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# Response of Drip Irrigation and Fertigation on Cumin Yield, Quality, and Water-Use Efficiency Grown under Arid Climatic Conditions

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Received: 18 September 2020; Accepted: 2 November 2020; Published: 4 November 2020



**Abstract:** A three-year field experiment was conducted at the Agricultural Research Station of Mandor, Jodhpur, Rajasthan, under arid climatic conditions in the rabi season of 2016–2019 with the objectives of evaluating the effect of drip irrigation and fertigation levels on cumin plant growth, yield, oil content, water-use efficiency, and water productivity. The pooled data revealed that the drip irrigation at 0.6 cumulative pan evaporation (CPE) recorded significantly higher plant height (31.4 cm), umbels plant<sup>-1</sup> (50.4), umbellates umbel<sup>-1</sup> (5.07), seeds umbel<sup>-1</sup> (5.34), test weight (4.60 g), seed yield (1063 kg ha<sup>-1</sup>), gross return (₹ 172,600 ha<sup>-1</sup>), net return (₹ 113,500 ha<sup>-1</sup>) and benefit, and cost ratio (2.9) over drip fertigation at 0.4 CPE and surface irrigation with 0.8 CPE. The fertigation with 80% recommended dose of fertilizer (RDF) being at par with 100% RDF recorded a significantly higher number of umbels plant<sup>-1</sup> (50.0), umbellates umbel<sup>-1</sup> (5.03), seeds umbellate<sup>-1</sup> (5.24), test weight (4.67 g), seed yield (1052 kg ha<sup>-1</sup>), gross return (₹ 170,900 ha<sup>-1</sup>), net return (₹ 111,700 ha<sup>-1</sup>), and benefit cost ratio (2.9) over fertigation with 60% RDF and control. Maximum water-use efficiency (5.7 kg ha<sup>-1</sup> mm<sup>-1</sup>) and water saving (39.04%) was observed under drip irrigation at 0.4 CPE followed by 0.6 CPE (4.8 kg ha<sup>-1</sup> mm<sup>-1</sup> and 18.86%, respectively).

**Keywords:** cumin; drip irrigation; fertigation; net return; WUE; yield

## 1. Introduction

Humans have been using cumin (*Cuminum cyminum*) in culinary dishes since ancient times for a variety of medicinal purposes from digestive issues to respiratory conditions. Cumin, a flowering plant in the family Apiaceae, native from east Mediterranean to East India has anti-inflammatory and antiviral properties. Cumin has beneficial effects in curing tastelessness, poor digestion, cardiovascular disease, swellings, vomiting, and chronic fever in humans [1,2]. Cumin seeds have nutritional quality

i.e., 100 g of seed include energy 370 kcal, dietary fiber 10.5 g, proteins, 22.27 g fat, 44.24 g carbohydrates, and 10.5 g fiber, as well as vitamins and minerals [3]. Several studies have revealed that cumin seeds can also increase vitamin C intake [4,5]. The presence of vitamin C in cumin seeds allows the spice to serve as an immune system booster [6]. The cumin seeds also contain about 2.5 to 3.6% essential oil which has a typical odor and a little bitter taste and is used in perfumery and for flavoring liquors and cordials [7].

In India, cumin is commonly grown in the arid and semi-arid area of the western part of the country. Rajasthan and Gujarat together contribute more than 95% of the Indian production. Cumin is concentrated in the districts of Jodhpur, Jalore, and Barmer contributing to 70% of the total area of the Rajasthan state [8]. The water requirements of cumin are lower than those of many other spices. The optimum growth temperature ranges are between 25 and 30 °C. Cumin crop requires a moderately cool and dry climate for good growth and production. High humidity, cloudy weather, more dew, and unseasonal rain after flowering of the crop are detrimental to cumin crop [9]. When humidity is more in atmosphere after flowering, the incidence of the disease is increased. Cumin is especially sensitive to *Alternaria* blight and *Fusarium* wilt [10]. In arid and semi-arid areas of the western part of the country, water is one of the main constraints in crop production due to deficit annual rainfall. The limited quantity of water available for irrigation calls for an urgent need for water-saving technology for improving the water productivity of cumin in water-scarce areas. Drip irrigation systems offer higher water-use efficiency on account of reduced losses such as evaporation, runoff, and percolation as compared to other irrigation systems. Drip irrigation systems also reduce the over exploitation of ground water [11,12]. The low water-requiring crops such as cumin must be greatly influenced by this water management strategy. There are reports that drip irrigation systems improve the water-use efficiency (WUE) by improving the yield with a minimum use of water [13].

Providing crop nutrients along with water through the fertigation method ensures a uniform and timely supply of nitrogen (N) without contamination of the environment through the leaching process [14]. Fertigation improves fertilizer-use efficiency and maintains nutritional balance and nutrient concentration at optimum levels. It saves energy and labor, provides opportunities to apply the nutrient at critical stages of crop growth, and results in high-quality crop productivity. Drip fertigation reduces ground water contamination with chemical fertilizers, retards incidence of pest or disease, escapes foliage burn, and avoids runoff. Drip fertigation also plays an important role in effective weed management and successful crop cultivation in undulating fields [15]. Several studies on drip fertigation at various parts of India on different vegetable crops have shown that the drip fertigation technique reduces fertilizer requirement by 40–60%, saves water by 20–60%, and increases the yield by 15–50% over the other methods of irrigation and fertigation [16,17]. The application of water and nutrient simultaneously to plants through fertigation enhances the photosynthesis process as plants produce new tissues to enhance biomass production [18]. Therefore, a field study was conducted to evaluate the potential of drip irrigation and fertigation on cumin yield, quality (oil content), and water-use efficiency grown under an arid zone of Rajasthan, India.

