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EFFECT OF NITROGEN, PHOSPHORUS, POTASSIUM AND SULPHUR ON GROWTH, YIELD AND NUTRIENT BALANCE OF FENNEL

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Abstract

The experiment was conducted at Regional Spices Research Centre, BARI, Gazipur during two consecutive years, 2020-2021 and 2021-2022 to observe the response of fennel (var. BARI Mouri-2) to N, P, K and S for maximizing the yield and quality. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The treatments were each of four levels of N (0, 80, 130 and 180 kg ha^{-1}), P (0, 50, 70 and 90 kg ha^{-1}), K (0, 40, 80 and 120 kg ha^{-1}) and three levels of S (0, 20 and 30 kg ha^{-1}). The N, P, K and S showed significant effect on the yield and yield attributes of fennel. The highest seed yield (1.98 tha^{-1}) and the maximum harvest index (94.18%) of fennel were found in 130-70-80-30 kg NPKS ha^{-1}. The net N, P, K and S balance ranged from -150 to -62.0, 0.12 to 5.68, 29.97 to 0.51 and 4.24 to 0.27 kg ha^{-1}, respectively. The cost benefit analysis also indicate that the highest net income (Tk.180947.00) was estimated in 130-70-80-30 kg NPKS ha^{-1} of fennel cultivation. The response curve reveled that application of 145-62.5-77.5-22.86 kg NPKS ha^{-1} might be the recommended nutrient package for achieving higher seed production in in Grey Terrace Soil of Madhupur Tract (AEZ-28).

Keywords: Fennel, Seed yield, nutrient management, nutrient balance sheet, MRR.

Introduction

Fennel (*Foeniculum vulgare* Mill. or *F. officinale* All.) belongs to Apiaceae family originated in Mediterranean region, used as spices as medicine and perfumary for its remarkable medicinal and aromatic properties (Devi *et al*., 2022). The edible protion of the crop is leaves, stalks, seeds, oils and bulbs (produced some species). The fennel seeds are aromatic, stimulant and carminative which contain volatile and fixed oil (Shehata and Moubarak, 2020). It is cultivated over in the Faridpur, Sariatpur, Madaripur, Gopalgonj, Pabna, Sirajganj, Jessore, Kushtia, Bogura, Rangpur, Natore and Jamalpur districts as a secondary crop with few hundred hectares of land most of the cases as a bordar crops. The average productivity is less, so the efforts have made to enhance the productivity of the fennel by the agronomic and soil management. Lake of HYV & hybrid varieties with modern production technologies, appropriate fertilizer recommendations, water stress, disease & insect pest infestations, climate change, inadequate marketing facilities

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etc., are the major constraints in upscaling the production. Farmers use imbalanced fertilizers to cultivate hybrid/ HYV crops that leads to mining out of the inherent plant nutrients from the soil and thus, fertility status of the soil severly declined in Bangladesh. Macro and micro-nutrients are essential components for providing crop nutrients needs in satisfactory crop production and maintain crop quality (El-Seifi *et al.*, 2015). Nitrogen is the element that limits crop yields. Most of the N in plants is in organic form: nucleic acid, some vitamins, hormones, membrane component, coenzymes and pigment. P is an essential component of the energy transfer compounds (ATP and other nucleiproteins), the genetic information system, cell membranes and phospho-proteins. K is serving as an enzyme activator or cofactor for some enzymes. It also aids in the maintenance of osmotic potential and water uptake. Sulphur helps in the synthesis of amiono acids, enzymes, vitamins, proteins, oils and chlorophyll. Among the various levels of NPK @ 60-40-40 kg ha^{-1} exhibited significant maximum growth, yield & yield attributes, and quality of fennel (Kusuma *et al.*, 2019 and Waskela *et al.*, 2017). Fertilizer package for fennel production in Grey Terrace soil has not been reported yet. Therefore, this study was initiated keeping the above fact in view, (i) to develop a suitable fertilizer package for sustainable fennel production (ii) to make a nutrient balance sheet for proper soil management and (iii) to observe the cost and benefit of fennel cultivation.

Materials and methods

The study was conducted at the Regional Spices Research Centre, BARI, Gazipur during two consecutive years of 2020-2021 and 2021-2022. The experimental site was situated at $23^0 59^/$ North Latitude and $90^0 24^/$ East Longitude, at an altitude of 8.4 m above the mean sea level. The soil of the experimental site belongs to Chhiata Soil series and has been classified as Grey Terrace Soil, which falls under Inceptisol in Taxonomy under the AEZ-28 (Madhupur Tract) Brammer, 1971. The initial soil samples of the experimental field were analyzed following standard and recommended methods (Table 1). The experiment was laid out in a Randomized Complete Block Design (RCBD) having three replications. There were four levels of nitrogen (0, 80, 130 and 180 kg ha^{-1}), four levels of phosphorus (0, 50, 70 and 90 kg ha^{-1}), four levels of potassium (0, 40, 80 and 120 kg ha^{-1}) and three levels of sulphur (0, 20 and 30 kg ha^{-1}). The treatment combinations were: T_1= 180-70-80-30 kg NPKS ha^{-1}, T_2= 130-70-80-30 kg NPKS ha^{-1}, T_3= 80-70-80-30 kg NPKS ha^{-1}, T_4= 0-70-80-30 kg NPKS ha^{-1}, T_5= 130-0-80-30 kg NPKS ha^{-1}, T_6=130-50-80-30 kg NPKS ha^{-1}, T_7= 130-90-80-30 kg NPKS ha^{-1}, T_8= 130-70-0-30 kg NPKS ha^{-1}, T_9= 130-70-40-30 kg NPKS ha^{-1}, T_{10}= 130-70-120-30 kg NPKS ha^{-1}, T_{11}= 130-70-80-0 kg NPKS ha^{-1}, T_{12}= 130-70-80-20 kg NPKS ha^{-1}. The cowdung used in the experimental soil contained 0.98% N, 0.21% P, 0.61% K, 0.123% S, 0.49% Ca and 0.28% Mg on dry basis. The whole amount of cowdung (5 t ha^{-1}), TSP, MoP, gypsum, zinc sulphate (5 kg ha^{-1}) and boric acid (6 kg ha^{-1}) was applied as basal and 1/3rd urea was applied in three equals at 5th, 9th and 11th week after sowing. The

