5 *Egypt. J. Phytopathol.,* Vol. **46**, No. 1, pp. 69-89 (2018)

Effect of Irrigation Intervals and Interplant Spacing Levels on Downy Mildew Epidemic and Productivity of Basil Plants

Eman Ghebrial W.R.* and Kenawy A.G.M.**
**Plant Pathol. Res. Inst., ARC, Giza, Egypt*
***Hort. Res. Inst., ARC, Giza, Egypt*

Field experiments were carried out under natural infection of basil downy mildew in the Experimental Farm of Sids Horticultural Research Station, Agric. Res. Center, Beni-Sweif governorate during 2016 and 2017 growing seasons in order to evaluate the efficacy of different irrigation intervals and interplant spacing levels on basil downy mildew epidemic caused by *Peronospora belbahrii* and productivity of basil plant. In general, irrigation intervals and interplant spacing levels significantly affect the disease incidence and severity as well as basil growth parameters (plant height, no. of branches, fresh and dry weights of herb, oil ratio and essential oil yields) at the end of the experiment. The high efficacy was obtained from plots irrigated at 12 day interval and planted at 20 cm spacing. Although, those irrigated at 16 day interval and planted at 25 cm spacing gave the highest reduction in disease incidence and severity but drastically affected plant growth and oil yield to the lowest value.

Keywords: *Downy mildew, Interplant spacing, Irrigation intervals, Peronospora belbahrii and Sweet basil.*

Sweet basil (*Ocimum basilicum* L., Family. Lamiaceae) is an economically important medicinal and aromatic herb crop, originated in Egypt and East Mediterranean and nowadays has cultivated all over the world (Simon *et al*., 1999 and Sadeghi *et al*., 2009). Basil is widely used for its therapeutic properties, as well as consumed dry or fresh herb for aromatic and culinary purposes. The extracts from fresh leaves and flowers can be used as aroma additives in food, pharmaceuticals and cosmetics (Simon *et al*., 1990 and Marotti *et al*., 1996). Moreover, essential oil of basil is known to posse's antimicrobial, insecticidal activities and recently it has found to have *in vivo* anti malaria activity (Zheljazkov *et al*., 2008).

Recently, downy mildew caused by the biotrophic oomycete *P. belbahrii* Thines sp. nov. (Belbahri *et al*., 2005 and Thines *et al*., 2009) has become one of the most destructive diseases of sweet basil in Egypt causing complete crop losses in some fields (Hilal and Ghebrial, 2014 & Ghebrial and Nada, 2017). Although there is no research on how the pathogen arrived in Egypt, infested basil seeds (Garibaldi *et al*., 2004) and/or infected plant materials are believed to facilitate the spread.

Epidemics of basil downy mildew largely depend upon climate conditions. The major environmental factors are air humidity, temperature and light. Downy mildew on basil is especially severe when foliage stays wet for extended periods (6 to 12 h). The pathogen requires at least 6 h of leaf wetness (free leaf moisture) after inoculation and at least 12 h for severe infections and, most important, in order to sporulate it requires the presence of moisture-saturated atmosphere (relative humidity ≥ 95 %) in the dark which completed within about 11 hours at 18^{o}C (Garibaldi *et al.*, 2007 and Cohen *et al.*, 2013). Sporulation of *Peronospora* sp. in the presence of favourable environmental conditions is quite intense: this can explain the quick spread of the epidemics of downy mildew observed. Although the distribution of the disease was generally uniform, symptoms appeared first with a patchy pattern in the central part of the fields, where relative humidity was the highest. Basal leaves, where air circulation was apparently poor, were severely affected by the disease.

Light strongly inhibits the sporulation of *P. belbahrii* on basil leaves but not the emergence of sporophores from stomata. Sporophores produced under light are abnormal and fail to form spores (Cohen *et al.*, 2013). Plant densities have profound influence on the development of foliar diseases in many crops. The density at which plants are placed is likely to affect relative humidity in the leaf canopy and the speed at which leaves dry after wetting during irrigation (O'Neill *et al.*, 2002). Higher plant densities support foliar diseases (Pande *et al.*, 1998 & Pande and Narayana Rao, 2002). There should be enough space between the plants to ensure good airflow within and between rows to reduce air humidity and to avoid vapor deposition on leaf surface, thus preventing infection and sporulation (Cohen and Rubin, 2015). Cohen and Ben-Naim (2016) showed that a 10 min interrupting dry period at 3 or 4 h during infection process had a strong negative impact on infection.

Also, vegetative growth and essential oils content are explicitly influenced by climate, soil conditions and agricultural practices (Carlo *et al.*, 2013). In suitable plant density, plants show efficient use of available water, light and nutrient while under high plant density, have a higher competition among plants. El-Gendy *et al.*, (2001) revealed that increase in plant space, increased greatly the number of branches, leaves and plant dry weight, whereas it decreased plant height.

Irrigation and soil moisture status are important factors stimulating downy mildew. Since irrigation affects soil water conditions, the severity of basil downy mildew can be potentially modified by changing irrigation practices. The frequency of irrigation application and flooding duration has a direct effect on the disease. Higher disease severity occurred with more frequent irrigation and longer duration of flooding. Decreasing the frequency of irrigation can also reduce the risk of disease, but this will need to be balanced with the water needs of the crops. On the other hand, water deficiency during the plant production can include main damages to development and also on effective materials of medical plants. Moeini *et al.* (2006) reported that as the water stress increased, the plant height and herb yield decreased. Ekren *et al.* (2012) revealed that water stress negatively affected the plant height and the yields of purple basil plant, while the essential oil ratio of the plant increased as the applied amount of irrigation water decreased. In contrast, applying

75% of field water capacity (FWC) on both sweet basil and American basil obtained the highest yield of herb and essential oil concentrations compared with other irrigation treatments (50% and 100% of FWC) (Khalid, 2006).

Many investigations have been done to control the disease of basil by spraying chemicals but a very few references on irrigation, plant densities and disease interaction are available. This experiment was, therefore, undertaken to find out the optimum plant spacing and irrigation intervals to manage downy mildew and to achieve maximum yields in basil.

