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Research Article
NPS Fertilizer and Spacing Effects on Yield and Quality of Coriander (*Coriandrum sativum* L.)

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Abstract

Background and Objective: Coriander (*Coriandrum sativum* L.) is a high-value culinary and medicinal herb that is simultaneously used as a spice throughout the world. Its growth and development require balanced plant nutrients with appropriate spacing for better yield and quality. But there was no research recommendation for the production of coriander in the study area. Hence, the objective of this study was to determine the optimum NPS rate and best spacing for coriander production. **Materials and Methods:** The field experiment was conducted in 2020/21 at Wolaita Sodo University, Ethiopia. The treatments consisted of four NPS fertilizer rates (0, 50, 100 and 150 kg ha^{-1}) and inter-row spacing (10, 20, 30 and 40 cm) that gave 16 treatments in a factorial arrangement. The design was RCBD with three replications. **Results:** The ANOVA results revealed that the main effects of NPS fertilizer and inter-row spacing significantly ($p \leq 0.05$) affected almost all parameters. The interaction showed a significant ($p \leq 0.05$) effect on the number of branches, number of umbels, number of umbellets, number of seeds, seed yield, above-ground biomass and harvest index. The highest 1000 seed weight (10.65 g) and highest essential oil (7.32 kg) were obtained from 100 kg NPS ha^{-1}. The highest seed yield (1366.7 kg) was achieved by 100 kg NPS ha^{-1} at 30 cm inter-row spacing whereas the lowest total seed yield (494.4 kg) was achieved by 0 kg NPS ha^{-1}. **Conclusion:** Based on the results of the current investigation, it can be concluded that 100 kg NPS ha^{-1} with 30 cm inter-row spacing was the best combination for coriander production in the area.

Key words: Coriander, essential oil, fertilizer, growth, quality, seed yield, spacing

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Coriander (*Coriandrum sativum* L.) is one of the most important vegetables, spices and medicinal plants which belong to the family Apiaceae. Coriander originated from the Mediterranean and Western Asia regions[1]. Ethiopia is one of the recognized centres of origin of coriander along with Central Asia and near East countries[2]. India is the leading producer and exporter of coriander and 2100 metric tons were exported all over the world in the early sixties. The major global producers are India, Morocco, Canada, Romania and Russia[3]. Among all producers, India is ranking first both in area and production[4]. In Ethiopia, about 21,645 ha of land is covered by coriander with its annual production estimated to be around 1,535 tons with national average productivity of 0.25 t ha^{-1}[5].

Coriander is a widely used annual medicinal spice because of its high nutritional and medicinal value[6]. Almost all parts (leaves, stems and seeds) are used having different flavours[7]. The entire plant of young coriander is used as an appetizer in preparing fresh chutneys and sauces. The crop is indicated as a good melliferous crop visited by honey bees that gives about 500 kg of honey from one hectare of land[8]. The seed contains significant quantities of carotene, thiamine, riboflavin, niacin, tryptophan, vitamin B_6, folate, vitamin C and E[9], iron, manganese, magnesium and dietary fibre to the diet[10].

Production of coriander is constrained by several factors that reduce yield and quantity[11]. Among those factors, fertilizer management and spacing have considerable practical importance. The fertility status of the soil can be reduced due to different cases like leaching, exporting, mineralization, immobilization etc. whereas, a reduction in plant population density per unit area may be due to a lack of knowledge about optimum row spacing. Therefore, extensive fertilizer applications are required to meet the crop demand for nutrients to obtain good return[12].

The fertilizer used in the proper amount is essential for the right growth, development and ultimately yield. Nitrogen, phosphorus, potassium and sulfur played an important role in increasing the growth and seed yield of coriander. Application of N and N, P and K increased seed and oil yield of coriander[13]. According to Yousuf *et al.*[13], the fertilizer treatment N_{70} P_{50} K_{30} S_{20} was observed to be the best suitable dose for the growth and yield of coriander. Farahani *et al.*[14] and Moslemi *et al.*[15] explained the application of phosphorous fertilizer increased the vegetative yield of coriander. Lokhande *et al.*[16] found two major nutrients: Nitrogen and phosphorus that is (N_{60}+P_{40} kg ha^{-1}) were found to be best for obtaining higher seed yield and yield attributes in coriander.

