

Effects of Mineral Fertilizer Doses and Ratios on Tea Yield and Quality

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Abstract

Mineral nutrients are essential to plant growth and development. The present study aimed to evaluate the effects of mineral fertilizer doses and N:P:K ratio on growth, yield, and raw material quality of the tea variety PH10 to improve the production of high-quality tea products. The field experiment was conducted from 2015 to 2017. A two-factor experiment was designed by split-plot design with three replications. The mainplot treatments were three fertilizer doses of N for one metric ton of fresh shoot products (30, 40, and 50 kg N ha⁻¹). The subplot treatments were two NPK ratios (3:1:1 and 3:1:2). Plant height, leaf canopy, plant diameter, shoot yield parameters, shoot components, biochemical compounds, and sensory quality for Oolong and Sencha tea products were evaluated. The results showed that increasing fertilizer doses from 30 up to 40 kg N per ton of fresh product improved remarkably growth, yield, and tea quality of PH10 variety. Different fertilizer ratios resulted in variations in plant growth, the content of carbohydrate, sensory quality for taste and flavor as well as total sensory quality with higher values at NPK ratio of 3:1:2. Applying mineral fertilizer with an NPK ratio of 3:1:2 and 40kg N per ton of fresh shoot products was recommended to bring about the most benefits of tea yield and quality as well as economic profit.

Keywords

Oolong tea, Sencha tea, mineral fertilizer, yield, quality

Introduction

Tea (*Camellia sinensis* L. O Kuntze.) is an important cash crop. Nowadays, tea is grown in 48 countries with a total area of around 4.2 million hectares and total production of 6.34 million tons (FAOSTAT, 2018). Vietnam is one among five world tea producers and ten world tea-exporters. In 2019, Vietnam exported

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137,000 tons at a value of USD 236 million (VITIC, 2020).

Although being a world tea producer and exporter, the export value of Vietnam tea products is still not high. The main reason is that the most product was in the form of raw material and poor competition of made tea products. To improve the quality of tea products, the processing techniques have been improved to satisfy the material requirement of high tea products such as green tea, Oolong, Longjing, or Sencha teas. Moreover, several introduced tea varieties such as Thuy Ngoc, Phuc Van Tien, or Kim Tuyen have been tested and released. Among these varieties, PH10 is a high yielding and highly tolerant to common pests and diseases, and has high raw material quality for producing Oolong and Longjing teas. However, to exploit the potential of tea production, the adoption of suitable cultivation techniques is necessary.

Being a perennial plant with high productivity, tea consumes annually a large amount of nutrients. The production of 1-ton tea required 8.8-12.2kg nitrogen (N), 1.0-1.2kg phosphorus (P), and 3.2-3.9kg potassium (K) (Tang *et al.*, 2020). Therefore, fertilizer supplements to return mineral nutrients need to be practiced frequently. Owuor (2001) reviewed that the use of fertilizers in tea production was widely practiced in tea production to improve tea productivity. Hajiboland (2017) also insisted that fertilizer was a common agricultural practice for higher production and increased tea quality. However, the abuse of chemical fertilizer did not improve soil fertility but harmed the soil bacterial community (Qiu *et al.*, 2014). Barbora (1991) reported that high N rates had harmful effects on the tea bush and its productivity. Furthermore, the redundancy of chemical fertilizer raises waste and environmental pollution as well as reduces economic efficiency. The previous studies suggest that mineral compounds be combined to improve tea yield and quality. Better yield responses were obtained with higher amounts of P and K compound nitrogenous fertilizers (Clowes, 1986). A combination of P and K was shown to be beneficial to quality (Willson & Choudhury, 1968). Venkatesan & Ganapathy

(2004) reported that tea quality was impaired when either N or K was used at high levels, but the impairment was reduced when these two minerals were combined at a ratio of 1:0.83. However, because of the different responses of tea varieties to fertilizer application (Amali *et al.*, 2019), the optimal mineral dose, as well as ratio, may be different for each tea variety. The objectives of this study were to evaluate the growth, yield, and raw material quality of tea variety PH10 to improve the production of high-quality tea products.