Materials and Methods

A two-year field experiment was conducted under natural infection in the Experimental Farm of Sids Horticultural Research Station, Agric. Res. Center, Beni-Sweif governorate during the seasons of 2016 and 2017 to find out the optimum plant spacing and irrigation intervals to manage downy mildew and to achieve maximum yields in basil. The soil of the experimental field was clay in texture (16.5 % sand, 30.1 % silt, 53.4 % clay, pH of 8.1, EC 1.2 dSm^{-1}; 1.3 % organic matter and 26.2, 10.1 and 176 ppm available N, P and K, respectively). The experiment was designed in a randomized complete blocks design as split plot arrangement, with three replications. The main plot assigned to the irrigation treatments, viz. irrigation at 8 days interval, 12 days interval and 16 days intervals and subplot (3 x 3.5 m) to plant space (10, 15, 20 and 25 cm).

In each season, the soil was mechanically ploughed and planked twice. During the preparation for cultivation, a mixture of calcium super-phosphate (15.5 % P_2O_5) as a source of phosphorus and potassium sulfate (48 % K_2O) as a source of potassium was added at the rate of 200 and 100 kg/fed, respectively. The uniform healthy basil seedlings (Balady variety), 10-15 cm length were transplanted into the field on May, 1st in the two experimental seasons on rows at different spaces. Weeds were removed by manual operations as needed and plants were irrigated regularly as necessary without creating any water stress until the plants adapted to the soil conditions and create uniformity among the plants, then irrigation treatments were applied as mentioned before. Nitrogen was applied in the form of ammonium sulphate (20.6 % N), at the rate of 400 kg/fed. (recommended rate) as follow: the first one was added after 21 days from transplanting and the second after 15 days from the first application. The remainder amounts were added after each cut. Monitoring and scouting the plants weekly for downy mildew and disease incidence and severity were estimated as follow:

Disease incidence:

Percentage of disease incidence was recorded as the number of diseased plants relative to the number of growing plants for each treatment, and then the average of disease incidence was calculated.

Disease severity:

Disease severity was measured according to Abd-Alla (2004). Percentage of disease severity was recorded according to the following equation:

$$\text{Disease severity } \% = [\sum (n \times c)] / (N \times C) \times 100$$

Whereas: n = Number of infected leaves, c = Category number, N = Total number of examined leaves and C = The highest category number of infection.

The plants were harvested three times in each growing season. The first cut was done on 1st July during the flowering stage, the second one was done on half of August and the last one on 1st October by cutting the vegetative parts of the plants 10 cm above the soil surface with three replications in each cut. The following biometric parameters were determined: plant height (cm), number of branches/plant, fresh and dry weights of herb yield (ton/fed.).

To determine the percentage and total yield of essential oil, the fresh plants (leaves and flowers) were collected from each treatment during the three cuts. They were dried by air and weighted (100g dry herb/treatment) representing each replicate then subjected to steam distillation and determined according to Guenther (1961).

Data were statistically analyzed for computing L.S.D. test at 5 % probability according to the procedure outlined by Snedecor and Cochran (1989).

Results

The different irrigation intervals and spacing create significant differences in their effects on disease incidence and severity (Tables, 1 and 2). Downy mildew of basil was increased in parallel to the amount of irrigation water applied in both years. Lowest disease incidence and severity were observed in 16 day irrigation interval plots followed by those of 12 day irrigation interval with significant differences between them. The disease incidence percentages obtained due to the 16 day irrigation interval treatment in the first season (2016) were 43.30, 62.96 & 51.95 and disease severity reported 27.82, 39.76 & 35.59 % for the first, second and third cut, respectively. While it reached 60.16, 79.29 & 69.08 for disease incidence and 36.53, 55.47 & 46.04 % for disease severity at 12 day irrigation interval treatment. The highest values were obtained from the 8 day irrigation interval plots that reached 86.49, 96.87 & 90.24 disease incidence and 46.57, 67.90 & 53.33 % for disease severity, respectively. The same trend was observed in the second season (2017).

On the other hand, wider plant spacing was decreased the downy mildew development as compared to that of the narrow spacing. The maximum percent of disease incidence was calculated from plots planted with 10 cm spacing which recorded 73.67, 91.19 & 83.35 and 44.52, 67.95 & 56.82 % disease severity followed by 15 cm spacing, being 67.72, 86.79 & 75.93 disease incidence and 39.83, 58.75 & 47.98 % disease severity for the three cuts, respectively during 2016 growing season, while the lowest values of disease incidence and severity (54.76, 67.43 & 58.27 and 29.88, 42.94 & 35.53 % for the three cuts, respectively) were obtained from plots planted with 25 cm spacing. The 20 cm plant spacing plots showed moderate effect on downy mildew incidence, being 57.12, 73.40 and 64.13 %, respectively while reached 33.65, 47.86 and 39.60 % in disease severity which lies in the same statistical group with the values of 25 cm spacing treatment. The same trend was observed with the second season (2017).

Table 1. Evaluation of different irrigation intervals and interplant spacing levels on disease incidence percent of basil downy mildew for three plant cuts during the two growing seasons 2016 and 2017 under field conditions