## 2. Materials and Methods

### 2.1. Field Experiment Site and Details

A field experiment was carried out during three consecutive *rabi* seasons of 2016–2017, 2017–2018, and 2018–2019 at the Agricultural Research Station, Mandor (Agriculture University, Jodhpur, India) to study the effect of drip irrigation and fertigation levels on seed yield and quality of cumin. Factorial randomized block design with three replications was used to design the field experiment. The treatments consisting of three drip irrigation levels, i.e., drip irrigation at 0.4 cumulative pan evaporation (CPE) ( $I_{0.4}$ ), drip irrigation at 0.6 CPE ( $I_{0.6}$ ), and drip irrigation at 0.8 CPE ( $I_{0.8}$ ), and three fertigation levels, i.e., fertigation with 60% recommended dose of fertilizer (RDF) ( $F_{60}$ ), fertigation with 80% RDF ( $F_{80}$ ), and fertigation with 100% RDF ( $F_{100}$ ) and one control (surface irrigation at 0.8 CPE

with 100% RDF). Cumin variety GC-4 was sown on 11th November in 2016, 6th November in 2017 and 3rd November in 2018. Sowing was done manually by using a 12 kg ha<sup>-1</sup> seed rate with a rows spaced of 30 cm apart and 1.5–2.5 cm depth. The area of each plot was 12.6 m<sup>2</sup>. The average crop duration of cumin was 127 days.

## 2.2. Soil Analysis

The available nitrogen, phosphorus, and potassium present in soils were determined by using standard protocols of Subbiah and Asija [19], the Olsen method [20], and the flame photometer method of Standford and English [21], respectively. The pH and organic carbon of soil were also tested before sowing the crop according to the standard protocols of Singh et al. [22] and Walkley and Black [23], respectively. Soil testing results revealed that the available nitrogen, phosphorus, and potassium content in experimental soils were 170 kg ha<sup>-1</sup>, 26 kg ha<sup>-1</sup>, and 391 kg ha<sup>-1</sup>, respectively. The organic carbon and pH of the experimental soils were 0.13% and 8.00, respectively.

## 2.3. Meteorological Observation and Cumulative Pan Evaporation

The periodical mean weekly weather parameters for the period of the experimentation recorded at the meteorological observatory of the Indian Council of Agricultural Research—Central Arid Zone Research Institute, (ICAR-CAZRI) Jodhpur (Figure 1). Daily and monthly mean values of climatic parameters namely, maximum and minimum temperatures, relative humidity, and rainfall were observed in observatory; however, cumulative pan evaporation was calculated daily with the open pan evaporimeter method.

The maximum temperatures during 2016, 2017, and 2018 of the crop-growing period were 32.6, 35.5, and 29.4 °C; however, corresponding values for minimum temperatures were 8.8, 8.2, and 10.1 °C. The annual rainfall at the experimental site during the crop-growing period was 23.3 mm during the first year of the experiment, but in the next two years, no rainfall was received. The maximum and minimum relative humidity during the crop-growing period were 89.00% and 12.00% in 2016, 72.00% and 12.00% in 2017, and 68.00% and 22.00% in 2018, respectively. Relative humidity was the highest in January during all the three years of the experiment.

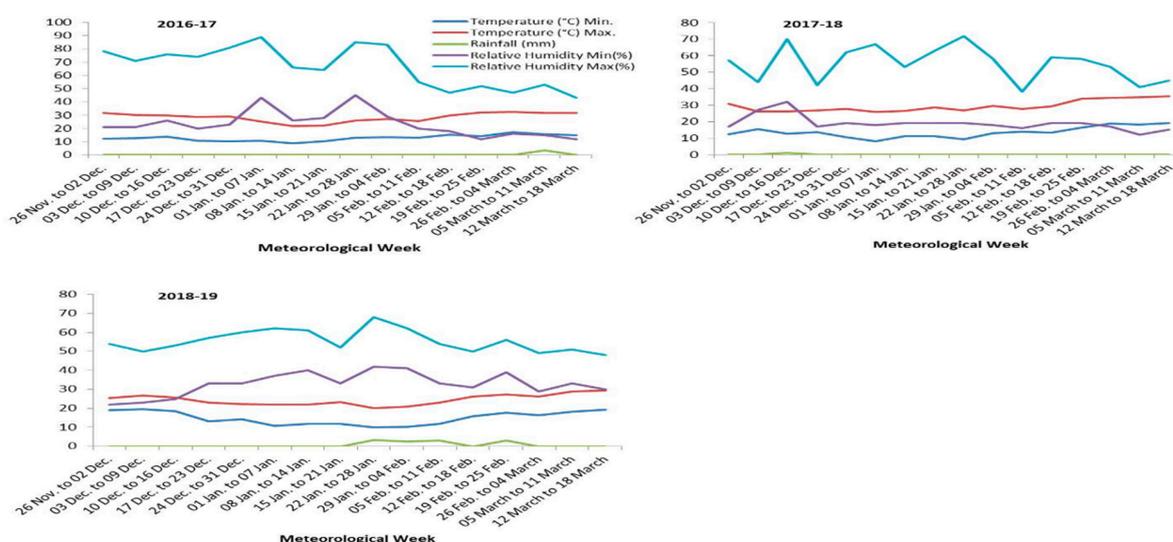


Figure 1. Weather parameters during the crop-growing period.

