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Evaluation of root yield and sugar content of new sugar beet hybrids under water deficit and optimum irrigation

M. Sharifi[(1)*] and S.A. Degghanian[(2)]

[(1)] *Master expert of Agricultural and Natural Resources Research Center Fars, Shiraz, Iran.*
[(2)] *Instructor of Agricultural and Natural Resources Research Center Fars, Shiraz, Iran.*

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ABSTRACT

To determine sugar content and root yield variation of new sugar beet hybrids under different irrigation levels, an experiment was carried out at Zarghan Agricultural Research Station ofFars Agricultural and Natural Resources Research Center, Shiraz, Iran. The study was conducted as split block based on a randomized complete block design with three replications for two years, 2009-10, using line source sprinkler system. The treatments consisted of six cultivars including 28064, 28058, 28928, Zarghan, Jaam, and Rasoul (susceptible check) in main plots, and three irrigation levels viz. control, medium stress, and severe stress in subplots. Irrigation levels were set according to the distance from lateral tube and 4 m distance was considered for imposition of irrigation levels. Combined analysis results showed that hybrid 28928 had the highest root yield. It also showed higher than average yield stability in both optimum and water deficit conditions. Zarghan cultivar had lower yield in water deficicit condition while in normal irrigation the result was opposite. Regression analysis showed a quadratic equation between sugar content and water consumption so that sugar content was decreased in the range of about 400-900 mm irrigation but increased in less than 400 mm and more than 900 mm. In spite of increasing sugar content, water deficicit cannot be recommended for sugar production owing to yield reduction.. Considering the positive response of root yield to water use, 1100 mm irrigation level is suggested for increasing both root yield and sugar content.

Keywords: Line-source sprinkler system, optimum irrigation, root yield, sugar beet *(Beta vulgaris* L.), sugar content

INTRODUCTION

As water consumption in the country's agricultural lands is higher than the water requirement of the plants, the water abundance coefficient is less than unit, therefore, one of the essential solutions for optimizing water use efficiency in agricultural lands is deficit irrigation (Keshavarz and Sadeghzadeh 2000). Optimum water use in agricultural production is known as one of the most important environmental factors influencing the growth and development of plants, especially in arid and semi-arid regions like Iran (Mirzaei et al. 2006).

Sugar-beet together with sugar cane are the most important source of sucrose production. Sucrose is a product with a high sweetening and maintainability which allows it to be used as ingredients or additives in a wide range of foods, beverages and pharmaceuticals (Cook and Scott, 1993). Sugar content is the amount of sugar in fresh weight of sugar beet which is usually measured by polarimetry method (Abdollahian-anaoghabi et al., 2005).

Sugar beet can grow in a wide range of drought stress conditions, but the total dry matter, root and sugar yields are largely influenced by the degree of water stress or different levels of irrigation (Davidoff and Hanks 1989). Hang and Miller (1986) showed that dry matter production of root and shoot increased with an increase in water consumption up to 85% of evapotranspiration. Damage caused by drought reduced root yield by less

*Corresponding author's email: sharifim@farsagres.ir

Table 1. Some physical properties of the soil in experimental site

Soil depth (cm)	Soil texture	Soil particle distribution			Bulk density (g cm^{-3})	Soil moisture (volume percent)	
		clay	loam	sand		Field capacity	Permanent wilting point
0-30	Silty clay	41	42.6	16.4	1.38	29.5	13.7
30-60	Silty clay	42	42.6	15.4	1.60	27.5	13.9

than 50% compared with normal condition but it did not influence sugar content (Inoue et al., 1984). Mirzaee and Rezvani (2008) showed that irrigation cutoff at the end of sugar beet growth will reduce sugar content, white sugar yield, and extraction coefficient of sugar. In general, water stress occurrence at the end of the growth period causes increase in root impurities including K and Na which consequently results in a significant reduction in the sugar yield and increase in molasses sugar. Akbari (1999) studied the effect of low irrigation on sugar beet yield and reported that by 30% reduction in water use, yield decreased by 10%, which was compensated by sugar content increase so that sugar yield experienced no considerable variation.