Interplant spacing (B)	Irrigation intervals (A)							
	Disease incidence %							
	First cut							
	Season of 2016				Season of 2017			
	8 days	12 days	16 days	Mean (B)	8 days	12 days	16 days	Mean(B)
10 cm	92.87	75.18	52.95	73.67	90.22	74.60	50.32	71.71
15 cm	89.45	66.40	47.30	67.72	87.55	62.52	44.73	64.93
20 cm	83.00	50.86	37.49	57.12	80.72	48.22	35.94	54.96
25 cm	80.65	48.19	35.44	54.76	76.15	47.17	31.64	51.65
Mean (A)	86.49	60.16	43.30	---	83.66	58.13	40.66	---
L.S.D. at 0.05	A = 3.16 B = 3.27 AB = 5.66				A = 1.38 B = 3.72 AB = 6.44			
Second cut								
10 cm	100.00	95.14	78.43	91.19	100.00	95.00	77.12	90.71
15 cm	100.00	88.89	71.48	86.79	100.00	87.24	68.42	85.22
20 cm	97.33	70.11	52.77	73.40	98.95	68.11	50.00	72.35
25 cm	90.14	63.00	49.16	67.43	88.44	60.60	46.82	65.29
Mean (A)	96.87	79.29	62.96	---	96.85	77.74	60.59	---
L.S.D. at 0.05	A = 6.20 B = 4.27 AB = 7.40				A = 3.04 B = 3.40 AB = 5.89			
Third cut								
10 cm	100.00	84.93	65.12	83.35	96.91	83.33	65.33	81.86
15 cm	94.49	73.66	59.63	75.93	90.12	70.15	58.88	73.05
20 cm	88.69	61.54	42.15	64.13	84.53	59.52	39.48	61.18
25 cm	77.76	56.17	40.89	58.27	73.62	53.00	38.81	55.14
Mean (A)	90.24	69.08	51.95	---	86.30	66.50	50.63	---
L.S.D. at 0.05	A = 2.00 B = 4.75 AB = 8.23				A = 1.32 B = 5.35 AB = 9.27			

The interaction effect of irrigation interval and different plant spacing was significant for the three plant cuts during the two successive growing seasons. Disease incidence and severity percent were the highest in interaction of 8 day irrigation interval and 10 cm plant spacing treatment and lowest in interaction of 16 day irrigation interval and 25 cm plant spacing treatment.

Table 2. Evaluation of different irrigation intervals and interplant spacing levels on disease severity percent of basil downy mildew for three plant cuts during the two growing seasons 2016 and 2017 under field conditions

Interplant spacing (B)	Irrigation intervals (A)							
	Disease severity %							
	First cut							
	Season of 2016				Season of 2017			
	8 days	12 days	16 days	Mean (B)	8 days	12 days	16 days	Mean(B)
10 cm	56.05	43.55	33.97	44.52	55.19	45.10	32.35	44.21
15 cm	50.86	38.73	29.91	39.83	52.00	39.29	27.65	39.65
20 cm	42.62	33.49	24.83	33.65	40.12	31.82	20.27	30.74
25 cm	36.73	30.33	22.57	29.88	36.73	29.10	18.80	28.21
Mean (A)	46.57	36.53	27.82	---	46.01	36.33	24.77	---
L.S.D. at 0.05	A = 3.83 B = 3.99 AB = 6.91				A = 4.55 B = 4.61 AB = 7.98			
Second cut								
10 cm	82.67	69.53	51.64	67.95	83.30	69.90	53.13	68.78
15 cm	75.63	57.45	43.18	58.75	72.18	57.20	40.33	56.57
20 cm	60.23	49.61	33.73	47.86	57.07	46.17	30.43	44.56
25 cm	53.07	45.29	30.47	42.94	51.41	43.83	28.65	41.30
Mean (A)	67.90	55.47	39.76	---	65.99	54.28	38.14	---
L.S.D. at 0.05	A = 5.13 B = 5.04 AB = 8.72				A = 2.13 B = 3.95 AB = 6.84			
Third cut								
10 cm	63.02	61.97	45.48	56.82	65.11	58.10	46.35	56.52
15 cm	57.25	48.58	38.12	47.98	55.90	44.95	39.99	46.95
20 cm	51.32	37.66	29.82	39.60	50.45	34.15	27.00	37.20
25 cm	41.73	35.94	28.92	35.53	41.52	32.77	26.80	33.70
Mean (A)	53.33	46.04	35.59	---	53.25	42.49	35.04	---
L.S.D. at 0.05	A = 3.99 B = 4.80 AB = 8.32				A = 3.75 B = 4.44 AB = 7.68			

As shown in Table 3 values of plant height were significantly affected by the irrigation treatments. As the irrigation intervals increased, the plant height was decreased for basil plants. The maximum plant height was obtained due to 8 day irrigation interval treatment, being 74.61, 95.28 and 70.18 cm in 2016 growing season for the three cuts, respectively and 79.14, 96.25 and 76.39 cm in 2017 season, respectively. Treatment of irrigation at 16 day interval resulted in a minimum plant height of 71.36, 88.67 and 65.86 cm in 2016 season and 74.94, 90.86 and 70.08 cm in 2017 growing season, while it reached 73.61, 93.92 and 68.55 cm in plots irrigated every 12 days in 2016 season and 77.36, 94.50 and 74.22 cm in 2017 growing season, respectively for the three cuts which are in the same statistical group with the values of 8 day irrigation interval treatment.

Results of plant spacing showed significant differences in plant height when cultivated at 25 cm spacing which showed statistical differences with the other plant spacing. Planting at 10 cm spacing showed the highest plant height compared to other plant spacing that recorded 74.48, 94.89 and 70.12 cm for the first, second and third cut, respectively in season of 2016 and 78.74, 95.07 and 75.00 cm, respectively for the three cuts in the season of 2017. Planting at 15 cm spacing gave moderate plant height values followed by 20 cm spacing which are in the same statistical group with the values of 10 cm plant spacing for the three cuts in the two growing seasons. The shortest plants were noticed in plots of the wide spacing (25 cm) that scored 71.26, 89.04 and 65.81 cm for the three plant cuts, respectively in the season of 2016 and 74.33, 91.59 and 70.78 cm for the three plant cuts, respectively in 2017 growing season.

The interaction between irrigation intervals and interplant spacing had significant effect on plant height. In 2016 growing season, the maximum plant height was obtained from plots irrigated every 8 days intervals and planting at 10 cm spacing (76.00, 97.45 and 73.00 cm for the three cuts, respectively), while the lowest plant height (68.67, 85.00 and 63.33 cm, respectively for the three cuts) was obtained from plots planted at 25 cm spacing and irrigated at 16 day intervals. The same trend was observed in the second season (2017).

Data in Table 4 reveal that irrigation intervals significantly influenced the number of branches of basil plants. The highest no. of branches was obtained from 12 day irrigation interval treatment which recorded 17.92, 41.79 and 38.87, respectively for the three plant cuts followed by those of 8 day irrigation interval treatment. The corresponding values were 16.92, 38.69 and 36.13, respectively in 2016 growing season. On the other hand, irrigation treatment at 16 day interval gave the lowest no. of branches (14.70, 34.92 and 31.95, respectively for the three plant cuts). The same trend was noticed in the second season, 2017.

