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ORIGINAL RESEARCH PAPER

Growth, yield, and quality responses of turmeric (*Curcuma longa* L.) to nitrogen fertilizer rate and timing of its application

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Abstract

Soil fertility decline is one of the factors that result in low productivity of turmeric (*Curcuma longa*, Zingiberaceae Lindl.,) in Ethiopia. An experiment was conducted to determine the effects of N rate and time of application on growth, yield, and quality of turmeric crops in Ethiopia. The trial consisted of five N rates: 0, 46, 69, 92, 115 kg ha^{-1}, and five split application times: full dose at emergence, two times (1/2), three times (1/3), four times (1/4), and five times (1/5) equally split applications, arranged in a split plot design with three replications. Plant heights, tiller number per plant, pseudo-stem girth, mother and finger rhizome numbers and weights, fresh rhizome yield, oleoresin and essential oil contents – all were significantly affected by the interaction effects of N rate and time of application. The three times split application of 115 kg N ha^{-1} produced higher values of these crop characteristics. This application rate also produced a better yield and quality than did two times of application, the most commonly used practice. Therefore, turmeric producers in southwestern Ethiopia should apply 115 kg N ha^{-1} in three equally split applications to improve turmeric yield and quality.

Keywords
essential oil; oleoresin; rhizome yield

Introduction

Turmeric (*Curcuma longa* L.) is one of the most widely grown spice crops in the southwestern part of Ethiopia. It is a versatile remunerative cash crop and its primary product is the cured dried rhizome [1]. Turmeric has a wide range of values such as an orange coloring powder used in the textile industry, in the food industry and it also has medicinal values. It is also appreciated for its aroma, flavor and oleoresin content [2]. According to Hailemichael et al. [3] turmeric is well known in every Ethiopian dish (kitchen) as a source of an ingredient used in the preparation of local sauces, e.g., "wot".

Turmeric has become one of the most important cash crops with a good economic return, especially for resource-poor farmers in southwestern Ethiopia [2,3]. The crop has been commercialized in a large private farm and also through major investment projects at national level. It offers a good scope for diversification of the existing arabica coffee-based cropping system of southwestern Ethiopia. Ethiopia exports turmeric mainly in their dried form and a little as oleoresin or essential oil extract [4]. In 2013, turmeric accounted for 8% (US$ 2.1 million) of the total spice export in Ethiopia [5].

The production of the turmeric crop in Ethiopia is, however, low as compared to other major turmeric producing countries. According to Addisu [6], the national productivity of turmeric in Ethiopia in 2012 was 2.4 t ha^{-1} as compared to 4.0 t ha^{-1}

in India. This production gap could be due to several factors among which declining soil fertility is one. Several studies have reported that turmeric is a nutrient exhaustive crop, particularly for nitrogen [1,7]. The high nutrient requirement of turmeric is due to its shallow rooting, prolonged growth period (up to 9 months), and the potential to produce large amounts of dry matter per unit area [6]. Nutrient uptake in turmeric is also dependent on the stage of development (a phase of moderate vegetative growth, a phase of active vegetative growth, a period of slow vegetative growth, and a phase approaching senescence [8]). The active vegetative growth and high dry matter production phases are the periods during which the maximum uptake of nutrients takes place [9].

Since nitrogen is highly mobile, its use and demand are continuously increasing as it is subjected to a high loss from the soil plant system [10]. For example, only 33–56% of applied fertilizer N was recovered by a potato crop in an irrigated coarse textured soil [11]. Split application of N is one of the strategies for improving N use by crops [12]. According to Follett and Hatfield [13], the time of N application plays a significant role in minimizing NO_3^- losses from agricultural land, especially for crops grown under wet and warm conditions. Southwestern Ethiopia is the major turmeric growing area that receives high rainfall where nutrient loss through leaching is very common [1]. This makes the nutrient unavailable during the critical stages of crop growth. It has also been reported that split application of N fertilizer keeps the nutrient availability throughout the active growth stages of turmeric [14]. However, in Ethiopia N has been applied using local practices, half at planting and half at emergence [1]. This research was therefore initiated to determine the optimum dose and right timing of application that will allow maximum yield of turmeric both in quantity and quality so as to meet the national production and export targets. The aim was to assess the response of N rate and time of application on the growth, yield, and quality of turmeric at Tepi, southwestern Ethiopia.