Saffarian et al. (2006) evaluated the effect of pre-harvest irrigation cutoff time on yield and quality of sugar beet. Their results showed that early irrigation cutoff at harvest decreased the amount of water in plant tissue due to a sharp decrease in soil water matric potential which consequently increased the sugar content. They also reported that due to the lower levels of sucrose in normal treatment, increased sucrose concentration results from root water loss, so irrigation cutoff can reduce dry matter percentage and sucrose content during harvest. Ucan and Gencoglan (2004) showed that with six irrigation levels with a maximum and minimum of 1331 and 419 mm, respectively, root yield was decreased significantly but the result was different for the sugar content. Kirda (2002) showed that deficit irrigation increased sucrose content during the growing season and reported deficit irrigation as one of the ways to maximize water use efficiency and yield. In this method, the plant is subjected to water stress at a specific growth stage or throughout the growing season.

MATERIALS AND METHODS

This study was conducted as split block based on randomized complete block design with three replications. Cultivar was considered as the first factor including 28064, 28058, 28928, Zarghan, Jaan and Rasoul (susceptible), and the other factor was irrigation level including normal, and moderate and severe water stress in three replications conducted at Zarghan Agricultural Research Station of Fars Agricultural and Natural Resources Research Center, Shiraz, Iran, in the form of a line source sprinkler system for two years (2009-10). Some physical properties of the soil at the experimental site are listed in Table 1. On an aluminum tube and in 6 m distance, 11.62 × 3.32-inch nozzles were located with 0.49 ls^{-1} discharge and 13.6 m spray radius. Nozzles were placed on razer tubes with 3.4-inch diameter and one-meter height. Irrigation levels were determined based on plant distance to lateral tube and 4m intervals were considered for irrigation regimes application. Accordingly, normal treatments were placed in 2-6 m distance, medium-stress treatments in 6-10 m distance, and severe-stress treatments in 10-14 m distance from the lateral tube. To avoid the error, the first two meters from the lateral tube were not included in the design. Cans with 80.12 cm^2 cross section were placed in the middle of each plot at 4, 8, and 12m distance from the main tube to measure water sprinklers. Planting rows were placed in parallel with the water pipe so that the run-off occurrence would not be in the line of irrigation treatments. Cultivars were planted in 12 × 2 m^2 plots of rectangular shape. Harvest was performed at about six m^2. In this experiment, the design of the sprinkler system and the placement of the plots were such that by increasing the distance from the main water supply, the amount of water received by the plants reduced and this condition was uniformly applied throughout the field so that the cultivars were evaluated in a uniform moisture gradient.

The between- and on-row spacings were 50 and 18-22 cm, respectively. Variation in soil moisture storage was determined by soil sampling at 0-15, 15-30, 30-60, and 60-90 cm depth. To obtain uniform emergence, the first and second irrigations were performed as furrow (the amount of water shown in Table 2 is the sum of furrow and system irrigation). Irrigation treatments were applied after seedling emergence and plant establishment. Irrigation was performed in a week interval and irrigation volume was obtained

Table 2. Average water use in different irrigation treatments in 2009-10

cultivars	Water use levels in different irrigation treatments in 2009 (mm)			Water use levels in different irrigation treatments in 2010 (mm)		
	Normal	Moderate stress	Severe stress	Normal	Moderate stress	Severe stress
28064	1201	705	402	761	498	339
28058	1192	702	377	746	487	355
28928	1211	707	393	718	487	351
Zarghan	1162	707	393	751	509	350
Jaam	1110	690	490	695	465	333
Rasoul (control)	1136	716	386	718	467	331

Table 3. Combined analysis results of different traits min 2009-10

S.O.V.	Na	K	Amino-N	Alkalinity	Sugar content	Extractable sugar	Molasses sugar	Extraction coefficient	Sugar yield	Whitesugar yield	Root yield
	Mean square										
Year	16.73*	2.27*	76.84**	89.83**	0.09	9.23	7.54**	285.64*	34.00*	35.74*	811.26**
Rep	1.91	0.17	2.02	3.55	4.63	5.85	0.26	22.57	3.43	2.57	106.07
Irrigation	4.21*	1.21**	56.70**	145.78**	23.93**	28.00**	0.20	80.62**	421.67**	260.40**	15150.69**
Rep	23.35**	0.61*	2.07*	5.53	16.74**	32.58**	3.48**	247.41**	20.16**	23.15**	334.29**
Year × Irrigation	0.63	0.07	0.27	1.61	0.59	0.92	0.07	6.64	1.20	0.91	28.18
Cultivar	6.23*	0.97**	3.17**	9.12**	1.69*	5.48**	1.42**	67.45**	9.49**	7.83**	282.09**
Year × cultivar	0.25	0.07	0.27	1.41	0.17	0.13	0.02	0.49	0.23	0.21	8.99
Rep	0.81	0.17	0.38	1.31	0.61	1.14	0.13	8.82	0.80	0.53	29.65
Irrigation × cultivar	1.18	0.15	0.41	1.52	0.81	1.42	0.12	9.50	3.69**	3.02**	103.43**
Year × irrigation × cultivar	0.41	0.13	0.12	1.03	0.30	0.47	0.07	3.29	0.88	0.72	29.252
Mean traits within two years	3.77	5.25	3.09	3.88	17.57	13.89	3.07	78.85	5.05	3.99	29.33
CV	23.23	7.49	15.05	29.51	4.00	7.32	11.62	3.72	14.85	17.20	13.69

