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Effects of water stress during vegetative and reproductive stages on seed yield and essential oil content of dill (*Anethum graveolens* L.)

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Abstract

The influence of water stress during vegetative and reproductive stages on plant height, fresh and dry biomass, seed yield and essential oil content of dill (*Anethum graveolens* L.) was investigated in 2006 and 2007 at the Research Farm of the University of Zanjan, Zanjan, Iran. The essential oil of the vegetative parts, flowers and seeds of cultivated dill were isolated by hydro distillation. The results showed that the plant height, fresh and dry biomass and seed yield of dill decreased with decreasing water availability. The largest reduction in plant height and biomass was observed under severe water stress during vegetative stage, but the greatest loss in seed yield occurred under severe water deficit during flowering and seed filling phases. The essential oil content of seeds and flowers was much higher than that of vegetative parts under all irrigation treatments. Although the essential oil percentage of dill flowers and seeds was increased with increasing the severity of water deficit, the highest essence yield per unit area was obtained under moderate water stress. It was, therefore, concluded that essential oil yield of dill could be improved by a moderate water stress during flowering and seed filling phases.

Key words: Biomass, dill, essential oil, seed yield, water stress.

Introduction

Dill (*Anethum graveolens* L.) is an annual and sometimes biennial herb of the parsley family, which is native to south-west Asia or south-east Europe [2]. It is used as a vegetable, a carminative, an aromatic and an antispasmodic [10, 17] and also as an inhibitor of sprouting in stored potatoes [15].

Dill seed is usually sown in early spring for seed and essential oil production. Rapid emergence and a vigorous crop can help to produce high quality yield at harvest [10]. Most of the oil is produced in the fruits and flowers, although leaves and stems also contain oil. The dill fruit is a schizocarp with paired carpels that split apart at maturity to release two pericarps, commonly referred to as "seed" [3]. The dill plant has a single stem with a terminal or primary umbellate flower as well as secondary umbels which develop further down the stem later in the growing season [4].

Water limitation is a major environmental constraint to the productivity of crop plants. Moisture deficiency not only limits plant growth and survival but also induces various physiological and metabolic responses like stomatal closure, decline in growth rate, solute and antioxidant accumulation and expression of stress specific genes [11]. Baher *et al.* [1] observed that the greater soil water stress decreased plant height and fresh and dry weight of *Satureja hortensis*, although the accumulation of oil increased significantly under severe water stress at the flowering stage. It has been suggested that under stress, due to the reduction in leaf area, a higher density of the oil glands results in an elevated amount of oil accumulation [6, 7, 18]. However, experiments with Cymbopogons have demonstrated that water stress alters the oil biogenetic capacity. This happens without any change in the oil gland count, as observed in the excised systems subjected to short-term stress conditions [13]. The amounts of essential oils produced under drought conditions were either maintained or enhanced, depending on the species and magnitude of the stress. In *Cymbopogon martinii*, water stress conditions promoted, either an increase, decrease or no change in the oil yield, in a genotype specific manner [16]. In geranium, water stress had a negative impact on green yield and essential oil yield as the intervals between stress application increased [12].

Although the secondary metabolite production is believed to be stimulated by stressful environment, there is too little experimental data to support this notion. Therefore, this research was designed to investigate the effects of limited irrigation on seed yield and essential oil content of dill at different stages of growth and development.

Materials and Methods

Two experiments were conducted in 2006 and 2007 at the Research Farm of the University of Zanjan (latitude 36°37'N, longitude 48°49.5'E, elevation 1643 m) to investigate the performance of dill plants under full and limited irrigation conditions. The soil was sandy loam, containing total N 0.12%, total P 13.4 ppm and total K 267 ppm, with a pH of 7.54. In both years, fertilizer (N and P at a rate of 45 and 40 kg ha^{-1}, respectively) was applied before sowing.