seeds of fennel var. BARI Mouri-2 were sown on 17 November both the years in 3 m x 3 m plot at line-to-line distance 30 cm. Seeds were soaked in water for 24 hours to facilitate germination, then the seeds were dried and treated with Autoistin (carbendazim) @ 2g kg^{-1} seeds to minimize the primary seed-borne disease. The seeds were mixed with some loose soil to allow uniform sowing in rows with a seed rate of 10 kg ha^{-1} at a depth of about one cm. The seeds were covered with loose soil properly just after sowing and gently pressed by hands with slight watering to enhance proper germination. Continuous sowing was done during sowing time but maintained plant to plant distance of 10 cm by thinning at 25 DAS. Intercultural operations such as four irrigations, three weeding and three times spray of Autoistin @ 2g l^{-1} of water for controlling damping off disease was done during the whole cropping period. The crops were harvested on 11-20 May both the years. Ten plants were selected randomly from each plot for counting some growth and yield parameters. For computing nutrient uptake at 60 DAS plants in every plot were cut at the bottom, chopped with a sharf knife, air dried for 3 days then oven dried for 72 hours at 65^0C followed by grinding the oven-dry samples by an electric grinding machine.Ten matured selected fennel plants from each plot were cut at the colar region, air-dried in the laboratory and finally oven-dried for 72 hours at 65^0C to estimate dry matter production. The dry matter was calculated by the following formula:

$$DM = [\{(DY /10) X NP\} X 10000)]/1000$$

Where, DM = Dry matter (kg ha^{-1})

DY = Total dry matter yield of 10 plants per plot (g)

NP = Total number of plants per m^2

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 (Singh *et al.*, 2017):

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 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 (AVRDC, 1990):

HI = EY / BY x 100

Where,

HI = Harvest index (%)

EY = Seed yield (kg)

BY = Biological yield (kg)

The analysis of variance of crop characters and nutrient uptake of the plant samples were done following the ANOVA test and the mean values were adjusted by LSD (Least Significant Difference) test at 5% level. R software (version 3.5.0) was used to analyse the data.

Table 1. Observed soil physical and chemical properties of the experimental site

Soil Chemical Properties	Analytical value	Analytical method
Textural class	Clay loam	Hydrometer method (Bouyoucos, 1962)
Bulk density (g cm^{-3})	1.39	Core sampling method (Blake, 1965b)
Particle density (g cm^{-3})	2.69	Pycnometer method (Blake, 1965a)
Soil pH	6.2	Soil: water=1:2.5 (Jackson, 1962)
Organic carbon (%)	0.89	Wet oxidation method (Walkley and Black, 1934)
Total N (%)	0.08	Micro Kjeldhal Method (Black, 1965)
Available P (ppm)	7.77	Bray and Kurtz method (Bray and Kurtz, 1945)
Exchangeable K (meq 100 g^{-1} soil)	0.08	N NH_4OAc Extraction method (Jackson, 1962)
Available S (ppm)	6.84	Calcium dihydrogen phosphate extraction method (Hesse, 1971)
Available B (ppm)	0.19	Calcium chloride extraction method (Christian and Feldman, 1970)
Available Zn (ppm)	0.58	DTPA Extraction method (Christian and Feldman, 1970)
Available Cu (ppm)	0.16	DTPA Extraction method (Christian and Feldman, 1970)
Available Mn (ppm)	0.72	DTPA Extraction method (Christian and Feldman, 1970)
CEC (meq 100 g^{-1} soil)	7.9	N NH_4OAc Extraction method (Yoshida et al., 1972)