Material and methods

Description of the study site

The trial was conducted at Tepi National Spices Research Center (TNSRC) during the main cropping season (under rain-fed conditions), from April 2016 to January 2017. The Center is in the Southern Nations, Nationalities, Peoples Regional State (SNNPR), Sheka administrative zone at Tepi town, located about 611 km far from Addis Ababa, the capital city of Ethiopia. It is located at 7°10′ N latitude and 35°25′ E longitude. The altitude of the site is 1,200 m above sea level and is characterized by hot, humid climate with an average annual rainfall of 1,559 mm and mean maximum and minimum temperatures of 30.23°C and 16.09°C, respectively [15]. The soil type is classified as a Nitisol, which is dominated by a loam texture and a pH range of 5.6 to 6.0 [16].

Experimental treatments and design

The treatments consisted of five levels of N (0, 46, 69, 92, and 115 kg N ha^{-1}) and five equally split applications of N fertilizer. The timing of N application was adjusted according to the growth stage of the turmeric plant [8]. Accordingly, the timings of N application were adjusted as follows: first time of application (full dose at emergence); second time of application (half at emergence, half at the lag growth stage); third time of application (1/3 at emergence, 1/3 at the lag growth stage, and 1/3 at the tillering stage); fourth time of application (1/4 at emergence, 1/4 at the lag growth stage, 1/4 at the tillering stage, and 1/4 at the slow growth stage), and fifth time of application (1/5 at emergence, 1/5 at the lag growth stage, 1/5 at the tillering stage, 1/5 at the slow growth stage, and 1/5 at the crop approaching maturity stage). At crop emergence, urea was immediately drilled between rows and incorporated into the soil, based on the treatments. The second, third, fourth, and fifth equally split N urea applications were made by side dressing at the specified growth stages of the crop: at the beginning of July, August, and September, and at the end of October, 2016, respectively.

The two factor treatments were arranged in a split plot design with three replications. The rates of N were assigned to the main plots and the time of N application to the subplots. The main plot and subplot sizes were 21.6 m^2 and 3.24 m^2, respectively. A distance of 1 m and 0.5 m separated the main plots and the subplots, and a distance of 2 m was allowed between blocks. Each plot had six rows of which the four middle rows were used for data collection. The recommended rate of 23 kg P_2O_5 ha^{-1} Triple Super Phosphate (TSP) [1] was applied uniformly to all plots at planting. Turmeric 'Dame', which was released by Tepi National Spices Research Center in 2007, was used for the trial. It is a high yielding turmeric cultivar adapted to a wide range of altitudes from low to mid-range (up to 2,000 m a.s.l) areas.

Experimental procedures

The field used for the trial was prepared following conventional tillage practices before planting of the turmeric. In accordance with the specifications of the design, a field layout was prepared and each treatment was assigned randomly to the trial plots within a block. After the seedbeds were leveled, the "seed" rhizomes ranging from 20–30 g [17] of uniform primary finger rhizomes were planted at the recommended spacing of 30 × 15 cm between rows and plants, respectively. Planting was carried out on April 29, 2016 using a manual row maker or a hand hoe. Weeds were removed by hand according to the locally recommended practices, starting from crop emergence until the plant canopy became closed. Other field management practices were applied as recommended for the crop.

Data collection

Growth, yield, and yield component data were collected at physiological maturity, recognized when plant leaves started drying and withering, and then quality analysis was performed after harvesting. Growth attributes such as plant height (cm), total number of tillers per plant, and pseudo-stem girth per plant (mm) were recorded from eight randomly selected plants from middle rows and their mean values were used for further data analysis. Yield and yield-related traits such as number of mother rhizomes per plant, number of finger rhizomes per plant, weight of mother rhizomes per plant, and weight of finger rhizomes per plant were collected from 18 representative sample plants (out of the 40 plants) after separating the primary and secondary finger rhizomes from their mother rhizomes. Fresh rhizome yield was calculated from total (mother, primary, and secondary) rhizome weights (g per net plot area) and converted onto an ha basis, and the data then expressed as kg ha^{-1}. Rhizomes were cleaned following harvesting and mother and finger rhizomes weighed separately.