Plant spacing positively affected no. of branches of basil plants. The highest no. of branches was due to planting at the space of 25 cm (17.29, 39.93 and 37.02, respectively) for the three plant cuts in the season of 2016 followed by the values obtained due to planting at the space of 20 cm (17.07, 39.51 and 36.33, respectively) which in general, are in the same statistical group with the values of 25 cm plant spacing for the three cuts in the two growing seasons. It was found out that decreasing plant spacing (10 cm) reduced the no. of branches to the lowest level with significant differences with the other plant spacing (15.51, 36.60 and 34.02, respectively) for the three cuts followed by 15 cm plant spacing treatment . The same trend was observed in the second season (2017).

Table 3. Evaluation of different irrigation intervals and interplant spacing levels on plant height (cm) for three plant cuts during the two growing seasons 2016 and 2017 under field conditions

Interplant spacing (B)	Irrigation intervals (A)							
	First cut							
	Season of 2016				Season of 2017			
	8 days	12 days	16 days	Mean (B)	8 days	12 days	16 days	Mean(B)
10 cm	76.00	74.67	72.78	74.48	80.67	78.67	76.89	78.74
15 cm	75.00	74.11	72.11	73.74	80.00	78.00	75.33	77.78
20 cm	74.44	73.55	71.89	73.29	79.89	78.11	75.22	77.74
25 cm	73.00	72.11	68.67	71.26	76.00	74.67	72.33	74.33
Mean (A)	74.61	73.61	71.36	---	79.14	77.36	74.94	---
L.S.D at 0.05	A = 2.24 B = 1.41 AB = 2.44				A = 2.02 B = 1.04 AB = 1.81			
Second cut								
10 cm	97.45	95.89	91.33	94.89	97.22	95.89	92.11	95.07
15 cm	97.22	94.45	89.55	93.74	97.11	95.11	91.89	94.70
20 cm	95.33	94.33	88.77	92.81	96.56	94.67	91.11	94.11
25 cm	91.11	91.00	85.00	89.04	94.11	92.33	88.33	91.59
Mean (A)	95.28	93.92	88.66	---	96.25	94.50	90.86	---
L.S.D at 0.05	A = 2.13 B = 2.28 AB = 3.95				A = 2.59 B = 1.05 AB = 1.81			
Third cut								
10 cm	73.00	70.04	67.33	70.12	78.00	75.78	71.22	75.00
15 cm	70.70	69.15	66.67	68.84	77.33	75.33	71.11	74.59
20 cm	69.56	68.33	66.11	68.00	76.78	74.44	70.44	73.89
25 cm	67.44	66.67	63.33	65.81	73.44	71.33	67.56	70.78
Mean (A)	70.18	68.55	65.86	---	76.39	74.22	70.08	---
L.S.D. at 0.05	A = 2.55 B = 2.12 AB = 3.67				A = 2.27 B = 1.24 AB = 2.14			

Irrigation intervals x plant spacing interaction were found to be significant. The results showed that under 12 day irrigation interval, the highest number of branches was obtained from 25 cm plant spacing treatment (18.87, 42.60 and 39.73) followed by 20 cm spacing treatment (18.40, 42.27 and 39.40) for the three cuts, respectively with no significant differences among them. Meanwhile, the lowest number of branches was obtained due to 8 day irrigation interval treatment and 10 cm plant spacing which recorded 13.53, 32.07 and 30.07, respectively for the first, second and third plant cuts. The same trend was observed in the second season (2017).

Table 4. Evaluation of different irrigation intervals and interplant spacing levels on No. of branches/plant for three plant cuts during the two growing seasons 2016 and 2017 under field conditions

Interplant spacing (B)	Irrigation intervals (A)							
	First cut							
	Season of 2016				Season of 2017			
	8 days	12 days	16 days	Mean (B)	8 days	12 days	16 days	Mean(B)
10 cm	16.00	17.00	13.53	15.51	15.40	18.00	13.07	15.49
15 cm	16.53	17.40	14.60	16.18	17.13	19.07	14.60	16.93
20 cm	17.40	18.40	15.40	17.07	18.27	19.80	15.60	17.89
25 cm	17.73	18.87	15.27	17.29	18.27	19.53	16.87	18.22
Mean (A)	16.92	17.92	14.70	---	17.27	19.10	15.04	---
L.S.D. at 0.05	A = 0.31 B = 0.36 AB = 0.63				A = 0.92 B = 0.39 AB = 0.68			
Second cut								
10 cm	36.73	41.00	32.07	36.60	38.40	43.20	36.07	39.22
15 cm	38.07	41.27	34.07	37.80	39.80	44.40	38.00	40.73
20 cm	39.67	42.27	36.60	39.51	42.20	45.60	39.00	42.27
25 cm	40.27	42.60	36.93	39.93	42.60	45.40	39.67	42.56
Mean (A)	38.69	41.79	34.92	---	40.75	44.65	38.19	---
L.S.D. at 0.05	A = 0.32 B = 0.51 AB = 0.88				A = 1.17 B = 0.41 AB = 0.71			
Third cut								
10 cm	34.00	38.00	30.07	34.02	36.00	40.87	33.00	36.62
15 cm	35.73	38.33	31.60	35.22	38.07	43.00	34.93	38.67
20 cm	37.20	39.40	32.40	36.33	38.40	44.00	35.87	39.42
25 cm	37.60	39.73	33.73	37.02	39.27	43.93	35.93	39.71
Mean (A)	36.13	38.87	31.95	---	37.94	42.95	34.93	---
L.S.D. at 0.05	A = 0.81 B = 0.79 AB = 1.37				A = 1.00 B = 0.46 AB = 0.80			

As indicated in Tables 5 and 6, there are different responses of herb fresh and dry weights to the increase in irrigation intervals. The highest fresh and dry weights were obtained at 12 day irrigation interval treatment that recorded 9.64, 13.77 & 10.32 and 1.26**,** 1.79 & 1.35 ton/fed. for the three cuts, respectively. These values show insignificant differences with the yields obtained at 8 day irrigation interval treatment that recorded values lower than irrigation treatment at 12 day interval (8.72, 11.78 & 9.14 and 1.19, 1.65 & 1.30 ton/fed., respectively) for the three cuts during 2016 growing season. This can be attributed to the higher percent of disease severity in the treatment of 8 day irrigation interval, which lead to higher defoliation among plants. Fresh and dry weights were drastically decreased due to water stress. The lowest weights were obtained at 16 day irrigation interval treatment (6.39, 9.03 & 7.17 and 0.96, 1.35 & 0.93 ton/fed., respectively). The same trend was observed in the season of 2017.

