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EFFECT OF SOIL MOISTURE LEVEL ON YIELD AND NUTRIENT BALANCE SHEET OF BLACK CUMIN*

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Abstract

A field experiment was conducted at Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur during *rabi* season of 2016-17 to evaluate the effects of soil moisture levels on black cumin (BARI Kalozira-1). The study site belongs to Shallow Red-Brown Terrace Soil of Salna series under AEZ-28 (Madhupur Tract). The experiment was set up in randomized complete block design with three replications, comprised five treatments assoil moisture levels: irrigation at 90%, 80%, 70%, 60% and 50% field capacity. The required number and amount of irrigation were 11 and 113.1mm, 8 and 108.1mm, 6 and 104.2mm, 4 and 99.4mm and 0 and 22.4mm in irrigation at 90%, 80%, 70%, 60% and 50% field capacity, respectively. The maximum seed yield (1243.0 kg ha^{-1}) was recorded under the highest moisture regime in irrigation at 90% field capacity of soil moisture. The minimum yield (165.5 kg ha^{-1}) was noted at 50% field capacity (where no irrigation was required). Net nutrient balance of N, K and S showed negative balance but P was positive. The maximum water use efficiency (10.51 kg ha^{-1} mm^{-1}) for yield was noted with irrigation at 90% field capacity, which may be recommended for black cumin cultivation in the study area. The cost-benefit analyses also indicate that the maximum net income (Tk. 123503.00) of black cumin cultivation has been achieved by maintaining the highest soil moisture through irrigating the crop at 90% of field capacity.

Keywords: Black cumin, irrigation, nutrient balance sheet, seed yield and water productivity.

Introduction

Black cumin (*Nigella sativa* L. family-Ranunculaceae) is an annual herb. Around 22 spices of black cumin are grown in worldwide. Among these, the seed of *Nigella sativa*, *N. damescene* and *N. arvensis* are used as medicinal and spices purposes. The black cumin seeds contain more than 100 chemical constituents such as protein, carbohydrates, alkaloids (nigellicines and nigelledine), saponin (ά-hedrerin), fixed and essential oils, vitamins, minerals and bioactive compounds (thymoquinone, thymol) etc. (Rajsekhar and Kuldeep, 2011). The consumption of black cumin has increased with time, but the production has declined compared to other vegetables and spices crops due to lack of improved hybrid varieties, quality seeds, improved production technologies, inadequate marketing facilities, climate change and shortage of land due to *Boro* & *Rabi* crops.

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Water stress is well known as one of the most significant factors hampering plant growth by affecting cell elongation directly and more indirectly by nutrients uptake, allocation of especially photisynthesis and physiological processes in plants and this in turn is reflected on growth, development and yield. Water stress during budding, anthesis, flowering stages of plants causes the most reduction in number, yield and quality of seed (Ghanbary *et al*., 2008). The effective role of water supply on the growth and yield of black cumin was observed by many investigators and found that providing optimum amounts of water resulted in better growth and yield and water stress showed negative impact on growth, yield and quality attributes. Research review shows that the black cumin is able to tolerate moderate levels of water stress (Bannayan *et al.*, 2008). Moreover, deficit irrigation is one way of maximizing water use efficiency (WUE) for higher yields per unit of irrigation water applied where crop is exposed to a certain level of water stress either during a particular period or throughout the entire growing season. Optimizing irrigation management together with appropriate crops for cultivation is highly demandable (Ghorbanli *et al.*, 1999). In Bangladesh, acute shortage of irrigation water during dry season is affecting the crop production in general and spices production in particular. Thus, for ensuring the sustainable black cumin seed production and combating the water crisis during *rabi* season, it is very important to go for judicious use of irrigation water. Both over-irrigation and under-irrigation are detrimental for crop production and economic point of view. An optimum amount of irrigation water should be applied at proper time of the crop need. Based on the aforesaid importance of dry land agriculture due to water scarcity and sustaining the production of spice crops like black cumin in order to meet its increasing demands, the present study was undertaken to:(i) to observe the effect of different soil moisture regimes on the seed yield of black cumin. (ii) to determine the water requirement of the crop for achieving the maximum yield potential of the crop and (iii) to make a nutrient balance sheet for proper soil management of the crop.

Materials and Methods

A field experiment was carried out at the research field of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur during *rabi* season of 2016-17 in Shallow Red-Brown Terrace Soil of Salna series under AEZ-28 (Madhupur Tract). The order of the studied soil falls under Inceptisols in USDA Soil Taxonomy. The geographic coordinates of the experimental location is $24^0 09^/$ North Latitude and $90^0 26^/$ East Longitude with elevation of 8.2 m from mean sea level. A description of some basic properties of the experimental soil collected from a depth of 0-30 cm prior to application of fertilizers is presented in Table 1. The maximum effective rooting depth of black cumin was assumed to be confined within 20 cm.