Quality data including oleoresin and essential oil contents were determined. To determine the oleoresin content (w/w) (%), the rhizomes were washed, boiled at 100°C for 45 minutes, and exposed to sun drying for 6 days, and then ground to a fine powder. Oleoresin content was measured for each treatment using a solvent extraction method based on an American Spice Trade Association procedure [18]. To determine the oleoresin content, 100 g of powdered samples was taken and placed in the thimble. This was then covered with a piece of cotton to prevent sample loss and then placed in an extractors which was linked to the solvent flask at the base through two tubes. One of the tubes was a side tube for the passage of solvent vapors and the other was a tube for refluxing the extracted liquid back to the flask of the Soxhlet apparatus.

More than half of the flask was filled with petroleum ether at 60–80°C. The assembly was fitted with a condenser and then heated on a mantle, and solvent added to the center of the thimble. The extraction was continued for 4 hours, after which the samples were allowed to cool. The solvent was then transferred to the evaporating flask of the rotary evaporator which was used for distilling off the solvent under vacuum. Finally, the flask was cooled in a desiccator and then weighed. The oleoresin content was calculated using the formula applied by several authors [18–20]: *Oleoresin content* (w/w) (%) = [*Weight of oil* (g)]/[*Weight of rhizome sample taken* (g)] × 100.

The essential oil content of each treatment was determined using hydro-distillation methods based on an American Spice Trade Association procedure [18: p. 48–50]. A Clevenger apparatus was used to determine the percentage of volatile oils present in the oil-bearing plants and their parts. Firstly, samples of 150 g were placed in 2-L clean flasks for each treatment. Next, approximately 500 mL of tap water was added to a flask. The flask was brought into the mantle and the set up was made. First, the stand rod and stand base were connected to each other. Secondly, the stand rod was connected to clump by clump holder, while the flask connected to stand rod by using the clump. Finally, the flask, stand rod, as well as the condenser was connected to the Clevenger or oil separator. The cold water was released by using the hose tube, after that the socket was connected to the heating mantle. The extraction was continued for 4 hours, then the heating mantle was disconnected from the sockets. Finally, the oil was removed from the oil separator or Clevenger apparatus using a pipette, and the water was separated from the oil by pressing the outlets of the pipette. The oil content was measured in g and calculated as a percentage based on the formula described by several authors [18–20]: *Essential oil content* (v/w) (%) = [*Weight of essential oil recovered* (g)]/ [*Weight of rhizome sample distilled* (g)] × 100.

Statistical analysis

The data recorded in this study were subjected to a full statistical analysis. Two-way analyses of variance (ANOVA) were carried out using SAS version 9.2 statistical software [21], after checking that all the assumptions for ANOVA were met by the data sets. Significant differences between treatment means were delineated by least significant differences (LSD) at the 5% probability level.

Results

Growth parameters

The analysis of variance revealed that the growth attributes such as plant height, number of tillers per plant, and pseudo-stem girth were all significantly ($p < 0.05$) influenced by the main effects of N rate and the time of its application, and also their interaction. The general trend indicated that increasing N rate increases the growth of the turmeric plant in this study area. The highest plant height (78 cm) was recorded when 115 kg N ha^{-1} was applied in three equal splits (Tab. 1). A greater number of tillers per plant was also produced when 115 kg N ha^{-1} was applied in three equally split applications, followed by the same N rate applied in two equal split applications, and 92 kg N ha^{-1} in three equally split applications (Tab. 2). The greatest pseudo-stem girth (16.5 cm) was recorded from plants which received 115 kg N ha^{-1} in three equal splits (Tab. 3). The lowest values of vegetative growth measures were recorded from the control treatment (i.e., the zero N application).