* and **: significant at 5 and 1% probability levels, respectively.

according to the following formula in normal treatment (minimum distance from water supply line):

(1) Net irrigation depth = root development depth × (FC-ϴ) × BD

Root depth will vary at different times.

The readily available water was considered as approximately 50% of the available water.

FC: field capacity

ϴ: soil moisture before irrigation

BD: soil bulk density

With one-time irrigation, the spraying rate of the sprinklers was calculated by collecting the water sprayed in the cups and at next times, the irrigation time was calculated. Meanwhile, with sprinkler water collection in each plot, the total amount of water reached to each plot at the end of the growing period was determined.

At harvest, root samples were taken from four lines. Sugar beet pulp was used for sugar content, sugar yield, white sugar content, impurities (amino nitrogen, sodium and potassium), molasses sugar and alkalinity coefficient measurement.

Due to the windy weather condition in the area and disorder occurrence on sprinkler irrigation movement to the severe stress treatment on wind direction, plants suffered severe dryness. Therefore, treatments comparison was performed from one side of the lateral tube and data were analyzed in split block design based on Hanks et al. (1980) design. Mean comparison was done using Duncan's test and other analyzes were performed using SAS, SPSS, Excel software.

RESULTS

Root yield

Effect of year, cultivar, irrigation, year × irrigation and irrigation × cultivar on root yield was significant (P<0.01, Table 3). In other words, significant difference was observed among the cultivars under different irrigation treatments. Year × cultivar interaction was not significant. Results showed that cultivars had similar reaction in two years, although the range of changes in the second year was lower but means overlapping led to the non-significant effect of year × cultivar interaction. Hybrid 28928 with an average of 33.8944 t ha^{-1} root yield was placed in one group with 28058 and 28064 hybrids and Rasoul cultivar had the lowest root yield (22.83 t ha^{-1}, Table 4). Root yield reduction was correlated with a decreased irrigation level and the highest root yield was obtained in normal irrigation (Figure 2). The effect of deficit irrigation on root yield reduction is in accordance with other studies (Taleghani et al. 2000; Noorjo 2009; Rytter 2005).

Table 4. Mean classification of different traits during 2009-10

Cultivar	Na	K	Amino-N	Alkalinity	Sugar content (%)	Extractable sugar (%)	Molasses sugar (%)	Extraction coefficient	Sugar yield (t ha^{-1})	White sugar yield (t ha^{-1})	Root yield (t ha^{-1})
	meq/100g sugar beet root										
28064	4.20 AB	5.41 AB	2.91 BCD	4.48 A	17.49 B	13.63 BC	3.26 AB	77.77 CD	5.29 A	4.11 B	30.94 A
28058	3.74 BC	5.18 BC	3.35 AB	3.33 B	17.5 B	13.84 BC	3.06 B	78.87 BC	5.33 A	4.18 AB	31.44 A
28928	3.11 C	5.09 C	3.28 ABC	3.24 B	17.54 B	14.12 AB	2.81 C	80.34 AB	5.82 A	4.69 A	33.89 A
Zarghan	3.10 C	5.01 C	2.48 D	4.14 A	18.17 A	14.87 A	2.70 C	81.67 A	5.47 A	4.5 AB	30.28 AB
Jaam	3.89 B	5.16 BC	3.66 A	3.23 A	17.37 B	13.63 BC	3.14 B	78.26 BCD	4.57 B	3.59 C	26.61 BC A
Rasoul (control)	4.57 A	5.64 A	2.88 DC	4.87 A	17.34 B	13.28 C	3.46 A	76.20 D	3.82 C	2.88 D	22.83 C

Means with same letter in each column are not significantly different ($P \leq 0.05$).