Plant population density determined by plant spacing is another factor that determines growth, yield and quality in coriander. Higher seed yield coupled with high net returns of coriander crop should be sown at 30 cm row spacing and fertilized with 90 kg N ha^{-1}[17]. Ajay *et al.*[18] reported that the growth parameters such as plant height, the number of branches/plants, fresh and dry weight of plants, yield and yield attributes were significantly increased up to row spacing of 30 cm and nitrogen level of 80 kg ha^{-1}. But these agronomic practices are location-specific and depend on soil and other climatic factors.

Despite Ethiopia being a centre of primary diversity for the crop[8], the attention given so far in research and development was very limited. Moreover, crop production remained low compared to its potential yield, which might be due to the deficiency of essential nutrients including nitrogen and phosphorus[19]. In Ethiopia, farmers have been producing different crops including coriander using the blanket recommendation of urea and DAP fertilizers[20]. But currently, DAP has been replaced by NPS fertilizers in Ethiopian Agriculture. Yet, there is no crop and area-specific NPS recommendation for coriander production. The lacks of information on NPS fertilizer application rates coupled with optimum crop density are major hindrances to the growth and yield of coriander in the Wolaita area. Hence, to alleviate the existing gap, the current research was designed to address the following objective: To determine the optimum rate of NPS fertilizer and inter-row spacing for better yield and quality of coriander in the Wolaita area, southern Ethiopia.

MATERIALS AND METHODS

Description of the study area: The experiment was carried out in 2020 and 2021 during the main cropping season under rain-fed conditions at Wolaita Sodo university, college of agriculture, department of the horticulture research site. The experimental site is geographically located at 6°49'N latitude, 37°45'E longitude with an altitude of 1886 m above sea level. The area receives an annual rainfall of 1520 mm and annual minimum and maximum temperatures were 14 and 25°C, respectively[21]. The type of soil is sandy clay loam with a pH of 5.9.

Treatments and experimental design: The treatments consisted of two factors: Four NPS fertilizer rates (0, 50, 100 and 150 kg NPS ha^{-1}) and four inter-row spacing (10, 20, 30 and 40 cm). Urea containing 46% N and blended NPS containing (19% N, 38% P_2O_5 and 7% S) was used as a source of nitrogen, phosphorus and sulfur. The experiment was arranged in 4×4 factorial combinations (16 treatments) and laid out using a Randomized Complete Block Design (RCBD) with three replications. Plant spacing was 15 cm between plants and each plot had a 1.8 m length and 2.4 m width with a gross area of 4.32 m^2. Based on the inter-row distances, each plot had a different number of rows i.e., 10 cm between rows, 24 rows per plot, 20 cm had 12 rows per plot, 30 cm had 8 rows and 40 cm had 6 rows per plot. Each row had 12 plants. Space between plots was 0.5 m and between blocks was 1 m that giving the total area 333.96 m^2 (36.3×9.2 m).

Data collection and measurements:

- **Days to 50% flowering:** These were recorded by counting the number of days from sowing to the time when 50% of the plants in each plot started to flower through visual observation
- **Days to 50% maturity:** These were recorded by counting the number of days from sowing to when 50% of the plant in each plot attained physiological maturity
- **Plant height (cm):** It refers to the height from the base of the ground surface to the apex tip of 10 randomly selected plants using a measuring tape at plant maturity
- **Number of basal leaves per plant:** It was determined by counting the number of basal leaves from 10 randomly selected plants of each plot at the time of maturity
- **Branch number per plant:** It was determined by counting the number of all branches from 10 plants randomly selected plants per plot at plant maturity
- **Umbel number per plant:** It was recorded by counting the number of umbels from 10 randomly selected plants during plant maturity
- **Umbellets number per plant:** It was recorded from 10 randomly selected plants in each plot by counting the umbellets and the average was taken
- **Seed number per umbel:** It was recorded from 10 randomly selected umbels per plant and seed per umbel was threshed separately after harvesting and seeds of each umbel were counted and averaged
- **Thousand seed weight (TSW) (g):** The number of thousand seeds were counted using an electronic seed counter from a bulk of shelled seed and weighed using sensitive balance at a seeds moisture level of 10.5%
- **Seed yield (kg ha^{-1}):** It was determined from the net harvestable area and measured when the moisture content of the seed was at a 10.5% moisture level by using a grain moisture tester, weighed using a sensitive balance and converted into a hectare basis
- **Essential oil (kg ha^{-1}):** These samples were collected from each plot and composited together and the essential oil extraction process was conducted at the Wolaita Sodo University Horticultural Laboratory by using a seed powdered sample of 10 g. The solvent used for the extraction was hexane. Hexane is boiled at 95 and when it condenses extracts oil from the powder. Water is used as a cooling agent. The apparatus used for extraction was a soxhlet
- **Harvest index:** The harvest index was calculated as the ratio of seed yield to above-ground dry biomass per plot and multiplied by 100 at harvest from the respective treatments