Yield and yield components

Both the main effects of N rate and time of application, as well as their interaction had a significant effect ($p < 0.05$) on the number of mother, primary, and secondary finger rhizomes per plant, fresh weight of mother, and finger rhizomes per plant and fresh rhizome yield. The maximum number of mother rhizomes per plant was recorded when 115 kg N ha^{-1} was applied in two and three equal splits (Tab. 4). Similarly, a higher number of both primary and secondary finger rhizomes per plant was recorded for this treatment (Tab. 5). The minimum number of mother and finger (both primary and secondary) rhizomes per plant was recorded from the unfertilized plot.

The largest fresh weight of mother rhizome per plant (88.2 g) was recorded from three equal split application of 115 kg N ha^{-1} whilst the lowest fresh weight was recorded from the unfertilized plot (Tab. 6). Similarly, a higher fresh weight of finger rhizomes

Tab. 1 Interaction effects of N rate and time of application on the height (cm) of *Curcuma longa* plants grown at Tepi, southwestern Ethiopia in 2016/2017.

Treatment	N rate (kg ha^{-1})				
N split	**0**	**46**	**69**	**92**	**115**
Sp1	58.26 ^{n}	67.83 ^{fg}	66.17 ^{ghi}	68.08 ^{fg}	70.96 ^{de}
Sp2	59.58 ^{mn}	67.38 ^{gh}	69.71 ^{ef}	72.67 ^{cd}	75.54 ^{b}
Sp3	57.62 ^{n}	65.21 ^{hij}	70.54 ^{e}	75.38 ^{b}	77.96 ^{a}
Sp4	61.54 ^{klm}	67.83 ^{fg}	62.08 ^{kl}	66.88 ^{gh}	73.96 ^{c}
Sp5	58.54 ^{n}	65.96 ^{ghi}	61.21 ^{lm}	64.42 ^{ij}	63.62 ^{jk}
LSD$_{(0.05)}$			2.26		
CV (%)			4.56		

Means followed by the same letters across column and rows are not significantly different at 5% level of significance; LSD – least significance difference; *CV* – coefficient of variance; Sp1 – N application of full dose at emergence; Sp2 – N application of half at emergence and half at the lag growth stage; Sp3 – N application of 1/3 at emergence, 1/3 at the lag growth stage, and 1/3 at tillering stage; Sp4 – N application of 1/4 at emergence, 1/4 at the lag growth stage, 1/4 at tillering stage, and 1/4 at the slow growth stage; Sp5 – N application of 1/5 at emergence, 1/5 at the lag growth stage, 1/5 at tillering stage, 1/5 at the slow growth stage, and 1/5 when approaching maturity stage.

Tab. 2 Interaction effects of N rate and time of application on tiller number of *Curcuma longa* grown at Tepi, southwestern Ethiopia in 2016/2017.

Treatment	N rate (kg ha^{-1})				
N split	**0**	**46**	**69**	**92**	**115**
Sp1	3.83 ^{m}	4.71 ^{hij}	4.79 ^{ghij}	4.96 ^{fgh}	5.12 ^{ef}
Sp2	3.71 ^{m}	4.67 ^{ij}	4.92 ^{fghij}	5.71 ^{c}	6.21 ^{b}
Sp3	3.21 ^{n}	4.33 ^{kl}	5.04 ^{fg}	6.21 ^{b}	7.04 ^{a}
Sp4	3.04 ^{n}	4.62 ^{j}	4.67 ^{ij}	5.33 ^{de}	5.50 ^{cd}
Sp5	3.04 ^{n}	4.21 ^{l}	4.29 ^{l}	4.62 ^{j}	4.58 ^{jk}
LSD$_{(0.05)}$			0.27		
CV (%)			7.63		

For additional notes, see Tab. 1.

Tab. 3 Interaction effect of N and time of application on pseudo stem girth (cm) of *Curcuma longa* grown at Tepi, southwestern Ethiopia in 2016/2017.