Materials and Methods

Experimental design

The experiment was conducted at the experimental field, Tea Research and Development Center, Northern Mountainous Agriculture and Forestry Science Institute, Phu Ho, Phu Tho, Vietnam from 2015 to 2017. Five-year-old plants of tea variety PH10 were used as experimental material. A two factorial experiment was designed by split plot design with three replications. The main plot treatments were three fertilizer doses of N for one metric ton of fresh shoot products, D1 (30 kg N ha⁻¹), D2 (40 kg N ha⁻¹), and D3 (50 kg N ha⁻¹). The sub-plot treatments were two NPK ratios, R1 (3:1:1) and R2 (3:1:2). The sub-plot area was 100m².

Crop management

During the experiment, composted manure was applied twice with 30 tons each time in January 2015 and 2017. Mineral fertilizers and fermented soybean were applied annually as shown in **Table 1**. Other crop management was done following the cultivation manual for tea production (TCN 446-2001).

Data collection

The growth parameters including plant height (cm), shape wide (cm), shape thickness (cm), and plant diameter (cm) were collected once per year in November (before pruning). Plant height was measured from above ground to canopy surface. Canopy width was measured at the largest position of the canopy surface. Canopy height was measured from the last

Table 1. Mineral fertilizer practices

Mineral	Type of fertilizer	Time	Amount
Nitrogen	CO(NH ₂) ₂	March	30%
		May	20%
		July	30%
		September	20%
Phosphorus	3 Ca(H ₂ PO ₄) ₂ .H ₂ O+7 CaSO ₄	January	100%
Potassium	KCl	February	60%
		April	40%
Magnesium	MgSO ₄ , 75 kg ha ⁻¹	February	60%
		May	40%
Fermented soybean	Ground soybean seed was soaked in freshwater and fermented in 40-60 days, 1 ton ha ⁻¹	February	50%
		August	50%

pruning scar to the highest position of the canopy surface. Insect and disease infection rates were determined by QCVN 01-38:2010/BNNPTNT. Fresh shoot yield and yield components including shoot density, shoot weight, and shoot length were collected at harvesting. The harvestable shoot was determined by cutting it apart with a bud plus 3 young leaves and a stem from a fish leaf. Shoot density was determined by counting the number of shoots on the standard frame (25 x 25cm). Shoot weight was measured by the average of 100 shoot samples. Shoot length was measured by an average of 50 shoot samples. Shoot components were calculated by fresh weight of bud, 1st leaf, 2nd leaf, and 3rd leaf, stem, and total shoot fresh weight. The fiber ratio was determined following the TCVN 1053:1986. Biochemical components were analyzed by corresponding methods for tannin, water extract, amino acid, and aromatic compound as detail in Hoang Le Thu *et al.* (2013). Sensory analysis of made Sencha and Oolong tea products were assessed following the standard evaluation by TCVN 3218-2012 and TCVN 1273:2019, respectively.

The economic efficiency from selling raw tea products of each fertilizer treatment was evaluated as follows: Profit (million VND ha⁻¹) = total revenue – total cost. The percentage of profit was calculated by the ratio of profit and total cost.

Data analysis

The data were subjected to analysis of variance according to Splitplot design using CROPSTAT 7.2 software. The least significant difference (LSD) test was used to compare the means among the treatments.

Results

Effect of doses and ratios of mineral fertilizer on growth of PH10 tea variety

The results in **Table 2** showed that fertilizer ratios had significant effects on growth parameters, except for plant diameter. In R1 treatment, plant height was higher but canopy width and height were lower than those in R2 treatment. There were upward trends in response of tea plants to increasing fertilizer doses for all growth parameters. However, the difference was not significant between higher doses (D2 and D3) for plant height, canopy height, and plant diameter. Among combined treatments, the highest values belonged to D2R1, D3R1, and D3R2 for plant height; D2R2, D3R1, D3R2 for canopy width; and D2R1, D2R2, and D3R2 for canopy height. The differences among treatments for plant diameter were not significant.

