	69.28a	68.15a	10.68b	11.52b	128.83b	125.78b
SS3[5]	70.59a	69.60a	13.59a	14.14a	140.67a	135.39a
F test	***	***	***	***	***	**
L.S.D (0.05)	*1.577*	*2.143*	*0.581*	*0.380*	*2.005*	*8.090*
Onion Cultivars (cvs)						
Giza 6	56.19c	59.24c	6.97c	7.50c	127.78b	122.89b
Texas (502)	61.91b	66.04b	10.60b	11.45b	111.56c	107.72c
Red Amposta	77.74a	78.40a	15.17a	14.58a	145.50a	145.06a
F test	***	***	***	***	***	***
L.S.D (0.05)	*1.977*	*1.067*	*0.347*	*0.381*	*1.819*	*4.027*
Interaction (IS * SS)						
F test	*	*NS*	***	***	*NS*	*NS*
Interaction (IS * cvs)						
F test	*NS*	**	***	***	***	*
Interaction (SS * cvs)						
F test	*NS*	**	***	***	***	*NS*
Interaction (IS * SS * cvs)						
F test	*NS*	***	***	*	***	*NS*

[1] IS1= surface drip irrigation system; [2] IS2= subsurface irrigation system
[3] SS1= set size 0.5 – 1.5 cm; [4]SS2 = Set size 1.5 – 2.5 cm; [5]SS3 = 2.5 – 3.5 cm

Table (2): Doubling and bolting of onion bulbs as affected by irrigation systems, sets sizes and onion cultivars.

Treatments	No. of unmarketable onion bulbs/plot						No. of marketable bulbs/plot	
	Doubling bulbs		Split bulbs		Early bolting bulbs			
	2012	2013	2012	2013	2012	2013	2012	2013
Irrigations system (IS)								
IS1	17.92	16.07	22.40	22.85	15.35	16.00	40.95	43.63
IS2	9.29	8.70	9.81	9.67	10.77	11.00	44.61	47.11
F test	**	***	***	*	*	*	*NS*	**
Sets Size(SS)								
SS1	12.89b	10.91b	14.58b	13.87b	13.16a	12.75a	44.38a	44.29ab
SS2	12.14b	12.90a	16.78a	14.62b	12.91a	13.75a	44.94a	48.63a
SS3	15.80a	13.35a	16.94a	20.28a	13.10a	13.90a	39.03b	43.18b
F test	*	*	***	*	*NS*	*NS*	***	*
L.S.D (0.05)	*1.342*	*1.764*	*1.126*	*4.224*	-	-	*0.877*	*4.402*
Onion Cultivars (cvs)								
Giza 6	13.55ab	10.93b	29.90a	27.93a	14.26b	14.62b	32.46c	33.16c
Texas (502)	6.32b	7.17c	10.63b	11.76b	8.83c	9.10c	55.88a	59.60a
Red Amposta	20.96a	19.06a	7.77c	9.07b	16.09a	16.68a	40.01b	43.34b
F test	***	***	***	***	***	***	***	***
L.S.D (0.05)	*7.446*	*1.317*	*2.515*	*3.785*	*1.722*	*1.749*	*3.159*	*2.483*
Interaction (IS * SS)								
F test	*	*	***	*NS*	*NS*	*NS*	***	*NS*
Interaction (IS * cvs)								
F test	***	***	***	***	*NS*	*NS*	***	***
Interaction (SS * cvs)								
F test	*	***	**	*NS*	*NS*	*NS*	*NS*	*N S*
Interaction (IS * SS * cvs)								
F test	*NS*	***	*	*NS*	*NS*	*NS*	*NS*	*NS*

[1] IS1= surface drip irrigation system; [2] IS2= subsurface irrigation system
[3] SS1= set size 0.5 – 1.5 cm; [4]SS2 = Set size 1.5 – 2.5 cm; [5]SS3 = 2.5 – 3.5 cm

Table (2): Doubling and bolting of onion bulbs as affected by irrigation systems, sets sizes and onion cultivars.