Results and Discussion

Yield attributes/ plant parameters

The yield attributes of fennel were significantly variable among the treatments (Table 2). The plant received the maximum days (116 days) to 50% flowring in T_2 (130-70-80-30 kg NPKS ha^{-1}) followed by T_1 (180-70-80-30 kg NPKS ha^{-1}) and T_7 (130-90-80-30 kg NPKS ha^{-1}). T_4 (70-80-30 kg PKS ha^{-1}) showed the minimum period (91.8 days) to reach 50% flowering. Treatment T_2 supplied optimum nutrients (both chemical and organic sources) attained better and prolonged growth and development subjected to delayed maturity. On the other hand, plant receiving inadequate of N, leads to early flower initiation in the plants in T_4. Similar result was reported by Ayub *et al.* (2011). The maximum plant height (153.8 cm) was found in T_2 (130-70-80-30 kg NPKS ha^{-1}) which was stastically identical to T_1 and the lowest plant height (113.8 cm) in T_4. This might be due to better availability of the nutrients to the plants. Application of N, P, K and S fertilizers enhanced the availability of nutrient elements which resulted in increased photosynthetic activities and translocation of photosynthates from source to sink then increased plant height. The results confirm the findings of Shehata and Moubarak (2020) and Godara *et al.* (2014). The maximum number of branches per plant (11.0) was recorded in T_2while minimum (4.7) in T_4. It may be due to application of N, P, K and S fertilizers maintained the soil fertility and enhance the phytohormones helps rapid multification of cells and celluatr elongation resulting in better growth of branches in plants. These results are in harmony with those obtained by Shehata and Moubarak (2020) and Moradi *et al.* (2011).

The number of umbels per plant was significantly influenced by the treatments (Table 3). The maximum number of umbels per plant (33.5) was found in T_2, while the minimum 12.0) in T_4. It is observed that the number of umbellets per plant directly influenced the number of capsules per plant. This was probably due to adequate nutrient uptake by plant in T_2 treatment resulting production of more branches as well as a greater number of umbels per plant. The present results are in agreement with the findings of Shehata and Moubarak (2020), Valiki *et al.* (2015) and Tuncturk *et al*. (2011). The highest number of umbellets (24.5) per umbel was recorded in T_2 and the lowest value (13.7) in T_4. Total number of umbellets per plant appeared to be the most important component since it is closely related with seed yield. Increase in number of umbellets per umbel indicated production of a greater number of seed per umbel, higher percentage of seed set and reduced shedding of seeds which resulted in increased yield (Koyani *et al.*, 2014). The maximum number of seeds per plant (202.8) was recorded in T_2 and the minimum number (112.2) in T_4. It may be due to application of N, P, K and S improved soil fertility in soil and supply nutrient elements to plant. Similar result was repported by Kusuma *et al*. (2019) and Kucha *et al.* (2018). The highest 1000-seed weight (6.17 g) was recorded in T_2 and the lowest seed weight (4.4 g) in T_4 (Table 4). The applied NPKS have facilitated the availabilty of balanced amount

Table 2. Effects of N, P, K and S on different growth parameters of fennel

Treatment	Days to 50% flowering			Plant height (cm)			Number branch per plant		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T_1	114a	115ab	114ab	153.7a	143.7ab	148.7ab	6.7ab	10.9b	8.8b
T_2	115a	118a	116a	158.7a	149.0a	153.8a	7.7a	14.3a	11.0a
T_3	110ab	114abc	112.2ab	149.7a	143.3ab	146.5b	5.7bcd	9.0cd	7.3cd
T_4	94e	90f	91.8e	110.0c	117.7e	113.8d	4.3d	5.0g	4.7g
T_5	99de	97e	97.8d	125.0b	124.0de	124.5c	4.7d	6.0fg	5.3fg
T_6	112a	113a-d	112.2ab	148.0a	138.5bc	143.3b	5.7bcd	9.0cd	7.3cd
T_7	113a	115ab	114.2ab	147.0a	140.6b	143.8b	5.7bcd	8.0de	6.8de
T_8	103cd	109cd	105.8c	129.0b	131.0cd	130.0c	5.0cd	7.0ef	6.0ef
T_9	118a	115ab	113.5ab	151.0a	142.0ab	146.5b	6.3abc	9.3c	7.8c
T_{10}	112a	114abc	113.3ab	147.7a	139.2b	143.5b	5.0cd	8.7cd	6.8de
T_{11}	105bc	107d	106.0c	126.7b	122.0e	124.3c	5.0cd	6.7f	5.8f
T_{12}	110ab	111bcd	110.8b	148.3a	140.8b	144.6b	5.3bcd	9.4c	7.4cd
CV (%)	3.02	3.11	3.07	5.17	3.46	4.43	15.15	7.29	10.66

Treatment means followed by the same letter(s) do not differ significantly at 5% level of probability by LSD test.

Table 3. Effects of N, P, K and S on different yield contributing parameters of fennel