#### 2.4. Water and Fertilizer Application

Drip laterals with a Hydrogel integral extruded (In-line) emitter were used, which have a discharge rate of 3.5 L h<sup>-1</sup> water at 2 kg cm<sup>-2</sup> input pressure in a drip system. The internal diameter of the drip lateral was 12 mm. Drip irrigation was scheduled at 4 days after the preceding irrigation with 1.5 kg cm<sup>-2</sup> output pressure on the basis of cumulative pan evaporation (CPE) of 0.4, 0.6, and 0.8. The application of surface irrigation (check basin irrigation method) was done on a basis of 0.8 CPE. Three levels of fertigation, 60, 80 and 100% recommended dose of fertilizer (RDF), were applied through soluble fertilizers i.e., urea and urea phosphate (16:44:0) in six splits at different stages i.e., 10% at 15 days after sowing (DAS), 10% at 30 DAS, 30% at 45 DAS, 30% 60 DAS, 10% at 75 DAS, and 10% at 90 DAS. A recommended dose of fertilizer 30 kg N ha<sup>-1</sup> and 20 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> in surface irrigation was given through urea and single super phosphate as a basal dose.

#### 2.5. Analyses of Plant Growth, Biomass, and Yield

The observations on plant height, branch plant<sup>-1</sup>, and number of umbels plant<sup>-1</sup> were recorded manually on five randomly selected representative plants from each plot of each replication separately, and the yield-attributing character and yield were also recorded as per the standard method. Harvesting was done on 18 March 2017, 8 March 2018, and 11 March 2019. The seed and straw yield were recorded from the net plot area of each treatment. The volatile oil in cumin was estimated by using Clevenger's apparatus [24].

#### 2.6. Analysis of Water Studies

Water-use efficiency (WUE) was calculated by using following formula given by Viets [25] and expressed in kg ha<sup>-1</sup> mm<sup>-1</sup>.

$$\text{WUE} = \text{Seed yield (kg ha}^{-1}\text{)}/\text{Actual Evapotranspiration (mm)} \quad (1)$$

Water productivity (economic) that is a function of gross income and volume of total water used by crop and expressed in (₹ m<sup>-3</sup>)

$$\text{Water productivity} = \text{Gross income (₹ha}^{-1}\text{)}/\text{Water used (m}^{-3}\text{)}. \quad (2)$$

#### 2.7. Economics Analysis

An economic analysis was done to compare the returns of the various drip irrigation and fertigation levels. Net return was determined by subtracting the total costs of production from the gross income determined from cumin seed yield. The cost of water for each irrigation treatment was calculated by multiplying the cost of a unit volume of water and the total quantity of irrigation water required for the cumin crop. Additionally, the cost of urea and urea phosphate fertilizer for each fertigation treatment was calculated. All other production costs including labor (land preparation, seeds, sowing, weeding, fertilizer application, spraying and harvesting), chemicals (insecticides and pesticides), and the drip irrigation system (low-density polyethylene pipe for main, sub-mains, and laterals, filters, fertilizer unit, pressure gauges, control valves, water meter, drippers, and other accessories) were computed on the basis of depreciation cost of the whole drip system.

#### 2.8. Statistical Analysis

The experimental data recorded in various observations were statistically analyzed in accordance with the 'Analysis of Variance' technique as described by Panse and Sukhatme [26]. The critical difference (CD) for the treatment comparisons was worked out wherever the variance ratio (F test) was found significant at a 5% level of probability. To elucidate the nature and magnitude of treatments effects, summary tables along with SEM<sub>±</sub> and CD (*p* = 0.05) were prepared.

### 3. Results and Discussion

#### 3.1. Effect of Drip Irrigation Levels on Cumin Plant Growth, Yield-Attributing Characteristics, and Yield

The study revealed that the application of drip irrigation significantly increased the growth and yield parameters viz. plant height (cm), branches plant<sup>-1</sup>, number of umbels plant<sup>-1</sup>, number of umbellates umbel<sup>-1</sup>, number of seeds umbellet<sup>-1</sup>, and test weight (g) during all three experimental years. The highest plant height (31.4 cm) was obtained with drip irrigation at 0.6 CPE (I<sub>0.6</sub>), which was at par with drip irrigation at 0.8 CPE. The number of branches plant<sup>-1</sup> was observed as significantly enhanced in all drip irrigation regimes over surface irrigation at a CPE of 0.8 (Table 1). Among the different drip irrigation regimes, no significant difference was observed with respect to the number of branches plant<sup>-1</sup>. The number of umbels plant<sup>-1</sup> and umbellates umbel<sup>-1</sup> were significantly increased by the application of all drip irrigation regimes over the surface irrigation at a CPE of 0.8. The application of drip irrigation at 0.6 and 0.8 CPE significantly increased umbels plant<sup>-1</sup> by 9.32% and 5.85% over drip irrigation at 0.4 CPE (I<sub>0.4</sub>) and 34.04% and 29.78%, over surface irrigation at CPE of 0.8, respectively. Drip irrigation at 0.6 CPE increased the number of seeds umbellet<sup>-1</sup> by 5.03% and 13.61% over the drip irrigation at 0.4 CPE and surface irrigation at a CPE of 0.8, respectively. The maximum number of umbellates umbel<sup>-1</sup> was observed under an application of drip irrigation at 0.6 CPE (5.07), which was at par with drip irrigation at 0.8 CPE (5.00). On a yearly average, seeds umbellet<sup>-1</sup> increased significantly under drip irrigation at 0.6 CPE over the rest of the treatments. The test weight of cumin seeds increased significantly with the application of drip irrigation at 0.6 CPE over the rest of the treatments and the percentage increase in test weight was 15.28% over surface irrigation. ANOVA for cumin plant growth and yield attributes showed that although irrigation (I) and Fertigation treatments were highly significant (5% probability), their interaction (F × I) was significant (5% probability) only for plant height, umbellate umbel<sup>-1</sup>, and seeds umbellate<sup>-1</sup> (Table 1). The yield of cumin increased significantly with the application of drip irrigation over surface irrigation (Table 2).