Sugar yield and white sugar yield

Except year × cultivar interaction, the other sources of variation had significant ($P<0.01$) effect on sugar yield and white sugar yield (Table 3). In other words, in both years and under different irrigation levels, cultivars showed statistically similar response. Hybrid 28928 with an average sugar yield and white sugar yield of 5.82 and 4.69 t ha^{-1}, respectively, was selected as the best hybrid. Rasoul cultivar had the lowest average sugar yield and white sugar yield of 3.82 and 2.88 t ha^{-1}, respectively (Table 4). Sugar yield is the most important economic index in sugar beet production which is the product of root yield and sugar content (Cook and Scott, 1993).

Sugar content and white sugar content

Irrigation variation treatments, year × irrigation and cultivar were statistically significant ($P<0.01$, Table 3). As shown in Table 4, the maximum sugar content (18.17%) and white sugar content (14.87%) were attributed to Zarghan cultivar. It should be noted that under sever stress, the highest sugar content was obtained. Sugar content and white sugar content values under severe stress (18.47 and 14.88, respectively), moderate stress (17.35 and 13.62, respectively), and normal treatments (16.88 and 1.18, respectively) were placed in three distinct groups which illustrates that with decrease in irrigation level, sugar content increased (Taleghani et al. 2000; Noorjo 2009; Bazobandi 1993). Based on the results of Winter (1989) and Jahad Aakbar et al. (2004), Na content in the root increased with an increase in irrigation level which consequently reduced sugar content.

Extraction coefficient of sugar

The effects of irrigation, year, year × irrigation and cultivar on extraction coefficient of sugar was significant (Table 3). The highest extraction coefficient of sugar was for Zarghan (81.67%) and 28928 (80.34%) and the lowest percentage (76.20%) was obtained for Rasoul (Table 4).

Comparison of sugar content and root yield variation with water use in different cultivars

Relationship of sugar content and root yield with water use in two years is shown in Figures 1 and 2. It can be seen that the relationship for sugar content is in a 2^{nd} degree and for root yield it is in a linear-type. In all cultivars, sugar content decreased in about 400-900 mm of irrigation water volume. However, due to root yield reduction in deficit irrigation, it is not recommended for sugar content increase.

Evaluation of yield stability of different cultivars with irrigation variation

In this study, the root yield stability of different cultivars in different environments was measured relative to the average root yield of all cultivars in those environments (Kramer and Boyer 1995; Edmeades et al., 1989) (Figure 3). The horizontal axis of Figure 3 represents the average yield of all cultivars under different irrigation treatments and the vertical axis represents the performance of each cultivar under irrigation treatments. The split line is actually the line drawn between the points resulting from the mean root yield of all cultivars under different environments. This line with the equation of $x = y$ and the 45° angle is the basis for stability comparison of other cultivars. The complete line is the most fitted line derived from root yield regression of each cultivar versus the average root yield of all cultivars in different water use rates. In this diagram, a complete line above the dashed line represents superiority over the average yield of all cultivars. Under both stress and normal conditions, the hybrids 28058, 28928 and 28064 had higher yield than the average of all cultivars. Zarghan cultivar had low yield under stress condition and higher than average yield under normal condition. However, Jaam and Rasoul cultivars had low yield under both stress and normal conditions.