Treatments	No. of unmarketable onion bulbs/plot						No. of marketable bulbs/plot	
	Doubling bulbs		Split bulbs		Early bolting bulbs			
	2012	2013	2012	2013	2012	2013	2012	2013
Irrigations system (IS)								
IS1	17.92	16.07	22.40	22.85	15.35	16.00	40.95	43.63
IS2	9.29	8.70	9.81	9.67	10.77	11.00	44.61	47.11
F test	**	***	***	*	*	*	*NS*	**
Sets Size(SS)								
SS1	12.89b	10.91b	14.58b	13.87b	13.16a	12.75a	44.38a	44.29ab
SS2	12.14b	12.90a	16.78a	14.62b	12.91a	13.75a	44.94a	48.63a
SS3	15.80a	13.35a	16.94a	20.28a	13.10a	13.90a	39.03b	43.18b
F test	*	*	***	*	*NS*	*NS*	***	*
L.S.D (0.05)	*1.342*	*1.764*	*1.126*	*4.224*	-	-	*0.877*	*4.402*
Onion Cultivars (cvs)								
Giza 6	13.55ab	10.93b	29.90a	27.93a	14.26b	14.62b	32.46c	33.16c
Texas (502)	6.32b	7.17c	10.63b	11.76b	8.83c	9.10c	55.88a	59.60a
Red Amposta	20.96a	19.06a	7.77c	9.07b	16.09a	16.68a	40.01b	43.34b
F test	***	***	***	***	***	***	***	***
L.S.D (0.05)	*7.446*	*1.317*	*2.515*	*3.785*	*1.722*	*1.749*	*3.159*	*2.483*
Interaction (IS * SS)								
F test	*	*	***	*NS*	*NS*	*NS*	***	*NS*
Interaction (IS * cvs)								
F test	***	***	***	***	*NS*	*NS*	***	***
Interaction (SS * cvs)								
F test	*	***	**	*NS*	*NS*	*NS*	*NS*	*N S*
Interaction (IS * SS * cvs)								
F test	*NS*	***	*	*NS*	*NS*	*NS*	*NS*	*NS*

[1] IS1= surface drip irrigation system; [2] IS2= subsurface irrigation system
[3] SS1= set size 0.5 – 1.5 cm; [4]SS2 = Set size 1.5 – 2.5 cm; [5]SS3 = 2.5 – 3.5 cm

Table (3): Bulbs parameters of three onion cultivars as affected by sets sizes and two irrigation systems.

Treatments	Average weight of single marketable bulb (g)		Average diameter of single marketable blub (cm)	
	2012	2013	2012	2013
Irrigations system (IS)				
IS1	133.39	128.32	6.29	5.64
IS2	152.42	154.20	7.11	7.09
F test	*NS*	*NS*	*NS*	*NS*
Sets Sizes (SS)				
SS1	123.01b	133.26b	6.33b	5.99b
SS2	153.46a	134.58b	6.57ab	6.31ab
SS3	152.25a	155.95a	7.22a	6.79a
F test	***	**	*NS*	*
L.S.D (0.05)	*6.893*	*13.75*	*0.774*	*0.519*
Onion Cultivars (cvs)				
Giza 6	107.59c	105.48c	5.82b	5.48b
Texas (502)	144.93b	142.15b	7.02a	6.79a
Red Amposta	176.19a	176.15a	7.28a	6.82a
F test	***	***	***	***
L.S.D (0.05)	*5.811*	*9.292*	*0.287*	*0.253*
Interaction (IS * SS)				
F test	*	*NS*	*NS*	*NS*
Interaction (IS * cvs)				
F test	***	**	*	**
Interaction (SS * cvs)				
F test	*NS*	*NS*	*NS*	*NS*
Interaction (IS * SS * cvs)				
F test	***	*NS*	*NS*	*NS*

[1] IS1= surface drip irrigation system; [2] IS2= subsurface irrigation system
[3] SS1= set size 0.5 – 1.5 cm; [4]SS2 = Set size 1.5 – 2.5 cm; [5]SS3 = 2.5 – 3.5 cm