Table 1. Soil properties of the experimental field

Soil characteristics	Analytical value	Analytical method
Physical properties		
Particle size distribution		Hydrometer method
Sand	17.30%	
Silt	45.80%	
Clay	36.90%	
Textual class	Silty clay loam	
Bulk density	1.38gcm^{-3}	Core sampling method
Particle density	2.63 gcm^{-3}	Pycnometer method
Porosity (%)	47.4	
Hydraulic conductivity (cm sec^{-1})	4.6 x 10^{-4}	Falling-head method
Field capacity (% by weight)	30.7	Gravimetric method
Initial moisture status (% by weight)	22.8	Gravimetric method
Chemical properties		
Soil pH	5.84	Soil: water=1:2.5
Total N (%)	0.09	Modified Kjeldhal Method
Organic C (%)	0.86	Wet oxidation method
C: N ratio	9.50	
Available P (ppm)	6.80	Bray and Kurtz method
Exchangeable K (meq100 g^{-1}soil)	0.06	N NH_4OAc extraction method
Exchangeable Ca (meq100 g^{-1} soil)	1.60	N NH_4OAc extraction method
Exchangeable Mg (meq100 g^{-1}soil)	0.71	N NH_4OAc extraction method
Exchangeable Na (meq100 g^{-1} soil)	0.38	N NH_4OAc extraction method
CEC (meq 100 g^{-1} soil)	9.00	N NH_4OAc extraction method
Available B (ppm)	0.19	Calcium chloride extraction method
Available Zn (ppm)	0.58	DTPA Extraction method
Available Cu (ppm)	0.19	DTPA Extraction method
Available Mn (ppm)	0.80	DTPA Extraction method
Available S (ppm)	7.8	Calcium dihydrogen phosphate extraction method

The experiment was set up in Randomized Complete Block Design (RCBD) with five treatment combinations were**:** I_1: Irrigation at 90% field capacity, I_2: Irrigation at 80% field capacity, I_3: Irrigation at 70% field capacity, I_4: Irrigation at 60% field capacity andI_5: Irrigation at 50% field capacity, having three replications. The experimental plot was fertilized with N, P, K, S, Zn and B @

80, 22, 60, 15, 1.7 and 1.2 kg ha^{-1}, in the form of urea, TSP, MoP, gypsum, zinc sulfate and boric acid, respectively with 5 t ha^{-1} cowdung on the basis of soil test value (STB). The cowdung used in the experiment contained 0.99% N, 0.19% P, 0.49% K, 0.11% S, 0.39% Ca and 0.20%Mg on dry basis. The whole amount of cowdung, TSP, MoP, gypsum, zinc sulfate and boric acid were applied as basal dose. Urea was applied in three equal installments at 5^{th}, 9^{th} and 11^{th} week after sowing. The seeds of black cumin cv. BARI Kalozira-1 were sown on 22 November 2016 in 3 m x 3 m plot at line to line distance of 20 cm. Seeds were soaked in water for 24 hours to facilitate germination. Then the seeds were dried and treated with Autostin (carbendazim) @ 2 g kg^{-1} seeds to minimize the primary seed-borne disease. The seeds were mixed with some loose soil to allow uniform sowing in rows @ 10 kg ha^{-1} of seed at about a depth of 1.0 cm. The seeds were covered with loose soil properly just after sowing and gently pressed by hands followed by light irrigation to enhance proper emergence. Continuous lines were made to maintain a plant to plant distance of 10 cm by thinning at 25 DAS and then the light irrigation was given immediately after thinning. The intercultural operations (three weeding and three times' spray of Autostin @ 2g l^{-1} of water spray for controlling damping off disease) were done in the whole cropping period. The observations on growth parameters like plant height and number of branches were recorded at 100 DAS. The crops were harvested on 20 March 2017, when about 50-60% of the capsules of plots were found visible to changing green to straw color. Ten plants were selected randomly from each treatment for recording some growth and yield contributing characters. The production of seed per plot was recorded from $1m^2$ of land to obtain the yield per hectare. The harvested plants were sun dried for four days and threshing was done by beating with wooden sticks. The seeds were winnowed and cleaned subsequently for recording data. Irrigation water was applied on the basis of soil moisture under each treatment to bring the soil moisture up to the field capacity level. Field capacity, having the maximum available water was considered to be the highest level of irrigation in order to avoid deep percolation loss of water.

Irrigation requirement was determined by using the following equation:

$$IR = \{(M_{FC} - M_{PI}) / 100\} \times \rho b \times D$$

Where,

IR = Irrigation requirement (cm)

M_{FC} = Soil moisture percentage at field capacity (weight basis)

M_{PI} = Soil moisture percentage in field prior to irrigation (weight basis)

ρb = Bulk density (g cm^{-3})

D = Rooting depth (cm)

Data on total number of irrigation, common irrigation (seed sowing to thinning) and total amount of irrigation water are presented in Table 2.

Table 2. Amount of irrigation water applied in different soil moisture levels for black cumin crop

No. of Irrigation	Rooting depth (cm)	Amount of irrigation water (mm) at different soil moisture levels treatment				
		I_1	I_2	I_3	I_4	I_5
1st	5	3.3	6.2	9.1	17.9	-
2nd	5	3.9	7.4	13.4	17.4	-
3rd	5	3.9	7.2	13.6	20.9	-
4th	7	5.8	12.0	13.1	20.8	-
5th	7	6.8	12.2	16.3	-	-
6th	7	6.8	10.9	16.3	-	-
7th	10	9.7	14.5	-	-	-
8th	10	11.0	15.3	-	-	-
9th	10	11.1	-	-	-	-
10th	12	14.2	-	-	-	-
11th	12	14.2	-	-	-	-
Common irrigation for seedling raising		22.4	22.4	22.4	22.4	22.4
Total		113.1	108.1	104.2	99.4	22.4

For calculating nutrient uptake, the ten plants selected and tagged earlier in each plot were cut at the bottom, chopped with sharp knife, air-dried in the laboratory and finally oven-dried for 72 hours at 65^0C. An electrically operated grinding machine was used to grind the oven-dried plant samples. The plant samples were then stored in polyethylene bag in desiccators for chemical analyses.