Treatment	No. of umbels per plant			No. of umbellets per umbel			No. of seeds per plant		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T_1	25.0b	31.3b	28.2b	13.3b	25.9ab	19.6a	218.7bc	140.6a	179.7abc
T_2	31.0a	36.0a	33.5a	18.7a	30.3a	24.5a	261.3a	144.3a	202.8a
T_3	23.3b	31.9b	27.6b	14.3b	22.4bc	18.4b	255.7ab	131.4ab	193.7ab
T_4	15.0d	9.0h	12.0f	8.0d	19.4c	13.7cd	118.7d	105.7c	112.2h
T_5	17.0cd	10.7gh	13.8ef	11.7bc	22.8bc	17.2bcd	124.0d	112.3bc	118.7gh
T_6	21.0bc	27.3cd	24.2cd	12.3bc	24.9b	18.6b	197.3c	130.2ab	163.8cde
T_7	22.0b	22.9e	22.5d	13.0bc	24.0bc	18.5b	190.7c	126.8abc	158.7cde
T_8	17.0cd	12.7gh	14.8e	10.3cd	22.7bc	16.5bcd	139.7d	133.4ab	136.5fg
T_9	25.0b	27.8c	26.4bc	12.0bc	23.7bc	17.8bc	208.0c	142.3a	175.2bcd
T_{10}	25.0b	29.8bc	27.4b	11.7bc	23.6bc	17.7bc	205.3c	145.1a	175.2bcd
T_{11}	16.7d	15.0f	15.8e	10.3cd	23.0bc	16.7bcd	143.7d	145.9a	144.8de
T_{12}	23.0b	24.0de	23.5d	13.0bc	23.1bc	18.1b	208.0c	132.1ab	170.1cd
CV (%)	11.71	8.81	10.27	12.85	11.90	12.7	2.07	10.39	12.05

Treatment means followed by the same letter(s) do not differ significantly at 5% level of probability by LSD test.

of essential nutrients throughout the whole plant growing season resulting better nourishment of plants and the formation of bold seeds ultimate increased the seed weight. These results are in agreement with the results observed by Kusuma *et al*. (2019) and Koyani *et al.* (2014).

Biomass and Seed yield

The biomass and seed yield of fennel were significantly influenced by the nutrient management (Table 4). The maximum biomass yield (4758.7 kg ha^{-1}) was found in T_2 (130-70-80-30 kg NPKS ha^{-1}), which was stastically similar to T_1 and T_9. The minimum biomass yield (2689.0 kg ha^{-1}) was noted in T4 (70-80-30 kg PKS ha^{-1}). The increament of biomass production might be attained to optium vegetative growth and production of more fresh weight of fennel crops. The maximum seed yield (1.98 t ha^{-1}) was found in T_2, which was followed by T_1 and T_9. The lowest seed yield (0.79 t ha^{-1}) was observed in T_4. The increased level of NPKS in plant due to increased availability in the soil medium and there after eficient absorption and translocation in various growths by way of active cell division and elongation resulting in higher plant height, number of primary and secondary branches. The growth and development of crops might be inluenced by NPKS elements have expressed larger canopy and considering higher chlorophyll content in leaves favored, cell elongation, photosynthates, metabololites and pro-active to reproductive phase which produe higher yield of crops. The indings of this investigation were in close conformity with those of Shehata and Moubarak (2020) and Waskela *et al*. (2017).

Days to maturity

Maturity at harvest is an important crop stage which can influence the quality of seeds. The seed vigority and longevity grdually increase from physiological maturity phase to late maturation phase (Sripthy and Groot, 2023). Matuity date of fennel was significantly influenced by the nutrient management (Table 5). The maximum maturation date (162 DAS) was required in T_2 (130-70-80-30 kg NPKS ha^{-1}) followed by T_1 and T_9. The minimum maturity date (145 DAS) was noted in T_4. This could be associated with the combined effect of NPKS with higher rates in extending the vegetative growth period of plants while delaying maturity. These results are agreed with the results noted by Godar *et al.*, 2014.

Harvest index

The harvest index was influenced by the NPKS treatments (Table 5). The maximum harvest index (41.61 %) was observed in T_2, followed by T_1 and T_9. The minimum harvest index (29.38 %) was noted in T_4. Maintaining optimum nutiernt availability resulted in better vegetative and reproductive growth and contributed to good harvest index of crops. Harvest index governed by several factors such as variety, growing condition, environmental factors, irrigation management and agronomic management. These results have also been opined by Kusuma *et al.* (2019).

Table 4. Effects of N, P, K and S on the yield components of fennel

Treatment	1000-seed weight (g)			Seed yield (tha^{-1})			Biomass yield ($kgha^{-1}$)		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T_1	5.3ab	6.0a	5.65ab	1.91a	1.83a	1.87ab	4646.7a	4609.3a	4628.0ab
T_2	5.7a	6.7a	6.17a	1.99a	1.98a	1.98a	4753.7a	4763.7a	4758.7a
T_3	5.4ab	6.0a	5.70ab	1.65b	1.77ab	1.71bcd	4281.0bcd	4554.0a	4417.5bc
T_4	4.5c	4.3b	4.40c	0.85d	0.73e	0.79f	2951.7g	2426.3c	2689.0e
T_5	5.0abc	4.3b	4.67c	0.98d	0.88e	0.93f	3294.3f	2554.0c	2924.2e
T_6	5.1abc	5.7a	5.37b	1.64b	1.71ab	1.67cd	4317.0bc	4519.3a	4418.2bc
T_7	5.1abc	6.3a	5.73ab	1.65a	1.61bc	1.63cd	4372.0b	4406.7a	4389.3bc
T_8	4.5c	4.3b	4.40c	1.32c	1.34cd	1.33e	4079.7de	3750.0b	3914.8d
T_9	4.9abc	6.3a	5.63ab	1.65b	1.97a	1.81abc	4402.3b	4754.7a	4578.5abc
T_{10}	4.8bc	6.7a	5.72ab	1.52bc	1.70ab	1.61d	4116.3cde	4563.7a	4340.0c
T_{11}	4.9abc	4.3b	4.65c	1.30c	1.28d	1.29e	4034.7e	3707.3b	3871.0d
T_{12}	4.8bc	6.0a	5.42b	1.52bc	1.77ab	1.65cd	4258.7bcd	4551.7a	4405.2bc
CV (%)	9.27	10.69	10.1	9.98	10.62	10.32	2.89	6.68	5.13

Treatment means followed by the same letter(s) do not differ significantly at 5% level of probability by LSD test.