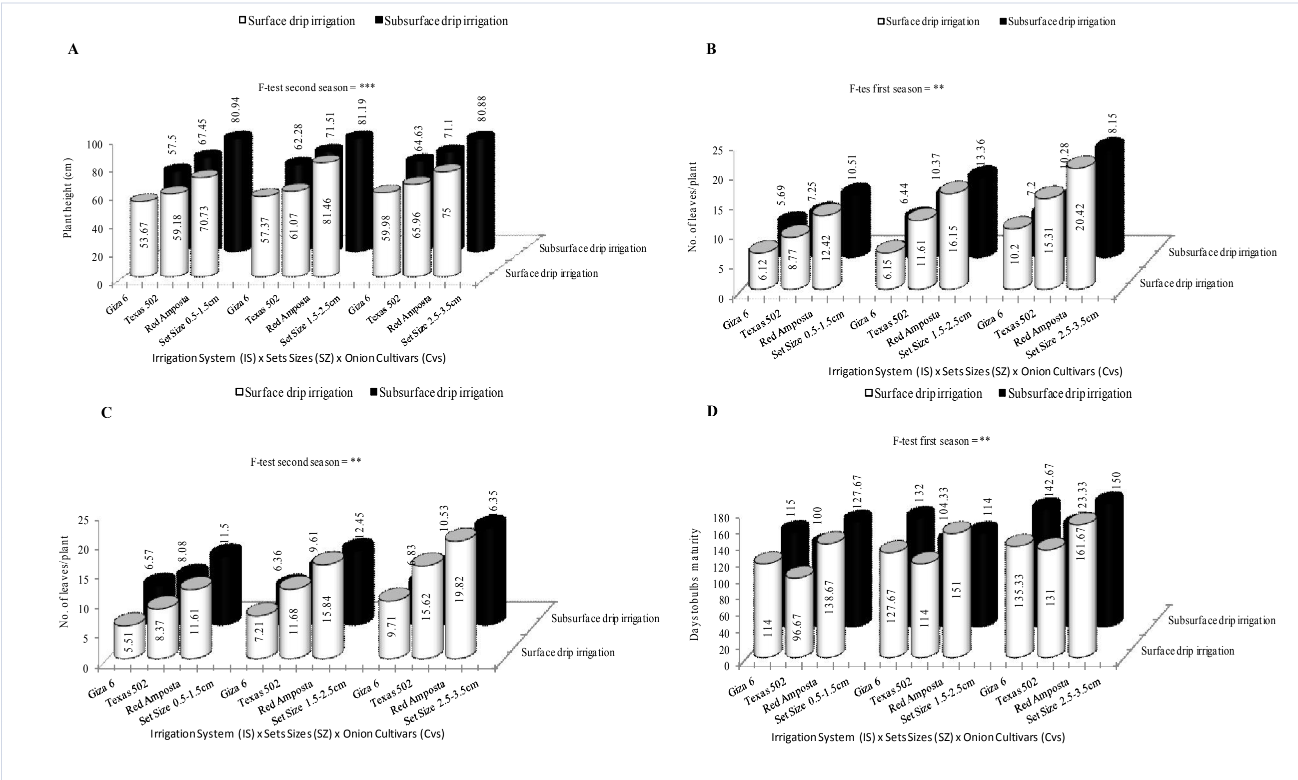

Fig (1): Interaction effects of irrigation systems (IS), sizes of sets (SS) and cultivars (cvs.) on growth and yield components parameters of onion: A) IS x SS x Cvs. on plant height at maturity (cm) (second season 2013), B) IS x SS x cvs. on no. of leaves/plant at maturity (first season 2012), C) IS x SS x cvs. on no. of leaves /plant at maturity (second season 2013), and D) IS x SS x cvs. on no. of days to maturity (first season 2012).