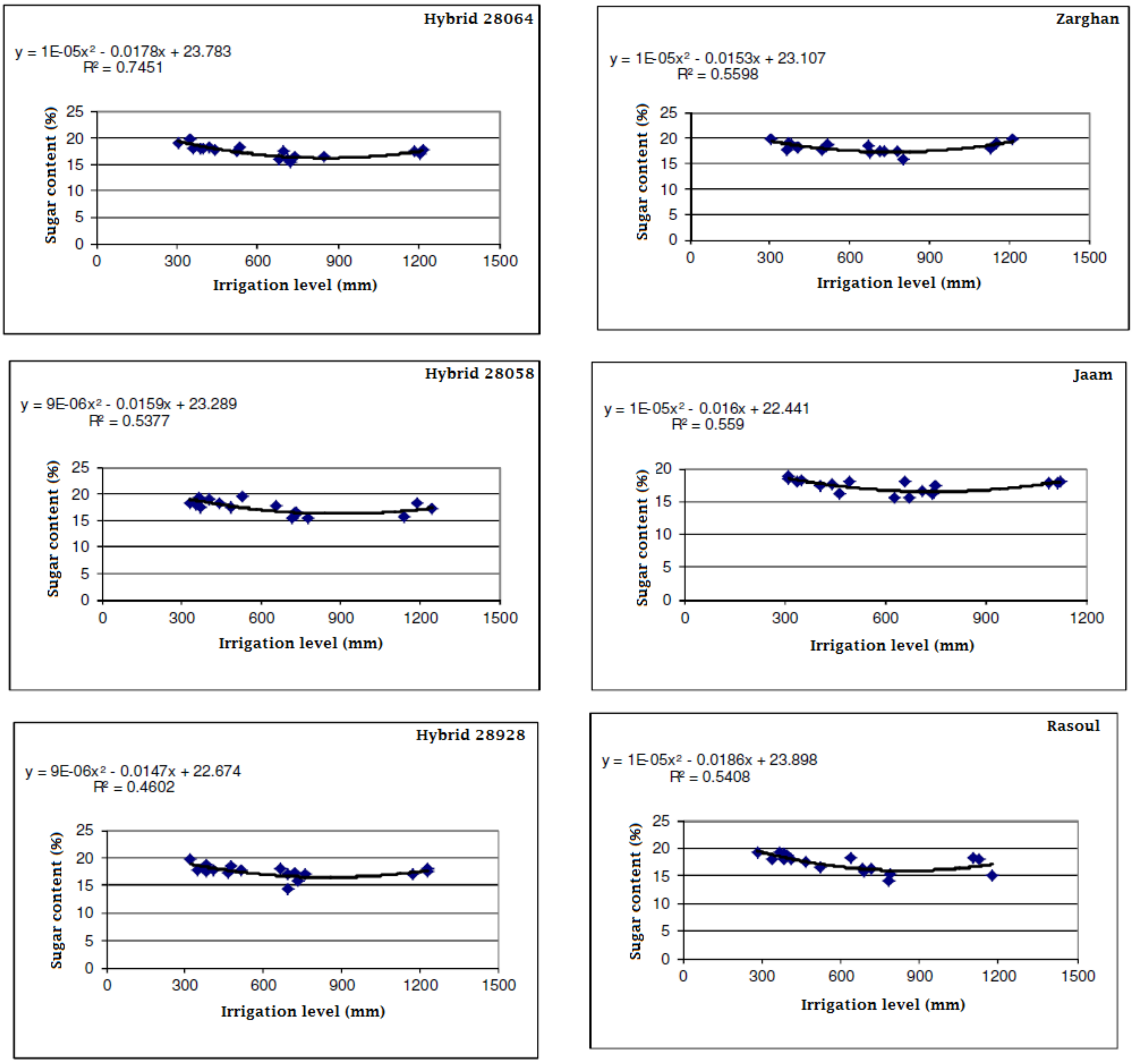

Figure 1. Sugar content variation in different cultivars and irrigation levels in 2008-09

Discussion

Comparison of water use and root yield of different cultivars showed that with increase in water use, root yield also increased. The increase in root yield was proportional to the increase in water use which means that doubled water use under normal irrigation compared with moderate stress almost doubled root yield but according to Figure 2, it can be deduced that the sugar beet response to increased water use continues to a certain extent and then the increase in root yield is negligible. With up to 1100 mm irrigation water, root yield increased sharply and then the rate slowed down. Sugar content increase was observed at less than 400 mm and more than 900 mm irrigation. However, due to the reduced root yield and sugar yield, irrigation water less than 400 mm is not recommended. Because of root yield increase through increasing water use, 1100 mm irrigation can be suggested for increasing root yield and sugar content. Therefore, according to the recent droughts, irrigation level should be set in order to increase root yield and sugar content. Taleghani et al. (2000) studied the effect of 100, 75, and 50% irrigation water levels according to plant water requirement and 0, 120, 240, and 360 kg N ha^{-1} on sugar beet root yield. Their results showed that root yield under 100% irrigation level according to plant water requirement was about 20% higher than 50% level but sugar content under dry condition was higher than wet condition.