Table 5. Effects of N, P, K and S on the yield and yield components of fennel

Treatment	Days to maturity			Harvest index (%)		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T_1	158abc	159ab	158ab	41.1	39.7	40.41
T_2	162a	161a	162a	41.86	41.56	41.61
T_3	155b-e	157abc	156bc	38.54	38.87	38.71
T_4	147g	144e	145d	28.79	30.09	29.38
T_5	149fg	146e	148d	29.75	34.46	31.8
T_6	156bcd	152c	154c	37.99	37.84	37.79
T_7	157abc	152c	155bc	37.74	36.53	37.13
T_8	1501d-g	144e	147d	32.36	35.73	33.97
T_9	160a	157abc	158ab	37.48	41.43	39.53
T_{10}	159ab	155bc	157bc	36.93	37.25	37.09
T_{11}	150efg	147de	148d	32.22	34.53	33.32
T_{12}	153c-f	154bc	154c	35.69	38.89	37.46
CV (%)	2.24	2.11	2.18	-	-	-

Treatment means followed by the same letter(s) do not differ significantly at 5% level of probability by LSD test.

Response of fennel to N, P, K and S

Fennel responsed significantly to added N, P, K and S. Howerver, from regression analysis, a quadratic response of fennel to N, P, K and S (R^2 =0.999, 0.9257, 1.3395 and 1, respectively) was recorded (Table 6). The seed yield increased upto 130, 70, 80 and 20 kg NPKS ha^{-1} and there after yield declined due tofurther application of higher dose. From the quadratic response function, the optimum dose of N, P, K and S for fennel cultivation estimated to be (145, 62.5, 77.5 and 22.86 kg ha^{-1}, respectively) and the maximum seed yield expected to be (1.99, 1.71, 1.94 and 1.65 t ha^{-1} for N, P, K and S respectively). Up to the optimum level (8.7, 12.5, 7.75 and 16 kg ha^{-1} for N, P, K and S) increased seed yield may be obtained for 1 kg NPKS application (use efficiency). Beyond optimum level reduction of seed yield (0.06, 0.2, 0.01 and 0.7 kg ha^{-1}) may be obtained for 1 kg NPKS (yield reduction).

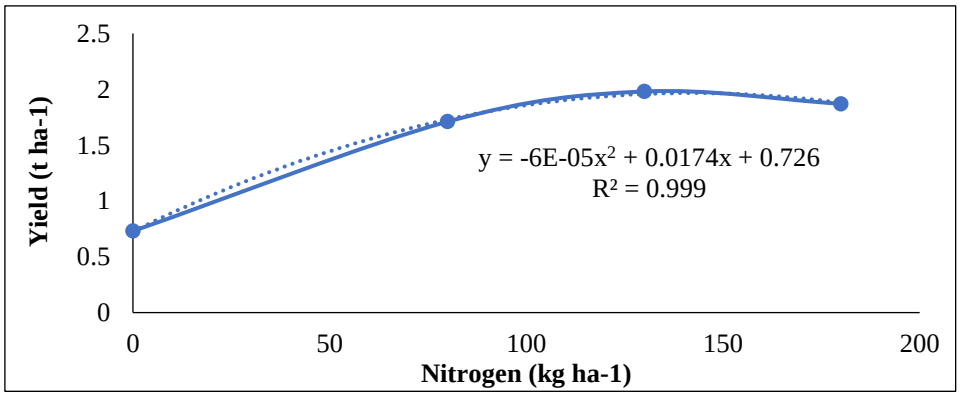

Fig. 1a. Relationship between seed yield and application of nitrogen on fennel.

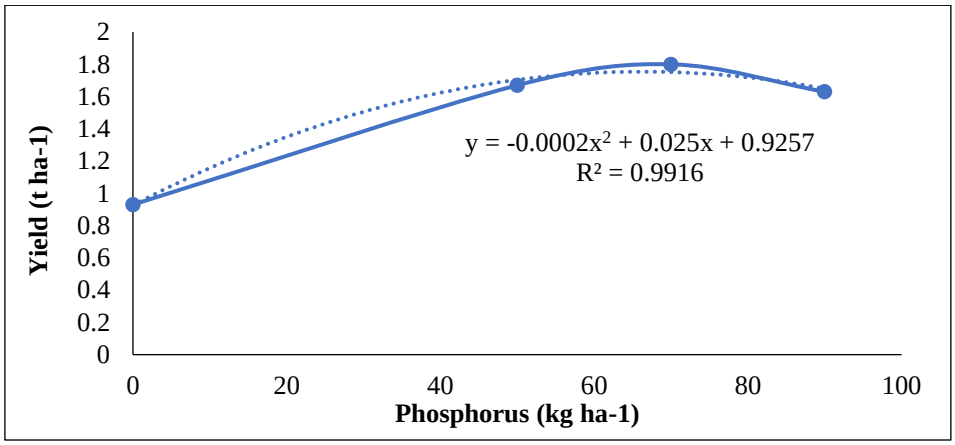

Fig. 1b. Relationship between seed yield and application of Phosphorus on fennel.