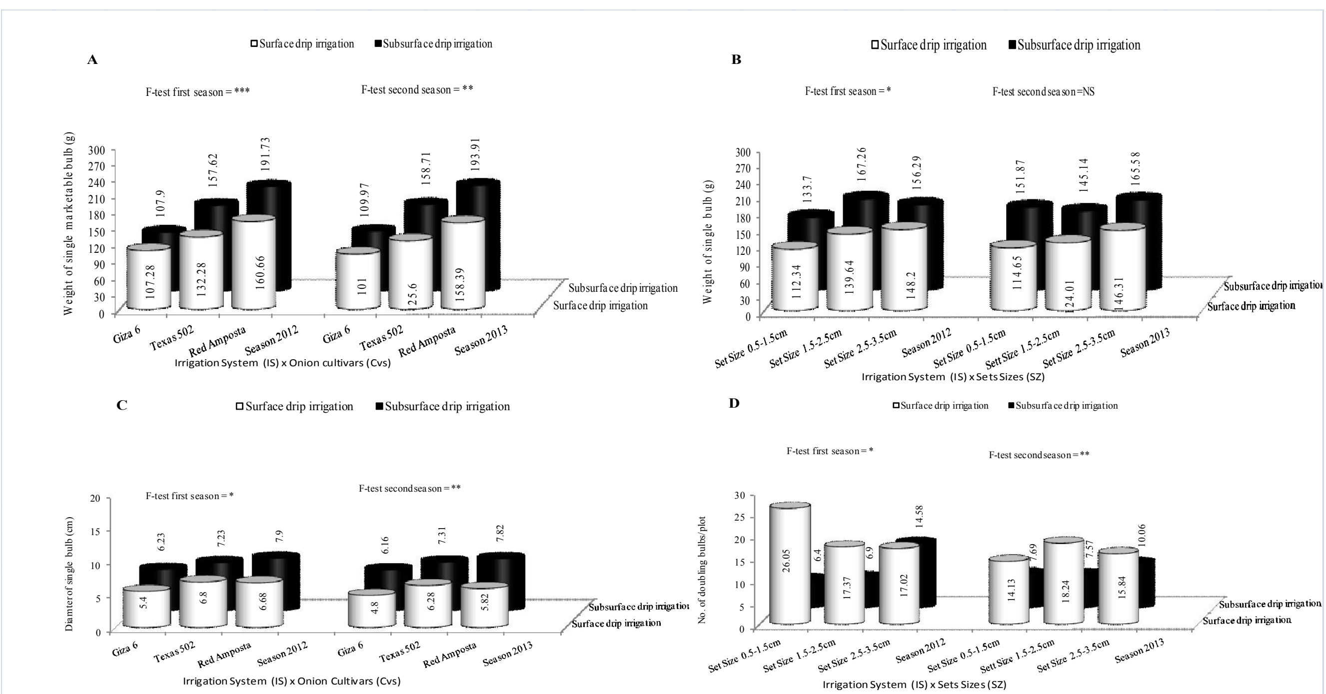

Fig (2): Interaction effects of irrigation systems (IS), sizes of sets (SS) and cultivars (cvs.) on growth and yield components parameters of onion: A) SS x IS on average weight of single bulb (g), B) cvs x IS on average weight of single bulb/plot (g), C) cvs. x IS on diameter of single bulbs/plot and D) SS x IS on no. of internal doubling bulbs/plot.