Nutrient uptake from the soil was calculated by using the formula:

Nutrient uptake = % A x Y / 100 kg ha^{-1}

Where,

% A = Nutrient content of plant in percent

Y = Total dry matter production of plant (kg ha^{-1})

Nutrient balance sheets were estimated by using the formula:

Nutrient balance (N, P, K, S) = Σ Input (N, P, K, S) – Σ Output (N, P, K, S)

Where,

Input: Chemical fertilizer, manure, BNF, deposition (rain), airborne, sedimentation

Output: Harvested crop parts, crop residues, leaching, gaseous losses, soil erosion

However, the nutrient balance in this study did not account for the addition of nutrients from rainfall, dry deposition, BNF and removal of nutrient by leaching, gaseous losses of N, or weed uptake of nutrients from the soil.

Harvest index was calculated by the following formula:

$HI = EY / BY \times 100$

Where,

HI = Harvest index (%)

EY = Seed yield (kg)

BY = Biological yield (kg)

Total consumptive use of water was calculated by the using equation:

$Wc = Iw + Sw + Pe$

Where,

Wc = Total consumptive use of water (mm)

Iw = Total amount of irrigation water applied (mm)

Sw = Soil moisture contribution (mm)

Pe = Effective rainfall (mm)

Soil moisture contribution was determined by using the following equation:

$Sw = (M_S - M_H/100) \text{ X } \rho b \text{ X } D$

Where,

M_S = Soil moisture percentage at sowing (weight basis)

M_H = Soil moisture percentage at harvest (weight basis)

ρb = Bulk density (g cm^{-3})

D = Rooting depth (cm)

Effective rainfall (Pe) was calculated by the using equation:

$Pe = 0.8P – 25$ if $P > 75$ mm $month^{-1}$

$Pe = 0.6P – 10$ if $P < 75$ mm $month^{-1}$

Where,

Pe = Effective rainfall (mm)

P = Rainfall (mm)

Water use efficiency (WUE) was estimated by following formula:

WUE = Total dry biomass or seed yield (kg ha^{-1}) / total consumptive use of water (mm)

Economic evaluation of different soil moisture levels was done considering the following rates of the materials: Urea@16Tkkg^{-1}, TSP@22Tkkg^{-1}, MoP @15 Tk kg^{-1}, gypsum @10 Tk kg^{-1}, boric acid @180 Tk kg^{-1}, zinc sulfate @200 Tk kg^{-1}, cowdung @1.5 Tk kg^{-1}, irrigation @1000 Tk per irrigation per ha, black cumin seed 180 Tk kg^{-1}, labor cost @350 Tk per day per man, land rent 25000 Tk per ha (According to the market price of the year 2016-2017).

The data were subjected to statistical analysis by using *R* version 3.5.0 software to find out the significance of variation resulting from the experimental treatments.

Results and Discussion

Plant height

Irrigation treatments significantly influenced the plant height (Table 3). The mean tallest plant (65.8 cm) was recorded in treatment I_1 (irrigation at 90% field capacity) followed by I_2 (62.2 cm), I_3 (49.1 cm) and the smallest plant (23.3 cm) was noted in treatment I_5 (irrigation at 50% field capacity) (Table 3). Maintenance of the highest level of soil moisture in I_1 plot (90-100% of FC) might have contributed to higher nutrient mobility and uptake by the crop thus, resulting maximum growth. Similar results are reported by (Karim *et al.*, 2017, Senyigit and Arslan, 2018).

Number of branches per plant

As shown in the Table 3, there was significant difference in number of branches per plant among the treatments, where the mean maximum number of branches per plant (7.5) being noted in treatment I_1 (irrigation at 90% field capacity) followed by I_2 (6.5), I_3 (6.1). The minimum number of branches per plant (4.3) was found in the treatment I_5 (irrigation at 50% field capacity). Higher soil moisture condition and higher availability of nutrients to crops in I_1 treatment might have favored in increasing the number of branches which ultimately contributed to the formation of additional number of capsules per plant. Thus, these parameters could act as good indicators for increasing yield potential in black cumin. These results were in agreement with the findings of Bannaya *et al.* (2008), Safaei *et al.* (2014) and Ghanespasanda *et al.* (2014).

Days to flower initiation

Results presented in Table 3 showed that the mean minimum period (60.67 days) was required for flower initiation in case of I_5 (irrigation at 50% field capacity) whereas the maximum period (65.67 days), was recorded in treatment I_1 (irrigation at 90% field capacity) which was statistically similar to treatment I_2 (irrigation at 80% field capacity) followed by I_3 and I_4. This result indicated that availability of insufficient soil moisture (irrigation at 50% of FC as in treatment

I_5) leads to restricted nutrient mobility and its' availability to crops resulting to early flowering and early maturity of crop. Similar result was noted by Norozpoor and Rezvani Moghaddam (2002).

Days to capsule setting

The reverse case was found in I_1 treatment where the maximum soil moisture was maintained that possibly favored in higher availability of nutrients and ultimately resulted in prolonged period (71.67 days) for capsule setting (Table 3).