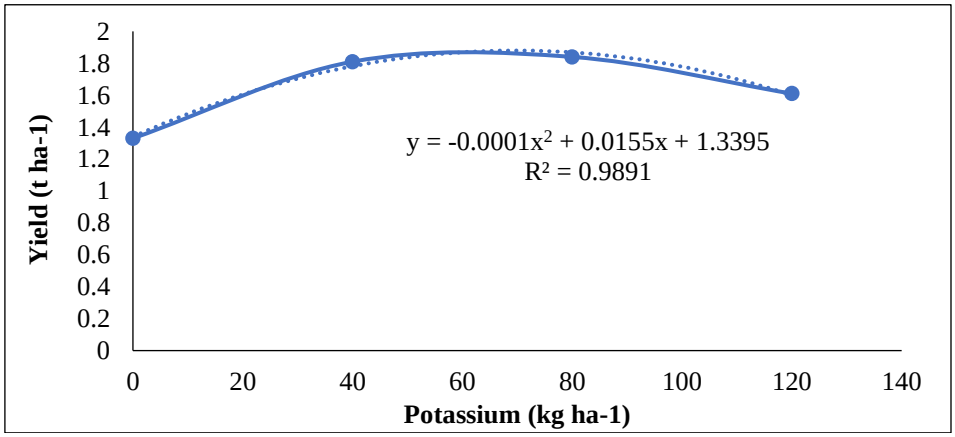

Fig. 1c. Relationship between seed yield and application of Potassium on fennel.

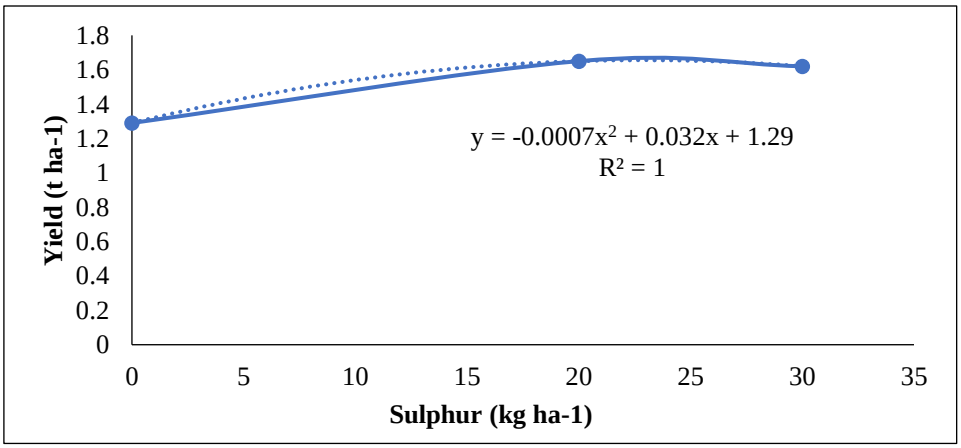

Fig. 1c. Relationship between seed yield and application of Sulphur on fennel.

Table 6. Response function of fennel to N, P, K and S for seed yield

Response function	Nitrogen	Phosphorus	Potassium	Sulphur
Regression equation	$Y = -6E\text{-}05N^2 + 0.0174N + 0.726$	$Y = -0.0002P^2 + 0.025P + 0.9257$	$Y = -0.0001K^2 + 0.0155K + 1.3395$	$Y = -0.0007S^2 + 0.032S + 1.29$
R^2	0.999	0.9916	0.9891	1
Optimum rate of Nutrient (kg ha^{-1})	145	62.5	77.5	22.86
Maximum seed yield (tha^{-1}) for optimum nutrient level	1.99	1.71	1.94	1.65
Production of seed (kg) for 1 kg Nutrient (use efficiency)	8.7	12.5	7.75	16
Beyond optimum level the reduction of seed (kg) for each 1 kg Nutrient	0.06	0.2	0.01	0.7
Optimum economic rate of Nutrient (kg ha^{-1})	144.99	62.49	77.5	22.87

Uptake of N, P, K and S

N, P, K and S uptake by the fennel were influencedby the treatments (Table 7-10). The maximum uptake of N, P, K and S (72.35, 15.35, 36.18 and 9.04 kg ha^{-1}, respectively) was found in T_2. The minimum uptake of N, K, S (33.89, 12.11 and 2.96 kg ha^{-1}, respectively) were recorded in T_4 and P (5.11 kg ha^{-1}) in T_5. Maintenance of optimum levels of N, P, K and S in soil had led to favoured in better plant growth and higher transpiration rate, thus the movement of nutrients was also higher. These findings are in agreement with reported by Kucha *et al*., 2018.