Table 5. Evaluation of different irrigation intervals and interplant spacing levels on herb fresh weight (ton/fed.) for three plant cuts during the two growing seasons 2016 and 2017 under field conditions

Interplant spacing (B)	Irrigation intervals (A)							
	First cut							
	Season of 2016				Season of 2017			
	8 days	12 days	16 days	Mean (B)	8 days	12 days	16 days	Mean (B)
10 cm	9.47	10.60	6.80	8.96	9.67	10.40	8.33	9.47
15 cm	9.40	9.87	6.80	8.69	9.60	9.93	8.13	9.22
20 cm	8.80	9.80	6.67	8.42	9.53	9.73	8.33	9.19
25 cm	7.20	8.27	5.27	6.91	8.07	7.93	7.00	7.67
Mean (A)	8.72	9.64	6.39	---	9.22	9.50	7.95	---
L.S.D.at 0.05	A = 1.99 B = 0.89 AB = 1.54				A = 0.78 B = 0.61 AB = 1.06			
Second cut								
10 cm	13.33	14.80	10.20	12.78	13.27	13.80	11.07	12.71
15 cm	12.13	14.73	9.07	11.98	12.93	13.47	10.40	12.27
20 cm	11.53	14.27	9.73	11.84	12.67	13.40	10.47	12.18
25 cm	10.13	11.27	7.13	9.51	12.03	12.60	10.07	11.57
Mean (A)	11.78	13.77	9.03	---	12.73	13.32	10.50	---
L.S.D. at 0.05	A = 2.17 B = 0.90 AB = 1.56				A = 1.05 B = 0.60 AB = 1.04			
Third cut								
10 cm	9.67	10.73	7.80	9.40	10.80	11.07	9.47	10.45
15 cm	9.47	10.60	7.27	9.11	10.73	10.93	9.27	10.31
20 cm	8.87	10.40	7.40	8.90	10.67	10.87	8.93	10.16
25 cm	8.53	9.53	6.20	8.09	9.07	9.33	7.73	8.71
Mean (A)	9.14	10.32	7.17	---	10.32	10.55	8.85	---
L.S.D. at 0.05	A = 1.80 B = 0.57 AB = 0.99				A = 0.56 B = 0.34 AB = 0.58			

Table 6. Evaluation of different irrigation intervals and interplant spacing levels on herb dry weight (ton/fed.) for three plant cuts during the two growing seasons 2016 and 2017 under field conditions

Interplant spacing (B)	Irrigation intervals (A)							
	First cut							
	Season of 2016				Season of 2017			
	8 days	12 days	16 days	Mean (B)	8 days	12 days	16 days	Mean (B)
10 cm	1.27	1.38	1.02	1.22	1.35	1.44	1.15	1.31
15 cm	1.26	1.30	1.02	1.19	1.36	1.41	1.12	1.30
20 cm	1.23	1.28	1.00	1.17	1.35	1.37	1.08	1.27
25 cm	1.01	1.08	0.79	0.96	1.16	1.13	1.01	1.10
Mean (A)	1.19	1.26	0.96	---	1.31	1.34	1.09	---
L.S.D. at 0.05	A = 0.08 B = 0.08 AB = 0.13				A = 0.06 B = 0.05 AB = 0.08			
Second cut								
10 cm	1.80	1.94	1.48	1.74	1.83	1.90	1.66	1.80
15 cm	1.70	1.92	1.36	1.66	1.81	1.85	1.56	1.74
20 cm	1.64	1.83	1.48	1.65	1.78	1.85	1.57	1.73
25 cm	1.46	1.46	1.07	1.33	1.63	1.73	1.51	1.62
Mean (A)	1.65	1.79	1.35	---	1.76	1.83	1.58	---
L.S.D. at 0.05	A = 0.19 B = 0.11 AB = 0.18				A = 0.14 B = 0.09 AB = 0.15			
Third cut								
10 cm	1.35	1.42	0.99	1.25	1.49	1.54	1.30	1.44
15 cm	1.33	1.38	0.98	1.23	1.41	1.51	1.27	1.40
20 cm	1.27	1.35	0.95	1.19	1.41	1.50	1.21	1.37
25 cm	1.23	1.24	0.80	1.09	1.27	1.31	1.04	1.21
Mean (A)	1.30	1.35	0.93	---	1.40	1.47	1.21	---
L.S.D. at 0.05	A = 0.19 B = 0.07 AB = 0.12				A = 0.10 B = 0.08 AB = 0.08			

The plant space significantly affects the variables of fresh and dry yields of basil. In 2016 growing season, the highest fresh and dry weights were obtained at 10 cm plant spacing treatment that recorded 8.96, 12.78 & 9.40 ton/fed. and 1.22, 1.74 & 1.25 ton/fed., respectively for the first, second and third cuts followed by 15 cm and 20 cm plant spacing treatments which are in the same statistical group with plants of 10 cm spacing treatment. On the other hand, the lowest fresh and dry weights (6.91, 9.51 & 8.09 and 0.96, 1.33 & 1.09 ton/fed.) were obtained due to planting at 25 cm plant spacing, respectively for the three cuts. The same trend was observed with the 2017 growing season.