Seeds of Iranian dill were obtained from the seed bank of the Research Institute of Forests and Rangelands, Tehran, Iran, and were sown in the field on 29 April 2006 and 25 April 2007. Experiments were carried out on the bases of randomized complete

block design with four replications. Each plot consisted of six rows of 10 m long. Plants were arranged 10 cm apart on the rows, with 25 cm between the rows. Irrigation treatments were full irrigation (control) to achieve 100% of field capacity (FC) during the growing season, two moderate (66% of FC) and two severe (33% of FC) water stresses during vegetative and reproductive stages. Plots were irrigated immediately after sowing, but subsequent irrigations were done in accordance with the treatments (Table 1).

Ten random plants at the full flowering stage were cut from the soil surface of the center rows of each plot, and plant height was measured. Subsequently these plants were weighed (fresh weight) and then oven-dried at 75°C for 48 h and reweighed (dry weight). At maturity, plants from 1 m^2 of each plot were harvested and seed yield per unit area for each treatment at each replicate was determined.

The experimental design for determination of essential oil contents was split-plot, with irrigation treatments in main plots and harvest times in sub-plots. Three harvests were carried out at vegetative (H_1), full flowering (H_2) and seed maturity (H_3) stages. At each stage, 20 plants from each plot were harvested and then dried in the shade for 2 weeks. The essential oils of vegetative parts (H_1), flowers (H_2) and seeds (H_3) were isolated by hydro distillation of dried dill parts in all glass apparatus. Essential oil of each sample,which was light yellow in colour, was dried over anhydrous sodium sulphate and weighed.

The data were analyzed by one–way ANOVA, using the Statistical Analysis System [14] and means were compared by Duncan's multiple range test at the 5% probability.

Results

Combined analysis of variance of the data (Table 2) showed that the plant height, fresh and dry biomass and seed yield per unit area were significantly affected by irrigation treatments but not by year. Interaction of irrigation and year on these traits was not significant (Table 2).The greatest plant height and fresh and dry biomass were achieved under full irrigation (S_0). These traits were significantly decreased with decreasing water availability, particularly during vegetative stage (Table 3). Consequently, the lowest plant height and biomass were observed under severe water stress during vegetative growth (S_2). In contrast, the lowest seed yield in both years was obtained under severe water deficit during flowering and seed filling phases (S_4). Plants that received comparatively more water produced significantly more seed yield per unit area (Table 3).

Both moisture availability and the growth phase at harvest had significant effects on essential oil content (Table 4). The percentage and yield of essential oil isolated from seeds (H_3) and flowers (H_2) were much higher than those of vegetative parts (H_1) under all irrigation treatments. Essential oil percentage of vegetative parts was increased with decreasing water availability at that stage. However, essential oil percentages of seeds and flowers were considerably improved, when plants were subjected to moderate and severe water deficit at different developmental stages (Table 5). In contrast, the highest essential oil yield per unit area was obtained from flowers under moderate water stress during flowering and seed filling phases (S_3H_2), while the lowest essence yield was produced from vegetative parts under severe water deficit during early growth (S_2H_1) in both years (Table 5).

Table 1. Irrigation treatments.

Treatment	Soil moisture (%)	Leaf water potential (Mpa)	Timing
Field capacity (S_0)	22.56	-0.53	During the growing season
Moderate stress (S_1)	15.04	-1.32	During vegetative stage
Severe stress (S_2)	7.52	-1.61	During vegetative stage
Moderate stress (S_3)	15.04	-1.32	During flowering and seed filling phases
Severe stress (S_4)	7.52	-1.61	During flowering and seed filling phases

Table 2. Combined analysis of variance of the effects of different irrigation treatments on some traits of dill.

Treatment	Df	Plant height	Fresh biomass	Dry biomass	Seed yield
Year (Y)	1	1.743ns	24467.9^{ns}	6895.9^{ns}	0. 009^{ns}
E_a	6	48.447	48664.7	2581.3	46.068
Stress (S)	4	614.169**	2251546.9**	86165.8**	8764.551**
Y × S	4	10.186^{ns}	3421.7^{ns}	672.6^{ns}	1.631^{ns}
E_b	24	5.205	27888.3	1631.6	23.391
CV%	-	3.44	13.95	14.97	3.65

ns, **: not significant at p>0.05 and significant at p≤0.01, respectively.