Number of leaves per plant

Irrigation treatments significantly influenced the number of leaves per plant (Table 3). The mean maximum number of leaves per plant (36.1) was recorded in treatment I_1 (irrigation at 90% field capacity) and the minimum leaves per plant (11.0) was noted in treatment I_5 (irrigation at 50% field capacity). Higher number of leaves in plant can produce higher amount of photosynthate, thus produced higher carbohydrate. Similar result was reported by English and Raja (1996).

Table 3. Effect of soil moisture levels on different growth parameters of black cumin

Soil moisture levels	Plant height (cm)	No. of Branches per plant	Days to flower initiation	Days to capsule setting	No. of leaves per plant
I_1	65.8a	7.5a	65.7a	71.7a	36.1a
I_2	62.2b	6.5b	65.3a	71.0a	31.1b
I_3	49.1c	6.1b	63.3b	68.3b	27.4c
I_4	38.6d	5.3c	63.0b	67.3b	19.7d
I_5	23.3e	4.3d	60.7c	65.7c	11.0e
CV (%)	1.97	4.58	0.84	1.29	2.92

Number of umbellets per plant

The number of umbellets per plant differed significantly due to variation of soil moisture status (Table 4). The mean maximum number of umbellets per plant (52.0) was recorded in treatment I_1 (irrigation at 90% field capacity), while the minimum number of umbellets per plant (11.7) in treatment I_5 (irrigation at 50% field capacity). The number of umbellets per plant directly influenced the number of capsules per plant. This was probably due to maintenance of optimum moisture regime that favored adequate nutrient uptake by plant and led to production of more branches as well as more number of umbellets per plant. These results are in agreement with the results of Ghamarina *et al.* (2014), Senyigit and Arslan (2018).

Number of capsules per plant

Results presented in Table 4 exhibited that the mean maximum number of capsules (45.8) per plant was produced by treatment I_1 (irrigation at 90% field capacity) and the minimum values (4.7capsules per plant) in I_5 representing irrigation at 50% field capacity. Total number of capsules per plant appeared to be the most important component since it is closely related with seed yield. Increase in number of capsules per plant indicated production of more number of flowers per umbel, higher percentage of capsule set and reduced shedding of flowers and capsules which resulted in increased yield. Similar results were documented by Akbarinia *et al*. (2005) and Mozaffari *et al.* (2000).

Capsule size

Capsule size is represented by the length and diameter of the capsule (Table 4). The mean maximum length (1.62 cm) and diameter (0.94 cm) of single capsule was observed in treatment I_1, while the minimum length (0.65 cm) and diameter (0.63 cm) of capsule was found in treatment I_5. Capsule growth is largely dependent on the rate of water accumulation and the water flow into the capsule in turn is dependent on the water potential difference between the capsule and plant. Capsule size directly affects the number of seeds per capsule which in turn impacted yield. Bigger size capsule had higher number of seeds. These results of present study are similar with the findings of Karim *et al*. (2017), Senyigit and Arslan (2018).

Weight of single capsule

The weight of single capsule was affected by the irrigation treatments (Table 4). The heaviest capsule (0.69 g) was recorded when irrigation was given at 90% field capacity and the lightest capsule (0.24 g) was observed with irrigation at 50% field capacity. Heavier capsules indicated the higher amount of seed. The result is in agreement with the research findings of Akbarinia *et al.* (2005).

Table 4. Effect of soil moisture levels on different yield components of black cumin

Soil moisture levels	No. of umbellets per plant	No. of capsule per plant	Capsule size		Single capsule weight (g)
			Capsule length (cm)	Capsule diameter (cm)	
I_1	52.0a	45.8a	1.62a	0.94a	0.69a
I_2	45.6b	39.6b	1.48b	0.88ab	0.60b
I_3	37.0c	31.9c	1.38b0	0.84bc	0.38c
I_4	26.0d	21.1d	1.15c	0.77c	0.33c
I_5	11.7e	4.7e	0.65d	0.63d	0.24d
CV (%)	3.65	5.02	5.24	4.82	10.17

Number of seeds per capsule

The number of seeds per capsule was influenced by the irrigation treatments (Table 5). The highest mean number of seeds per capsule (126.6) was noted in I_1 treatment (irrigation at 90% field capacity) and the lowest number of seeds per capsule (52.9) being observed with irrigation at 50% field capacity. Higher number of seeds per capsule is the indicator of higher yield per plant. The same opinion was made by Gorbanli *et al*. (1999) and Mozaffari *et al.* (2000)

1000-seed weight

The weight of 1000-seed was significantly affected by the irrigation treatments (Table 5). The highest weight of 1000-seed (2.72 g) was recorded in treatment I_1 and the lowest weight (1.1 g) was noted in treatment I_5. The 1000-seed weight might have influenced by several factors such as variety, growing condition, climatic factors, and soil properties, cultural and nutrient management. Similar trends of results were obtained by Ghanespasanda *et al.* (2014) and Gorbanli *et al*. (1999).

Seed yield

The data presented in Table 5 revealed that irrigation treatments influenced the seed yield of black cumin. The maximum mean seed yield (1243.0 kg ha^{-1}) was obtained with the maximum soil moisture level in I_1 treatment (irrigation at the attainment of 90% field capacity) and the minimum seed yield (165.5 kg ha^{-1}) in I_5 treatment (irrigation at 50% field capacity). The higher seed yield of black cumin under higher soil moisture regimes may be attributed to higher availability of nutrients and attainment of improved yield contributing components which ultimately resulted in higher seed yield. The present results are in agreement with the results obtained by Bannayan *et al.* (2008) and Karim *et al.* (2017).

