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Effect of Applying Integrated Mineral and Organic Fertilizers on Seed Yield, Yield Components and Seed Oil Content of Black Cumin in Central Highlands of Ethiopia

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ABSTRACT

Black cumin (*Nigella sativa* L.) is an important spice crop in Ethiopia. However, the yield of the crop is low due to low soil fertility and poor soil fertility management practices. Here, a field research was conducted to evaluate the effects of applying mineral and organic fertilizers on seed yield and oil content of black cumin. The treatment consisted of three rates of combined nitrogen and phosphorus (NP) fertilizer (20/15, 40/30, 60/45 kg N/P_2O_5 ha^{-1}), three rates of blended mineral nitrogen, phosphorus, sulfur and boron (NPSB) fertilizers (0, 50 and 100 kg NPSB ha–1), and three rates of vermicompost (VC) (0, 3 and 6 t ha^{-1}). The experiment was laid out as a randomized complete block design in a factorial arrangement with three replications. The results showed that the interaction of mineral fertilizers and VC significantly ($P < 0.05$) influenced seed yield and seed oil content. Increasing rates of the three fertilizers increased seed yield, but reduced the seed oil content. We concluded that applying 60/45 kg N/P_2O_5, 100 kg NPSB, and 3 t ha^{-1} of VC resulted in optimum seed yield (2.1 t ha^{-1}), which is twice as much as the average yield of the crop in the country. However, the highest seed oil content (39.70%) was recorded at the rates of minimum N/P_2O_5 and zero rates of both NPSB and VC. This implies that integrated application of mineral and organic fertilizers can double productivity of the crop and improve farmers' income in the study area.

Introduction

Black cumin is an annual, herbaceous, flowering plant that belongs to the family Ranunculaceae (buttercup). The leaves of the black cumin plant are paired; where the lower leaves are short, the upper leaves are long (Malhotra, 2012). Generally, leaves are 2.5–3.0 cm long, cut into lanceolate segments, and reach about a hundred in number. The number of branches per plant varies from 7–16. The number of capsules per plant varies from 13–45, and each pod or capsule contains about 50–130 seed numbers (Datta, 2014).

Black cumin (*Nigella sativa* L) is grown in various agro-ecological zones with the best yield and growth performance in cooler and dry regions. Temperature variations (5–26 0C) occur, but the optimum range is 12–140C for good growth and yield performance of the crop (Weiss, 2002). In general, black cumin performs very well in the highlands of Ethiopia with an average altitude ranging between 1500–2300 m above sea level and an annual rainfall of 400–500 mm, with observed reductions in yield as altitude increases (Girma et al., 2015; Kifelew et al., 2017). In Ethiopia, black cumin is a widely cultivated seed spice that grows from mid-altitude to highland agro-ecological zones. The regions in Ethiopia

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that widely produce black cumin are Oromia, Amhara, Gambella, and the Southern Nations and Nationalities. All of these regions are producing black cumin in their mid-altitude to highland agro-climatic zones (Teshome and Anshiso, 2019). The crop is susceptible to frost and the occurrence of frost at any growth stage may result in a yield reduction to a total yield loss (Kifelew et al., 2017). That is why it is cultivated in the cooler regions of the country, where the incidence of frost occurrences is rare.

The economic parts of the crop seeds are important criteria for seasoning and give a pleasant aroma, and taste to foods like bread and pickles (Thippeswamy and Naidu, 2005). The seeds of black cumin accumulate 30–45% seed oil. The seed oil of black cumin is used as a raw material in the healthcare and food industries for different purposes, including medicine, soap production, body lotion, and perfume production (Kara et al., 2015). The Ethiopian varieties of black cumin are rich in fixed seed oil and accumulate up to 50% thymol, a monocyclic phenolic compound (Adam et al., 2007). This is an important compound found in the crop which has a pleasant smell and strong antibacterial properties (Adam et al., 2007). This strong antibacterial property of the crop makes black cumin an important raw material for traditional and modern medicine to cure different diseases (Zaoui et al., 2000; Black et al., 2005). The extracted fixed oil of black cumin also contains 0.27–1.3% essential (volatile) oil (Ozel et al., 2009).

In Ethiopia, black cumin is an important cash earner for smallholder farmers in the local as well as international markets. The crop is used locally as a flavoring for food, as a medicine, and as a commercial source of foreign exchange in the country. Ethiopian black cumin is often exported to Sudan, Saudi Arabia, and other Arab countries, which account for more than 98% of the nation's exports of the crop (Ermias et al., 2015; Teshome and Anshiso, 2019). The demand for black cumin seeds and their oil has been increasing in Ethiopia. The crop is also the second vital cash crop that is exported to the international market, next to ginger (Teshome and Anshiso 2019).

However, the yield of the crop in the country is very low. The national average yield of black cumin in Ethiopia is only 0.89 t ha^{-1} (MoARD, 2019). Earlier, Kifelew et al. (2017) reported that the national average productivity of black cumin varieties "Dershaye" and "Eden" produced 0.9–1.6 t ha–1 of seed yield. This means the potential seed yield of the crop is higher than the actual yield obtained by farmers in the country. However, there is a large yield gap between the actual and potential yield of black cumin in the country (Dessie et al, 2020).

Poor soil fertility management practices are a major cause of the low yield and quality of black cumin in the country (Ermias et al., 2015; Teshome and Anshiso, 2019; Dessie et al., 2020). Likewise, in Ethiopia, soil fertility is fast dwindling because of increasing rates of cultivation without restoring soil nutrients, lack of crop rotation, frequent soil erosion, low and inappropriate use of mineral fertilizers, and loss of soil organic matter (SOM) (Adam, 2006; Getachew et al., 2014). Continuous use of chemical fertilizers also leads to deterioration in soil chemical, physical, and biological properties and soil health (Mahajan et al., 2008). Reducing the application of chemical fertilizers is one of the main goals of sustainable agriculture (Moradzadeh et al., 2021). Furthermore, some data from the Ethiopian Agricultural Transformation Agency (ATA) shows that essential micronutrient deficiencies have also become a common problem in the highlands of Ethiopia, where so far no micronutrient-containing fertilizers have been applied to the crop (Wako and Usmane, 2020).

Despite the enormous importance of the seed spice and the steady growth of research in Ethiopia, research on the spice sector, particularly black cumin, has been very limited. In this regard, research undertaken in South West Ethiopia to investigate the different rates of NP fertilizer on yields of black cumin showed that the highest seed yield of 1.34 t ha^{-1} was obtained from 60/40 kg of N/P ha^{-1} (Ebrie et al., 2015). Adam (2006) reported the highest black cumin seed yield of 1.87 t ha^{-1} in response to applying 60 kg ha–1 of UREA in north Ethiopia. In India under irrigation conditions, a yield of 2.67 t ha^{-1} of black cumin was reported by (Ahmed et al., 2004). Zahoor and Abdul (2007) reported that the split application of nitrogen might increase black cumin yield.