Treatment	N rate (kg ha^{-1})				
N split	**0**	**46**	**69**	**92**	**115**
Sp1	11.69 ^{ijk}	12.54 ^{efgh}	11.56 ^{jk}	11.74 ^{hijk}	12.63 ^{efg}
Sp2	11.29 ^{kl}	13.16 ^{cde}	12.48 ^{efghi}	13.88 ^{c}	15.01 ^{b}
Sp3	10.47 ^{m}	12.56 ^{efg}	13.61 ^{cd}	15.00 ^{b}	16.51 ^{a}
Sp4	10.68 ^{lm}	11.98 ^{ghijk}	11.52 ^{jk}	12.99 ^{def}	13.65 ^{cd}
Sp5	10.12 ^{m}	12.42 ^{efghi}	11.48 ^{jkl}	10.23 ^{m}	12.26 ^{fghij}
LSD$_{(0.05)}$			0.81		
CV (%)			8.75		

For additional notes, see Tab. 1.

Tab. 4 Interaction effects of N rate and time of application on number of mother rhizomes per plant of *Curcuma longa* grown at Tepi, southwestern Ethiopia in 2016/2017.

Treatment	N rate (kg ha^{-1})				
N split	**0**	**46**	**69**	**92**	**115**
Sp1	2.67^{m}	3.92^{hi}	4.42^{bc}	4.04^{fg}	4.29^{cd}
Sp2	2.58^{mn}	3.79^{i}	4.25^{de}	4.46^{b}	4.75^{a}
Sp3	2.46^{n}	3.38^{k}	4.12^{ef}	4.42^{bc}	4.83^{a}
Sp4	2.54^{mn}	3.33^{k}	3.79^{i}	3.96^{gh}	4.54^{b}
Sp5	2.62^{m}	3.04^{l}	3.38^{k}	3.62^{j}	4.08^{fg}
LSD$_{(0.05)}$			0.16		
CV (%)			5.61		

For additional notes, see Tab. 1.

Tab. 5 Interaction effects of N rate and time of application on primary and secondary finger rhizome number per plant of *Curcuma longa* grown at Tepi, southwestern Ethiopia in 2016/2017.

Treatment	N rate (kg ha^{-1})				
N split	**0**	**46**	**69**	**92**	**115**
Primary finger rhizome number (plant^{-1})					
Sp1	6.54^{lm}	8.12^{fg}	8.42^{ef}	8.75^{de}	8.62^{de}
Sp2	7.00^{k}	7.75^{ghi}	8.00^{gh}	8.96^{cd}	9.62^{ab}
Sp3	7.17^{jk}	7.71^{hi}	7.83^{ghi}	8.54^{e}	10.00^{a}
Sp4	7.00^{k}	7.08^{k}	7.54^{ij}	7.92^{ghi}	9.25^{bc}
Sp5	6.58^{l}	6.17^{m}	7.04^{k}	7.92^{ghi}	7.71^{hi}
LSD$_{(0.05)}$			0.39		
CV (%)			6.58		
Secondary finger rhizome number (plant^{-1})					
Sp1	9.62^{jklm}	11.38^{f}	11.12^{fg}	11.96^{e}	12.42^{d}
Sp2	9.50^{klm}	10.38^{i}	12.75^{cd}	13.50^{b}	14.25^{a}
Sp3	9.50^{klm}	9.79^{jk}	10.83^{gh}	12.58^{d}	14.50^{a}
Sp4	8.33^{lm}	9.96^{j}	10.50^{hi}	11.21^{fg}	13.08^{c}
Sp5	9.29^{m}	9.71^{jkl}	9.41^{klm}	11.00^{fg}	10.96^{g}
LSD$_{(0.05)}$			0.41		
CV (%)			5.01		

For additional notes, see Tab. 1.

per plant (223.43 g) was recorded from three times split applications of 115 kg N ha^{-1} followed by the three times split application of 92 kg N ha^{-1} (Tab. 7). Furthermore, the maximum fresh rhizome yield per hectare (69,252 kg) was obtained from the plot which had received 115 kg N ha^{-1} in three equal applications, whilst the minimum yield was recorded from the 0 kg N ha^{-1} plot (Tab. 8). This result also clearly indicated that increasing the split application of N more than three times did not benefit the turmeric crop, as the fresh weight of the mother and finger rhizomes and overall yield were decreased with increasing split applications more than three times. However, the three times split application of N consistently produced a better yield and yield components than did the single and twice application treatment. The turmeric plant benefited more when N was applied in three equally split applications than other locally grown crops, where a two times split application is frequently practiced.