**Table 1.** Effect of drip irrigation and fertigation levels on the growth and yield attributes of cumin (pooled data of three years).

Treatment	Plant Height (cm)	Number of Branches plant <sup>-1</sup>	Number of Umbels plant <sup>-1</sup>	Number of Umbellate umbel <sup>-1</sup>	Number of Seeds umbellet <sup>-1</sup>	Test Weight (g)
<b>Irrigation levels</b>						
Drip irrigation at 0.4 CPE (I <sub>0.4</sub> )	29.8	6.90	46.1	4.93	5.06	4.44
Drip irrigation at 0.6 CPE (I <sub>0.6</sub> )	31.4	7.11	50.4	5.07	5.34	4.60
Drip irrigation at 0.8 CPE (I <sub>0.8</sub> )	30.7	6.98	48.8	5.00	5.20	4.45
SEm±	0.2	0.08	0.5	0.02	0.03	0.04
CD (p = 0.05)	0.6	0.27	1.7	0.08	0.10	0.13
<b>Fertigation levels</b>						
Fertigation with 60% RDF (F <sub>60</sub> )	29.9	3.48	45.9	4.94	5.13	4.35
Fertigation with 80% RDF (F <sub>80</sub> )	31.1	3.52	50.0	5.03	5.24	4.67
Fertigation with 100% RDF (F <sub>100</sub> )	30.9	3.46	49.5	5.04	5.23	4.46
SEm±	0.2	0.04	0.5	0.02	0.03	0.04
CD (p = 0.05)	0.6	0.12	1.7	0.08	0.10	0.13
<b>Control vs. Others</b>						
Surface irrigation at 0.8 CPE with 100% RDF (S <sub>0.8</sub> F <sub>100</sub> )	27.4	3.26	37.6	4.60	4.70	3.99
Others	30.6	3.49	48.4	5.00	5.20	4.49
SEm±	0.3	0.06	0.9	0.04	0.05	0.07
CD (p = 0.05)	1.0	0.20	3.0	0.14	0.17	0.23
C.V						
Fertigation (F)	*		*	*	*	*
Irrigation (I)	*		*	*	*	*
Fertigation × Irrigation (I × N)	*		*	*	*	*
Control/others	*	*	*	*	*	*

Significant at \* 5% probability level.

**Table 2.** Effect of drip irrigation and fertigation levels on yield and oil content of cumin (pooled data of three years).

Treatment	Seed Yield (Kg/ha)				Oil Content (%)			
	2016–2017	2017–2018	2018–2019	Pooled	2016–2017	2017–2018	2018–2019	Pooled
<b>Irrigation levels</b>								
Drip irrigation at 0.4 CPE (I <sub>0.4</sub> )	1252	857	695	934	3.53	3.51	3.21	3.42
Drip irrigation at 0.6 CPE (I <sub>0.6</sub> )	1395	1007	786	1063	3.60	3.59	3.43	3.54
Drip irrigation at 0.8 CPE (I <sub>0.8</sub> )	1374	1028	798	1067	3.61	3.50	3.42	3.51
SEm±	21.5	30.7	15.6	14.4	0.07	0.07	0.10	0.04
CD ( <i>p</i> = 0.05)	64.0	91.1	46.4	40.8	0.20	0.21	0.29	0.12
<b>Fertigation levels</b>								
Fertigation with 60% RDF (F <sub>60</sub> )	1292	887	717	966	3.64	3.53	3.28	3.48
Fertigation with 80% RDF (F <sub>80</sub> )	1372	1005	780	1052	3.67	3.56	3.34	3.52
Fertigation with 100% RDF (F <sub>100</sub> )	1357	1001	782	1046	3.43	3.51	3.44	3.46
SEm±	21.5	30.7	15.6	14.4	0.07	0.07	0.10	0.04
CD ( <i>p</i> = 0.05)	64.0	91.1	46.4	40.8	0.20	0.21	0.29	0.12
<b>Control vs. Others</b>								
Surface irrigation at 0.8 CPE with 100% RDF (S <sub>0.8</sub> F <sub>100</sub> )	824	539	530	631	3.35	3.30	3.13	3.26
Others	1340	964	760	1021	3.58	3.53	3.36	3.49
SEm±	27.8	39.6	20.2	24.9	0.09	0.09	0.13	0.06
CD ( <i>p</i> = 0.05)	82.6	117.6	59.9	70.7	0.25	0.28	0.38	0.20
C.V					5.60	6.17	8.93	
Fertigation (F)	*	*	*	*	*			
Irrigation (I)	*	*	*	*				
Fertigation × Irrigation (I × N)	*		*	*				
Control/others	*	*	*	*				*

Significant at \* 5% probability level.