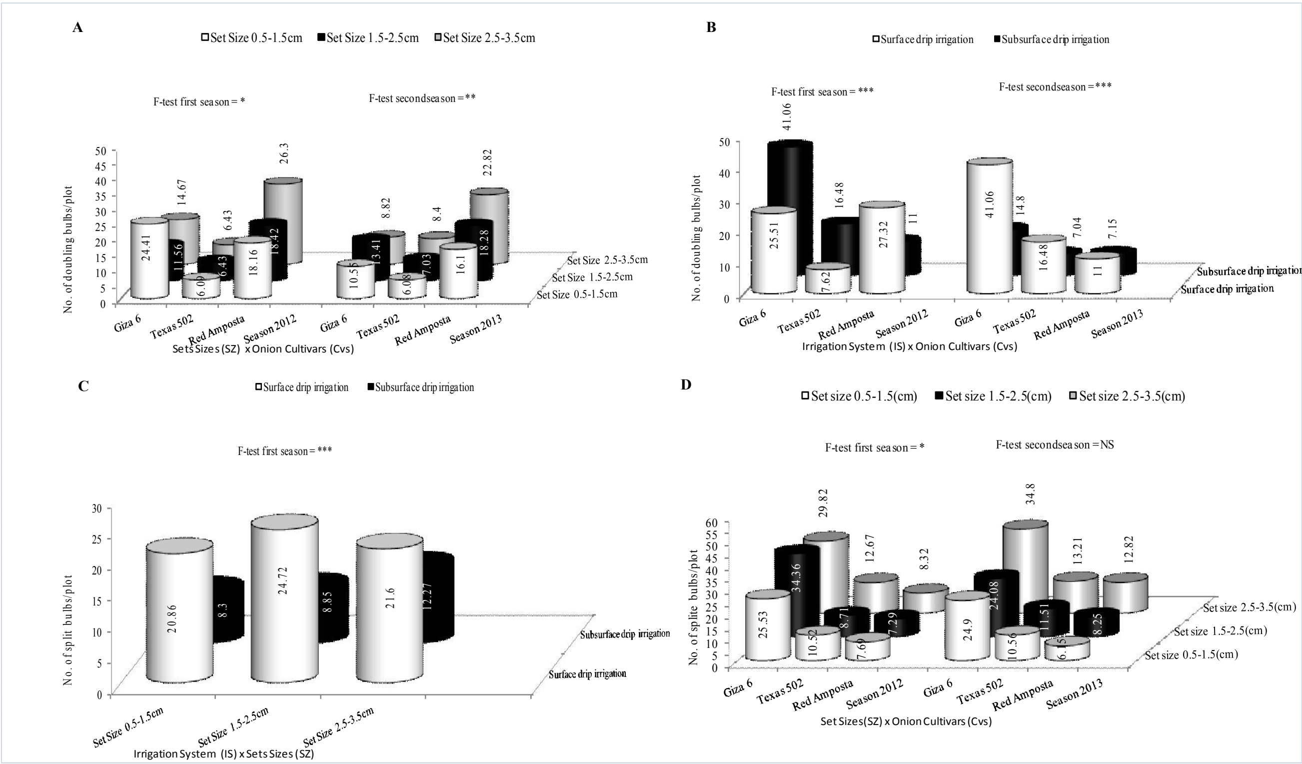

Fig (3): Interaction effects of irrigation systems (IS), sizes of sets (SS) and cultivars (cvs.) on yield components parameters of onion: A) cvs. x SS on no. of internal doubling bulbs/plot, B) cvs x IS no. of internal doubling bulbs/plot, C) SS x IS no. of external doubling bulbs/plot (first season 2013) and D) cvs. x SS on no. of external doubling bulbs/plot.

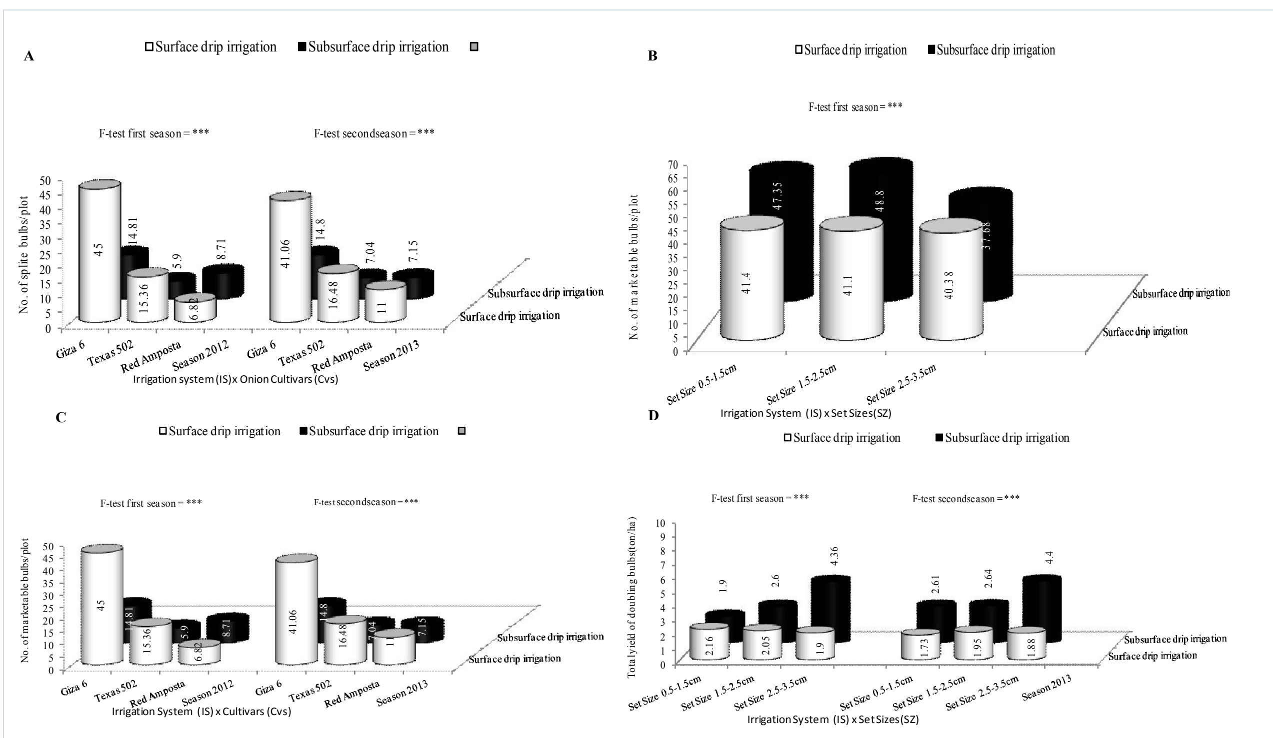

Fig (4): Interaction effects of irrigation systems (IS), sizes of sets (SS) and cultivars (cvs.) on yield components parameters of onion: A) cvs. x IS on no. of external doubling bulbs/plot, B) SS x IS on no. of marketable bulbs/plot (first season 2013), C) cvs. x IS on no. of marketable bulbs/plot and D) SS x IS on total yield of internal doubling bulbs (ton/ha).