In Iran, Maleki et al. (2021) reported that application of mineral fertilizer at the rates of 120 kg N ha^{-1}, 96 kg P ha^{-1}, and 120 kg K ha^{-1} resulted in a significantly increased black cumin seed yield of about 0.9 t ha^{-1}. However, when the researchers applied combined mineral and organic fertilizer at the reduced rates of 40 kg N ha^{-1}, 32 kg P ha^{-1}, and 40 kg K ha^{-1}, coupled with 30 t manure ha^{-1} to black cumin, they achieved the highest seed yield of about 1.1 t ha^{-1}. Research undertaken to evaluate the effect of different rates of NK fertilizer on the seed oil content of black cumin indicates that the highest seed oil content of 45% was recorded on application of 50 kg K ha^{-1} without N fertilizer on loam-textured and calcareous soils of Turkey (Zehra et al., 2017).

Increased application of N fertilizer significantly decreases seed oil content in contrast to increasing yields of the seed due to the tradeoff between protein and oil accumulation affected by N fertilizer (Zheljazkov et al., 2013; Zehra et al., 2017). In other study results, it was reported that integrated use of N/P mineral fertilizer and organic fertilizer also improved the yields, volatiles, and seed oil percentages of black cumin (Ali and Hassan 2014; Oren et al., 2001). The same authors also reported that integrated use of inorganic and organic fertilizers is used to full exploitation of the genetic potential of crops and has considerable positive effects on plant physiology for crop growth, development, and sustainable production in the middle Nile delta of Egypt.

In Ethiopia, the West Shewa Zone has one of the best potentials among agro-ecological zones in the Oromia National Regional State, which contributes a significant quantity of black cumin production. In West Shewa, 1348 ha of land were covered by black cumin, and 1006.8 t of the crop was produced in the 2016 cropping calendar, with an average productivity of about 0.8 t ha^{-1}, which is below the potential yield of the crop (West Shewa Post Harvest Assessment Annual Report, 2016 unpublished). On the other hand, recently released varieties in Ethiopia produced seed yields ranging between 0.9 and 2.15 t ha^{-1} on research fields (MoARD, 2016). Therefore, there is a huge yield gap between the potential seed yield of the crop and the actual seed yield obtained in the research area in particular, as well as in the country in general. Thus, the gaps should be narrowed by improving the productivity of the crop through soil fertility management practices. Here, it was hypothesized that the application of mineral NP, blended NPSB, and VC can increase the seed yield, yield components, and seed oil content of black cumin. The objective of the study was to evaluate the effects of applying NP, blended NPSB, and VC fertilizers on the yield, yield components, and oil content of black cumin in the central highlands of Ethiopia.

Materials and Methods

Description of the study area and experimental materials

Field experiments were undertaken at two sites (Ambo and Dandi) in the central highlands of Ethiopia, located at geographical coordinates of 090 02’ North latitude and 380 12’ East longitude, and 80 57’ North latitude and 380 07’ East longitude, respectively. A black cumin variety (Dershaye) was used as a test crop. The variety is characterized by an upright vegetative growth, with condensed branches that are leafy at the head with leaves 2.5–3.0 cm long. It yields 0.9–1.9 t ha–1 on the field station, and survives at 1850–2800 meters above sea level with an annual rainfall of 400–500 mm and an optimum temperature of 12–140C. This variety of black cumin was selected for its abundance in the country (MoARD, 2009). It was released in 2009 by the Ethiopian Institute of Agricultural Research (EIAR) in Melkassa Agricultural Research Center.

Urea [$CO(NH_2)_2$] (46% N), Tri-super phosphate (TPS) (46% P_2O_5) and blended NPSB fertilizer (18.9% N, 37.7% P_2O_5, 6.95% S, and 0.1% B) were used as mineral fertilizer, while VC was used as a source of organic fertilizer. VC was prepared at the Ambo Agricultural Research Center from chopped maize stalk, fresh broad leaves, and residue of soya bean mixed with 30% cow dung and 10% topsoil buried in a pit for about 12 weeks using red earthworm (Eiseniafetida) to break down organic residues. In the VC pit, above 75% moisture was maintained for the periods of time remain in the pith. The obtained VC was mixed, shade dried, sieved, and prepared for application.

Treatment and experimental design

The treatment consisted of three rates of combined NP fertilizer (20 kg N and 15 kg P_2O_5, 40 kg N and 30 kg P_2O_5, 60 kg N and 45kg P_2O_5 ha^{-1}), three rates of blended NPSB fertilizer (0, 50, and 100 kg NPSB ha^{-1}), and three rates of VC (0, 3 and 6 t VC ha^{-1}). The experiment was laid out as a randomized complete block design in a factorial arrangement and replicated three times per treatment. The treatments were assigned to each plot randomly. The experiment was undertaken during the 2017/2018 main cropping season.

Soil sampling and analysis

Soil samples were taken by auger randomly from 0–30 cm before planting. The samples were composited into one sample from which the analysis of both physical and chemical soil parameters was carried out. The soil was broken into small crumbs and thoroughly mixed. The sub sample of the composite was labeled, foreign materials were removed, air dried, ground using mortar and pestle, sieved through a 2 mm sieve, and soil was sieved through a 0.2 mm sieve to determine the organic matter. Soil pH was determined from the filtered suspension of a 1:10 soil to water ratio using a glass electrode attached to a digital pH meter. The texture of the soil was determined by the particle size distribution analyzing method, which uses the Bouyoucos Hydrometer method (Day, 1965).

Organic carbon was determined by the Walkley-Black method (Bartlett et al., 1994) and the percentage of organic matter (OM) was calculated by multiplying the percent of organic carbon by 1.724. Total nitrogen was determined using the Kjeldhal method (Navas et al., 2013). Available phosphorus was determined by the Olsen method of extraction with the help of 0.5 M $NaHCO_3$ for 30 minutes (Olsen et al., 1954). Exchangeable basic cations (Ca, Mg, K, and Na) were determined by saturating the soil samples with a 1M NH_4OAC (ammonium acetate) solution at pH 7.0 (Thomas, 1983). Then Ca and Mg were determined by using atomic absorption spectrophotometry (AAS), while exchangeable K and Na were measured by a flame photometer from the same extract. Soil CEC (Cation Exchangeable Capacity) and exchangeable cations were determined by the ammonium acetate method.

Experimental procedure and crop management

The size of each plot used for this study was 2.4 m x 1.2 m (2.88 m^2). Spacing of 0.5 and 1.0 m was maintained between the plots and blocks, respectively. Each plot was leveled manually before sowing the seeds. After the seed-bed was leveled, rows of 20 cm were manually made and seeds of the improved black cumin variety "Dershaye" were sown into rows (12 kg ha^{-1}). Planting was undertaken on 17 and 18 August 2017 at the Dendi site and Ambo site, respectively. During sowing, the whole amount of phosphorus (TSP 46% P_2O_5 and blended NPSB) and half the nitrogen (UREA 46% N) were applied in rows and the remaining UREA was top-dressed during the flower initiation stage as per the treatments. VC was applied one week before planting per the treatment. All other agronomic (crop management) practices were followed uniformly as per the recommendation. One outermost row on both sides of a plot and 10 cm on each end of the rows were considered as the border. Harvesting was done from the net plot when the crop capsule color changed to pale/yellow. The harvested produce was packed in sacks and the above ground-biomass weight was automatically measured; after drying in the sun for about two weeks, threshing and winnowing were done manually, and seed weight was measured after the seed moisture content was adjusted to 10%.