Our results revealed that drip irrigation at 0.6 CPE ( $I_{0.6}$ ) enhanced the plant height by 15% and 5.36% over surface irrigation at CPE of 0.8 and drip irrigation at 0.4 CPE, respectively. These results are in close agreement with the results of Kunapara et al. [27], who reported that the highest plant height was observed at 0.8 Irrigation water/Crop evapotranspiration (IW/ETc) ratio. Drip irrigation significantly enhanced the number of branches per plant. It might be attributed to the availability of sufficient soil moisture for plant growth through drip irrigation, which led to an enhanced leaf area index and accelerated photosynthetic rate. In our present study, maximum cumin seed yield was recorded with an application of drip irrigation at 0.8 CPE followed by drip irrigation at 0.6 CPE during each experimental year except for 2016–2017. The lowest plant height and seed yield were obtained at 0.4 CPE due to an insufficient availability of water compared to the requirement of the crop. It might be due to excessive irrigation along with better nutrition leading to vegetative growth and a shortened reproductive phase [28]. The reduction in the yield with surface irrigation was due to less relative leaf water content and water potential. Yield attributes and yield increased due to better water utilization and uptake of nutrients and an excellent soil–water air relationship with higher oxygen concentration in the root zone. Another reason might also be due to the optimum moisture conditions in the entire root zone of the crop, which enhance the physiological activities of plants resulting in increased dry matter accumulation [29]. Bafna et al. [30] and Raina et al. [31] observed that frequent water application maintained the soil moisture almost near the field capacity; thereby, the crop did not experience moisture stress during the growth period.

Similar findings have been reported by Lal et al. [32], who revealed that irrigation regimes 0.6 IW/CPE ratio with drip irrigation had superior seed yields of fenugreek. Kunapara et al. [33] reported that an application of drip irrigation with 0.8 IW/ETc yielded higher seed yield, plant height, and dry matter in cumin. Kanwar et al. [34] reported that drip irrigation at 75% CPE recorded the highest growth and yield, but it was on par with drip irrigation at 50% CPE. Various studies have reported that an increased number of irrigations at 0.6 CPE or 0.8 CPE is beneficial for achieving higher seed yield [35–39]. Jat et al. [40] found that scheduling irrigation through drip at a 0.8 IW/CPE ratio with paired row planting was at par with 1.0 IW/CPE ratio that recorded significantly higher seed and straw yields as well as growth and yield attributes. Similar results were also obtained by Godara et al. [41] and Meena et al. [42]. Many researchers reported that irrigating crop with drip irrigation gave better seed yield as compared to surface irrigation [13,43–45]. Overall, the drip irrigation has a regulating effect on reducing energy use and soluble nutrient losses, creating well-aerated conditions, minimizing over irrigation, and increasing water-use efficiency by maintaining high soil matric potential in the root zone of the plant [46,47]. Drip irrigation enhances yield with low water availability because the congenial conditions for better growth are maintained in the root zone throughout the crop growth period [27].

### 3.2. Effect of Fertigation Levels on Cumin Plant Growth, Yield-Attributing Characteristics, and Yield

In the present investigation, there was a significant influence of different fertigation levels on plant growth and yield parameters viz. plant height (cm), number of umbels plant<sup>-1</sup>, umbellets/umbel<sup>-1</sup>, seeds/umbellate<sup>-1</sup>, test weight (g), seed, straw, and biological yield of cumin except for the number of branches per plant<sup>-1</sup> during the mean of experimental years (Table 1). The maximum number of branches per plant<sup>-1</sup> (3.52) was recorded with fertigation with 80% RDF, but there was no significant difference within fertigation levels. An application of fertigation with 80% RDF significantly increased umbels plant<sup>-1</sup> by 8.93% and 32.97%, respectively, over the fertigation with 60% RDF and surface irrigation with 100% RDF. Maximum numbers of umbellets/umbel<sup>-1</sup> (5.04) were recorded with an application of fertigation with 100% RDF and seeds/umbellate<sup>-1</sup> with fertigation with 80% RDF as the mean over the years. The test weight of cumin seeds was significantly increased with the application of fertigation with 80% RDF, and the percentage increase in test weight was 17.04, 7.35, and 4.70% over surface irrigation with 100%, fertigation with 60%, and 100% RDF. The yield of cumin significantly increased with the application of different levels of fertigation over the control (Table 2). ANOVA results

showed that fertigation (F), irrigation (I), and their interaction (F × I) were significant (5% probability) for cumin seed yield (Table 2).

Our results revealed that the maximum plant growth and cumin seed yield was recorded with the application of fertigation with 80% RDF followed by fertigation with 100% RDF during all the years of the experiment. Plant height was significantly influenced by fertigation with 80% RDF and increased by 4.01% and 13.50% over fertigation with 60% RDF and surface irrigation with 100% RDF, respectively, which was at par with fertigation with 100% RDF. Kanwar et al. [34] and Honnappa et al. [48] reported that an application of fertilizers at 100% RDF recorded the highest plant height and was at par with fertigation at 75% RDF in fenugreek. The reason behind the higher yield is maintaining an optimum level of moisture in the rhizosphere zone by a controlled application of water through drip that favored the mineralization of inorganic nutrients and resulted in better growth and development of the crop; or, this might be due to an application of water-soluble forms of nutrients under each treatment, while treatments that received higher fertigation levels showed more yield [49]. The increasing levels of fertigation limited the fertilizers to the moist zone of the soil, where the active root zones are concentrated, thus leading to an enhanced better availability of nutrients, superior vegetative growth, and finally yield [50]. A similar influence of fertigation on the growth and yield in crops was reported by Godara et al. [41], Meena et al. [42], and Koyani et al. [51].