Effect of fertilizer doses and ratios on yield components of PH10 tea variety

In R2 treatment, shoot density, shoot length, and shoot fresh yield were higher than those in

Table 2. Effect of fertilizer doses and ratios on the growth of PH10 tea variety

Doses	Ratios	Plant height (cm)	Canopy width (cm)	Canopy height (cm)	Plant diameter (cm)
D1	R1	78.5 ^c	138.2 ^e	14.6 ^d	3.57 ^a
	R2	78.6 ^c	140.2 ^d	15.4 ^c	3.53 ^a
D2	R1	79.8 ^a	143.7 ^c	16.4 ^a	3.66 ^a
	R2	79.2 ^b	146.8 ^b	16.8 ^a	3.51 ^a
D3	R1	80.4 ^a	147.3 ^{ab}	15.9 ^b	3.74 ^a
	R2	79.9 ^a	148.5 ^a	16.3 ^{ab}	3.59 ^a
<i>Fertilizer doses</i>					
D1		78.5 ^b	139.2 ^c	15.0 ^b	3.55 ^b
D2		79.5 ^a	145.2 ^b	16.6 ^a	3.59 ^{ab}
D3		80.2 ^a	147.9 ^a	16.1 ^a	3.67 ^a
<i>Fertilizer ratios</i>					
R1		79.6 ^a	143.0 ^b	15.6 ^b	3.66 ^a
R2		79.2 ^b	145.2 ^a	16.2 ^a	3.54 ^a

Note: Different superscripts in the same column show significance between treatments at $P < 0.05$ by LSD.

R1 treatment. However, the differences between fertilizer ratios were not significant for yield and yield components. Increasing fertilizer dose supported better yield and yield components, but the significances were only found among higher dose treatments (D2 and D3) with D1 treatment for shoot density and shoot fresh yield. Among combined treatments, shoot density ranged from 279.3 to 340.0 shoot m⁻², treatment D1R1 had the lowest shoot density, significantly lower than other treatments, except for D1R2 treatment. D1R1 also had the lowest shoot length which lower than D2R2 and D3R1 treatment, and shoot yield which lower than all other treatments (Table 3).

Effect of fertilizer doses and ratios on pest infection of PH10 tea variety

The infestation rates of green leafhopper, red spider mite, and yellow tea thrip were significantly higher in R2 treatment than those in R1 treatment. Increasing fertilizer doses also led to an increase in pest infestation rates. However, significant differences were only found among fertilizer doses for infestation rates of green leafhopper and red spider mite. Among

combined treatments, infestation rates of all pests were highest in the combined treatment of D3 with R2 and R1 (Table 4).

Effect of fertilizer doses and ratios on economic efficiency of raw tea products

D2R2 and D3R1 brought about the highest profits (95.2 and 94.5 million VND ha⁻¹, respectively). D2R2 also had the highest percentage of profit (80.2%). The lowest economic efficiency came from fertilizer application of D1R1 with only 69.8 million VND ha⁻¹ for profit and 64.6% for the percentage of profit (Table 5).

Effect of fertilizer doses and ratios on shoot components of PH10 tea variety

There were insignificant effects of fertilizer doses as well as ratios on shoot components of PH10 tea variety. The differences among combined treatments were not significant for almost all parameters except for the ratio of stem between D3R2 with other treatments, and the fiber ratio between D3R1 with D1R2 and D2R1 treatments (Table 6).

Table 3. Effect of fertilizer doses and ratios on yield and yield components of PH10 tea variety