Data collection and measurement

Plant height (cm), number of branches per plant (count), number of capsules per plant (count), seed count per capsule, above ground-biomass yields, seed yield, and seed oil content were measure and recorded.

Seed oil content measurement (%)

The total fixed oil or fat content was measured by a nuclear magnetic resonance spectrophotometer (NMR). A seed sample of 22 g of black cumin was taken and dried in an oven at 105 0C for two hours and cooled in a dissector for 30 minutes. After cooling, the seeds were filled into NMR tube and inserted into the NMR to directly measure the total fixed oil percentage or fat content (Hutton et al., 1999).

Statistical analysis

In all cases, the variations in the two locations of the study were not significantly different and the error variances were homogeneous. Therefore, the data were subjected to a combined analysis of variance (ANOVA) for the two locations using SAS 9.2 (SAS, 2004). Tukey's test at 95% confidence intervals was employed to evaluate the significant differences between mean values.

Partial budget analysis

Pooled experimental data were compared on adjusted yields, input costs and output benefits. Partial budget analysis was done using the existing market prices for inputs (NP, NPSB mineral fertilizers, and VC preparation costs) at a planting time for variable cost analysis, while for the output benefits (seed yield), the farm gate price at the time of the crop harvest was used for benefit analysis. All costs and benefits were calculated for a hectare in Ethiopian currency (ETB ha^{-1}). Where, 24.16 ETB was equivalent to 1 US dollar during the cropping season. The tools used for economic analyses were partial budget analysis, dominance analysis, and marginal analysis (CIMMYT, 1988).
Partial budget analysis is usually used to evaluate the differences in costs and benefits among different rates of NP and NPSB mineral fertilizer application and VC. Its components are:-

Adjusted yield (ton ha⁻¹)

The yields of all treatments were adjusted downward by 10% to minimize plot management effects by the research or to reflect the actual farm level performance.

Gross field benefit (GFB in ETB ha⁻¹)

This factor was calculated as the product of the field price and the adjusted seed yield for each treatment.

GFB = Pf xYadj. (1)

Where, Pf= farm gate price (ETB kg^{-1}) and Yadj= adjusted yield.

Total variable costs (TVC)

Total variable cost is the sum of field cost of fertilizer purchase, fertilizer transportation, VC preparation and the cost of fertilizer applications in ETB–1.

Net benefits (NB)

It was calculated as the difference between the GFB and TVC for each treatment in ETB ha^{-1}

NB= GFB-TVC (2)

The dominance analysis procedure, which was used to select potentially profitable treatments, comprised of ranking treatments in an ascending order of total variable cost from the lowest to the highest cost to eliminate treatments costing more but producing a lower or equal net benefit than the next lowest costing treatment, was undertaken (CIMMYT, 1988).

Marginal rate of return (%):

For each pair of ranked treatments, a marginal rate of return (MRR) was calculated as follows:

$$MRR\% = \frac{\triangle NB}{\triangle TVC} x100 \quad (3)$$

The MRR% between any pair of undominated treatments denotes the return per unit of investment in rates of NP, NPSB, and VC application expressed as a percentage (CIMMYT, 1988).

Results

Physical and Chemical Properties of the Experimental Soil

Soil samples from the top layer (0–30 cm) revealed specific soil characteristics (Table 1.). The result of the physical soil analysis showed that the soil texture of both experimental areas was clay, which is the most suitable for the successful growth and production of black cumin due to its good water holding capacity, root penetration, moisture retention during the late growth stage, and good plant nutrient retention capacity (Orgut, 2007). The pH of the soil at both Ambo and Dandi site was found to be moderately acidic according to the rating of (Murphy, 1968). The optimum pH for black cumin production ranges from 6.5 to 7.5 (Orgut, 2007; Läuchli and Grattan, 2012). For producing the crop, pH values of 10 and more, as well as 4 and less, would result in very poor yields (Kebede et al., 2009). According to Barrow (2017), the availability of phosphate increases when soil pH is between the range of 6.0 and 7.0. This means there is a slight limitation in soil pH to grow black cumin as a result of which some amendment may be required.

The cation exchange capacity (CEC) of soils of both districts was found to be in the range of very high according to the rating of Landon (1991). This shows that the soils of both sites have no limitation in terms of the exchange of cations for producing black cumin. The organic carbon content of the soil at the experimental site in Dendi district was found to be medium, according to the rating of (Berhanu Debele, 1980), as cited by (TéklaignTadese, 1991). However, that of the experimental site in Ambo district was found to be high, according to the rating of the same authors. According to the same authors, the total nitrogen content of the soils of both experimental sites is high. This means it is only the Dendi site that has a limitation on organic carbon content, whereas the site in the Ambo district has a good amount of soil organic carbon content. These results also show that the soils of both experimental sites have considerable total nitrogen content, which could release enough nitrate or ammonium for uptake by the plant during the growing season upon mineralization. However, the results showed that there are limitations in organic carbon content, especially at the site in Dendi district. Therefore, there appears to be a requirement for the application of organic fertilizer to grow the crop. The available phosphorus content was found to be in the medium range according to the rating of (Cottenie, 1980; Landon, 2014). This means the soils of both sites would require the application of phosphorus from external sources.

According to the rating of FAO (2006), the soils of both experimental sites have low contents of calcium, high contents of potassium, medium contents of magnesium, and very high cation exchange capacity. This shows that the soil has no limitation in potassium content and cation exchange capacity. However, the exchangeable calcium content was low, indicating its relative deficiency and possible predisposal of the soil to soil acidity. There also appears to be a limit on the availability of exchangeable magnesium in the soils of both sites.

Plant height

The main effects of the combined NP fertilizer, the blended fertilizer, and VC significantly ($P \leq 0.01$) influenced plant height. In addition, the interaction of NP and blended NPSB mineral fertilizer significantly ($P \leq 0.05$) affected this variable. No other interaction had a significant effect on this variable (Table 2).

Table. 1. Selected physical and chemical properties of the experimental sites at Ambo and Dendi Districts in central Ethiopia during the main cropping season of 2017/18

	Ambo		Dendi		Reference
Property	**Value**	**Rating**	**Value**	**Rating**	
pH (1:2.5 soil-water ratio)	5.62	Moderately acidic	5.78	Moderately acidic	(Murphy, 1968)
Organic carbon (%)	1.92	Medium	1.67	Medium	(Berhanu Debele, 1980; Tekalign Tadese, 1991)
Total N (%)	0.168	High	0.162	High	(Berhanu Debele, 1980; Tekalign Tadese, 1991)
Available P (mg kg soil^{-1})	10.12	Medium	10.17	Medium	(Cottenie, 1980)
CEC (cmol$_{(+)}$ kg soil^{-1})	42.44	Very high	45.07	Very high	(Landon, 1991)
Na^{+1} (cmol$_{(+)}$ kg soil^{-1})	0.45	Non-saline	0.49	Non-saline	(Richards, 1954)
K^{+1} (cmol$_{(+)}$ kg soil^{-1})	0.82	High	0.84	High	(FAO, 2006)
Ca^{+2} (cmol$_{(+)}$ kg soil^{-1})	3	Low	3.3	Low	(FAO, 2006)
Mg^{+2}(cmol$_{(+)}$ kg soil^{-1})	1.4	Medium	1.5	Medium	(FAO, 2006)
Bulk density	1.42	Medium	1.46	Medium	
Particle density	2.61	Medium	2.57	Medium	
Porosity (%)	45.59	Medium	46	Medium	
Sand (%)	17.8		10		
Silt (%)	32.7		23.7		
Clay (%)	49.4		66.3		
Texture	Clay		Clay		