Data analysis: The data was subjected to Analysis of Variance (ANOVA) for RCBD in factorial arrangements using statistix8 software. All significant mean separation was compared using the Least Significant Difference (LSD) test at a 5% probability level.

RESULTS

Days to 50% flowering: The results of the analysis of variance indicated that the main effect of NPS fertilizer had a significant ($p \leq 0.05$) effect on days to 50% flowering but inter-row spacing and the interaction effects were non-significant (Table 1). Regarding days to 50% flowering, the shortest days (50.42) to flowering were observed with 100 kg ha^{-1} NPS fertilizer applied which was statistically the same with 50 and 150 kg ha^{-1}. The most delayed or the longest days (53.58) were observed with zero fertilizer (Table 2).

Days to 50% maturity: The current investigation revealed that the main effect of NPS fertilizer rates had a significant ($p \leq 0.05$) effect on days to 50% maturity but inter-row spacing and the interaction effects were non-significant (Table1). The shortest days to 50% maturity (90.08) were observed from 100 kg ha^{-1} NPS fertilizer applied whereas the longest (95.33) days were observed from zero fertilizer (Table 2). Moreover, the fertilized plots did not show statistically significant differences among each other through the fastest was 100 kg NPS ha^{-1}. On average the maturity range was about 5.27 days due to fertilizer application.

Plant height: The analysis of variance indicated that plant height was significantly ($p \leq 0.05$) influenced by the main effects of NPS fertilizer rates and inter-row spacing whereas their interaction was non-significant (Table 1). The plant

Table 1: Mean square values of ANOVA for the effect of NPS fertilizer rates and inter-row spacing on some selected traits coriander at Wolaita Sodo, 2020/21

Variables	Rep	FR	SP	FR×SP	Error	CV (%)
Degree of freedom	2	3	3	9	30	
Days to 50% flowering	14.15	28.75*	29.14ns	3.88ns	9.83	6.06
Days to 50% maturity	67.90	97.39*	3.39ns	1.63ns	31.70	6.08
Plant height (cm)	0.98	1679.40**	98.35*	8.25ns	28.46	9.39
Number of basal leaves/plant	0.19	0.55*	0.47*	0.06ns	0.15	8.34
Number of branches/plant	0.32	21.12**	8.44**	1.50*	0.60	12.26
Number of umbel/plant	18.84	131.64**	80.63**	13.00*	5.77	14.12
Number of umbel lets/plant	46.99	2336.05**	771.45**	256.97**	37.57	15.69
Number of seed/umbel	0.90	201.17**	58.71**	31.41*	11.21	16.44
Seed yield/plant (g)	0.62	14.41**	19.10**	2.54**	0.20	15.35
Seed yield (kg ha^{-1})	36347	880985**	230297**	96014**	12618	13.68
Harvest index	79.37	600.77**	475.57**	145.73**	25.71	10.91
Thousand seed wt.(g)	1.50	10.60**	3.26ns	0.25ns	1.17	11.21
Essential oil yield (kg ha $^{-1}$)	1.45	59.35**	0.62ns	0.14ns	0.24	9.27

**, * and ns indicate, significant at p<0.01, significant at p<0.05 and non-significant, respectively, Rep: Replication, FR: Fertilizer rate, SP: Inter-row spacing and CV (%): Coefficient of variation