Overall, drip fertigation is a highly efficient method for fertilizer application, as it minimizes losses and the adverse environment effects on crop production. Both water and nutrients applied through irrigation will be efficiently used by the plants for photosynthesis, thereby causing greater synthesis, translocation, and accumulation of carbohydrates [18,52]. Various studies have evaluated that fertigation is the only replacement of the conventional method that can achieve higher fertilizer-use efficiency, reduce water and fertilizer application, and lead to higher economic returns [53–60].

### 3.3. Effect of Drip Irrigation Levels on Oil Content of Cumin Seed

In experimental results, the highest oil content in cumin seed was observed under drip irrigation at 0.6 CPE in two experimental years, but in 2016–2017, it was observed under drip irrigation at 0.8 CPE. There were no significant differences among the treatments (Table 2). The application of drip irrigation at 0.6 CPE increased the oil content by 8.58% over surface irrigation. It has been reported that the essential oil yields per plant increase significantly with the increasing water regimes regarding the crop water need, but the linalool content of oil was reduced when increasing the irrigation level [61]. Jordan et al. [62] and Khazaie et al. [63] found that the irrigation regime had no significant effect on *Thymus hyemalis*, *Thymus vulgaris*, and *Hyssopus officinalis* essential oil content. Naresha et al. [64] conducted a field experiment to evaluate the quality, yield, and economics of *rabi* groundnut as influenced by irrigation scheduling and phosphogypsum levels. The highest oil content and oil yield were obtained with moisture regimes at 1.0 IW/CPE, and the maximum oil content was found with 40 kg S ha<sup>-1</sup>. These results were in close confirmity with the result of Chattopaddhyay and Ghosh [65] and Patel et al. [66]. Meena et al. [12] reported that the oil content of seed was not influenced significantly due to drip irrigation treatments in fennel.

### 3.4. Effect of Fertigation Levels on Oil Content of Cumin Seed

The highest oil content in cumin seed was observed with an application of fertigation with 80% RDF during 2016–2017, 2017–2018, and in year averages, except for 2018–2019, where the highest oil content was recorded with fertigation with 100% RDF. There was no significant difference within all fertigation levels. In 2016–2017, 2017–2018, and 2018–2019, the determined cumin oil content was 3.67%, 3.56%, and 3.34% under fertigation with 80% RDF, respectively (Table 2). ANOVA results showed that fertigation and irrigation and their interaction (F × I) were not significant (5% probability) for oil content in cumin seed (Table 2).

During the experimental year 2018–2019, the reduction in oil content was thought to be the result of unsuitable weather conditions. The increased temperature and water stress during grain filling might

be a major cause of reduced oil concentration. The lowest oil content was recorded in treatment surface irrigation at 0.8 CPE with 100% RDF. The reduction in oil content due to higher nitrogen doses was due to the fact that extra available nitrogen enhances the degradation of carbohydrates (tri-carboxylic cycle) to acetyl CoA, thereby enabling processes of reductive amination and transamination to produce more amino acids [67] and cause increased seed protein content with a corresponding decrease in seed oil content [68]. Jain et al. [69] revealed drip fertigation and irrigation interval effects on growth, productivity, nutrient, and water economy in summer peanut and observed that the oil and moisture contents in kernels did not differ significantly due to various fertigation schedules.

### 3.5. Economic Analysis in Relation to Drip Irrigation

The CPE (0.4, 0.6, and 0.8)-based drip irrigation enhanced the gross returns, net returns, and B:C ratio as compared to surface irrigation (Table 3). The highest gross return and B:C ratio was observed in an application of drip irrigation at 0.8 CPE during two experimental years, but in 2016, the highest gross returns, net returns, and B:C ratio were observed with drip irrigation at 0.6 CPE (Table 3). Both treatments were at par with each other during the mean of the years. The lowest value of net return and B:C ratio was observed in surface irrigation and drip irrigation at 0.4 CPE. The pooled data showed a maximum gross return (₹ 170,900 ha<sup>-1</sup>), net return (₹ 111,700 ha<sup>-1</sup>), and benefit cost ratio (2.9) with fertigation with 80% RDF followed by fertigation with 100% RDF (Table 3). ANOVA for gross return and net returns showed that irrigation (I), fertigation, and their interaction (F × I) were equally significant (5% probability).

In our present study, the highest pooled B:C ratio was 2.9, which was equal at both 0.6 IW/ETc and 0.8 IW/ETc. Our economic results are in close agreement with the study of Kunapara et al. [27], who reported the highest B:C ratio (2.39) at 0.8 IW/ETc with a lateral spacing of 0.6 m in cumin. Jat et al. [40] also found that drip irrigation at an IW/CPE ratio 0.8 with paired row planting, being at par with 0.8 IW/CPE ratio in normal row planting and 1.0 IW/CPE ratio in normal and paired row planting, recorded significantly higher net returns and a B:C ratio over 0.4 and 0.6 IW/CPE ratios with normal and paired row planting. The cost of this treatment was comparatively lower than its additional income, which led to more returns under this treatment. Our results were also similar with the findings of Rao et al. [70] in cumin.