Table 2. Mean squares for yield and yield components of black cumin as affected by the application of mineral NP and blended NPSB fertilizers and VC in central highlands of Ethiopia during the 2017/18 main cropping season

Source	DF	Mean squares						
		PHt	**NBP**	**NCPP**	**NSPC**	**BMY**	**SY**	**Oil (%)**
Block	2	10.92ns	0.17ns	4.18ns	5.394ns	0.11ns	0.00ns	0.062
NP	2	1068.63**	26.58**	120.12**	1094.73 **	15.48**	1.11**	10.422**
NPSB	2	226.96**	46.60**	157.03**	1237.31 **	13.06**	1.10**	0.516**
VC	2	74.28**	8.00**	62.06**	90.17**	4.00**	0.36**	1.115**
NP*NPSB	4	40.08*	3.36*	20.59**	80.75**	0.22ns	0.04**	0.370**
NP*VC	4	2.96ns	0.55ns	4.13ns	9.75ns	0.480*	0.00ns	0.178*
NPSB*VC	4	0.94ns	0.74ns	3.14ns	9.484ns	0.37ns	0.01ns	0.242**
NP*NPSB* VC	8	1.81ns	1.10ns	4.27ns	15.75**	0.69**	0.02*	0.201**
Error	52	12.14	0.92	5.02	5.348	0.17	0.00	0.059

*significantly affected at ($P \leq 0.05$); **significantly affected at ($P \leq 0.01$); ns = no significant difference; DF= Degrees of freedom; NBP = number of braches plant^{-1}; PHt = plant height; NCPP = number of capsule plant^{-1}; NSPC = number of seed per capsule; BMY = above ground yield; SY = seed yield

Increasing the amount of the combined NP fertilizer increased plant height, along with the increasing rates of the blended NPSB fertilizer. The tallest black cumin plants were produced already in response to the interaction effect of the medium rate of NP (40/30 kg N/P_2O_5) and the highest rate of blended NPSB fertilizer (100 kg blended NPSB ha^{-1}). Increasing the rates of the NP fertilizers to the highest levels (60/45 kg and N/P_2O_5 kg ha^{-1}) across the highest rate of the blended NPSB fertilizer (100 kg blended NPSB ha^{-1}) did not further increase plant height. Thus, the optimum plant height of black cumin was attained in response to the application of 40/30 kg N/P_2O_5 and 100 kg blended NPSB ha^{-1} which exceeded the height of black cumin plants attained in response to the lowest rates of NP fertilizers (20/15 kg N/P_2O_5) and zero blended NPSB ha^{-1} by about 25% (Table 3).

Table 3. Plant height, number of branches and Number of capsule per plant of black cumin as affected by interaction of NP and NPSB fertilizer in central highlands of Ethiopia during the 2017/18 main cropping season

NP rate (kg $N/P_2O_5ha^{-1}$)	NPSB rate (kg ha^{-1})	PHt (cm)	NBP (count)	NCPP (count)
20/15	0	53.23^{c}	6.51^{d}	17.59^{c}
	50	55.64^{c}	8.38^{c}	20.34^{ab}
	100	57.16^{bc}	9.50^{bc}	20.18^{c}
40/30	0	55.82^{bc}	8.49^{c}	18.97^{c}
	50	60.09^{b}	8.61^{c}	20.19^{c}
	100	66.34^{a}	10.19^{ab}	24.13^{ab}
60/45	0	66.28^{a}	8.26^{c}	19.53^{c}
	50	68.14^{a}	10.66^{a}	25.26^{a}
	100	69.24^{a}	11.43^{a}	25.92^{a}
CV		5.680	10.523	10.501

Means sharing the same letter superscripts are not significantly different from each other at 5% level of significance; PHt = plant height; NBP = number of branch $plant^{-1}$; NCPP = number of capsule $plant^{-1}$; NPSB = blended nitrogen, phosphorus, sulfur and boron fertilizer

Number of branches per plant

Similar to plant height, the main effects of the combined NP fertilizer, the blended fertilizer, and VC significantly ($P \leq 0.01$) affected the number of branches per plant. What is more, the interaction of NP and blended NPSB mineral fertilizer significantly ($P \leq 0.05$) affected this variable. No other interaction had a significant effect on this variable (Table 2).

Increasing the combined NP mineral fertilizer significantly increased the number of branches across the increasing rates of the blended fertilizer. Thus, the application of 40/30 kg N/P_2O_5 and 100 kg blended NPSB ha^{-1} resulted in the highest number of branches per plant. However, the number of branches per plant decreased significantly by about 19% when the rate of the blended NPSB fertilizer was zero kg ha^{-1}. But, with the increase in the rate of this fertilizer to 50 and 100 kg ha^{-1}, the number of branches increased significantly again, but remained in statistical parity with the number of branches produced at the aforementioned medium rates of NP fertilizers and highest rate of NPSB fertilizers, where the optimum number of branches per plant was already obtained. However, the smallest number of branches per plant was recorded in response to the application of 20/15 kg N/P_2O_5 and 0 kg blended NPSB ha^{-1} (Table 3). Thus, the number of branches per plant produced in response to the application of 40/30 kg N/P_2O_5 and 100 kg blended NPSB ha^{-1} exceeded the number of branches per plant produced in response to applying 20/15 kg N/P_2O_5 and 0 kg blended NPSB ha−1by about 57% (Table 3).

Capsule number per plant

The main effects of the combined NP fertilizer, the blended fertilizer, and VC significantly ($P \leq 0.01$) influenced number of capsule per plant. The interaction of NP and blended NPSB mineral fertilizer also significantly ($P \leq 0.01$) affected capsule number per plant. No, other interaction had a significant effect on this variable (Table 2).

The number of capsules per plant increased significantly in response to increasing the combined application of NP fertilizer across the increasing rates of the blended fertilizer. Similar to the number of branches produced per plant, the highest number of capsules per plant was already produced in response to the application of 40/30 kg N/P_2O_5 and 100 kg blended NPSB ha^{-1}. However, the number of capsules produced per plant decreased significantly by about 19% when the rate of the blended NPSP fertilizer hit the zero rate. But, with the rates of NPSB fertilizer were increased to 50 and 100 kg ha^{-1}, the number of capsules produced per plant increased significantly but remained in statistical parity with the number of capsules per plant produced at the aforementioned medium rates of NP fertilizers and highest rate of blended NPSB fertilizers. The application of 20/15 kg N/P_2O_5 and all other three rates of blended NPSB ha^{-1}, 40/30 kg N/P_2O_5, and 0 and 50 kg of blended NPSB ha^{-1}, 60/45 kg N/P_2O_5 and zero blended NPSB ha^{-1} resulted in the lowest number of capsules per plant. The number of capsules per plant produced in response to the application of 40/30 kg N/P_2O_5 and 100 kg blended NPSB ha^{-1} exceeded the number of capsules per plant produced in response to the application of 20/15 kg N/P_2O_5 and 0 kg blended NPSB ha^{-1} by about 37% (Table 3).