The effect of irrigation intervals and plant spacing interaction on plant growth was favourable to high fresh and dry weights of basil plants. In the first season (2016), the highest fresh and dry weights (10.60, 14.80 & 10.73 ton/fed.) and (1.38, 1.94 & 1.42 ton/fed., respectively for the three plant cuts) belonged to treatment of irrigation at 12 day interval and 10 cm plant spacing followed by 15 cm plant spacing (9.87, 14.73 & 10.60 ton/fed. and 1.30, 1.92 & 1.38 ton/fed.) and 20 cm plant spacing that recorded 9.80, 14.27 & 10.40 ton/fed. and 1.28, 1.83 & 1.35 ton/fed., respectively for the three plant cuts with no significant differences among them. While the lowest fresh and dry weights (5.27, 7.13 & 6.20 ton/fed. and 0.79, 1.07 & 0.80 ton/fed., respectively) were obtained from the treatment of irrigation at 16 day interval and planted at 25 cm spacing. The same trend was noticed in the growing season of 2017.

Also, total dry weight was significantly affected by plant space, irrigation intervals and their interactions (Table, 7). The highest total dry weight was obtained when plants were irrigated every 12 day interval that recorded 4.40 and 4.64 ton/fed. during the two growing seasons, respectively followed by plots irrigated at 8 day interval. While irrigation at 16 day interval significantly reduced the total dry herb weight to the lowest values during the two seasons. On the other hand, planting at 10 cm space gave higher total dry weight that recorded 4.22 and 4.55 ton/fed., respectively during the two growing seasons followed by 15 cm and 20 cm plant spacing which are statistically not significant with 10 cm plant space treatment. The lowest values were obtained with 25 cm plant space treatment.

Table 7. Evaluation of different irrigation intervals and interplant spacing levels on total herb dry weight (ton/fed.) for three plant cuts during the two growing seasons 2016 and 2017 under field conditions

Interplant spacing (B)	Irrigation intervals (A)							
	Season of 2016				Season of 2017			
	8 days	12 days	16 days	Mean	8days	12 days	16 days	Mean
10 cm	4.42	4.74	3.49	4.22	4.67	4.88	4.11	4.55
15 cm	4.29	4.60	3.36	4.08	4.58	4.77	3.95	4.43
20 cm	4.14	4.46	3.43	4.01	4.54	4.72	3.86	4.37
25 cm	3.70	3.78	2.66	3.38	4.06	4.17	3.56	3.93
Mean (A)	4.14	4.40	3.24	---	4.46	4.64	3.87	---
L.S.D. at 0.05	A = 0.35 B = 0.26 AB = 0.45				A = 0.23 B = 0.19 AB = 0.29			

As seen in Table 8 the average essential oil ratio of the sweet basil is significantly affected by the irrigation treatments during the two growing seasons. In 2016, the highest average oil ratio was obtained at 16 day irrigation interval treatment (0.90, 0.97 and 0.96 %, respectively for the three plant cuts), being 0.85, 0.91 and 0.92 % in 2017 season. Irrigation at 12 day interval treatment was in the same statistical group with the values of 16 day interval treatment. The corresponding values were 0.87, 0.89 and 0.92 % oil ratio in 2016 growing season and 0.82, 0.87 and 0.88 %, respectively during 2017 growing season. Meanwhile, the lowest percent of essential oil (0.80, 0.85 and 0.81 % and 0.73, 0.81 and 0.80 %) for the three plant cuts during the two growing seasons, respectively was obtained from the treatment of 8 day irrigation interval which was in the same statistical group with the values obtained at 12 day irrigation interval treatment.

Table 8. Evaluation of different irrigation intervals and interplant spacing levels on oil percentage for three plant cuts during the two growing seasons 2016 and 2017 under field conditions

Interplant spacing (B)	Irrigation intervals (A)							
	First cut							
	Season of 2016				Season of 2017			
	8 days	12 days	16 days	Mean (B)	8 days	12 days	16 days	Mean (B)
10 cm	0.70	0.80	0.75	0.75	0.62	0.72	0.82	0.72
15 cm	0.80	0.88	0.88	0.85	0.70	0.80	0.82	0.77
20 cm	0.82	0.90	0.97	0.90	0.78	0.88	0.87	0.84
25 cm	0.87	0.90	0.98	0.92	0.83	0.88	0.90	0.87
Mean (A)	0.80	0.87	0.90	---	0.73	0.82	0.85	---
L.S.D. at 0.05	A = 0.09 B = 0.07 AB = 0.12				A = 0.12 B = 0.07 AB = 0.12			
	Second cut							
10 cm	0.77	0.80	0.90	0.82	0.67	0.77	0.80	0.75
15 cm	0.82	0.85	0.93	0.87	0.83	0.83	0.87	0.84
20 cm	0.85	0.92	1.00	0.92	0.85	0.92	0.97	0.91
25 cm	0.95	0.97	1.05	0.99	0.87	0.95	0.98	0.93
Mean (A)	0.85	0.89	0.97	---	0.81	0.87	0.91	---
L.S.D. at 0.05	A = 0.11 B = 0.06 AB = 0.11				A = 0.07 B = 0.08 AB = 0.14			
	Third cut							
10 cm	0.73	0.80	0.88	0.80	0.68	0.78	0.80	0.75
15 cm	0.80	0.92	0.93	0.88	0.75	0.85	0.85	0.82
20 cm	0.82	0.97	1.00	0.93	0.88	0.92	1.00	0.93
25 cm	0.87	0.98	1.03	0.96	0.88	0.95	1.03	0.95
Mean (A)	0.81	0.92	0.96	---	0.80	0.88	0.92	---
L.S.D. at 0.05	A = 0.13 B = 0.09 AB = 0.15				A = 0.11 B = 0.08 AB = 0.13			

Essential oil ratio was increased in parallel to the interplant space in both years. The highest essential oil percentage was obtained from plots planted at 25 cm spacing (0.92, 0.99 and 0.96 %, respectively for the three plant cuts) followed by 20 cm plant spacing with no significant differences among them during the season of

2016. Moreover, the lowest percentage of essential oil was obtained from 10 cm plant spacing treatment followed by plant spacing at 15 cm with no significant differences between them. The same trend was observed in 2017 growing season. On the other hand, the highest essential oil percentage (0.98, 1.05 and 1.03 %, respectively for the three cuts) was related to treatment of irrigation interval of 16 day with the plant spacing of 25 cm and the lowest one (0.70, 0.77 and 0.73 %, respectively for the three plant cuts) was obtained at treatment of irrigation interval at 8 day with 10 cm plant spacing.