Table 2: Effect of NPS fertilizer rates and inter-row spacing on some phenology and growth traits of coriander, 2020/21

NPS-fertilizer rates	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Number of basal leaves
0 kg	53.58^{a}	95.33^{a}	40.59^{c}	4.43^{c}
50 kg	52.58^{ab}	94.75^{ab}	58.57^{b}	4.54^{bc}
100 kg	50.42^{b}	90.08^{b}	69.00^{a}	4.79^{ab}
150 kg	50. 58^{b}	90. 17^{b}	59.12^{b}	4.89^{a}
LSD	2.62	4.69	4.45	0.32
Inter row spacing				
10 cm	53.167	93.000	59.33^{a}	4.42^{b}
20 cm	53.083	93.083	59.07^{a}	4.59^{ab}
30 cm	50.750	92.167	55.39^{ab}	4.84^{a}
40 cm	50.167	92.083	53.48^{b}	4.80^{a}
LSD (5%)	NS	NS	4.45	0.32
CV (%)	6.06	6.08	9.39	8.34

Mean with the same letter in each column are non-significant at 5% probability, CV: Coefficient of variation, LSD: Least significant difference and NS: Non-significant

height linearly increased with the addition of NPS up to 100 kg ha^{-1} and showed a declining trend beyond. The tallest plant height (69.00 cm) was recorded by fertilizer 100 kg NPS ha^{-1} whereas, the shortest plant height (40.593 cm) was recorded from zero NPS (Table 2). The addition of 100 kg NPS ha^{-1} has increased the height by about 69.99 % as compared to zero fertilizer. In the case of inter-row spacing, the tallest plant height (59.33 cm) was recorded by 10 cm followed by 20 cm inter-row spacing (59.07 cm) which are statistically the same. But the shortest plant height (53.48 cm) was recorded by 40 cm inter-row spacing (Table 2).

Number of basal leaves: The investigation revealed that the main effects of NPS fertilizer rates and inter-row spacing significantly (p<0.05) affected the number of basal leaves but their interaction was non-significant (Table 1). The number of basal leaves increased with the increasing application of NPS. The highest number of the basal leaf (4.89) was recorded by the addition of 150 kg NPS ha^{-1} followed by 100 kg NPS ha^{-1} (4.79) which was statistically on par whereas the lowest (4.43) was recorded by zero kg ha^{-1} NPS. In the case of row spacing, the results followed a similar trend to that of NPS rates. The highest number of the basal leaf (4.84) was recorded by 30 cm inter-row spacing followed by 40 cm (4.80) which was statistically the same but the lowest (4.42) was recorded at 10 cm row spacing (Table 2).

Branches number per plant: The analysis of variance revealed that both main effects of NPS fertilizer rates and inter-row spacing and their interaction had a significant (p<0.05) effect on branch number per plant of coriander (Table 1). The highest (8.97) branch numbers per plant were recorded by the interaction of 100 kg NPS ha^{-1} and 30 cm inter-row spacing application that was statistically on par with results (8.70 and 8.57) obtained by 100 kg ha^{-1} NPS with 40 cm inter-row and 150 kg ha^{-1} NPS with 30 cm inter-row spacing, respectively. Whereas the unfertilized plot with 10 cm inter-row spacing recorded the lowest (4.0) branch number per plant (Table 3). The range of branch numbers was 4.97 which indicated more than double as compared to the lowest value.

Table 3: Interaction effect of NPS and inter-row spacing on the number of branches per plant of coriander at Wolaita, 2020/21

	Inter-row spacing (cm)			
NPS rates (kg ha^{-1})	10	20	30	40
0	4.00^{h}	4.80^{gh}	4.70^{gh}	5.20^{efgh}
50	4.87^{fgh}	5.40^{defg}	5.90^{cdefg}	7.23^{b}
100	6.10^{bcdef}	6.47^{bcde}	8.97^{a}	8.70^{a}
150	6.6^{bcd}	6.73^{bc}	8.57^{a}	7.00^{bc}
LSD (5%)	1.29			
CV (%)	12.26			