Number seeds per capsule

The main effects of the combined NP fertilizer, the blended NPSB fertilizer, and VC significantly ($P \leq 0.01$) influenced the number of seeds per capsule. In addition, the interaction of NP and blended NPSB mineral fertilizer; and NP and VC, as well as the interaction of three factors (two ways interaction) also significantly ($P \leq 0.01$) affected this variable (Table 2).

Increasing the rate of the combined NP fertilizer and blended NPSB mineral fertilizer increased the number of seeds per capsule but slightly increased across the increasing rates of VC. Thus, the optimum number of seeds per capsule of black cumin was produced already in response to the applying the medium rates of NP fertilizers (40/30 kg N/P_2O_5) and the highest rate of blended NPSB fertilizer (100 kg NPSB ha^{-1}). Thus, for example, the number of seeds per capsule obtained from the optimum application of 40/30 kg N/P_2O_5, 100 kg blended NPSB $ha^{-1,}$ and 0 ton VC ha^{-1} exceeded the number of seeds per capsule produced in response to the application only 20/15 kg N/P_2O_5 and zero blended NPSB ha^{-1} combined with zero VC by about 25% (Table 4). However, application of 40/30 kg N/P_2O_5 together with 100 kg blended NPSB ha^{-1} and 3 or 6 t VC per hectare also resulted in the production of the highest numbers seeds per capsule, which were in statistical parity with the number of seeds per capsule produced by black cumin plants supplied with only 40/30 kg N/P_2O_5 and 100 kg NPSB ha^{-1}. Similarly, application of 60/45 kg N/P_2O_5 together with 50 and 100 kg blended NPSB ha^{-1}, and the three rates of VC resulted in the highest number of seeds per capsule.

Above-ground biomass

The main effects of combined NP fertilizer, blended NPSB, and VC significantly ($P \leq 0.01$) influenced above-ground biomass yield. Similarly, the one-way interaction of mineral NP fertilizer and VC also significantly ($P \leq 0.05$) influenced this variable. However, the three-factor (two-way) interaction of the three fertilizers also significantly ($P \leq 0.01$) influenced this variable (Table 2).

Increasing the rates of the combined NP mineral fertilizer and the blended NPSB fertilizer increased the biomass yield of the plant across the increasing rates of VC. Thus, the highest biomass yields were obtained in response to the application of 60/45 kg N/P_2O_5, 100 kg blended NPSB ha^{-1}, and both 3 t and 6 t vermicompost ha^{-1}. Thus, the optimum biomass yield of the crop was obtained already in response to the application of the highest rate of the NP fertilizer (60/45 kg N/P_2O_5 ha^{-1}) and the highest rate of the blended fertilizer (100 kg NPSB ha^{-1}), and the moderate rate of VC, i.e., 3 t h^{-1}(Table 4). On the other hand, the lowest above-ground biomass yield of the crop was obtained in response to the application of 20/15 kg N/P_2O_5 and zero rate of the blended NPSB ha^{-1} combined with all three rates of VC. Thus, the above-ground biomass yield was obtained in response to the application of 60/45 kg N/P_2O_5, 100 kg blended NPSB ha^{-1}, and 3 t VC ha^{-1} exceeded the biomass yield which was obtained in response to the application of 20/15 kg N/P_2O_5 and at zero rate of the blended NPSB ha^{-1}, combined with zero rate of VC by about 56% (Table 4).

Seed yield

Similar to the biomass yield, the seed yield of the crop was significantly ($P \leq 0.01$) influenced by the main effects of the combined NP fertilizer, blended NPSB, and VC. Furthermore, the three-factor (two-way) interaction of the three fertilizers also significantly ($P \leq 0.05$) influenced this variable (Table 2).

Table 4. Yield and yield components of black cumin as influenced by the application of mineral NP, blended NPSB, and vermicompost in Central Highlands of Ethiopia during the main cropping season of 2017/18

NP rate (kg N/P_2O_5 ha^{-1})	NPSB rate (kg ha^{-1})	Vermicompost (t ha^{-1})	No. seed Capsule^{-1}	Above-ground biomass Yield (t ha^{-1})	Seed Yield (t ha^{-1})	Seed oil content (%)
20/15	0	0	84.18^{j}	5.94^{j}	1.09^{i}	39.70^{ab}
	50		91.15^{f-j}	6.56^{f-j}	1.29^{ghi}	38.62^{d-g}
	100		92.58^{e-i}	7.60^{c-g}	1.40^{fgh}	39.27^{a-d}
40/30	0		88.63^{g-j}	6.41^{g-j}	1.28^{hi}	38.30^{e-i}
	50		91.50^{f-j}	7.42^{e-h}	1.59^{def}	38.58^{d-g}
	100		105.20^{ab}	7.36^{f-i}	1.76^{cd}	38.17^{f-i}
60/45	0		89.83^{f-j}	7.59^{c-g}	1.43^{fgh}	37.97^{ghi}
	50		103.05^{a-d}	7.75^{c-f}	1.78^{cd}	38.15^{f-i}
	100		107.73^{a}	7.85^{c-f}	1.78^{cd}	37.57^{i}
20/15	0	3	85.67^{ij}	6.10^{ij}	1.21^{hi}	39.05^{b-e}
	50		86.53^{ij}	6.95^{f-j}	1.41^{fgh}	39.52^{abc}
	100		94.12^{e-h}	7.59^{c-g}	1.58^{def}	39.32^{a-d}
40/30	0		92.08^{f-i}	7.31^{f-i}	1.63^{c-f}	38.48^{e-h}
	50		96.38^{c-f}	7.24^{f-i}	1.62^{c-f}	38.78^{c-f}
	100		103.55^{abc}	8.75^{bcd}	1.85^{bcd}	38.70^{d-g}
60/45	0		92.91^{e-i}	7.50^{c-h}	1.46^{e-h}	38.37^{e-h}
	50		103.13^{a-d}	8.76^{bc}	1.85^{bcd}	38.48^{e-h}
	100		108.03^{a}	9.24^{ab}	2.1^{ab}	37.80^{hi}
20/15	0	6	87.12h^{ij}	6.24h^{ij}	1.28^{hi}	39.92^{a}
	50		89.05^{f-j}	7.35^{f-i}	1.59^{def}	39.48^{abc}
	100		95.80^{d-f}	7.46^{d-h}	1.65^{c-f}	39.62^{ab}
40/30	0		89.17^{f-j}	7.37^{e-i}	1.63^{c-f}	38.83^{c-f}
	50		99.70^{b-e}	7.32^{f-i}	1.74^{cde}	38.45^{e-h}
	100		109.67^{a}	8.71^{b-e}	1.89^{bc}	38.32^{e-i}
60/45	0		95.52^{efg}	7.76^{c-f}	1.57^{d-g}	38.65^{d-g}
	50		109.43^{a}	8.78^{bc}	1.9^{bc}	38.55^{d-g}
	100		110.20^{a}	10.16^{a}	2.2^{a}	38.12^{f-i}
CV			2.34	5.27	5.67	0.63