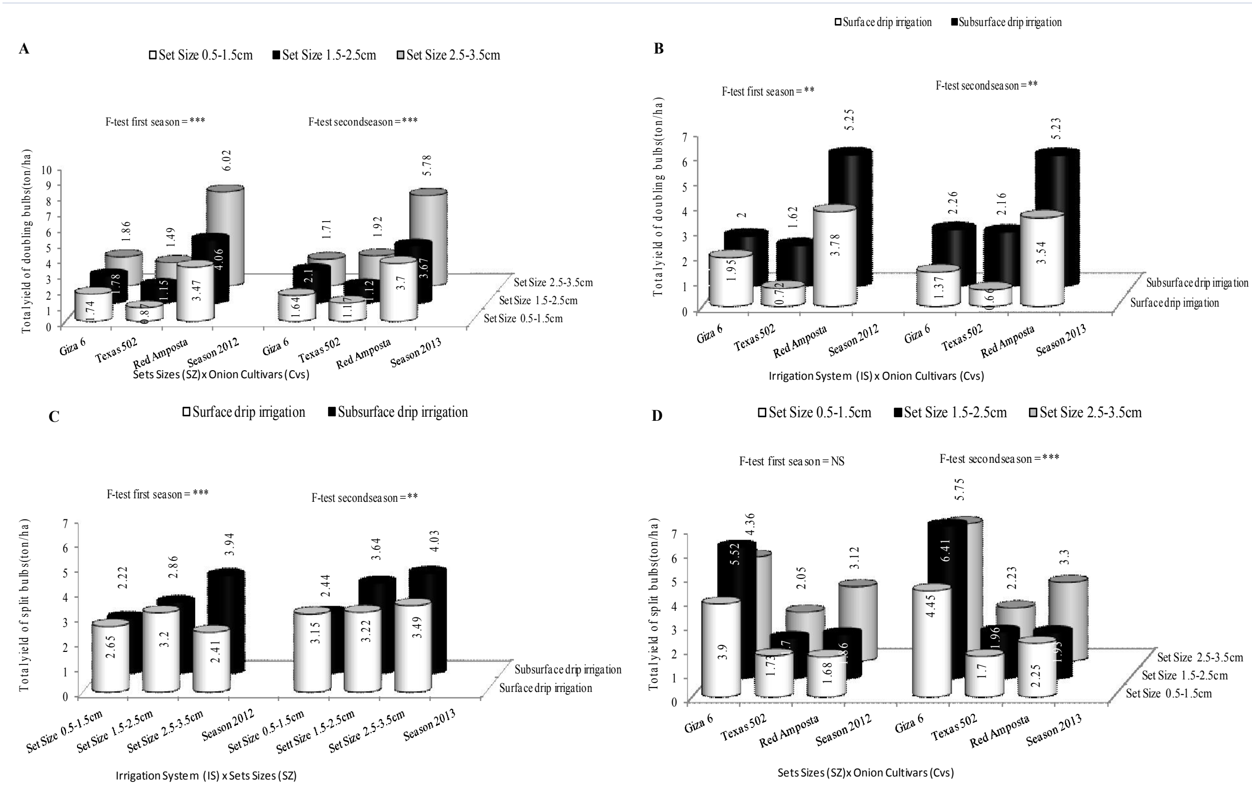

Fig (5): Interaction effects of irrigation systems (IS), sizes of sets (SS) and cultivars (cvs.) on yield components and yield parameters of onion: A) Cvs. x SS on total yield of internal doubling bulbs(ton/ha), B) cvs x IS on total yield of internal doubling bulbs(ton/ha), C) SS x IS on total yield of internal doubling bulbs(ton/ha) and D) cvs. x SS on total yield of external doubling bulbs(ton/ha) .