Essential oil yield is the product of the essential oil percentage by the dry matter yield per unit area. According to the obtained results, the oil yield was significantly affected by the differences among irrigation intervals and interplant spacing levels (Table, 9). The highest yield of essential oil was obtained when plants were irrigated every 12 day interval which recorded 10.95, 15.70 and 12.28 kg/fed., respectively in the season of 2016; however, irrigation treatment at 8 day interval gave moderate yield of essential oil with no significant differences with the values at 12 day irrigation interval treatment (9.49, 13.89 and 10.38 kg/fed., respectively for the three plant cuts). Meanwhile the lowest value was recorded from 16 day irrigation interval treatment. These results may be due to the decrement in herb dry weight of this treatment. The same observation was found in 2017 growing season.

Interplant spacing affects the yield of basil essential oil. In the first season (2016), the highest essential oil yield (10.42, 15.20 and 10.95 kg/fed., respectively for the three plant cuts) was obtained from plots planted at 20 cm spacing followed by the yields obtained from 15 cm plant spacing treatment with no significant differences among them. Planting at 10 cm space gave moderate yield of essential oil (9.20, 14.22 and 9.98 kg/fed., respectively). On the other hand, the lowest value of essential oil yield, being 8.74, 13.10 and 10.33 kg/fed., respectively for the first, second and third plant cut was obtained from 25 cm plant spacing treatment. The same trend was found in the season of 2017.

The interaction of irrigation intervals and interplant spacing greatly affected the oil yield. The treatment of irrigation at 12 day interval along with planting at 20 cm planting space gave higher oil yield which recorded 11.50, 16.81 and 13.04 kg/fed., respectively for the three plant cuts during the season of 2016, being 12.13, 16.99 and 13.73 kg/fed., respectively in 2017 growing season.

Consequently, total oil yield was significantly affected by irrigation intervals and interplant spacing as indicated in Table, 10. Irrigation at 12 day interval gave higher values of total oil yield (38.93 and 39.65 kg/fed.) during the two growing seasons, respectively. The lowest value was obtained when plants were irrigated at 16 day interval. However, planting at 20 cm space gave the higher total oil yield during the two growing seasons. The corresponding values were 36.57 and 39.14 kg/fed., respectively. The treatment of irrigation at 12 day interval combined with planting at 20 cm space gave higher oil yield which recorded 41.35 and 42.85 kg/fed., respectively for the two growing seasons.

Table 9. Evaluation of different irrigation intervals and interplant spacing levels on oil yield (kg/fed.) for three plant cuts during the two growing seasons 2016 and 2017 under field conditions

Interplant spacing (B)	Irrigation intervals (A)							
	First cut							
	Season of 2016				Season of 2017			
	8 days	12 days	16 days	Mean (B)	8 days	12 days	16 days	Mean (B)
10 cm	8.87	11.05	7.67	9.20	8.33	10.44	9.41	9.39
15 cm	10.30	11.50	9.01	10.27	9.51	11.27	9.14	9.97
20 cm	10.10	11.50	9.65	10.42	10.44	12.13	9.40	10.66
25 cm	8.69	9.73	7.79	8.74	9.71	10.00	9.10	9.60
Mean (A)	9.49	10.95	8.53	---	9.50	10.96	9.26	---
L.S.D. at 0.05	A = 1.53 B = 1.09 AB = 1.89				A = 1.57 B = 1.02 AB = 1.76			
Second cut								
10 cm	13.81	15.48	13.37	14.22	12.20	14.52	13.24	13.32
15 cm	13.91	16.28	12.62	14.27	15.06	15.34	13.44	14.61
20 cm	13.97	16.81	14.83	15.20	15.13	16.99	15.11	15.74
25 cm	13.88	14.23	11.19	13.10	14.93	16.51	14.82	15.42
Mean (A)	13.89	15.70	13.00	---	14.33	15.84	14.15	---
L.S.D. at 0.05	A = 1.97 B = 1.50 AB = 2.59				A = 1.52 B = 1.71 AB = 2.96			
Third cut								
10 cm	9.91	11.34	8.69	9.98	10.19	12.29	10.38	10.95
15 cm	10.59	12.60	9.03	10.74	10.57	12.88	10.84	11.43
20 cm	10.39	13.04	9.43	10.95	12.43	13.73	12.07	12.74
25 cm	10.61	12.14	8.24	10.33	11.20	12.48	10.72	11.47
Mean (A)	10.38	12.28	8.85	---	11.10	12.85	11.00	---
L.S.D. at 0.05	A = 2.00 B = 0.83 AB = 1.44				A = 1.81 B = 1.15 AB = 1.99			

Table 10. Evaluation of different irrigation intervals and interplant spacing levels on total oil yield (kg/fed.) for three plant cuts during the two growing seasons 2016 and 2017 under field conditions

Interplant spacing (B)	Irrigation intervals (A)							
	Season of 2016				Season of 2017			
	8 days	12 days	16 days	Mean	8 days	12 days	16 days	Mean
10 cm	32.59	37.87	29.73	33.40	30.72	37.25	33.03	33.67
15 cm	34.80	40.38	30.66	35.28	35.14	39.49	33.42	36.02
20 cm	34.46	41.35	33.91	36.57	38.00	42.85	36.58	39.14
25 cm	33.18	36.10	27.22	32.17	35.84	38.99	34.64	36.49
Mean (A)	33.76	38.93	30.38		34.93	39.65	34.42	
L.S.D. at 0.05	A = 5.28 B = 2.64 AB = 4.57				A = 4.74 B = 2.35 AB = 4.08			