Residual soil N, P, K and S after crop harvest

The data presented in Table 7-10 reveled that application of N, P, K and S influenced the residual N, P, K and S fertility status of soil under fennel cultivation. The maximum residual N (1698 kg ha^{-1}), P (21.22 kg ha^{-1}), K (61.89 kg ha^{-1}) and S (13.21 kg ha^{-1}) were recorded in T_1, T_2, T_{10} and T_5, respectively. The minimum residual N (1610 kg ha^{-1}), P (15.66 kg ha^{-1}), K (32.43 kg ha^{-1}) and S (9.44 kg ha^{-1}) were recorded in T_4, T_5, T_8 and T_9, respectively. It can be inferred from the results that higher nutrient availability leds to higher N, P, K and S mining and ultimately resulted in less N, P, K and S reserves in soil.

Apparent N, P, K and S balance

Apparent N, P, K and S balance of fennel were influenced by the application of N, P, K and S fertilizers (Table 7-10). The apparent NPKS balance ranged from (-204.87 to -95.47, -72.64 to 5.67, -87.53 to 12.38 and -27.43 to -1.15 kg ha^{-1} for N, P, K and S, respectively). The maximum apparent balance of N (-95.47 kg ha^{-1}), P (5.67 kg ha^{-1}), K (-12.38 kg ha^{-1}) and S (-1.15 kg ha^{-1}) were recorded in T_2, T_5, T_8 and $T_{11,}$ respectively. The minimum apparent balance of N (-204.87 kg ha^{-1}), P (-72.64 kg ha^{-1}), K (-87.53 kg ha^{-1}) and S (-27.43 kg ha^{-1}) were noted in T_8, T_7, T_{10} and T_4, respectively. The apparent negative N, P, K and S balance of soil indicate that soil is unable to supply sufficient N, P, K and S for proper growth and development of crops. The findings of Singh *et al*. (2017) also confirm these results.

Net N, P, K and S balance

Nutrient balance might be termed as nutrient budget or nutrient audit in cultivated land to maintain higher soil productivity in the future. Positive balance indicated the nutrient accumulation and negative balance shows nutrient depletion. To achieve nutrient sustainability, the quantity of nutrient inputs and outputs should be equal. Negative nutrient balance may eventually cause soil degradation and adversely affect crop production. On the other hand, excess nutrient accumulation may lead to soil, water and air pollution. The net N, P, K and S balance are presented (Table 7-10). The net NPKS balance ranged from (-150.0 to -62.0, 0.12 to 5.68, -29.97 to -0.51 and -4.24 to -0.27 kg ha^{-1}, respectively. The maximum net balance of N (-62 kg ha^{-1}), P (5.68 kg ha^{-1}), K (-0.51 kg ha^{-1}) and S

(-0.22 kg ha^{-1}) were recorded in T_1, T_4, T_{10} and T_5, respectively. The minimum net balance of N (-150 kg ha^{-1}), P (0.12 kg ha^{-1}), K (-29.97 kg ha^{-1}) and S (-4.24 kg ha^{-1}) were obtained in T_4, T_5, T_8 and T_{11}, respectively. It may be due to higher availability of nutrients in root zone and enhanced bio-chemical activities of fennel plants.

Table 7. Effect of N, P, K and S on N balance sheet of fennel

Treatment	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})					
T_1	1760	180	69.76	1698	-172.24	-62
T_2	1760	130	72.35	1620	-197.65	-140
T_3	1760	80	64.53	1680	-95.47	-80
T_4	1760	0	33.89	1610	-116.11	-150
T_5	1760	130	38.25	1688	-163.75	-72
T_6	1760	130	66.30	1660	-163.7	-100
T_7	1760	130	64.09	1685	-140.91	-75
T_8	1760	130	55.13	1630	-204.87	-130
T_9	1760	130	70.39	1675	-144.61	-85
T_{10}	1760	130	64.23	1688	-137.77	-72
T_{11}	1760	130	55.34	1670	-164.66	-90
T_{12}	1760	130	65.71	1629	-195.29	-132

Table 8. Effect of N, P, K and S on P balance sheet of fennel

Treatment	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= F
	(kg ha^{-1})					
T_1	15.54	70	15.28	16.98	-53.28	1.44
T_2	15.54	70	15.35	16.22	-54.93	0.68
T_3	15.54	70	12.38	19.57	-53.59	4.03
T_4	15.54	70	5.11	21.22	-59.21	5.68
T_5	15.54	0	5.55	15.66	5.67	0.12
T_6	15.54	50	12.82	15.98	-36.74	0.44
T_7	15.54	90	12.73	20.17	-72.64	4.63
T_8	15.54	70	9.78	18.24	-57.52	2.7
T_9	15.54	70	15.11	16.68	-53.75	1.14
T_{10}	15.54	70	13.45	17.02	-55.07	1.48
T_{11}	15.54	70	9.68	19.05	-56.81	3.51
T_{12}	15.54	70	12.35	17.56	-55.63	2.02