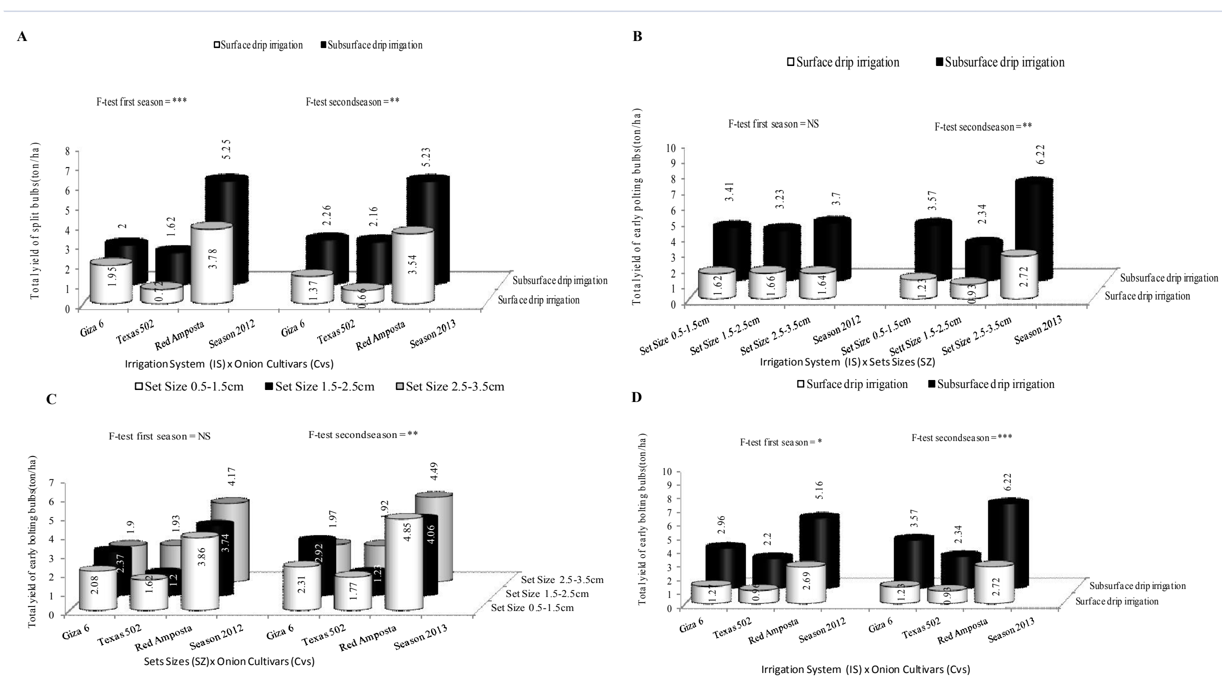

Fig (6): Interaction effects of irrigation systems (IS), sizes of sets (SS) and cultivars (cvs.) on yield components and yield parameters of onion: A) cvs x IS on total yield of internal doubling bulbs (ton/ha), B) SS x IS on total yield of early doubling bulbs (ton/ha), C) cvs. x SS on total yield of early doubling bulbs(ton/ha) and D) cvs. x IS on total yield of early doubling bulbs(ton/ha).