Table 3. Mean plant height, fresh and dry biomass and seed yield of dill under different irrigation treatments (S).

Treatment	Plant height (cm)	Fresh biomass (g/m^2)	Dry biomass (g/m^2)	Seed yield (g/m^2)
S_0	78.07a	1950.0a	421.4a	175.40a
S_1	62.69d	856.1d	220.0c	152.90b
S_2	54.48e	580.6e	144.6d	130.30c
S_3	70.25b	1446.0b	310.3b	114.80d
S_4	65.75c	1170.0c	252.0c	89.99e

Different letters in each column indicating significant difference at p ≤ 0.05.

Table 4. Combined analysis of variance of the effects of limited irrigation and harvest time on essential oil percentage and yield.

Treatment	df	Essential oil	Essential oil yield
Year(Y)	1	0.0000162ns	0.477ns
Rep /Y	6	0.052	0.420
Stress(S)	4	1.293**	4.918**
Y×S	4	0.007ns	0.144ns
Ea	24	0.013	0.220
Harvest time(H)	2	24.879**	156.738**
Y×H	2	0.005ns	0.497ns
S×H	8	0.588**	7.468
Y×S×H	8	0.008	0.076
E_b	60	0.013	0.256
CV(%)	-	5.28	14.78

ns, **: not significant at p>0.05 and significant at p≤0.01, respectively.

Table 5. Mean essential oil percentage and yield of dill affected by irrigation treatments (S) and harvest time (H).

Treatment	Essential oil (%)	Essential oil yield (g/m^2)
S_0H_1	0.405j	0.325g
S_0H_2	0.893g	3.761c
S_0H_3	1.761e	3.090d
S_1H_1	0.527i	0.262g
S_1H_2	1.478f	3.231d
S_1H_3	1.830de	2.798de
S_2H_1	0.650h	0.216g
S_2H_2	1.796e	2.540ef
S_2H_3	1.938cd	2.526ef
S_3H_1	0.403j	0.312g
S_3H_2	1.980c	6.146a
S_3H_3	2.027c	2.326ef
S_4H_1	0.404j	0.317g
S_4H_2	2.177b	5.471b
S_4H_3	2.299a	2.070f

Different letters in each column indicating significant difference at $p \leq 0.05$.

Discussion

Effect of water deficit on crop performance can vary when it occurs during different stages of growth and development [19]. In general, water stress during vegetative stage has the greatest impact on plant height and biomass, while during reproductive development it has the most deleterious effect on seed yield of dill (Table 3). No significant interaction of irrigation and year (Table 2) indicates that the deductions of these traits due to water stress are similar in both years. Water deficit during vegetative stage limits leaf area expansion and induces early leaf senescence, leading to reductions in dry matter accumulation and grain yield [8]. In contrast, coincidence of water stress with reproductive stages reduces durations of flowering and seed filling and consequently lowers the number of grains per plant, mean grain weight and grain yield per unit area. These reductions increase with increasing the severity of water limitation [8].

Stress induced alterations in oil accumulation are considered to be mainly due to its effect on plant growth and differentiation. Reduction of leaf area under stress enhances the density of the oil glands and oil accumulation [5, 18]. Holtzer *et al*. [9] have pointed that, depending upon the plant species, drought stress can increase, decrease or have no effect on the levels of metabolites. The results of our research clearly indicated that although essential oil percentage of dill flowers and seeds increased with decreasing water availability, the highest essential oil yield per unit area was produced under moderate water stress (Table 5). Therefore, moderate water limitation during flowering and seed filling phases can improve essence yield of dill per unit area. However, severe water deficit during reproductive stages can reduce essence yield as a consequence of a large reduction in seed yield per unit area (Table 3).

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