Discussion

Irrigation and soil moisture status are important factors stimulating downy mildew of basil. Percent of disease incidence and severity of basil downy mildew was increased by decreasing irrigation intervals. This may be due to increasing duration of flooding that leads to increasing humidity among plants and consequently, increasing the period of leaf wetness duration, making the conditions favourable to fungus development and sporulation. Cohen and Ben-Naim (2016) considered that periods of $\geq$ 4 h with relative humidity $\geq$ 95 % are conducive for infection of basil with downy mildew and periods of $\geq$ 7h with relative humidity $\geq$ 95 % are conducive for sporulation of *P. belbahrii*. Results of this study suggest that percentages of incidence and severity of basil downy mildew were significantly higher in narrow plant spacing than in wider plant spacing. This is primarily because narrow plant spacing (higher plant densities) influences the micro-climate in favor of downy mildew development. Wider spacing between plants (low plant densities) facilitates more aeration in the crop canopy, which results in the quick drying of the leaves making the conditions less favourable for disease development. Thus, the duration period of leaf wetness in wider spacing is reduced than that required for disease development. In contrast, narrow spacing among plants results in reduction of temperature, air circulation as well as reduction of light in between the dense plant population. Also, closer plant spacing increased humidity and cuts light. These results are consistent with previous reports (Haware and McDonald, 1993; Pande *et al.*, 1998 & Pande and Narayana Rao, 2002).

As the irrigation interval was increased, the basil plant height and number of branches per plant were decreased. Similar results were reported by Misra and Srivastava, 2000; Singh, 2002; Omidbaigi *et al.*, 2003; Moeini *et al.*, 2006. Ekren *et* *al.* (2012) reported that one of the first signs of water shortage is the decrease in turgor which causes a decrease in both growth and cell development, especially in the stem and leaves. However nitrogen, phosphorous and potassium (NPK) and protein contents were affected by water stress, which resulted in less nitrogen and phosphorous absorption in roots and shoots, which in turn inhibit plant growth (Mirsa and Strivastava, 2000; Khalid, 2001; Hendawy & Khalid, 2005 and Khalid, 2006). Total fresh weight of basil plants was decreased by increasing irrigation intervals due to the vegetative growth that was encouraged by the irrigation water. It is known that the green herb yield of the basil plant depends on different factors such as irrigation, fertilization, plant density, temperature and genotype and is moderately affected by the environmental conditions. The results showed a similarity to the results given by (Arabaci and Bayram, 2004; Telci *et al.*, 2005 and Erşahin, 2006). The dry weight of the plants was decreased by increasing irrigation intervals. This could be the result of a reduction in chlorophyll content and consequently, photosynthesis efficiency, as reported by Abdul-Hamid *et al.*, 1990; Castonguay and Markhart, 1991; Nunez-Barrious, 1991; Viera *et al.*, 1991 and Khalid, 2006. On the other hand, percentage of essential oil in basil plants was increased by decreasing irrigation intervals, while the essential oil yield was decreased. This may be due to increasing the dry matter percent in plant as a result of decreasing irrigation intervals. These results are in line with those of Baher *et al.*, (2002) and Khalid (2006) who reported that an increase in essential oil percentage was observed under two water stress levels: 50 % (drought) and 125 % (excessive water) of field water capacity, while the highest yield of essential oil (g plant^{-1}) was obtained with the 100 and 75 % field water capacity treatments. Also, Singh (2002) reported that increasing the total herbage and oil yields of basil with increase in the level of irrigation was due to favourable moisture conditions maintained throughout the crop growth period. Under higher moisture supply, the crop covered the ground faster and developed sufficient photosynthetic area for maximum utilization of solar radiation resulting in significant increase in herb and oil yield of sweet basil.

On the other hand the highest branches were observed in wider plant spacing. These results are in line with those obtained by (Bekhradi *et al.*, 2014) who reported that number of lateral branches increase in multiple harvesting that cut the stem above the first internodes and allow plants to produce lateral branches. So, low density of planting is recommended for multiple harvesting and high density is suggested for one times harvest. Also, interplant spacing greatly affects growth and yields of essential oil of basil plants. Results obtained from the present study were comparable with (Sadeghi *et al.*, 2009) who reported that under optimum plant density, plants show efficient use of available water, light and nutrient while under high plant density, have a higher competition among plants.

According to the results of this research we concluded that basil is sensitive to irrigation intervals and plant density, the development and cultivation of sweet basil at 12 day irrigation interval and 20 cm interplant spacing provided protection against downy mildew infection and affected disease severity at an important level as well as increased yields of sweet basil. Consequently, the incorporation of this treatment in an integrated management programs should bring positive results, both in terms of reducing disease intensity and the amount of fungicides used.

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(Received 05/02/2018;
in revised form 06/03/2018)

تأثير فترات الري ومسافات الزراعة المختلفة على وبائية مـرض البيـاض الزغبـي وانتاجيـة نبـات الـريحـان

ايمان وجيه راغب غبريال* و عادل جلال محمود قناوى**
*معهد بحوث أمراض النباتات، مركز البحوث الزراعية، الجيزة
**معهد بحوث البساتين، مركز البحوث الزراعية، الجيزة

تم اجراء تجارب في الحقل تحت ظروف العدوى الطبيعية بمرض البياض الزغبى فى الريحان خلال عامى 2016 و 2017 فى مزرعة البساتين بمحطة البحوث الزراعية بسدس-مركز البحوث الزراعية- محافظة بنى سويف من اجل تقييم فعالية فترات رى ومسافات زراعة مختلفة على وبائية مرض البياض الزغبي والذى يسببه *Peronospora belbahrii* وانتاجية نباتات الريحان الحلو (الصنف البلدي). بشكل عام، اثرت فترات الرى ومسافات الزراعة معنويا على نسبة وشدة المرض وعلى معدلات نمو النبات (طول النبات، عدد الأفرع، الوزن الطازج والجاف للعشب، نسبة وكمية الزيت) فى نهاية التجربة. لوحظ أعلى تأثير فى القطعة التى تم ريها كل 12 يوم وزراعة النباتات على مسافة 20 سم. بالرغم من أن الري كل 16 يوم والزراعة على مسافة 25 سم أعطت أعلى أنخفاض فى نسبة وشدة المرض ولكن أثرت بشكل كبير على نمو النبات وانتاجية الزيت الى أدنى قيمة.