**Table 3.** Economics of drip irrigation and fertigation levels in cumin (pooled data of three years).

Treatment	Gross Returns ( $\times 10^3$ ₹ ha <sup>-1</sup> )				Net Returns ( $\times 10^3$ ₹ ha <sup>-1</sup> )				B:C
	2016–2017	2017–2018	2018–2019	Pooled	2016–2017	2017–2018	2018–2019	Pooled	Pooled
<b>Irrigation levels</b>									
Drip irrigation at 0.4 CPE (I <sub>0.4</sub> )	212.8	128.6	114.6	152.0	154.2	70.1	56.1	93.5	2.6
Drip irrigation at 0.6 CPE (I <sub>0.6</sub> )	237.1	151.1	129.8	172.6	178.0	91.9	70.6	113.5	2.9
Drip irrigation at 0.8 CPE (I <sub>0.8</sub> )	233.6	154.2	131.7	173.2	173.8	94.5	71.9	113.4	2.9
SEm±	3.7	4.6	2.6	2.3	3.7	4.6	2.6	2.3	
CD ( <i>p</i> = 0.05)	10.9	13.7	7.7		10.9	13.7	7.7	6.4	
<b>Fertigation levels</b>									
Fertigation with 60% RDF (F <sub>60</sub> )	219.7	133.1	118.4	157.0	161.3	74.7	60.0	98.7	2.7
Fertigation with 80% RDF (F <sub>80</sub> )	233.2	150.8	128.7	170.9	174.1	91.6	69.5	111.7	2.9
Fertigation with 100% RDF (F <sub>100</sub> )	230.6	150.1	129.0	169.9	170.7	90.1	69.0	110.0	2.8
SEm±	3.7	4.6	2.6	2.3	3.7	4.6	2.6	2.3	
CD ( <i>p</i> = 0.05)	10.9	13.7	7.7	6.5	10.9	13.7	7.7	6.5	
<b>Control vs. Others</b>									
Surface irrigation at 0.8 CPE with 100% RDF (S <sub>0.8</sub> F <sub>100</sub> )	140.1	80.8	87.5	102.8	96.1	36.7	43.4	58.7	2.3
Others	227.8	144.6	125.3	165.9	168.7	85.5	66.2	106.8	2.8
SEm±	4.7	5.9	3.3	3.9	4.7	5.9	3.3	3.9	
CD ( <i>p</i> = 0.05)	14.0	17.6	9.9	11.2	14.0	17.6	9.9	11.2	
C.V	5.01	9.98	6.36		6.80	17.12	12.10		
Fertigation (F)	*	*	*	*		*	*	*	
Irrigation (I)	*	*	*	*	*	*	*	*	
Fertigation × Irrigation (I × N)	*	*	*	*	*	*	*	*	
Control/others	*	*	*	*	*	*	*	*	

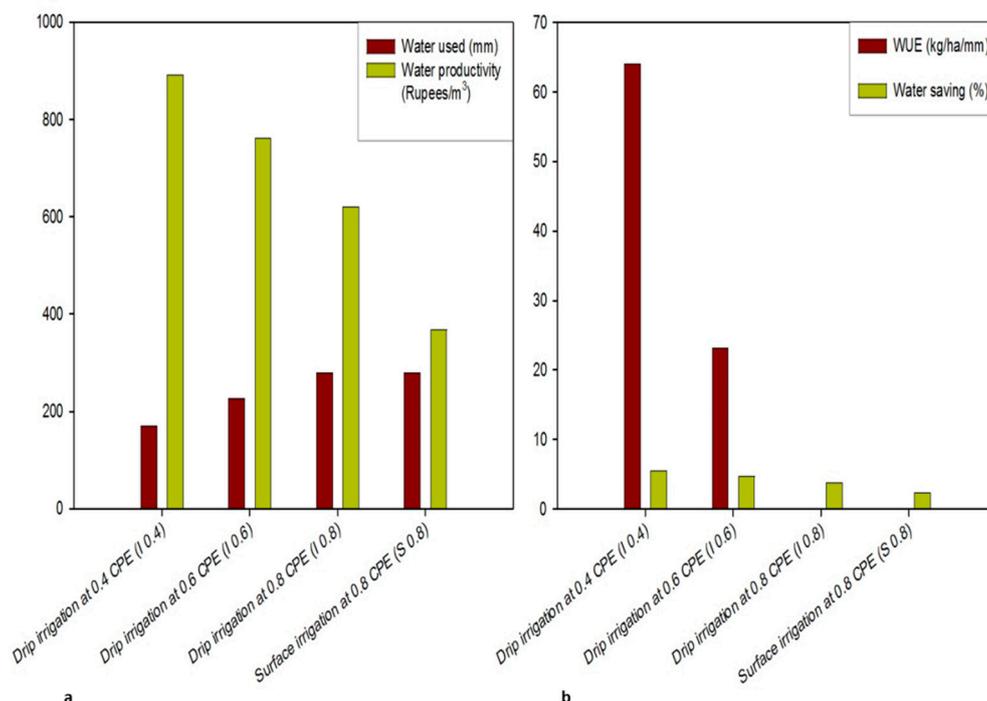
Significant at \* 5% probability level.

### 3.6. Economic Analysis in Relation to Fertigation Levels

In our present study, in terms of application of fertigation, the highest gross return, net return, and benefit cost ratio was observed with the application of fertigation with 80% RDF. These findings are in agreement with Sadarunnisa et al. [71], who reported that the B:C ratio was the highest (1.49) in turmeric supplied with 75% RDF through fertigation. Giana et al. [72] reported that the drip fertigation at 75% RDF recorded the significantly highest net returns and B:C ratio of fennel, whereas it remained equally effective with drip fertigation at 100% over surface irrigation with conventional fertilization. Some studies also reported a superiority of drip fertigation over conventional fertilization in terms of productivity and economics [38,39,73–75].