Under stress condition, there are two reasons for leaf and root growth reduction including low pressure potential that slow down cell development and reduced stomatal conductance which

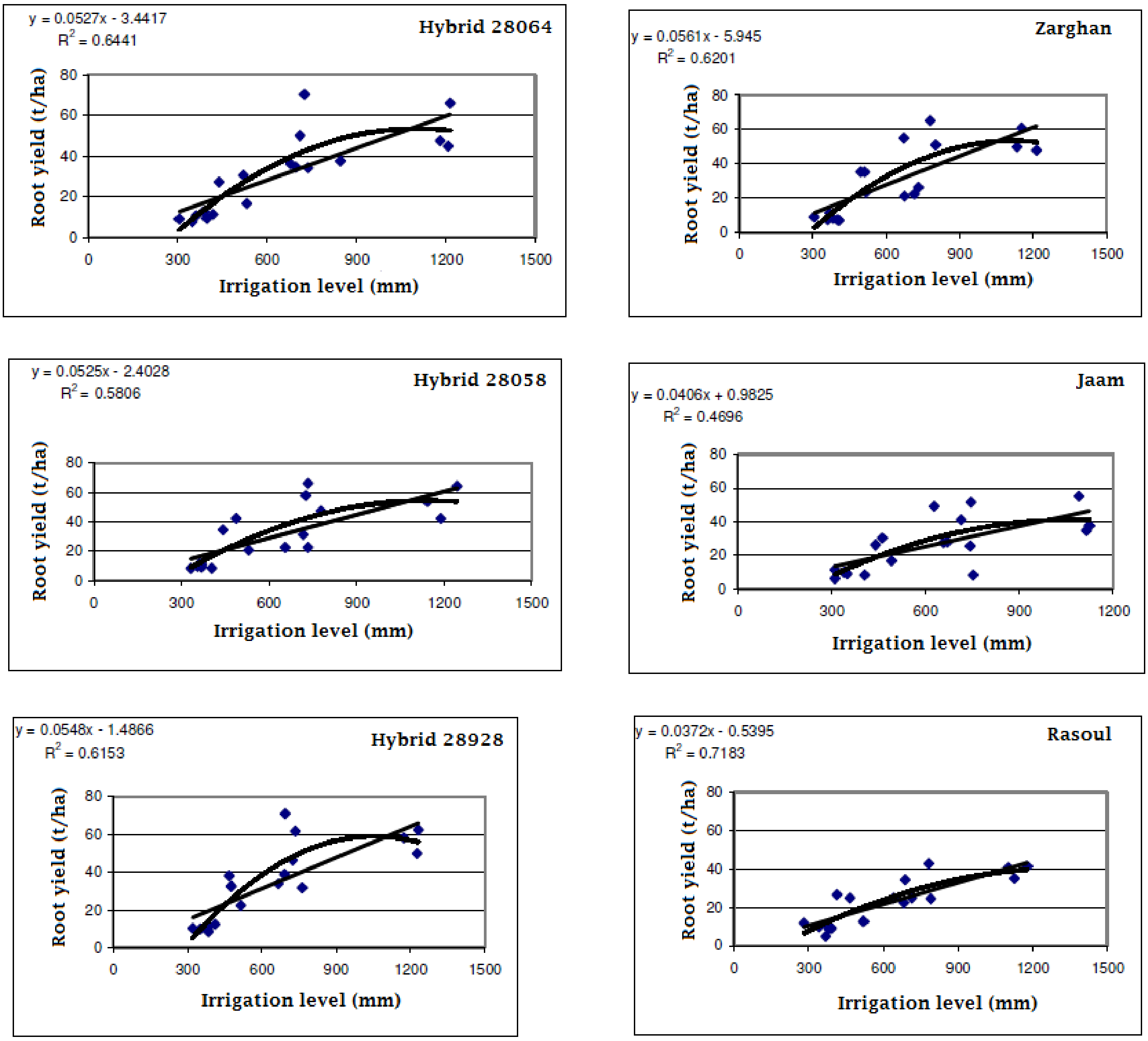

Figure 2. Root yield variation in different cultivars and irrigation levels in 2008-09

decreased CO_2 absorption for the dry matter production (Cook and Scott 1999). Parvizi and Yazdi samadi (1994) concluded that stress increased sugar content, K and root alkalinity but white sugar content decreased. In a study in Italy, Barbiri (1982) reported that irrigation increased the average root yield and root size but reduced sucrose content and delay in irrigation or its cutoff increased sucrose content.

Among the studied cultivars, Zarghan had low yield under stress condition and higher yield than the average under normal condition. Therefore, owing to high root and sugar yield under normal condition, Zarghan is a proper cultivar for growing under normal condition but the hybrid 28928 had higher root yield and sugar content compared with the other cultivars, therefore, this hybrid is recommended for stress condition. However, further studies with different stress conditions are needed.