Increasing the rates of the combined NP mineral fertilizer and the blended NPSB fertilizer increased the seed yield of the plant across the increasing rates of VC. Similar to its above-ground biomass yield, the crop attained its highest seed yields at the application rates of 60/45 kg N/P_2O_5, 100 kg blended NPSB ha^{-1}, and both 3 t and 6 t vermicompost ha^{-1}. Thus, the optimum seed yield of the crop was obtained already at the application rates of 60/45 kg N/P_2O_5 ha^{-1}, 100 kg NPSB ha^{-1}), and 3 t VC ha^{-1} (Table 4). However, the lowest seed yields of the crop were obtained in response to the application of 20/15 kg N/P_2O_5 and zero rate of the blended NPSB ha^{-1} combined with all three rates of vermicompost. For example, the seed yield obtained in response to the application of 60/45 kg N/P_2O_5, 100 kg blended NPSB ha^{-1}, and 3 t VC ha^{-1} exceeded the seed yield obtained in response to the application of 20/15 kg N/P_2O_5 and zero rate of the blended NPSB ha^{-1} combined with the zero rate of VC by about two-fold (93%) (Table 4). This seed yield is also twice as much as the national average seed yield of 0.89 t ha^{-1} (MoARD, 2019) obtained from farmers' fields in the country. This seed yield is almost equal to the highest seed yield of the crop that ranges between 0.9–2.15 t ha^{-1}(MoARD, 2016), which is obtained from improved varieties in research fields in the country.

Total seed oil (%)

The main effects of combined NP fertilizer, blended NPSB, and VC also significantly ($P < 0.01$) influenced seed oil yields of black cumin. Similarly, the one-way interaction of mineral combined NP fertilizer and blended NPSB mineral fertilizer significantly ($P \leq 0.01$) influenced seed oil yields, as well as the interaction of combined NP and VC also significantly ($P < 0.05$) influenced this variable. However, the three-factor (two-way) interaction of the three fertilizers also significantly ($P < 0.01$) influenced seed oil yield of black cumin (Table 2).

Increasing the rates of the combined NP mineral fertilizer decreased the seed oil yield of the crop. Similarly, with increasing rates of blended NPSB mineral fertilizer, the seed oil yields of the crop slightly decrease or remain constant. However, application of VC together with the mineral fertilizers tended to increased seed oil content. Thus, the highest seed oil yields of the crop were obtained in response to the application of 20/15 kg N/P_2O_5, 0 kg of blended NPSB ha^{-1} along with 0 and 6 t ha^{-1} of VC; as well as 20/15 kg N/P_2O_5, 50 kg of blended NPSB ha^{-1} along with 3 and 6 t ha^{-1} of VC. Thus, the highest seed oil yield was obtained in response to the application of 20/15 kg N/P_2O_5, 0 kg blended NPSB ha^{-1}, and 6 t VC ha^{-1} exceeded the seed oil yield obtained in response to the application of maximum NP and Blended NPSB, while zero VC resulted in about 6%.

Partial budget analysis

The result of the partial budget analysis showed that applying 60/45 kg N/P_2O_5 ha^{-1}, 100 kg blended NPSB ha^{-1}, and 6 t VC ha^{-1} incurred the highest total variable cost of 18,123 ETB (Ethiopian Birr) ha^{-1} followed by the application of 60/45 kg N/P_2O_5 ha^{-1}, 50 kg blended NPSB ha–1, and 6 t VC ha^{-1} which incurred a total variable cost of 17,243 ETB (Annex Table 1). The net benefit-cost ratio showed that at the cost of one ETB, the net benefit ranged from 7.0 to 36.85 ETB in all non-dominated treatments. The highest marginal rate of return was obtained for the application of 40/30 kg N/P_2O_5 ha^{-1}, 50 kg NPSB ha^{-1}, zero VC followed by the application of 20/15 N/P_2O_5 ha^{-1}, 50 kg NPSB ha^{-1}, and zero kg VC ha^{-1} with 2778.79% and 922.73%, respectively. The highest net benefit of 82,677 ETB ha^{-1} was obtained in response to the application of 60/45 kg N/P_2O_5 ha–1, 100 kg NPSB ha^{-1}, and 3 t VC ha^{-1} followed by 60/45 kg N/P_2O_5 ha^{-1}, 100 kg NPSB ha^{-1}, and 6 t VC ha^{-1} that resulted in 80,877 ETB ha^{-1}, while the lowest net benefit (47,754 ETB ha-1) was obtained at the application rate of 20/15 kg N/P_2O_5 ha^{-1}, zero rate of NPSB ha^{-1}, and zero rate of VC ha^{-1} (Table 5).

Discussion

Plant height

The increase in plant height in response to the rise in concentrations of all three fertilizers may be attributed to the roles that the nutrients contained in the fertilizers, particularly nitrogen which may have played a role in promoting photosynthesis and vigorous growth of the black cumin plants. The optimum plant height was already obtained at the medium rate of nitrogen and phosphorus application, together with the highest rate of the blended NPSB fertilizer.

Thus, significant increases were obtained in response to increasing the combined NP and blended NPSB fertilizers, which could be attributed to the roles each nutrient plays in plant physiology, e.g. cell division, elongation, and growth, thereby leading to the production of taller plants. This postulation is consistent with that of Gonzalez *et al.* (2001) who reported that NP mineral fertilizer and organic fertilizer supplied most of the essential plant nutrients at the growth stage, resulting in hastened cell division and elongation which led to enhanced levels of growth and, ultimately, taller black cumin plants.

Table 5. Marginal rate of return analysis of N/P_2O_5, NPSB mineral fertilizer and vermicompost for black cumin production (two site pooled data) 2017/2018

N/P_2O_5 kg ha^{-1}	NPSB kg ha^{-1}	VC t ha^{-1}	Yield t ha^{-1}	Yadj tons ha^{-1}	P_f ETB kg $^{-1}$	Gross benefit ETB ha^{-1}	TVC ETB	NB ETB	MRR%
20/15	0	0	1.09	0.981	50	49,050	1296	47,754	-
	50		1.29	1.161	50	58,050	2176	55,874	922.73
	100		1.4	1.26	50	63,000	3056	59,944	462.50
40/30	50		1.59	1.431	50	71,550	3353	68,197	2778.79
	100		1.76	1.584	50	79,200	4233	74,967	769.32
60/45	50		1.78	1.602	50	80,100	4643	75,457	119.51
	100	3	2.1	1.89	50	94,500	11823	82,677	100.56

VC = vermicompost; TVC = Total variable cost; Yadj = Adjusted grain yield; GFB = Gross field benefit; P_f = Farm gate price; NB = Net benefit; MRR = Marginal rate of return
Means sharing the same letter superscripts are not significantly different from each other at 5% level of significance

In line with the results of present study, Ebrie *et al.* (2015) reported that the tallest plants of black cumin were observed in plots that received 60/40 kg of N/P ha^{-1}. Rana *et al.* (2012) also reported that the tallest plants of black cumin were observed in response to application of 60/120 kg of N/P ha^{-1}. Yosef (2008); Tuncturk et al. (2012) also reported that the plant height of black cumin increased with higher doses of NP fertilizer.