### 3.7. Water Studies

The water use in 0.8 CPE levels of drip as well as surface irrigation was recorded as the highest among all the levels of irrigation (Figure 2a). A minimum quantity of water (170.4 mm) was used in drip irrigation at 0.4 CPE. In the experimental study, water-use efficiency ranged from 3.8 to 5.5 kg ha<sup>-1</sup> mm<sup>-1</sup> for drip irrigation as compared to 2.3 kg ha<sup>-1</sup> mm<sup>-1</sup> under conventional method of surface irrigation. The highest water-use efficiency was recorded with drip irrigation at the 0.4 CPE level and the lowest under surface irrigation at 0.8 CPE (Figure 2b). The highest economic water productivity (892 m<sup>-3</sup>) was recorded with drip irrigation at 0.4 CPE as compared to surface irrigation and increased levels of drip irrigation (Figure 2a). The drip irrigation at 0.4 CPE recorded the highest water saving (64%) compared to surface irrigation at 0.8 CPE (Figure 2b).



**Figure 2.** Effect of drip irrigation levels on water use, water productivity, water-use efficiency, and water saving (pooled data of three years). (a): water used and water productivity; (b): Water use efficiency and water saving.

In our present investigation, we found that drip irrigation increased the water-use efficiency, water productivity, and water saving over the surface irrigation. Drip irrigation at 0.4 CPE (I<sub>0.4</sub>) show better water-use efficiency as compared to other regimes of drip irrigation and surface irrigation. Saved water with drip irrigation at 0.4 CPE (I<sub>0.4</sub>) and 0.6 CPE (I<sub>0.6</sub>) was 109 mm and 52.7 mm over

the surface irrigation at 0.8 CPE ( $S_{0.8}$ ), respectively. Bhunia et al. [36] also found that drip irrigation levels from 0.6 to 1.0 ETc saved water by 261.84 to 76.4 mm over surface irrigation, which used 540 mm of water. This increase in water saving might be due to the efficient use of water, which was applied to maintain the appropriate soil moisture along with the maximum yield obtained with the minimum quantity of water. The quantity of water was almost as per the crop need in case of drip irrigation. Similar findings have also been reported by Datta and Chatterjee [76] in fenugreek and Bandyopadhyay et al. [77] in wheat.

The irrigation water-use efficiency depends on irrigation level. A uniform distribution of water in the root zone increases various physiological processes, minimizes the leaching losses of water, enhances the rate of photosynthesis, and enables efficient plant nutrient uptake, due to which the seed yield increases. The increased irrigation levels must have enhanced nutrients availability leading to better root development, which extracted more soil moisture. It might also be due to more vegetative growth under an adequate supply of water, which in turn increased the evapotranspiration losses. Irrigation scheduling in a micro irrigation system provides water to the plants, which matches the crop evapotranspiration rate and provides optimum irrigation at critical growth stages, resulting in high water-use efficiency [78–81].

Higher water-use efficiency with a lower level of drip irrigation might be due to a greater increase in seed production as compared to an increase in water use [82]. Surface irrigation obtained lower water-use efficiency due to a loss of irrigation water from sandy loam soil through deep percolation, reduced irrigation runoff, and the irrigation of a smaller portion of soil volume, which resulted in higher water use but minimum economic yield. Singh et al. [13] also revealed improved water productivity by the drip irrigation method against the surface irrigation method. It is also proven that the highest irrigation water productivity was recorded at 0.8 IW/CPE treatments and it reduced as the irrigation level increased [70].

#### 4. Conclusions

Drip irrigation and fertigation constitute the potential agronomic intervention that significantly enhanced the cumin plant growth, yield, oil content in cumin seeds, water-use efficiency, and nutrient-use efficiency. The application of drip irrigation at 0.6 CPE significantly increased the number of umbels per plant and number of seeds per umbellate over the other treatments. Whereas, the number of umbellates per umbel was significantly enhanced by the application of all drip irrigation regimes over the surface irrigation at 0.8 CPE. The maximum cumin seed yield was recorded with an application of drip irrigation at 0.8 CPE followed by drip irrigation at 0.6 CPE. The oil content in cumin seed was increased with respect to drip irrigation. The application of drip irrigation at 0.6 CPE increased the oil content by 8.58% over surface irrigation. The application of drip irrigation showed more gross return and a higher B:C ratio than surface irrigation. The plant growth, yield, and oil content in cumin seed were also significantly enhanced by fertigation with 80% RDF. In terms of application of fertigation, the highest gross return, net return, and B:C ratio was recorded with the application of fertigation at 80% RDF. Therefore, fertigation along with drip irrigation is an important agronomic intervention to enhance the cumin productivity and profitability.

**Author Contributions:** Conceptualization, M.A.M., N.G., Data curation, S., H.S.; Funding acquisition, H.O.E.; Investigation, M.L.M., N.G., S., H.S.; Methodology, S., H.S.; Software, H.O.E.; Validation, M.L.M.; Visualization, H.O.E.; Writing—review and editing, N.G., H.O.E. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work was supported by the Deanship of Scientific Research at King Saud University through research group number RG-1440-012. This research was funded by the Mission for Integrated Development of horticulture, Department of Agriculture & Cooperation, Ministry of Agriculture, Krishi Bhavan, New Delhi.

**Acknowledgments:** The authors extend their appreciation to the Deanship of Scientific Research at King Saud University (RG-1440-012) and also thank Ministry of Agriculture, Krishi Bhawan, New Delhi and Agriculture University Jodhpur.

**Conflicts of Interest:** The authors declare no conflict of interest.

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