Tab. 6 Interaction effects of N rate and time of application on fresh weight of mother rhizome per plant (g plant^{-1}) of *Curcuma longa* grown at Tepi, southwestern Ethiopia in 2016/2017.

Treatment	**N rate (kg ha^{-1})**				
N split	**0**	**46**	**69**	**92**	**115**
Sp1	42.77 ^{i}	44.69 ^{i}	53.75 ^{efgh}	59.85 ^{d}	66.00 ^{c}
Sp2	51.63 ^{fgh}	50.11 ^{h}	56.25 ^{def}	66.36 ^{c}	77.51 ^{b}
Sp3	42.43 ^{i}	55.08 ^{defg}	64.77 ^{c}	75.42 ^{b}	88.20 ^{a}
Sp4	42.55 ^{i}	50.59 ^{gh}	51.64 ^{fgh}	65.92 ^{c}	74.00 ^{b}
Sp5	43.05 ^{i}	56.37 ^{def}	54.36 ^{efgh}	56.72 ^{de}	68.49 ^{c}
LSD$_{(0.05)}$			4.79		
CV (%)			11.04		

For additional notes, see Tab. 1.

Tab. 7 Interaction effects of N rate and time of application on fresh weight of finger rhizome per plant of *Curcuma longa* grown at Tepi, southwestern Ethiopia in 2016/2017.

Treatment	**N rate (kg ha^{-1})**				
N split	**0**	**46**	**69**	**92**	**115**
Sp1	100.17 ^{pq}	130.15 ^{lm}	141.30 ^{ij}	160.48 ^{ef}	164.76 ^{e}
Sp2	102.53 ^{pq}	132.83 ^{klm}	157.94 ^{efg}	179.39 ^{d}	195.46 ^{c}
Sp3	105.80 ^{op}	133.87 ^{jkl}	148.01 ^{hi}	206.48 ^{b}	223.43 ^{a}
Sp4	114.57 ^{n}	130.05 ^{lm}	154.77 ^{fgh}	160.73 ^{ef}	174.78 ^{d}
Sp5	96.33 ^{q}	110.89 ^{no}	126.25 ^{m}	139.41 ^{jk}	152.99 ^{gh}
LSD$_{(0.05)}$			7.57		
CV (%)			6.98		

For additional notes, see Tab. 1.

Tab. 8 Interaction effects of N rates and time of application on fresh rhizome yield (kg ha^{-1}) of *Curcuma longa* grown at Tepi, southwestern Ethiopia in 2016/2017.

Treatment	**N rate (kg ha^{-1})**				
N split	**0**	**46**	**69**	**92**	**115**
Sp1	31,764.70 ^{pq}	38,853.21 ^{lm}	43,345.07 ^{j}	48,962.47 ^{fgh}	51,280.73 ^{e}
Sp2	34,258.55 ^{no}	40,652.50 ^{kl}	47,597.16 ^{ghi}	54,612.93 ^{d}	60,659.77 ^{c}
Sp3	32,940.21 ^{op}	41,989.43 ^{jk}	47,284.31 ^{hi}	62,644.16 ^{b}	69,251.83 ^{a}
Sp4	34,914.66 ^{n}	40,142.79 ^{l}	45,869.06 ^{i}	50,368.40 ^{ef}	55,285.89 ^{d}
Sp5	30,974.58 ^{q}	37,168.03 ^{m}	40,135.21 ^{l}	43,585.00 ^{j}	49,218.45 ^{fg}
LSD$_{(0.05)}$			1,830.20		
CV (%)			5.43		

For additional notes, see Tab. 1.

Tab. 9 Interaction effects of N rates and time of application on oleoresin (% w/w) and essential oil content (% v/w) of *Curcuma longa* grown at Tepi, southwestern Ethiopia in 2016/2017.