Number of branches per plant

The increased number of branches were recorded in response to increasing the combined application of NP and blended NPSB fertilizers, which could be ascribed to the complementary effect of nitrogen and phosphorus on metabolic and physiological functions, since nitrogen is a component of chlorophyll and phosphorus is a source of energy storage and transfer (ATP and ADP) that promotes plant cell division, elongation, and increased lateral growth and capsule formation (Hammo, 2006; Fageria, 2016). In line with the results of the present study, Ebrie et al. (2015) reported the highest number of branches per plant of black cumin on plots that received 60/40 kg of N/P ha^{-1}. Similarly, Moradzadeh et al. (2021) also reported that the application of biological NPK increased the efficiency of mineral urea to maximize the branch number of black cumin and to make the highest number of auxiliary branches of black cumin in plots that received a combination of biological NPK and a moderate amount of UREA.

Number of capsules per plant

It was observed that moderate doses of combined NP and higher doses of blended NPSB mineral fertilizer resulted in an optimum capsule number per plant. This implies that sulfur in the blended fertilizer is the most influential mineral in the formation of capsules due to its essential role in the process of DNA formation and nuclear division, which leads to higher capsule formation. This assumption is supported by findings reported by Khurana and Chetterjee (2002) which state sulfur has an essential role in the processes of DNA formation and nuclear division as well as in the process of cellular division, which leads to a high number of branches and capsule formation. The significant increase in the number of capsules per plant obtained in response to increasing the combined NP and blended fertilizers could be attributed to the roles of the two nutrients (nitrogen and phosphorus) in plant metabolism and physiological function in cytokinin synthesis, which promotes cell division, expansion, and increased capsule formation during the mid-growth stage (Rahayu et al., 2005).
In line with the results of the present study, Ali et al. (20015) reported the highest number of capsules per plant of black cumin with the application of 120–40–60 kg N–P–K mineral fertilizers. Similarly, Hammo (2006); Rana et al. (2012); and Tuncturk et al. (2012) also reported an increased capsule number per plant of black cumin with an increased NP fertilizer level. A study undertaken by different researchers revealed that the number of capsules per plant of black cumin has a wide range, depending on soil factors and climatic factors (Ebrie et al., 20015).

Number of seed per capsule

In the current findings, the optimum numbers of seeds per capsule of black cumin were produced in response to the application of 40/30 kg N/P_2O_5, 100 kg blended NPSB ha^{-1}, along with three rates of vermicompost. As the application of NP increased from 40/30 kg N/P_2O_5 to 60/45 N/P_2O_5 along with the three rates of VC without blended NPSB mineral fertilizer, the number of seeds per capsule significantly decreased. This implies that blended NPSB mineral fertilizer is the most influential in the formation of seed number per capsule due to the influence of boron in flower formation and seed formation in the capsule. The interaction of NP blended NPSB mineral fertilizer and vermicompost significantly increased the number of seeds per capsule of black cumin. This was probably due to the effects of N and P, important plant nutrients, having complementary metabolic and physiological functions, thereby affecting cell division and elongation. Nitrogen and phosphorus have an enhancing effect on cytokinin synthesis, which promotes nuclear cell division and seed formation in pods. According to Hammo (2006); Fageria (2016), increased application of NP in plants improves physiological function such as nuclear cell division and elongation, resulting in an increase in seed formation.

The current study was in line with the findings of Toncer and Kizil (2004), who reported that the number of seeds per capsule produced by black cumin plants increased as the rate of NP fertilizer increased. Ali et al. (2015) also reported the highest number of seed per capsule of black cumin achieved by the application of 120–40–60 kg N–P–K mineral fertilizer, respectively. Ebrie et al. (2015) also reported the highest number of seeds per capsule of black cumin achieved by the application of 40/60 N/P mineral fertilizer. The same author states that the number of seeds per capsule is the reservoir capacity of the crop yield. The author concluded the number of capsules per plant and the number of seeds per capsule as good indicators of seed yield.

Above-ground biomass

The significantly maximized above-ground biomass of black cumin in response to applying the three fertilizers may have been caused by enhancements in nutrient uptake by the plant, improved soil organic carbon, as well as physical and chemical properties, improved water infiltration, and enhanced microbial activity of the soil, which promoted optimal vegetative growth. This can be attributed to the availability of adequate available nitrogen and phosphorus in the soil, which may have been absorbed sufficiently by the plants. This may have promoted enhanced growth in the plants. They may have induced formation of many branches and capsules, resulting in higher above-ground biomass yields (Ashraf et al., 2005). This also confirms the finding of Gonzales et al. (2001) who reported that organic fertilizers and inorganic fertilizers supplied most of the essential nutrients at a growth stage, resulting in an increase in growth parameters.

In agreement with the current findings, Ashraf et al. (2005); Tuncturk et al. (2012); Ebrie et al. (2015) found that NP levels had a significant influence on the above-ground biomass yield of black cumin.

Seed yield

The interaction of NP, blended NPSB mineral fertilizers, and VC also significantly increased the seed yield of black cumin. In the current findings, the optimum seed yield of black cumin was already attained at the application of 60/45 kg N/P_2O_5, 100 kg blended NPSB ha^{-1} and 3 t of VC. This could be because the seed yield of black cumin responded to higher rates of combined NP and blended NPSB along with organic fertilizers as a result of increased soil organic matter, improved soil structure, water-holding capacity, and improved nutrient cycling, which helps to maintain soil nutrient status. This assumption is consistent with the findings of Saha et al. (2008), who state that using organic fertilizer in conjunction with inorganic fertilizer increases soil organic matter, improves soil structure, soil microbial activity, water holding capacity, and promotes plant growth and productivity. The availability of boron in blended NPSB mineral fertilizer may have also promoted vegetative growth and seed formation through increased branching and flower differentiation in plants that leads to higher seed yields. This hypothesis is consistent with that of Soetan et al. (2010) who stated that boron plays an important role in the formation of cell walls, pollen germination, cell division, flowering, and flowering processes that lead to high fruit yield and seeds in crop plants. Also, in agreement with these results, Maleki et al. (2021) reported that the application of mineral fertilizer at rates of 120 kg N ha^{-1}, 96 kg P ha^{-1}, and 120 kg K ha^{-1} resulted in a significantly higher black cumin seed yield. However, the researchers found that the seed yield of the crop improved further when they applied reduced rates of 40 kg N ha^{-1}, 32 kg P ha^{-1}, and 40 kg K ha^{-1}, together with 30 t manure ha^{-1}. This indicated that the synergetic roles of mineral and organic fertilizers enhanced productivity of the crop as observed in this study.