Mean followed by the same letter are no-significant at 5% probability, CV: Coefficient of variation and LSD: Least significant difference at 5% probability level

Table 4: Interaction effect of NPS and inter-row spacing on yield and yield components of coriander at Woaliata, 2020/21

NPS (kg ha^{-1})	Interrow spacing (cm)	NUPP	Number of umbellate/plant	Number of seed/umbel	Seed yield (kg ha^{-1})	Harvest index
0	10	8.47^{f}	19.33^{h}	14.17^{f}	700.0^{fgh}	37.10^{gh}
	20	9.07^{f}	20.0^{h}	14.23^{f}	455.1^{j}	37.46^{gh}
	30	16.17^{cde}	22.33^{h}	14.97^{f}	517.6^{hij}	39.47^{fgh}
	40	16.27^{cde}	23.5^{gh}	16.13^{ef}	386.7^{j}	32.94^{h}
50	10	14.73^{e}	27.37^{fgh}	15.03^{f}	797.8^{ef}	37.99^{gh}
	20	15.63^{de}	33.3^{efg}	21.33^{cde}	727.0^{fg}	41.42^{fg}
	30	19.9^{abc}	38.93^{cde}	22.37^{cd}	678.6^{fghi}	57.07^{bc}
	40	19.4^{abcd}	49.0^{bc}	22.67^{cd}	546.3^{ghij}	57.33^{bc}
100	10	15.23^{e}	33.07^{efg}	18.67^{cdef}	937.8^{de}	37.80^{gh}
	20	21.33^{ab}	45.3^{bcd}	21.87^{cd}	1127.8^{bc}	47.86^{de}f
	30	23.27^{a}	71.0^{a}	29.87^{a}	1366.7^{a}	65.87^{a}
	40	22.02^{a}	70.0^{a}	28.33^{ab}	1038.3^{cd}	62.95^{ab}
150	10	17.0^{cde}	37.27^{def}	22.23^{cd}	1000.0^{cd}	41.83^{efg}
	20	18.0^{bcde}	45.03^{bcd}	22.87^{bc}	1261.1^{ab}	50.18^{cde}
	30	19.3^{abcd}	54.27^{b}	24.07^{bc}	1103.7^{bcd}	51.13^{cd}
	40	16.3^{cde}	35.47^{def}	17.20^{def}	494.4^{ij}	45.10d^{efg}
LSD (5%)	4.01	10.22	5.58	75.00	8.45	
CV (%)	14.12	15.69	16.44	15.35	10.91	

Mean with the same letter in each column are no-significant, NUPP: Number of umbels per plant, AGB: Above-ground biomass, LSD: Least significant difference, CV: Coefficient of variation

Number of umbels per plant: The number of umbels was directly related to the yield of coriander that is more umbels per plant ensures more seed yield. The results of the present experiment showed the umbel number was significantly ($p\leq0.05$) affected by the interaction effects of NPS fertilizer rates and inter-row spacing (Table 1). The number of umbels showed an increasing trend with the addition of NPS fertilizers up to 100 kg ha^{-1} but slightly declined then after. The umbels number per plant varied from 8.47 recorded by zero fertilizer with 10 cm inter-row spacing to 23.27 recorded by 100 kg ha^{-1} with 30 cm spacing. The number of umbels per plant has shown a 174.73% advantage due to the application of 100 kg ha^{-1} NPS fertilizer in 30 cm spacing as compared to zero fertilizer in 10 cm inter-row spacing (Table 4).

Number of umbellets per plant: The umbellets number was significantly ($p\leq0.05$) affected by the interaction effect of NPS fertilizer rates and inter-row spacing (Table 1). The higher number (71.0 and 70) umbellets per plant were recorded from the application of 100 kg NPS ha^{-1} with 30 and 40 cm inter-row spacing, respectively which was statistically on par. Whereas, the lowest number (19.33) was obtained by zero application of NPS with 10 cm inter-row spacing (Table 4).