Doses	Ratios	Shoot density (shoot m ⁻²)	Shoot weight (g)	Shoot length (cm)	Shoot yield (tons ha ⁻¹)
D1	R1	279.3 ^b	1.03 ^a	6.11 ^b	8.90 ^c
	R2	309.4 ^{ab}	1.00 ^a	6.79 ^{ab}	9.78 ^b
D2	R1	315.2 ^a	1.08 ^a	7.11 ^{ab}	10.13 ^b
	R2	338.1 ^a	1.09 ^a	7.18 ^a	10.70 ^{ab}
D3	R1	340.0 ^a	1.16 ^a	7.48 ^a	10.88 ^a
	R2	330.5 ^a	1.10 ^a	7.15 ^{ab}	10.42 ^{ab}
<i>Fertilizer doses</i>					
D1		294.4 ^b	1.02 ^a	6.45 ^a	9.34 ^b
D2		326.7 ^a	1.09 ^a	7.15 ^a	10.42 ^a
D3		335.2 ^a	1.13 ^a	7.32 ^a	10.65 ^a
<i>Fertilizer ratios</i>					
R1		311.5 ^a	1.09 ^a	6.90 ^a	9.97 ^a
R2		326.0 ^a	1.06 ^a	7.04 ^a	10.30 ^a

Note: Different superscripts in the same column show significance between treatments at $P < 0.05$ by LSD.

Table 4. Effect of fertilizer doses and ratios on pest infection of PH10 tea variety

Doses	Ratios	No. GLH tray ⁻¹	No. RSM leaf ⁻¹	No. YTT shoot ⁻¹
D1	R1	3.3 ^c	2.3 ^c	2.9 ^c
	R2	3.5 ^c	2.1 ^c	2.8 ^c
D2	R1	4.5 ^b	2.2 ^c	2.9 ^c
	R2	3.7 ^c	2.1 ^c	2.9 ^c
D3	R1	4.8 ^b	4.0 ^b	3.8 ^b
	R2	6.4 ^a	4.8 ^a	4.6 ^a
<i>Fertilizer doses</i>				
D1		3.4 ^c	2.2 ^b	2.8 ^a
D2		4.1 ^b	2.2 ^b	2.9 ^a
D3		5.6 ^a	4.4 ^a	4.2 ^a
<i>Fertilizer ratios</i>				
R1		4.2 ^b	2.8 ^b	3.2 ^b
R2		4.5 ^a	3.0 ^a	3.5 ^a

Note: No. Number; GLH - Green leafhopper; RSM - Red spider mite; YTT - Yellow tea thrip. Different superscripts in the same column show significance between treatments at $P < 0.05$ by LSD.

Effect of fertilizer doses and ratios on biochemical components of PH10 tea variety

Biochemical components in tea leaves of PH10 variety were not significantly different between fertilizer ratios, except for carbohydrates with higher value in R2 treatment

compared to that in R1 treatment. The differences among biochemical components at fertilizer doses were found in tannin, water extract, and aromatic compound contents. Tannin content was lowest at D2 treatment, whereas water extract and aromatic compound

contents were lowest at D1 treatment. At D2, aromatic compound content was significantly higher than those at other treatments. The highest tannin contents were found in D1R1 and D3R2 treatments. The water extract was highest in D3R1 treatment which was significantly higher than that in D1R1 and D1R2 treatment. Amino

acid content ranged from 1.98 to 2.49%, D1R1 had the lowest value but just significantly lower than D2R2 and D3R1. Carbohydrate and aromatic compound contents ranged from 2.19 to 3.08% and from 49.03 to 51.06%, respectively, with the highest values in D2R2 treatment (**Table 7**).

Table 5. Effect of fertilizer doses and ratios on the economic efficiency of raw tea product of PH10 tea variety

Doses	Ratios	Total cost (mil. VND ha ⁻¹)	Total revenue (mil. VND ha ⁻¹)	Profit (mil. VND ha ⁻¹)	Percentage of profit (%)
D1	R1	108.2	178.0	69.8	64.6
	R2	113.3	195.6	82.3	72.7
D2	R1	114.8	202.6	87.8	76.6
	R2	118.8	214.0	95.2	80.2
D3	R1	123.1	217.6	94.5	76.8
	R2	125.0	208.4	83.4	66.8

Table 6. Effect of fertilizer doses and ratios on shoot mechanical components of PH10 tea variety