Table 9. Effect of N, P, K and S on K balance sheet of fennel

Treatment	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= F
	(kg ha^{-1})					
T_1	62.4	80	33.34	42.49	-66.57	-19.91
T_2	62.4	80	36.18	41.85	-64.37	-20.55
T_3	62.4	80	31.82	45.5	-65.08	-16.9
T_4	62.4	80	12.11	60.68	-69.61	-1.72
T_5	62.4	80	13.72	58.22	-70.46	-4.18
T_6	62.4	80	31.82	48.92	-61.66	-13.48
T_7	62.4	80	32.99	47.22	-62.19	-15.18
T_8	62.4	0	17.59	32.43	-12.38	-29.97
T_9	62.4	40	35.27	45.23	-21.9	-17.17
T_{10}	62.4	120	32.98	61.89	-87.53	-0.51
T_{11}	62.4	80	19.66	59.47	-63.27	-2.93
T_{12}	62.4	80	30.43	47.96	-64.01	-14.44

Table 10. Effect of N, P, K and S on S balance sheet of fennel

Treatment	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= F
	(kg ha^{-1})					
T_1	13.68	30	8.79	11.69	-23.2	-1.99
T_2	13.68	30	9.04	12.48	-22.16	-1.02
T_3	13.68	30	6.19	12.69	-24.8	-0.99
T_4	13.68	30	2.96	13.29	-27.43	-0.39
T_5	13.68	30	3.79	13.41	-26.48	-0.27
T_6	13.68	30	7.07	12.99	-23.62	-0.69
T_7	13.68	30	6.59	12.91	-24.18	-0.77
T_8	13.68	30	5.48	12.98	-25.22	-0.7
T_9	13.68	30	8.7	12.75	-22.23	-0.93
T_{10}	13.68	30	8.25	12.01	-23.42	-1.67
T_{11}	13.68	0	3.09	9.44	-1.15	-4.24
T_{12}	13.68	20	7.94	10.41	-15.33	-3.27

Cost-benefit analysis of NPKS Fertilizer for fennel

The results of cost-benefit analysis related with application of different rates of NPKS fertilizer are presented in Table 10-11. Generally, the benefits of NPKS fertilizer application exceed the farmer`s traditional practice both in yield and

return. The highest gross margin (Tk 267300 ha^{-1}) was found in T_2 (130-70-40-30 kg NPKS ha^{-1}) while its variable cost was Tk. 86353 ha^{-1}. The purpose of marginal analysis is to reveal how the net benefit increases as the amount of investment increases (Perrin *et al.*, 1979). The marginal rate of returns (3060%) was also recorded in the same treatment (T_2) followed by T_9 (441%). The finding is in close conformity with reported of Koyani *et al.* (2014).

Table 10. Cost benefit analysis of fennel as influenced by NPKS fertilizers

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	
T_1	18434	29250	41755	89439	252450	163011	2CD
T_2	16698	27900	41755	86353	267300	180947	1CUD
T_3	14962	27000	41755	83717	230850	147133	5CD
T_4	12185	26550	41755	80490	106650	26160	12CD
T_5	8998	27450	41755	78203	125550	47347	11CD
T_6	14498	27000	41755	83253	225450	142197	6CD
T_7	18898	29700	41755	90353	220050	129697	8CD
T_8	14298	26550	41755	82603	179550	96947	9CD
T_9	15498	28350	41755	85603	244350	158747	3CUD
T_{10}	17898	28800	41755	66203	217350	151147	4CUD
T_{11}	14613	27450	41755	83818	174150	90332	10CD
T_{12}	16003	27450	41755	85208	222750	137542	7Cd

Unit price: Urea=16 Tk.kg^{-1}, TSP=22 Tk.kg^{-1}, MoP=15 Tk.kg^{-1}, Gypsum=12.5 Tk.kg^{-1}, Cowdung= 1.5 Tk.kg^{-1}, Boric acid= 150 Tk.kg^{-1}, Zinc sulphate=180 Tk.kg^{-1}, irrigation cost =3175 Tk.ha^{-1}, land rent=20000 Tk.ha^{-1}, tractor cost=4500Tk.ha^{-1}, seed cost=180 Tk.kg^{-1}, seed sale price= 135 Tk.kg^{-1} (2021-22), respectively, labor=450 Tk.$day^{-1}person^{-1}$ and marketing cost= 2500 Tk. (2021-22).

Table 11. Marginal analysis of cost undominated treatment of NPKS fertilizers on yield of fennel

Treatment	Gross margin (Tk. ha^{-1})	Variable cost (Tk. ha^{-1})	Marginal increase in gross margin (Tk. ha^{-1})	Marginal increase in variable cost (Tk. ha^{-1})	Marginal rate of return (%)
T_2	267300	86353	22950	750	3060
T_9	244350	85603	27000	19400	441
T_{10}	217350	66203	-	-	-

Conclusion

It may be conculated from the results of the present investigation that seed yield of fennel increased with the application of NPKS. The highest seed yield of 1.98 tha^{-1} and the highest net income (Tk. 180947.00) and the maximum marginal rate of returns (3060%) for fennel cultivation were achieved by maintaining 130-70-80-30 kg NPKS ha^{-1}. The net balance of N, P, K and S by fennel crop was highly favoured by the application of N, P, K and S fertilizers. The net nutrient balance of N, K and S showed negative balance but P was positive. The response curve showed, 145-62.5-77.5-22.86 kg NPKS ha^{-1} might be the best nutrient management package for fennel cultivation in Grey Terrace Soil of Madhupur Tract (AEZ-28).

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