Number of seeds per umbel: The current investigation revealed seed number per umbel was significantly ($p\leq0.01$) affected by the interaction effects of NPS fertilizer rates and inter-row spacing (Table 1). The seed number had shown a wide range of yield variation from 14.17-29.87. The highest average seed number per umbel (29.87) was recorded by 100 kg NPS ha^{-1} with 30 cm inter-row spacing while statistically similar but numerically different (28.33) result was found by 100 kg ha^{-1} NPS applied with 40 cm inter-row spacing. The lowest average number (14.17) was obtained from zero NPS applied with 10 cm inter-row spacing (Table 4).

Seed yield per hectare (kg): The analysis of variance indicated that seed yield was significantly ($p<0.01$) influenced by main factors and their interaction (Table 1). A significant increase in seed yield per hectare was observed in response to NPS fertilizer rates and inter-row spacing. Treatment or plots with 100 kg ha^{-1} NPS with 30 cm row spacing gave the highest

Table 5: Effect of NPS fertilizer rates and inter-row spacing on quality of coriander

NPS rates (kg ha^{-1})	1000 seed weight (g)	Essential oil content (kg ha^{-1})
0	8.62^{b}	2.20^{d}
50	9.15^{b}	5.11^{c}
100	10.65^{a}	7.32^{a}
150	10.23^{a}	6.37^{b}
LSD	0.90	0.41
Interrow spacing (cm)		
10	9.07	5.04
20	9.38	5.09
30	10.11	5.53
40	10.09	5.35
LSD	NS	NS
CV (%)	11.21	9.27

Mean with the same letter in each column are no-significant at 5% probability, CV: Coefficient of variation in percentage and LSD: Least significant difference at 5% probability level

significant seed yield (1366.7 kg) that was superior to others except for treatment that 150 kg NPS ha^{-1} applied to 20 cm (1261.1 kg). But the lowest yield (386.7 kg) was recorded by zero fertilizer with 40 cm inter-row spacing (Table 4). The yield variation of the 980.0 kg range was recorded due to appropriate fertilization and spacing which has a significant economic benefit for the producers in the study area. Furthermore, an optimum amount of NPS rate with optimum spacing showed about 253.42% yield advantage as compared to the control (zero fertilizer).

Harvest index: The result of the present investigation showed that the harvest index was significantly ($p\leq 0.01$) affected by the main and interaction effect of NPS fertilizer rates and inter-row spacing (Table 1). The highest harvest index (65.87%) was obtained by the interaction of (100 kg NPS with 30 cm inter-row spacing) followed by (100 kg NPS with 40 cm inter-row spacing), while the lowest (32.94%) was obtained by unfertilized (Table 4).

Thousand seed weight: The results of the analysis of variance indicated that the main effect of NPS fertilizer had a significant ($p\leq 0.01$) effect on thousand seed weight but that of inter-row spacing and the interaction was non-significant (Table1). The highest 1000-seed weight (10.65 g) was obtained by 100 kg ha^{-1} NPS followed by 10.23 g obtained by 150 kg ha^{-1} NPS which was statistically similar whereas the lowest (8.62 g) was recorded by zero NPS (Table 5).

Essential oil (kg ha^{-1}): The analysis of variance indicated that the essential oil content was highly significantly ($p\leq 0.01$) influenced by the main effect of NPS fertilizer but neither the main effect of inter-row spacing nor the interaction effects had shown a significant effect (Table 1). The highest essential oil content (7.32 kg) was recorded by the 100 kg ha^{-1} NPS followed by 150 kg ha^{-1} (6.37 kg) whereas the lowest (2.20 kg ha^{-1}) was recorded by unfertilized (Table 5). The range of essential oil content was 5.12 kg ha^{-1} which is of paramount importance in the production of coriander since it is the most important and economic quality parameter. According to the current investigation, about a 232.7% increment in essential oil content as compared to control (zero fertilizer) was observed due to fertilizer effects.

DISCUSSION

The application of different rates of NPS fertilizer and different inter-row spacing used at Wolaita Sodo, Ethiopian in the 2020 and 2021 cropping seasons showed variation in terms of flowering date in coriander could be attributed to cumulative effects of nitrogen for growth enhancement and that of phosphorus nutrient that enhances reproductive phase that fastened flowering and subsequent maturity. This result was in line with Gutema *et al.*[22] who confirmed that the number of days to 50% flowering was significantly affected by the main effects of NPS rates and varieties of fenugreek. According to the report, the rate of NPS increasing from zero to 200 kg ha^{-1} reduced the number of days required to reach 50% flowering from 65.89-62.11 days.