Biomass yield

Biomass yield of black cumin was significantly influenced by the irrigation treatments (Table 5). The maximum mean biomass yield (2595.0 kg ha^{-1}) was obtained when irrigation were applied at the attainment of 90% field capacity and the minimum biomass yield (727.0 kg ha^{-1}) in irrigation at 50% field capacity. Plant photosynthetic capacity and the pattern of carbon distribution among its organs are generally governed by moisture availability of soil. Similar results are reported by Gorbanli *et al*. (1999) and Mozaffari *et al.* (2000).

Harvest Index

Results stated in Table 5showed that the harvest index was influenced by the irrigation treatments. The maximum average harvest index (47.89%) was recorded underirrigation at 90% field capacity (I_1) followed by 44.74% at applied irrigation at 80% field capacity (I_2) and the lowest harvest index (22.76%) was observed with irrigation at 50% field capacity (I_5). It is clearly understood from the results that water stressed plant had a lower proportion of assimilates than well-watered plants. These results were in agreement with the research findings of Mozaffari *et al.* (2000). Maintenance of higher soil moisture resulted in better vegetative growth, which might have supported directly to the reproductive organs and contributed to a good harvest index of the crop. After pollination, the materials are transmitted to seeds and the water plays an important role in transmission process of materials. So, lack of optimum soil moisture, transmission process of water decreased, resulting in the reduced harvest index as have also been opined by Safaei *et al*. (2014) and Mozzafari *et al.* (2000).

Table 5. Effect of soil moisture levels on yield components, seed yield, biomass yield and harvest index of black cumin

Soil moisture levels	No. of seeds per capsule	1000-seed weight (g)	Seed Yield (kg ha^{-1})	Biomass Yield (kg ha^{-1})	Harvest Index (%)
I_1	126.6a	2.72a	1243.0a	2595a	47.89
I_2	111.8b	2.47b	993.4b	2220b	44.74
I_3	98.0c	2.19c	734.0c	1936c	37.91
I_4	65.7d	1.53d	563.5d	1580d	35.66
I_5	52.9e	1.10e	165.5e	727e	22.76
CV (%)	1.64	3.59	7.17	7.37	-

Nitrogen uptake

Nitrogen uptake by black cumin under different soil moisture levels was studied to understand the movement of N in black cumin plants under different soil moisture conditions (Table 6). Significant difference in N uptake of black cumin occurred by different soil moisture levels. Increased soil moisture led to increased N uptake by plant, which contributed vigorous growth of plants. The maximum uptake of N (134.14 kg ha^{-1}) was observed under higher frequency of irrigation in I_1 treatment followed by I_2 (101.92 kg ha^{-1}), I_3 (65.99 kg ha^{-1}) and I_4 (51.23 kg ha^{-1}) and the minimum uptake (15.07 kg ha^{-1}) in T_5 (irrigation at 50% field capacity). Maintenance of optimum soil moisture levels in soil had favored in better plant growth as well as transpiration rate, thus the N movement was also higher. Similar result is found by English and Raja (1996).

Residual soil N after crop harvest

The data presented in Table 6 revealed that irrigation treatments affected the residual N fertility status of soil. The maximum value of residual N (1793.3 kg ha^{-1}) was recorded in I_5 treatment (irrigation applied at 50% field capacity) followed by I_4 (1789.7kg ha^{-1}), I_3 (1782 kg ha^{-1}) and I_2 (1771.7 kg ha^{-1}) and the minimum value (1766.3 kg ha^{-1}, respectively) was noted treatment I_1 (irrigation at 90% field capacity). It can be inferred from the results that higher moisture availability led to higher N mining and ultimately resulted in less N reserves in soil. It may also be calculated that the amount of nutrient (N) up taken by crops is inversely related to the amount of nutrients reserve in soil. These results are in agreement with the research findings of Ahmadian *et al.* (2011)**.**

Apparent N balance

Apparent N balance was influenced by irrigation treatments (Table 6). The minimum negative apparent N balance (-29.06 kg ha^{-1}) was recorded at treatment I_1 (irrigation at 90% field capacity) and the maximum negative apparent N balance (-120.5 kg ha^{-1}) was noted in in I_5 treatment (irrigation applied at 50% field capacity).

Net N balance

Nitrogen balance may also be termed as N budget or N audit in cultivated land to maintain higher soil productivity in the future. Positive balance indicated the N accumulation and negative balance shows N depletion. To achieve N sustainability, the quantity of N inputs and outputs should be equal. Negative N balance may eventually cause soil degradation and adversely affect crop production. On the other hand, excess N accumulation may lead to soil and water pollution. The irrigation treatments created considerable impact on soil fertility (Table 6). Negative balance of N was increased with increasing soil moisture level. The minimum negative net N balance (-6.7 kg ha^{-1}) was observed in I_5 treatment (irrigation applied at 50% field capacity) followed by I_4 (-10.3 kg ha^{-1}), I_3 (-18 kg ha^{-1}) and I_2 (-28.3 kg ha^{-1}) and the maximum negative net N balance (-33.7 kg ha^{-1}) was recorded at treatment I_1 (irrigation at 90% field capacity). Maintenance of higher soil moisture in I_1 treatment has led to higher mobility and translocation of nutrients (N) that might have resulted in maximum exhaustion of N in soil and exhibited the maximum negative balance of N.