Treatment	N rate (kg ha^{-1})				
N split	0	46	69	92	115
			Oleoresin content (% w/w)		
Sp1	14.70 ^{d}	13.45 ^{i}	13.82 ^{h}	13.88 ^{h}	14.48 ^{e}
Sp2	13.18 ^{j}	14.13 ^{g}	14.72 ^{cd}	14.65 ^{de}	15.26 ^{b}
Sp3	13.20 ^{j}	14.63 ^{de}	14.92 ^{c}	15.23 ^{b}	15.52 ^{a}
Sp4	13.53 ^{i}	14.15 ^{g}	14.32 ^{fg}	14.59 ^{de}	15.14 ^{b}
Sp5	13.57 ^{i}	13.90 ^{h}	13.90 ^{h}	14.45 ^{ef}	14.71 ^{d}
LSD$_{(0.05)}$			0.21		
CV (%)			1.92		
			Essential oil content (% v/w)		
Sp1	1.53 ^{k}	2.12 ^{i}	2.33 ^{h}	2.26 ^{hi}	2.49 ^{g}
Sp2	1.66 ^{jk}	2.76 ^{e}	2.97 ^{d}	3.23 ^{c}	3.89 ^{b}
Sp3	1.76 ^{j}	2.95 ^{d}	3.32 ^{c}	3.85 ^{b}	4.14 ^{a}
Sp4	1.65 ^{jk}	2.52 ^{g}	2.61 ^{fg}	2.69 ^{ef}	2.83 ^{de}
Sp5	1.66 ^{jk}	2.15 ^{i}	2.15 ^{i}	2.49 ^{g}	2.50 ^{g}
LSD$_{(0.05)}$			0.15		
CV (%)			7.64		

For additional notes, see Tab. 1.

Quality parameters

Both oleoresin and essential oil contents were significantly ($p < 0.05$) affected by N rate and time of application as well as their interaction. The highest oleoresin (15.52% w/w) and essential oil (4.14% v/w) contents were recorded from the three time applications of 115 kg N ha^{-1} (Tab. 9). The oleoresin and essential oil contents varied from 13.18% and 1.53% to 15.52% and 4.14% on unfertilized plots and with the highest rate of N (115 kg N ha^{-1}) application, respectively (Tab. 9). These contents exceeded the lowest by 17.75% and 170.59%, respectively. Similar to yield, better turmeric quality was also recorded when N was applied in three split applications than with just two.

Discussion

Nitrogen is the principal nutrient for all plants, which significantly increases the vegetative growth of turmeric more than any other nutrients [22]. It plays a primary role in protein synthesis and cell multiplication and elongation. It is a major constituent of enzymes and chlorophyll that are catalytic agents in promoting cell division and photosynthetic assimilation, which in turn boost plant growth and development [23]. It also enhances the efficacy of other nutrients such as potassium and phosphorus in improving the yield of turmeric [22]. An increase in turmeric vegetative growth measures such as plant height, tiller number, and thickness of pseudo-stems in treatments receiving higher N rates was probably due to the better N status of the plant during shoot elongation and the growth period. It might also contribute to the rapid conversion of synthesized carbohydrates into protein, which increases the number and size of growing cells, resulting ultimately in increased overall growth [24].