Doses	Ratios	Weight ratio of tea shoot components (%)					Fiber ratio (%)
		Bud	1 st leaf	2 nd leaf	3 rd leaf	Stem	
D1	R1	6.3 ^a	10.2 ^a	20.0 ^a	32.5 ^a	31.0 ^a	12.1 ^{ab}
	R2	6.3 ^a	10.7 ^a	20.3 ^a	32.4 ^a	30.4 ^a	13.4 ^a
D2	R1	6.4 ^a	10.6 ^a	20.6 ^a	32.7 ^a	29.9 ^a	12.7 ^a
	R2	6.5 ^a	10.9 ^a	20.7 ^a	33.5 ^a	28.5 ^b	12.4 ^{ab}
D3	R1	6.5 ^a	10.4 ^a	19.9 ^a	32.4 ^a	30.9 ^a	10.7 ^b
	R2	6.4 ^a	10.6 ^a	19.8 ^a	32.1 ^a	31.1 ^a	12.5 ^{ab}
<i>Fertilizer doses</i>							
D1		6.3 ^a	10.4 ^a	20.1 ^a	32.5 ^a	30.7 ^a	12.8 ^a
D2		6.4 ^a	10.7 ^a	20.6 ^a	33.1 ^a	29.2 ^a	12.5 ^a
D3		6.5 ^a	10.5 ^a	19.8 ^a	32.2 ^a	31.0 ^a	11.6 ^a
<i>Fertilizer ratios</i>							
R1		6.4 ^a	10.4 ^a	20.1 ^a	32.5 ^a	30.6 ^a	11.8 ^a
R2		6.4 ^a	10.7 ^a	20.2 ^a	32.7 ^a	30.0 ^a	12.7 ^a

Note: Different superscripts in the same column show significance between treatments at $P < 0.05$ by LSD.

Effect of fertilizer doses and ratios on sensory quality of Oolong and Sencha tea products

The effects of fertilizer doses and ratios on sensory quality parameters were shown in **Table 8**. The result pointed out that the scores of the

shape of dry tea leaves and color water of made tea were not different among fertilizer doses and between two fertilizer ratios. Similarly, scores of flavor were not different among fertilizer doses, but different between fertilizer ratios with higher value belonging to made tea product in R2

treatment. In R2 treatment, made tea products also had a higher taste and overall scores compared to those in R1 treatment. Among fertilizer doses treatment, D1 had the lowest score for the taste of made tea, D2 had the highest mark for the overall score. The differences were

also not significant among combined treatments for shape and color scores. D2R2 treatment showed the highest scores for flavor and taste. It also had the highest score overall with a score of 17.08, meanwhile, D1R1 had the lowest score (15.96).

Table 7. Effect of fertilizer doses and ratios on biochemical components of PH10 tea variety

Doses	Ratios	Tannin (%)	Water extract (%)	Amino acid (%)	Carbohydrate (%)	Aromatic compound (%)
D1	R1	26.47 ^a	41.72 ^{bc}	1.98 ^b	2.19 ^c	49.03 ^c
	R2	25.48 ^{bc}	41.55 ^c	2.22 ^{ab}	2.37 ^{bc}	49.66 ^{bc}
D2	R1	25.52 ^b	42.21 ^{abc}	2.36 ^{ab}	2.38 ^{bc}	49.80 ^{bc}
	R2	24.78 ^c	42.19 ^{abc}	2.49 ^a	3.08 ^a	51.06 ^a
D3	R1	25.5 ^{bc}	42.55 ^a	2.43 ^a	2.36 ^{bc}	50.05 ^b
	R2	26.38 ^a	42.33 ^{ab}	2.32 ^{ab}	2.44 ^b	49.83 ^{bc}
<i>Fertilizer doses</i>						
D1		25.98 ^a	41.64 ^b	2.10 ^a	2.28 ^a	49.35 ^c
D2		25.15 ^b	42.20 ^a	2.43 ^a	2.73 ^a	50.43 ^a
D3		25.94 ^a	42.44 ^a	2.38 ^a	2.40 ^a	49.94 ^b
<i>Fertilizer ratios</i>						
R1		25.83 ^a	42.16 ^a	2.26 ^a	2.31 ^b	49.63 ^a
R2		25.55 ^a	42.02 ^a	2.34 ^a	2.63 ^a	50.18 ^a

Note: Different superscripts in the same column show significance between treatments at $P < 0.05$ by LSD.