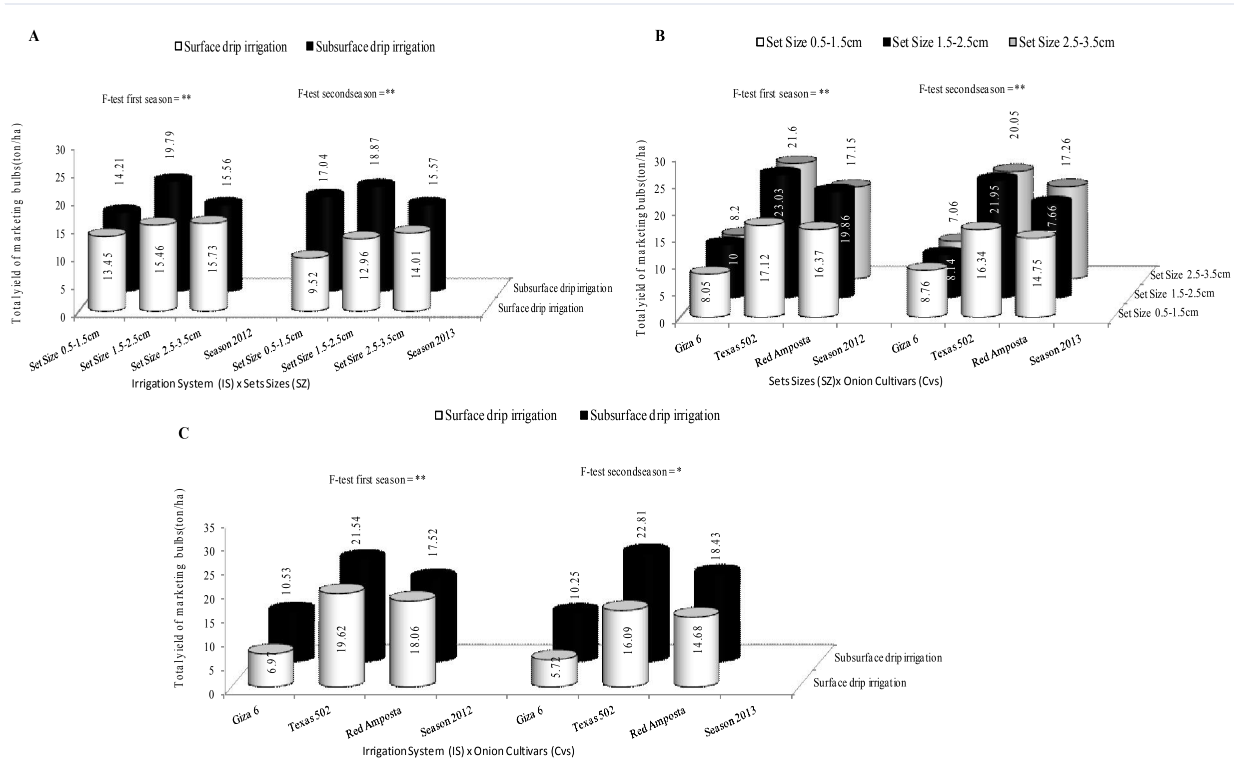

Fig (7): Interaction effects of irrigation systems (IS), sizes of sets (SS) and cultivars (cvs.) on yield components and yield parameters of onion: A) SS x IS on total yield of marketable bulbs(ton/ha), B) cvs x SS on total yield of marketable bulbs(ton/ha), and C) cvs. x IS on total yield of marketable bulbs(ton/ha).

Table (4): Total yield of marketable and unmarketable bulbs (doubling and bolting bulbs) of three onions cultivars grown using different sets sizes and two irrigation systems.

Treatments	Total yield of unmarketable onion bulbs (ton/ha)						Total yield of marketable bulbs (ton/ha)	
	Doubling bulbs		Split bulbs		Early bolting bulbs			
	2012	2013	2012	2013	2012	2013	2012	2013
Irrigations system (IS)								
IS1	2.03	1.85	2.75	3.29	1.64	1.60	14.88	12.16
IS2	2.95	3.22	3.01	3.37	3.46	4.04	16.53	17.16
F test	*NS*	**	*NS*	*NS*	***	**	*	*
Sets Size (SS)								
SS1	2.03b	2.17b	2.43b	2.79c	2.52a	3.00a	13.85c	13.28b
SS2	2.33b	2.29b	3.03a	3.43b	2.44a	2.74b	17.63a	15.92a
SS3	3.12a	3.14a	3.18a	3.76a	2.66a	2.80ab	15.65b	14.79a
F test	***	***	**	***	*NS*	*NS*	**	**
L.S.D (0.05)	*0.368*	*0.413*	*0.440*	*0.294*	-	*0.221*	*1.662*	*1.428*
Onion Cultivars (cvs)								
Giza 6	1.79b	1.82b	4.59a	5.54a	2.11b	2.40b	8.75c	7.98c
Texas (502)	1.17c	1.41c	1.82b	1.96c	1.58c	1.64c	20.58a	19.45a
Red Amposta	4.52a	4.38a	2.22b	2.50b	3.92a	4.47a	17.79b	16.56b
F test	***	***	***	***	***	***	***	***
L.S.D (0.05)	*0.190*	*0.295*	*0.711*	*0.341*	*0.425*	*0.295*	*1.224*	*1.184*
Interaction (IS * SS)								
F test	***	***	***	**	*NS*	**	**	**
Interaction (IS * cvs)								
F test	**	**	***	**	*	***	**	*
Interaction (SS * cvs)								
F test	***	***	*NS*	***	*NS*	***	**	**
Interaction (IS * SS * cvs)								
F test	***	*	*	*	*NS*	**	**	*

[1] IS1= surface drip irrigation system; [2] IS2= subsurface irrigation system
[3] SS1= set size 0.5 – 1.5 cm; [4]SS2 = Set size 1.5 – 2.5 cm; [5]SS3 = 2.5 – 3.5 cm.

Conclusion

The results of the present study provided applicable and effective solutions to control the doubling, split and early bolting of onions bulbs. Optimizing the irrigation system, sizes of bulbs sets and suitable cultivars can significantly reduce the number and yield of doubling, split and early bolting bulbs and increase the number and yield of marketable bulbs. Subsurface drip irrigation significantly enhanced yield and yield component of marketable bulbs. The medium/large sizes of bulbs sets (1.5-2.5cm and 2.5-3.5cm) improved the yield and yield components of marketable bulbs and significantly reduced the doubling, split and early bolting bulbs. The onion cultivar 'Texas 502' produced the greatest yield of marketable bulbs and recorded the least yield of unmarketable bulbs. Applying the combinations of subsurface drip irrigation, medium/large sizes of bulbs sets (1.5 – 3.5 cm) and the onion cultivar 'Texas 502' significantly reduced the yield of unmarketable bulbs (bolting, split and early bolting) and consequently increased the yield of marketable bulbs.

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