Therefore, the integrated use of inorganic fertilizers with organic fertilizers is a sustainable approach for efficient nutrient usage, which enhances the efficiency of the chemical fertilizers while reducing nutrient loss (Schoebitz and Vidal, 2016). In line with the results of this study, Ebrie et al. (2015) reported that the highest seed yields of black cumin (1.34 t ha^{-1}) were obtained under the application of 60/40 kg ha^{-1} of NP. Also, Ali et al. (2005) reported a maximum seed yield (2.3 t ha^{-1}) of black cumin and higher dry matter in plots that received 120–40–60 kg ha–1 of N–P–K mineral fertilizer, respectively. Yosef (2008), Tuncturk et al. (2012) and Ali et al. (2015) also reported that increasing nitrogen and phosphorus doses positively influenced seed yield in black cumin. While chemical fertilizers are important inputs for increasing crop productivity, an over-reliance on chemical fertilizers alone, combined with a decline in some soil properties, resulted in a decrease of crop yield over time (Hepperly et al., 2009; Moradzadeh et al., 2021).

Total seed oil (%)

It was observed that increasing the rates of the mineral NP and blended NPSB reduced seed oil content of black cumin, but increasing the rate of the VC increased this attribute of the seed. This may be ascribed to the tradeoff between protein and oil accumulation in the seeds of the plant. This assumption is supported by Ali and Hassan (2014) and Zehra et al. (2017) who stated that the application of higher doses of nitrogen significantly decreased oil content of black cumin. Since nitrogen is an integral part of the protein, it promotes protein formation and significantly decreases oil accumulation. In contrast, the increase in seed oil content in response to the application of vermicompost may be attributed to the role that vermicompost plays in supplying not only the major plant nutrients but also micronutrients and organic carbon, which are essential for oil synthesis in plants. This suggestion is supported by Shaalan (2005) who found that manure and compost increased the seed oil yield of black cumin.

This result is also corroborated by the findings of Ashraf et al. (2005) who reported that the seed oil content of black cumin was significantly higher at the lowest rate of nitrogen application. In other studies, the yield of sunflower oil decreased or remained fixed in response to the addition of N, but higher doses resulted in a decrease in oil content (Zheljazkov et al., 2008). Similarly, it was reported that an enhanced level of oil yield per plant occurred in sweet basil in response to increased application of organic fertilizer (El-Gendy et al., 2001). In another study, the application of higher doses of vermicompost yielded maximum essential oil in *Anethum graveolens* (Darzi et al., 2015).

Partial budget analyses

Partial budget analyses were used to identify the technological packages that are not only profitable but also exhibit good margin and remain profitable in different situations of input and output prices, respectively. In the current study, the marginal rate of return analysis showed that all non-dominated treatments were economically viable, because the results of all non-dominated treatments were higher than the minimum value marginal rate of 100% return (CIMMYT, 1988). The highest net benefit of (82,677 ETB ha^{-1}) was obtained at the rate of 60/45 N/P_2O_5 and 100 kg ha^{-1} blended NPSB mineral fertilizer and 3 ton ha^{-1} VC (Table 5). This might be due to the fact that integrated application of NP, blended NPSB and VC improved the yield and yield components of black cumin, thereby adding to the economic advantage of cultivating black cumin. Therefore, treatments with 60/45 N/P_2O_5 and 100 kg ha^{-1} NPSB mineral fertilizer and 3 ton ha^{-1} VC can be used by the farmers in the study area. It can be considered as the best combination for optimum black cumin yield, thereby offering a high marginal rate of return above the proposed minimum acceptable rate of return of 100% (CIMMYT, 1988). This could be used to enhance the productivity and benefits of the crop on a sustainable basis in the study area.

Conclusion

The results of this study demonstrated that applying 60 kg N and 45 kg P_2O_5 together with 100 kg blended NPSB mineral fertilizers and 3 t ha^{-1} of VC resulted in an optimum seed yield (2.1 t ha^{-1}) of black cumin in the central highlands of Ethiopia (Ambo and Dendi districts). These amounts of fertilizers interacted and resulted in the highest net benefit (82,677 ETB ha^{-1}), implying that the fertilizers in combination can make profits and are sustainable for farmers. This application of the fertilizers at these rates improved the seed yield of the crop by about 100%. The results also revealed that higher seed oil contents were obtained by reduced rates of the mineral fertilizers and vermicompost. This study implied that nitrogen, phosphorus, sulfur, and boron are key nutrients to be applied together with the organic fertilizer to improve seed yield in black cumin by about 100% and increase the income of smallholder farmers in the study area. Future research on black cumin can focus on evaluating the effects of mineral and organic fertilizers on seed yield and oil contents of different black cumin varieties in the study area.

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Conflict of interest
The authors indicate no conflict of interest for this work

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Annex Table1. Partial budget and dominance analysis of N/P_2O_5, NPSB mineral fertilizer and VC for black cumin production (two site data pooled) in 2017/2018

N/P_2O_5 kg ha^{-1}	NPSB kg ha^{-1}	VC (t ha^{-1})	Yields t ha^{-1}	Yadj. t ha^{-1}	GFB ETB ha^{-1}	TVC ETB	NB ETB	B:C Ratio	Dominance test
20/15	0	0	1.09	0.981	49,050	1,296	47,754	36.85	UD
	50		1.29	1.161	58,050	2,176	55,874	25.68	UD
40/30	0		1.28	1.152	57,600	2,473	55,127	22.29	D
20/15	100		1.4	1.26	63,000	3,056	59,944	19.62	UD
40/30	50		1.59	1.431	71,550	3,353	68,197	20.34	UD
60/45	0		1.43	1.287	64,350	3,763	60,587	16.10	D
40/30	100		1.76	1.584	79,200	4,233	74,967	17.71	UD
60/45	50		1.78	1.602	80,100	4,643	75,457	16.25	UD
	100		1.78	1.602	80,100	5,523	74,577	13.50	D
20/15	0	3	1.21	1.089	54,450	7,596	46,854	6.17	D
	50		1.41	1.269	63,450	8,476	54,974	6.49	D
40/30	0		1.63	1.467	73,350	8,773	64,577	7.36	D
20/15	100		1.58	1.422	71,100	9,356	61,744	6.60	D
40/30	50		1.62	1.458	72,900	9,653	63,247	6.55	D
60/45	0		1.46	1.314	65,700	10,063	55,637	5.53	D
40/30	100		1.85	1.665	83,250	10,533	72,717	6.90	D
60/45	50		1.85	1.665	83,250	10,943	72,307	6.61	D
	100		2.1	1.89	94,500	11,823	82,677	6.99	UD
20/15	0	6	1.28	1.152	57,600	13,896	43,704	3.15	D
	50		1.59	1.431	71,550	14,776	56,774	3.84	D
40/30	0		1.63	1.467	73,350	15,073	58,277	3.87	D
20/15	100		1.65	1.485	74,250	15,656	58,594	3.74	D
40/30	50		1.74	1.566	78,300	15,953	62,347	3.91	D
60/45	0		1.57	1.413	70,650	16,363	54,287	3.32	D
40/30	100		1.89	1.701	85,050	16,833	68,217	4.05	D
60/45	50		1.9	1.71	85,500	17,243	68,257	3.96	D
	100		2.2	1.98	99,000	18,123	80,877	4.46	D

TVC = Total variable cost; Yadj. = Adjusted yield; GFB = Gross field benefit; NB = Net benefit; D = dominated; UD =Undominated.