Table 6. Effect of soil moisture levels on N balance sheet after harvest of black cumin

Soil moisture levels	Initial soil N status	Added N through fertilizer	N uptake	Residual soil N after harvest	Apparent N balance	Net N balance
	A	B	C	D	D-{(A+B)-C} =E	D-A=F
	(kg ha^{-1})					
I_1	1800	129.5	134.14a	1766.3e	-29.06	-33.7
I_2	1800	129.5	101.92b	1771.7d	-55.88	-28.3
I_3	1800	129.5	65.99bc	1782.0c	-81.51	-18
I_4	1800	129.5	51.23c	1789.7b	-88.57	-10.3
I_5	1800	129.5	15.70c	1793.3a	-120.5	-6.7
CV (%)	-	-	5.97	0.10	-	-

Phosphorus uptake

Phosphorus uptake by black cumin was studied to understand the translocation of P in black cumin plants under different moisture regimes (Table 7). Significant difference in P uptake of black cumin occurred due to different soil moisture levels. Increased soil moisture led to increased P uptake by plant, which contributed to vigorous growth of plants. The maximum uptake of P (12.28 kg ha^{-1}) was observed under higher frequency of irrigation in I_1 treatment followed by I_2 (9.12 kg ha^{-1}), I_3 (6.21 kg ha^{-1}) and I_4 (4.36 kg ha^{-1}) and the minimum uptake (0.58 kg ha^{-1}) in T_5 (irrigation at 50% field capacity).

Residual soil P after harvest

The data presented in Table 7 revealed that irrigation treatments affected the residual P fertility status of soil. The maximum value of available P after harvest (16.2 kg ha^{-1}) was recorded in I_5 treatment (irrigation applied at 50% field capacity) followed by $I_4$15.8 kg ha^{-1}), I_3 (15.6 kg ha^{-1}) and I_2 (15 kg ha^{-1}) and the minimum value (14.4 kg ha^{-1}) was noted treatment I_1 (irrigation at 90% field capacity). It can be inferred from the results that higher moisture availability led to higher P mining and ultimately resulted in less P reserves in soil.

Apparent P balance

The minimum negative apparent P balance (-18.42 kg ha^{-1}) was recorded in I_1 treatment (irrigation at 90% field capacity) followed by I_2 (-20.98 kg ha^{-1}), I_3 (-23.29 kg ha^{-1}) and I_4 (-24.94 kg ha^{-1}) and the maximum negative value (-28.82 kg ha^{-1}) was recorded at I_5 treatment (irrigation at 50% field capacity).

Table 7. Effect of soil moisture levels on P balance sheet after harvest of black cumin

Soil moisture levels	Initial soil P status	Added P through fertilizer	P uptake	Residual soil P after harvest	Apparent P balance	Net P balance
	A	B	C	D	D-{(A+B)-C} =E	D-A=E
	(kg ha^{-1})					
I_1	13.6	31.5	12.28a	14.4c	-18.42	0.8
I_2	13.6	31.5	9.12b	15.0bc	-20.98	1.4
I_3	13.6	31.5	6.21b	15.6ab	-23.29	2.0
I_4	13.6	31.5	4.36b	15.8a	-24.94	2.2
I_5	13.6	31.5	0.58c	16.2a	-28.32	2.6
CV (%)	-	-	12.79	2.61	-	-

Net P balance

The irrigation treatments created considerable impact on P reserve in soil (Table 7). The maximum net P balance (2.6 kg ha^{-1}) was recorded in I_5 treatment (irrigation applied at 50% field capacity) followed by I_4 (2.2kg ha^{-1}), I_3 (2.0kg ha^{-1}) and I_2 (1.4kg ha^{-1}). The minimum P balance (0.8 kg ha^{-1}) was calculated at treatment I_1 (irrigation at 90% field capacity). It may be due to higher soil moisture availability might have caused higher P availability to plants and ultimately higher P mining from soil.

Potassium uptake

Potassium uptake by black cumin under different soil moisture levels were studied (Table 8). Significant difference in K uptake by black cumin occurred under different soil moisture levels. Increased soil moisture led to increased K uptake by plant, which contributed increased growth and yield. The maximum uptake of K (89.12 kg ha^{-1}) was observed under higher frequency of irrigation in I_1 treatment followed by I_2 (69.40 kg ha^{-1}), I_3 (37.94 kg ha^{-1}) and I_4 (35.97 kg ha^{-1}) and the minimum uptake (11.69 kg ha^{-1}) in T_5 (irrigation at 50% field capacity).

Residual soil K after harvest

The data presented in Table 8 showed that irrigation treatments affected the residual K fertility status of soil. The maximum value of residual K (42.6 kg ha^{-1}) was recorded in I_5 treatment (irrigation applied at 50% field capacity) followed by I_4 (38.4 kg ha^{-1}), I_3 (35 kg ha^{-1}) and I_2 (34.3 kg ha^{-1}) and the minimum value (32.5 kg ha^{-1}) was noted treatment I_1 (irrigation at 90% field capacity). It can be inferred from the results that higher moisture availability led to higher K mining and ultimately resulted in less K nutrients reserves in soil.