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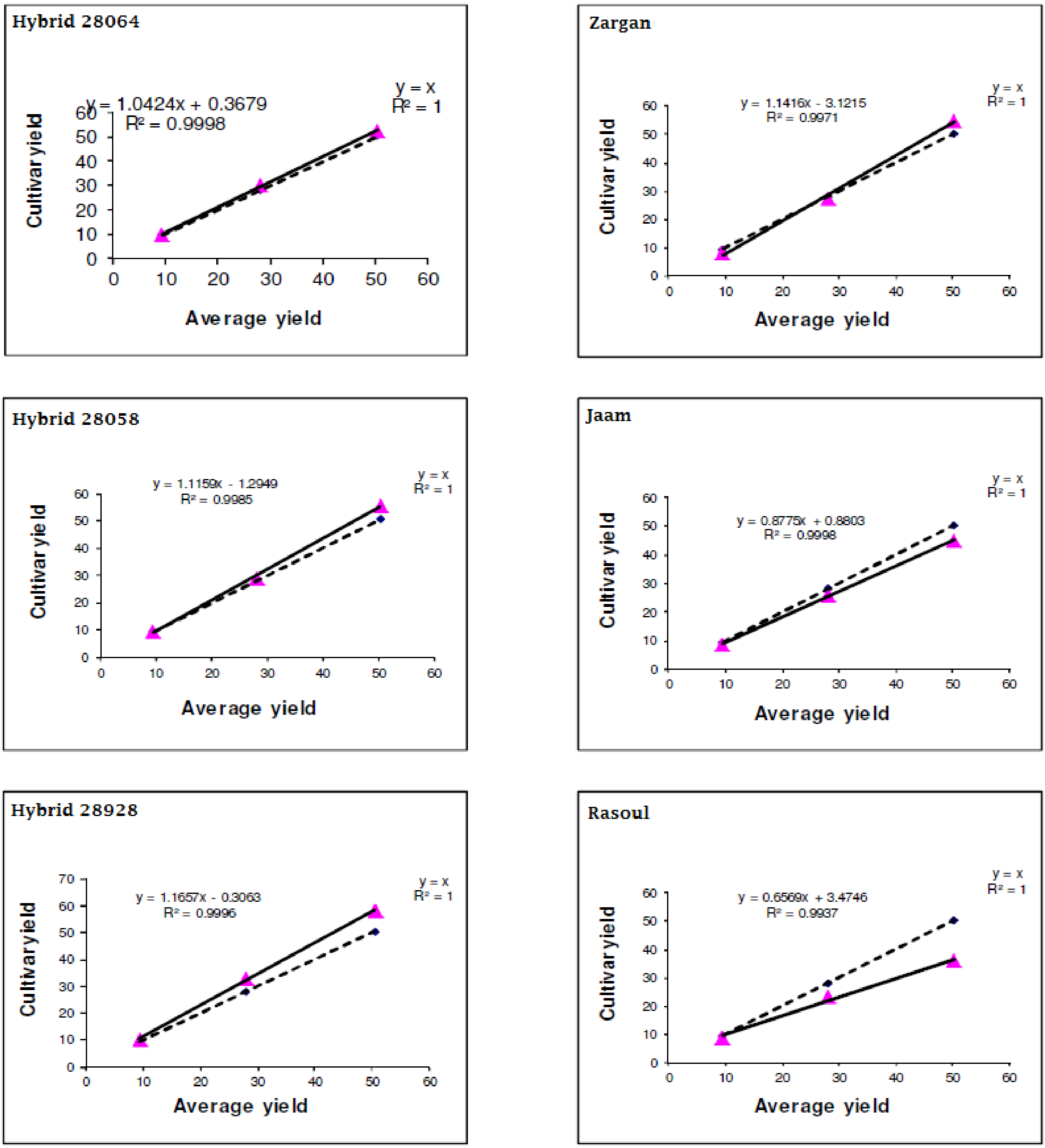

Figure 3. Evaluation of yield stability of different cultivars under different irrigation levels (the dashed line with X = Y equation which is fitted between the points of average root yield of all cultivars in different environments is a basis for stability comparison of other cultivars with an angle coefficient of 1. The complete line actually represents the fitted line between the root yields of each cultivar versus the average yield of all cultivars.

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