The application of NPS fertilizer rates had a significant difference in days to 50% maturity was associated with the faster growth of plants due to the nitrogen effect. Again the hastened maturity might be because phosphorus nutrient enhances the reproductive phase that fastened flowering and subsequent maturity. This result was in line with the report of Javiya *et al.*[23] who reported that the growth and reproductive phase development of coriander is significantly affected by fertilizer application. Again Usman[24] indicated that higher NPK and S doses at wider spacing had induced seed yield and early maturity. Similarly, Usman[24] reported enhanced flowering and maturity due to NPS fertilizers in his experiment conducted at three different locations on coriander. He reported early maturity (116.00 days) by using 90 kg NPS ha^{-1} at Lume in 2019/20 and (103.33 and 106.33 days) from 150 kg NPS ha^{-1} at Adami Tulu and Lume in 2020/21, respectively, in Ethiopia whereas, there was significantly delayed maturity across years and locations due to zero fertilizer rates.

The increase in plant height due to applied NPS fertilizers could be attributed to the cumulative effects of the contributions of these fertilizers to the growth and development of the crop. Nitrogen induces cell multiplication and elongation thereby vegetative growth under optimum conditions, P is the main element involved in energy transfer for cellular metabolism in addition to its structural role and sulfur plays the role in the formation of chlorophyll and encouraged vegetative growth. Similar research done so far confirmed this result as reported by Seid[25]. He reported enhanced growth in the height of the crop because nitrogen, phosphorus and sulfur nutrients are involved in vital plant functions and contributed to better growth. According to Usman[24], the tallest plant height of (131.67, 121.2 and 127.5 cm) was recorded at Adami Tulu, Dugda and Lume with fertilizer rates of 90, 90 and 120 kg ha^{-1}, respectively in 2019/20 and the highest plant height (106.73, 118.1 and 115.07 cm) was recorded at Adami Tulu, Dugda and Lume with fertilizer rate of 120, 150 and 150 kg ha^{-1} in 2020/21, respectively, while the shortest plant height was obtained at zero fertilizer rates in both year. Again in line with the current result, Singh[26] reported increased plant height due to increased uptake of nitrogen, which is the constituent of protein and protoplasm, vigorously inducing the vegetative development of the plant hence the longest plant height was achieved.

The observed crop behaviour under closer spacing is in close conformity with the findings that in many crops up to a certain level of population, the plant elongates rapidly due to mutual shading but beyond this, elongation is checked due to reduced availability of photosynthesis. Similar results were observed in previous studies[16,17].

The numbers of basal leaves in response to the increasing rate of blended NPS fertilizer and row spacing might be due to more accessibility of N, P and S at the high rates of NPS that in turn might have played a positive role in cytokinin synthesis and cell division and thereby accelerated the vegetative growth of plants. This result was in line with Cook *et al.*[27] who stated the positive role of P found in NPSB fertilizer in emerging radicle and seminal roots during seedling establishment in wheat. Hossain and Pariari[28] reported similar findings. They concluded that higher nitrogen and phosphorus fertilizer application promotes vegetative growth in coriander as compared to zero or control treatment.

The highest branch number per plant due to higher levels of NPS fertilizer rates with wider plant spacing could be attributed to the optimum supply of NPS fertilizer to wider row spacing associated with high photosynthetic activity leading to vigorous vegetative growth and branching. This result was in line with Diwan *et al.*[17] who reported that greater inputs under wider spacing resulted in profuse branching which might have helped in larger canopy development and delayed plant to attain the reproductive phase. Present findings also follow those reported by Lokhande *et al.*[16] and Nabi *et al.*[29] who reported that the maximum number of lateral branches (7.75) was recorded with the highest level of nitrogen (100 kg N ha^{-1}) application through urea.