Apparent K balance

The minimum negative apparent K (-0.18 kg ha^{-1}) was recorded in I_1 treatment (irrigation at 90% field capacity) followed by I_2 (-18.1 kg ha^{-1}), I_4 (-47.43 kg ha^{-1}) and I_3 (-48.86 kg ha^{-1}) and the maximum negative (-67.51 kg ha^{-1}) was recorded at I_5 treatment (irrigation at 50% field capacity).

Net K balance

The irrigation treatments created considerable impact on soil K fertility (Table 8). Negative balance of K increased with increasing soil moisture level. The minimum negative net K balance (-4.2 kg ha^{-1}) was observed in I_5 treatment (irrigation applied at 50% field capacity) followed by I_4 (-8.4 kg ha^{-1}), I_3 (-11.8 kg ha^{-1}) and I_2 (-12.5 kg ha^{-1}). The maximum negative net K balance (-14.3 kg ha^{-1}) was recorded at treatment I_1 (irrigation at 90% field capacity). It may be due to higher availability of soil moisture as well as higher mobility and exhaustion of K.

Table 8. Effect of soil moisture levels on K balance sheet after harvest of black cumin

Soil moisture levels	Initial soil K status	Added K through fertilizer	K uptake	Residual soil K after harvest	Apparent K balance	Net K balance
	A	B	C	D	D-{(A+B)-C} =E	D-A=E
	($kg\ ha^{-1}$)					
I_1	46.8	75	89.12a	32.5d	-0.18	-14.3
I_2	46.8	75	69.40b	34.3c	-18.1	-12.5
I_3	46.8	75	37.94c	35.0c	-48.86	-11.8
I_4	46.8	75	35.97cd	38.4b	-47.43	-8.4
I_5	46.8	75	11.69d	42.6a	-67.51	-4.2
CV (%)	-	-	1.48	1.10		-

Sulfur uptake

Sulfur uptakes by black cumin under different soil moisture levels are presented in the Table 9. Significant difference in S uptake by black cumin have been recorded under different soil moisture regimes. Increased soil moisture led to increased S uptake by plant, which ultimately contributed growth and yield of black cumin. The maximum uptake of S (11.82 kg ha^{-1}) was observed under higher frequency of irrigation in I_1 treatment followed by I_2 (8.73 kg ha^{-1}), I_3 (5.92 kg ha^{-1}) and I_4 (3.71 kg ha^{-1}). The minimum uptake (0.65 kg ha^{-1}) of S was noted under water stress condition in T_5 treatment (irrigation at 50% field capacity closed to wilting point) might have led to the maximum S reserve in soil.

Residual soil S after harvest

Post-harvest S contents in soil varied significantly with the variation of irrigation levels (Table 9). The maximum value of residual S (15.1 kg ha^{-1}) was recorded in I_5 treatment (irrigation applied at 50% field capacity) followed by I_4 (14.3kg ha^{-1}), I_3 (13.0 kg ha^{-1}) and I_2 (11.9 kg ha^{-1}). The minimum value (11.3 kg ha^{-1}) being documented in treatment I_1 (irrigation at 90% field capacity). It can be inferred from the results that higher moisture availability led to higher S mining and exhaustion and ultimately led to minimum S reserves in soil.

Apparent S balance

The minimum negative apparent S (-2.99 kg ha^{-1}) was recorded in I_5 treatment (irrigation at 50% field capacity) followed by I_1 (-12.98 kg ha^{-1}), I_2 (-15.47kgha^{-1}) and I_3 (-17.18kgha^{-1}) and the maximum negative (-18.09 kgha^{-1}) value was recorded in I_4 treatment (irrigation at 60% field capacity).

Net S balance

Balance of S was reduced with increasing soil moisture level (Table 9). All irrigation treatments showed negative balance of S and in the order I_5 (0.5 kgha^{-1})> I_4 (-1.3kg ha^{-1}) >I_3 (-2.6kg ha^{-1}) >I_2 (-3.6 kg ha^{-1}). The maximum S depletion or net negative S balance (-4.3 kg ha^{-1}) was recorded at treatment I_1 (irrigation at 90% field capacity). It is clear that higher the soil moisture availability higher is the S mobility, translocation and maximum use of S by the crop.

Table 9. Effect of soil moisture levels on S balance sheet after harvest of black cumin

Soil moisture levels	Initial soil S status	Added S through fertilizer	S uptake	Residual soil S after harvest	Apparent S balance	Net S balance
	A	B	C	D	D-{(A+B)-C} =E	D-A=E
	(kg ha^{-1})					
I_1	15.6	20.5	11.82a	11.3d	-12.98	-4.3
I_2	15.6	20.5	8.73ab	11.9d	-15.47	-3.7
I_3	15.6	20.5	5.92b	13.0c	-17.18	-2.6
I_4	15.6	20.5	3.71b	14.3b	-18.09	-1.3
I_5	15.6	20.5	0.65c	15.1a	-2.99	-0.5
CV (%)	-	-	13.46	3.07	-	-

Table 10. Total amount of irrigation water, soil moisture contribution and effective rainfall during the cropping period of black cumin under different soil moisture levels

Soil moisture levels	Common irrigation for seedling establishment (mm)	No. of irrigation	Amount of imposed irrigation water (mm)	Total amount of irrigation (mm)	Soil moisture (mm)	Effective rainfall (mm)
I_1	22.4	11	90.7	113.1	3.7	1.53
I_2	22.4	08	85.7	108.1	4.6	1.53
I_3	22.4	06	81.8	104.2	5.7	1.53
I_4	22.4	04	77.0	99.4	6.8	1.53
I_5	22.4	-	-	22.4	7.3	1.53

Soil moisture contribution and effective rainfall

Data on soil moisture contribution and effective rainfall are given in Table 10. The minimum soil moisture contribution (3.7 mm) was recorded under higher frequency of irrigation in treatment I_1 (irrigation at 90% field capacity). The maximum value (7.3 mm) being noted in treatment I_5(irrigation at 50% field capacity). Most of the water demand of the crop in I_1 treatment (the highest irrigation level) has been fulfilled by the irrigation water that has led to minimum use or contribution of soil water, but the crop grown under the lowest moisture level in I_5 treatment has undergone water stress condition and led to the maximum exhaustion or use of soil moisture.