The increase in number of mother and fingers rhizomes per plant due to high N application could be ascribed to its roles in growth and tissue differentiation [25]. It can be also explained on the basis of the physiological fact that N plays a major role in protein and nucleic acids synthesis and protoplasm formation. The decreases in growth with reduced N levels could be the reason for a decline in the number of mother and finger rhizomes on the unfertilized plot. With such reduced growth components, net photosynthesis will be lower so that it is difficult for the plant to supply adequate amounts of substrate to the sinks, i.e., the rhizomes. An increase of N level could promote an increase in the number of leaves per plant which would synthesize more carbohydrates and would act as a substrate for the growth and development of rhizomes. The increase in fresh weight of mother and finger rhizomes per plant at a high rate of N application might be also associated with the higher number of mother, primary, and secondary finger rhizomes per plant recorded at the same rate. The greater average rhizome yield from high rates of N application could be associated with more luxuriant growth, foliage and leaf area and the higher supply of substrate which helped in producing larger rhizomes, hence resulting in higher yields [26]. Additionally, the greater yields at higher N rates may be due to increased stem size and number of rhizomes per plant, which might result from an increase in the number of leaves per plant. The maximum fresh rhizome yield was recorded from the maximum rate of N applied (115 kg N ha^{-1}), indicating that application of N beyond this rate could contribute even further to the yield of the crop. Our findings further advance the recommendation of an appropriate N application rate for the turmeric crop in the study area. According to Lupi and Temteme [1], 69 kg N ha^{-1} was considered as a reliable N rate for turmeric production at Tepi, southwestern Ethiopia. Considering the response of turmeric in rhizome yield in our study, it appears that the N fertilization threshold for high turmeric rhizome yield is a high one. Therefore, it is advisable to test higher rates of N in future research in order to produce conclusive results for the maximum beneficial N rate for maximum yield of turmeric here. Our results also showed that a split application of N increases N use efficiencies that produce more yield than a single, full dose application at planting. In this study, even the most commonly used methods of application, a two-time split application, produced lower rhizome yields than did a three times application indicating that N loss is high when applied only once at planting or with a two-time split application. The turmeric producers in southwestern Ethiopia should now apply N in three split applications instead of the latter common practice. The study area is well known for its high rainfall which is responsible for the leaching of nutrients, including N fertilizers.

The increased oleoresin and essential oil contents in rhizomes with high levels of N application may be due to the improved nutrition of plants at the most appropriate growth stage for their production. This indicates the positive relationships between soil N availability and its uptake, and their functional role in the synthesis of volatile oils and oleoresin in the turmeric rhizome. Sangwan et al. [27] have reported that the synthesis and oil contents of aromatic plants is enhanced when there is a high availability of soil N and increased uptake by plants.

Conclusions

Maximum rhizome yield and improved oleoresin and essential oil contents were obtained from an application of 115 kg ha^{-1} N in three equal splits (1/3 at emergence + 1/3 at the lag growth stage + 1/3 at tillering) as compared to the commonly used two times split application practiced for many crops. Therefore, an application of 115 kg N ha^{-1} in three equal splits can be suggested for the farmers in the Tepi area to maximize rhizome yield and quality. Further research should however be conducted in the future to determine the maximum N requirements of the turmeric crop for maximum yield and oil production.

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Wzrost, plonowanie i jakość ostryżu długiego (*Curcuma longa* L.) w odpowiedzi na poziom nawożenia azotem oraz termin jego aplikacji

Streszczenie

Spadek żyzności gleby jest jednym z czynników powodujących niską produktywność *Curcuma longa* (ostryżu długiego = szafranu indyjskiego = kurkumy; Zingiberaceae Lindl., imbirowate) w Etiopii. Eksperyment przeprowadzono w celu określenia wpływu poziomu nawożenia N i sposobu jego aplikacji na wzrost, plonowanie oraz jakość plonów kurkumy w Etiopii. Doświadczenie obejmowało pięć dawek N (0, 46, 69, 92, 115 kg ha^{-1}) oraz pięć terminów aplikacji [pełna dawka przy wschodach, dwa razy (po 1/2), trzy razy (po 1/3), cztery razy (po 1/4) i pięć razy (po 1/5) równomiernie podzielonych dawek] w układzie podbloków losowanych w trzech powtórzeniach. Określono wysokość roślin, liczbę rozgałęzień na roślinę, obwód pseudo-łodygi, liczbę i masę kłączy macierzystych i bocznych, plon świeżego kłącza, zawartość oleożywicy oraz olejków eterycznych. Wszystkie parametry były istotnie uzależnione od efektów interakcji pomiędzy poziomem nawożenia N a sposobem jego aplikacji. Podzielenie dawki 115 kg N ha^{-1} na trzy części wpływało na wyższe wartości analizowanych parametrów roślin. W tych warunkach uzyskano również większą wysokość i jakość plonu w porównaniu do dwukrotnej aplikacji, będącej najczęściej stosowaną praktyką. Dlatego producenci kurkumy w południowo-zachodniej Etiopii powinni stosować 115 kg N ha^{-1} w trzech jednakowo podzielonych dawkach w celu poprawy plonowania i jakości kurkumy.