Table 8. Effect of fertilizer doses and ratios on sensory quality of Oolong and Sencha teas

Doses	Ratios	Shape	Color	Flavor	Taste	Overall
D1	R1	4.10 ^a	4.07 ^a	3.97 ^c	3.83 ^c	15.96 ^c
	R2	4.03 ^a	4.03 ^a	4.13 ^{abc}	4.13 ^{ab}	16.38 ^b
D2	R1	4.23 ^a	4.20 ^a	4.03 ^{bc}	4.03 ^{bc}	16.43 ^b
	R2	4.07 ^a	4.10 ^a	4.47 ^a	4.33 ^a	17.08 ^a
D3	R1	4.10 ^a	4.20 ^a	4.00 ^{abc}	4.03 ^{bc}	16.27 ^b
	R2	3.97 ^a	3.90 ^a	4.23 ^{abc}	4.23 ^{ab}	16.47 ^b
<i>Fertilizer doses</i>						
D1		4.07 ^a	4.05 ^a	4.05 ^a	3.98 ^b	16.17 ^b
D2		4.15 ^a	4.15 ^a	4.25 ^a	4.18 ^a	16.76 ^a
D3		4.04 ^a	4.05 ^a	4.12 ^a	4.13 ^a	16.37 ^b
<i>Fertilizer ratios</i>						
R1		4.14 ^a	4.16 ^a	4.00 ^b	3.96 ^b	16.22 ^b
R2		4.02 ^a	4.01 ^a	4.28 ^a	4.23 ^a	16.64 ^a

Note: Different superscripts in the same column show significance between treatments at $P < 0.05$ by LSD.

Discussion

Effects of fertilizer doses and ratios on tea growth and yield

Our findings in this experiment showed that increasing doses of fertilizer induced the upward trend of growth and yield parameters of the PH10 tea variety. However, the increases in these parameters were not significant when fertilizer doses increased from 40 to 50 kg N ton⁻¹. The ratio of NPK application had no significant effects on shoot yield and yield component, but significant on the growth of tea (except for plant diameter). At NPK ratio of 3:1:2, the plant height of the tea plant was lower, but leaf canopy parameters were higher than those at the ratio of 3:1:1.

In Pakistan, Zaman *et al.* (2011) recorded that shoot length and fresh leaves yield was highest at the highest level when N was applied from 0 to 375 kg N ha⁻¹. Following Zaman *et al.* (2011) that the positive trend of increasing yield when supplying N up to 200 kg N ha⁻¹ in Tanzania (Anon, 2006), and 300 kg N ha⁻¹ (Rikhter & Lyashko, 1979). In India, Gogoi *et al.* (1994) stated that yield benefits could be gained when P was applied up to 50 kg P₂O₅ ha⁻¹. Similarly, Barbora (1991) reported that yield response to potash was quadratically reaching a peak at 170 kg K₂O ha⁻¹. Meanwhile, in Pakistan, Islam *et al.* (2019) showed that application of P from 0 to 225 kg P₂O₅ ha⁻¹ significantly enhanced plant height, number of leaves, leaf length, number of branches and fresh leaf yield. No improvement of yield by K application was found in Kenya (Willson, 1975) or Iran (Sedaghatoor *et al.*, 2009). However, the available K content of the topsoil is found to be linearly correlated with tea yield (Singh & Pathak, 2018). A foliar K application could escalate crop yield in tea (Barman *et al.*, 2003). A better yield response to N is obtained when there is an adequate supply of P and K (Ellis, 1976; Owuor, 2001). Combination of each three levels of N (300, 350 and 400 kg N ha⁻¹), P (250, 300 and 350 kg P₂O₅ ha⁻¹), and K (150, 200 and 250 kg K₂O ha⁻¹), Mudau *et al.* (2017) found no differences in tea growth for plant height, the number of branches, stem girth, fresh and dry