Consumptive use of water and water use efficiency

The total consumptive use of water and water use efficiency of the crop have been presented in Table 11. The highest consumptive use of water (118.33 mm) was marked under treatment I_1 followed by I_2 (114.23 mm), I_3 (111.43 mm), I_4 (107.73 mm) and the lowest value (31.23 mm) being noted in treatment I_5. In case of irrigation treatments, the maximum water use efficiency (21.94 and 10.51 kg ha^{-1} $mm^{-1}$for biomass and seed yield, respectively) was documented in treatment I_1 (irrigation at 90% field capacity) followed by I_2 (19.47 and 8.69 kg ha^{-1} $mm^{-1}$for biomass and seed yield, respectively), I_3 (17.37 and 6.59 kg ha^{-1} $mm^{-1}$for biomass and seed yield, respectively) and I_4 (14.67 and 5.23 kg $ha^{-1}mm^{-1}$for biomass and seed yield, respectively). It is important to note here that the treatment I_5 (irrigation at 50% field capacity, equivalent to wilting point) did not receive any irrigation at all. The total water use (from soil moisture contribution and rainfall) was only 31.23 mm that has led to attain the highest water use efficiency (23.28 k $gha^{-1}mm^{-1}$) on the basis of biomass yield of only 727.0 kg ha^{-1} (the lowest) as compared to the highest yield of 2595.0 $kgha^{-1}$ under the highest irrigation regime in I_1 treatment. But in case of seed yield of black cumin the highest water use efficiency (10.51 kg $ha^{-1}mm^{-1}$) was recorded under the highest irrigation frequency in I_1 treatment. Thus, considering the seed yield and water use efficiency of black cumin the treatment I_1 (irrigation at 90% field capacity) may be selected for cultivation of the crop in the studied area.

Table 11. Total consumptive use of water and water use efficiency of black cumin as affected by soil moisture levels

Soil moisture levels	Total consumptive use of water (mm)	Biomass yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Water use efficiency (kg ha^{-1} mm^{-1})	
				On the basis of biomass yield	On the basis of seed yield
I_1	118.23	2595.0	1243.0	21.94	10.51
I_2	114.23	2220.0	993.4	19.43	8.69
I_3	111.43	1936.0	734.0	17.37	6.59
I_4	107.73	1580.0	563.5	14.67	5.23
I_5	31.23	727.0	165.5	23.28	5.29

Cost-benefit analysis of irrigation forblack cumin

The results of cost-benefit analysis related with application of different soil moisture levels are presented in Table 12. Generally, the benefits of application of irrigation water exceed the non-irrigated treatment both in yield and return. The highest net income (123503 Tk) was recorded in I_1(Irrigation at 90% field capacity) followed by I_2 (86675 Tk) and the negative net income (-400747 Tk) in I_5 (Irrigation at 50% of field capacity). The highest marginal rate of returns (74.79%) was notedinI_4 (Irrigation at 60% field capacity) followed by44.82% inI_2treatment (Irrigation at 80% field capacity) (Table 13).

Table 12. Cost benefit analysis of black cumin as affected by soil moisture levels

Treatment	Variable cost (Tk)				Income (Tk)		Rank
	Input cost	Labor cost	Fixed cost	Total variable cost	Gross income	Net income	
	A	B	C	D=A +B+C	E	F= E-D	
I_1	37337	32900	30000	100237	223740	123503	1
T_2	31337	30800	30000	92137	178812	86675	2
T_3	27337	29400	30000	86737	132120	45383	3
T_4	23337	28000	30000	81337	101430	20093	4
T_5	15337	25200	30000	70537	29790	-40747	5

Table 13. Marginal rate of return (MRR) in black cumin cultivation as affected by soil moisture levels

Treatment	Variable cost (TK)	Net income (TK)	MRR (%)	Rank
I_5	70537	-40747	-	-
I_4	81337	20093	74.79	1
I_3	86737	45383	29.16	4
I_2	92137	86675	44.82	2
I_1	100237	123503	36.74	3

Conclusion

It may thus be concluded from the results of the present study studies that seed yield of black cumin increased with the increased soil moisture level. The highest seed yield potential (1243.0 kg ha^{-1}) with the highest water use efficiency (10.51 $kgha^{-1}mm^{-1}$) of the crop may be achieved in the Shallow Red-Brown Terrace Soil of Salna Series under the highest soil moisture regime (irrigation at 90% of field capacity). The total requirement of irrigation water was 113.1 mm which was applied through 11 irrigations. Nutrient mining or negative nutrient balance of N, P, K and S were observed in the study. So, for achieving equilibrium nutrient balance and maintaining sustainable increased soil productivity, proper management of soil fertility was recommended.

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