The significant effects of NPS rates and inter-row spacing on the number of umbels per plant could be due to the balanced nutrition and spacing that helped for optimum vegetative growth which gave a conducive environment for the crop to express its genetic potential. Thus, plants with optimum (100 kg NPS ha^{-1} with 30 com inter-row spacing) could develop more and could produce more branches resulting in a greater number of umbels per plant. The current finding was in agreement with some findings reported by Izgi[30] who reported the highest number of umbels by 100 kg ha^{-1} and the lowest number (10.1) by 60 kg ha^{-1} nitrogen application. Again Nabi *et al.*[29] reported the significant effects of N and P fertilizers on umbel number per plant in coriander.

In the same way as umbels per plant, the number of umbellets per umbel was also significantly increased with higher fertilizer and optimum inter-row spacing. This could be due to better growth of branches and umbels that contributed to the higher number of umblellets. This was also substantiated by the findings of Nabi *et al.*[29] who reported the maximum number of umbels, umblellets and seeds per umbel due to the interaction effects of N and P fertilizers used in their experiment. The current investigation is also supported by the findings of the study conducted by Dharmatti *et al.*[31]. They reported the optimum availability and uptake of nutrients, in turn, resulted in higher photosynthesis, tissue differentiation and assimilation of translocation and turn, leading to better vegetative growth and yield attributes such as the number of umbels per plant, number of umbellets per plant and seeds per umbel.

The highest seed yield per plant and thereby per hectare (1366.7 kg) could be attributed to the highest number of yield components and better vegetative growth manifested by optimum fertilizers (100 kg ha^{-1} NPS) application coupled with optimum (30 cm) inter-row spacing. The highest branch numbers, umbels and umbellets that have a direct correlation would have contributed to the highest seed yield. This result corroborated with Menaria and Maliwal[32] in fennel and Sinta *et al.*[33] in coriander who reported that yield attributes, seed, oil yield and oil content were all enhanced by the application of N, S and Zn fertilizers. The best fertilizer combination was NPKS (80+40+40+20) kg ha^{-1} [34]. Similar results were achieved and reported by Dharmatti *et al.*[31].

The significant variation in harvest index which is an indication of economic yield might be due to optimum nutrients to crops with wide spacing encouraging a high harvest index. This result agrees with Kassu *et al.*[35] who reported a maximum harvest index at the highest row spacing of chickpeas than the lowest row spacing. Similarly, the highest 1000 seed weight might be due to the optimum dose of NPS fertilizer application contributing to increasing the efficiency of major nutrients and thus, leading to higher seed weight and yield. The findings of this investigation were in close conformity with those of Moniruzzaman *et al.*[34] and Idrees *et al.*[36] who obtained the highest 1000 seeds weight with the highest nitrogen and phosphorus dose while Tuncturk *et al.*[37] reported thousand-seed weight was affected by different doses of nitrogen and sulfur on fenugreek.

The essential oil content was significantly affected by NPS fertilizer application might be due to the contribution of balanced nutrients played important role in physiological processes to maximize its oil content as was observed by total seed yield and 1000 seed weights. The seed quality due to balanced nutrition such as fullness has positively affected the essential oil content up to the optimum rate of application. This result was in close conformity with[34,38], who found the effect of fertilizer (nitrogen and phosphorus) on essential oil rate. Usman[24] also reported that increasing the amount of NPS fertilizer significantly increased essential oil content as compared to zero fertilizer. Again P treatments showed that increasing P fertilizer significantly increased the percentage and yield of essential oils[39].

CONCLUSION

The current investigation indicated that the location-specific cultural practices recommendation is very important for maximization of yield and quality in coriander. Among the tested rates of NPS fertilizer and inter-row spacing, it can be concluded that using 100 kg ha^{-1} NPS fertilizer with 30 cm inter-row spacing was found to be optimum for growth, yield and quality of coriander production.

SIGNIFICANCE STATEMENT

This study will help small-scale farmers to determine the application of appropriate doses of fertilizers in combination with appropriate spacing to maximize crop yield and quality. Fertilizer optimization has both economical and environmental concerns whereby excess addition of fertilizers has the potential to produce pollutants both in the air and soils. This finding at the same time benefits the researchers to work more in different areas of crop production. Also, investors can use the information to boost the production and productivity of coriander in the most economically feasible way.

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