root weight, and fresh and dry stem weight due to treatment combinations. However, treatment combinations of 300 kg N + 300 kg P₂O₅ + 200 kg K₂O ha⁻¹ (3:3:2) supported the best growth with the highest value for fresh and dry shoot weight, number of leaves, and leaf area. In Kenya, yield response of tea is the same between NPK 20:10:10 and 25:5:5:5 (Owuor & Othieno, 1996). Sitienei *et al.* (2013) also indicated no much difference between N-K treatments, but the yield of made tea had a positive correlation with N application and a negative correlation with K application. In India, the recommended fertilizer ratios were an NK ratio of 1:0.45 to 1:1.66 for the southern part and NPK of 2:1:2 or 2:1:3 for the northern part (Singh & Pathak, 2018). In Vietnam, with the total amount of N, P₂O₅, and K₂O of 300 kg ha⁻¹, NPK ratio of 3:2:1 was the most optimal dose for Phuc Van Tien and Shan Chat Tien varieties with the highest yield and yield components, following by 3:2:1, 3:1:1, and 2:1:1 (Nguyen Huu La, 2014).

Effects of fertilizer doses and ratios on quality of raw material and made tea products

Our results indicated that raw material components, leaf amino acid content, and sensory quality for shape and color of made tea were not affected by fertilizer dose and ratio. Differences between fertilizer ratios were found in carbohydrate content, sensory quality for taste, flavor, and overall score with higher values at NPK ratio of 3:1:2. The difference among fertilizer doses was found in contents of tannin and aromatic compound, and sensory quality of taste and overall, with the lowest value for tannin content and highest values for other parameters at the treatment of 40 kg N ton⁻¹.

Sedaghatoor *et al.* (2009) reported that N application alone had significant effects on chemical components of tea leaf including tannin and water extract, whereas the combination of N and K, and K application alone were significant on the caffeine percentage. Similarly, Takeo (1992) and Nishino (1999) found that yield and green tea quality seemed to be improved somewhat by higher application of N. Nevertheless, some researchers found the decline

in black tea quality with high rates of N application (Malenga, 1987; Owuor *et al.*, 1994). Meanwhile, Owuor *et al.* (1995) found that there is no quality benefit/loss from increased N rate. Ruan *et al.* (1999) found that increases in the contents of free amino acids, caffeine, polyphenols in tea leaves, and flavor compounds in brewed Oolong tea by K application. Singh & Pathak (2018) reviewed that K offers abiotic and biotic stress toleration in tea plants and also improves biochemical parameters and organoleptic quality of tea. Lin *et al.* (2012) indicate that the sensory and biochemical qualities of green tea were lowered by P deficiency. The P deficient green tea displayed decreased concentrations of water extract, total polyphenols, flavonoids, total free amino acids, increased concentrations of water-soluble sugars, but unchanged concentrations of total catechins. Combinations of P and K and N were shown to be beneficial to enhance tea quality (Willson & Choudhury, 1968). Mudau *et al.* (2017) reported that the treatment combination of 300 kg N + 300 kg P₂O₅ + 200 kg K₂O increased the concentration of total polyphenols, whereas other treatments did not consistently affect them. Owuor *et al.* (1987) reported that tea quality was similar to rates of N for NPK 20:10:10 and NPKS 25:5:5:5. Singh & Pathak (2018) observed that a major increase in tea quality could be achieved when a balanced NK ratio (1:0.83) is the practice in the field. In Vietnam, Nguyen Huu La (2014) suggested 3:1:2 was the best NPK ratio for green tea production.

Conclusions

Increasing fertilizer doses from 30 up to 40 kg N ton⁻¹ of fresh product remarkably improved growth, yield, and made tea quality of PH10 variety. Different fertilizer ratios resulted in variations in plant growth, the content of carbohydrate, sensory quality for taste and flavor as well as total sensory quality with higher values at NPK ratio of 3:1:2. Applying mineral fertilizer with 40 kg N per ton of fresh shoot products and NPK ratio of 3:1:2 brought about the highest tea yield and quality as well as economic profit.

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