Effect of Potassium on Tea Plant Growth

Subjects: Soil Science

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Potassium is among the three essential macronutrients for tea plants, along with nitrogen and phosphorous, and plays important roles in growth and stress response. Potassium is absorbed by plants in larger amounts than any other mineral element except nitrogen and, in some cases, calcium. Potassium is positively correlated with the elements nitrogen, copper, and zinc. Sufficient potassium dramatically improves the yield and quality of tea: it accelerates metabolism, promotes synthesis of catechins, and strengthens biotic and abiotic resistance by activating and regulating different enzymes. Moderate application of potassium fertilizers, along with potassium-solubilizing bacteria, can regulate the ratio of different forms of potassium and increase available potassium in soils of tea gardens.

Keywords: Camelia sinensis ; potassium ; soil ; growth

1. Effect of Potassium on Biomass of the Tea Plant

Studies have shown that when potassium is inadequate (potassium < 100 μmol/L), the biomass of roots, stems and leaves decreases, while the root–shoot ratio improves [1][2][3][4][5]. When potassium is adequate, there is an increase in overall biomass [6]. After the potassium concentration reaches a certain extent (800 μmol/L), the dry weights of roots, stems, and leaves plateau [5]. Gong Xuejiao et al. [3] obtained similar results: with an increase in potassium concentration, the biomass of whole plants, twigs, stems and roots increased linearly, reached a peak when the potassium concentration was 682~865 μmol/L, and then slowly decreased. Gong [6] also defined the optimal range of potassium content in adult leaves (10.03~10.83 mg/g) and twigs (17.72~19.11 mg/g), plus the optimal concentration (4.69~5.96 mmol/L) for promoting chlorophyll synthesis and speeding up the net photosynthetic rate of adult leaves. The potassium level is also related to plant age: The preservation of potassium aboveground and the annual absorption increases with age [1].

Potassium fertilizers are necessary for tea gardens in potassium starvation to make the plants grow and thrive. Within the safe dosage range, either potassium chloride (KCl) or potassium sulfate (K_2SO_4) can increase yield and quality effectively [7], and the latter can increase the proportion of quality tea [8]. Lei Qiong [9] insisted that potassium fertilizers can not only balance different forms of potassium in soils, but also work with nitrogen and phosphorus to produce massive amounts of good tea. Ruan et al. [1] found that when the exchangeable potassium content in the soil of tea gardens is lower than 80 mg/kg, there is a significant increase in yield after application of K_2SO_4 or KCl. The single use of base manure in autumn has similar or even better effects, making it possible to reduce labor costs. The study results also indicated that the yield rises markedly when the dose of KCl or K_2SO_4 is 124 or 156 kg/ha, respectively, and it is at the highest level when the dose is 248 or 312 kg/ha, respectively (**Table 1**). A smaller potassium supply harms tea production, changes the biochemical characteristics of the tea plant, and threatens the nutritional status of tea leaves [10][11].

Table 1. Optimal Levels of K in Soil for Tea Crop.

Site	Time	Soil Conditions	Experimental Conditions	Tree Age	Fertilizer	Optimal Levels of K in Soil	References
China	1990~2010	-	field experiment	-	KCl and K_2SO_4	124 kg/ha~160 kg/ha	[1]
China	1999~2004	-	field experiment	-	K_2O	K_2O:MgO = 1:0.15~1:0.25	[12]
Low-hilly red soil tea garden; China	2004	Red soil	field experiment	>5-year-old	K_2SO_4 and KCl	20~50 kg/ha	[8]
Low-hilly red soil tea garden; China	2004	Red soil	field experiment	<5-year-old	KCl	<225 kg/ha	[8]

Site	Time	Soil Conditions	Experimental Conditions	Tree Age	Fertilizer	Optimal Levels of K in Soil	References
Sichuan Academy of Agricultural Sciences; China	2014	-	hydroponic experiment	12-month-old	K_2SO_4	4.69 mmol/L~5.96 mmol/L	[6]
UPASI Tea Experimental Farm; India	2000~2004	-	field experiment	-	KCl	N:K = 1:0.83 or 1:0.62	[13][14]
UPASI Tea Experimental Farm; India	2000~2004	-	field experiment	-	K_2SO_4	N:K = 1:0.21 or 1:0.42	[13][14]

2. Effects of Potassium on Metabolism in Camelia Sinensis

Potassium facilitates almost all biochemical reactions in plants. The proper amount of potassium strengthens photosynthesis and metabolism of sugars and proteins, which ultimately promotes the production of catechins. On the other hand, suboptimal concentrations of potassium slow the plant's ability to exchange gases by increasing stomatal resistance. This in turn slows the activity of ribulose 1,5-bisphosphate (RuBP) carboxylase, and consequently reduces the net photosynthetic rate. Potassium also maintains the transmembrane proton gradient of chloroplasts and thylakoids in the light and ensures the high pH of chloroplast stroma, which enables photophosphorylation and CO2 assimilation [15].

Potassium deficiency disturbs the synthesis of metabolic enzymes in the tea plant. The activity of catalase (CAT), ascorbate peroxidase (APX) and monodehydroascorbate reductase (MDAR) in tea leaves significantly decreases under potassium deficiency [5]. Potassium deficiency also reduces photosynthetic electron transport capacity and affects the normal progression of photosynthesis. Excessive potassium accelerates the metabolic rate of GA (gallic acid), gallocatechol (GC), catechin (C), epicatechin gallate (ECG), epigallocatechin gallate (EGCG), etc., which is not conducive to catechin accumulation [16].

To a certain extent, potassium and magnesium can stimulate the production of terpenes in tea. Among the acid-hydrolyzed aroma components, the content of oxidized linalool and linalool in tea is higher. Potassium indirectly regulates the synthesis of terpenes by affecting the activity of 3-hydroxy-3-methylglutaryl-coenzyme A (HMG-CoA) reductase. It is only at a certain level of HMG-CoA reductase that more terpenes can be produced. Magnesium also plays a role in synthesizing terpenes. In this process, it assists in metabolism of potassium in the plant as well [17].

After the use of potassium fertilizers, α-cubebene and other isopentenyl-diphosphate volatile substances are increased and geraniol is decreased [18]. The principles behind it are stated as follows: α-cubebene is produced by the mevalonic acid (MVA) pathway. In the second step of this pathway, MVA is produced from HMG-CoA with the help of HMG-CoA reductase.

Adequate potassium increases the levels of some free amino acids. For example, there is an increase in phenylalanine, which is a precursor to the volatile substances benzaldehyde, benzyl alcohol and phenylethyl alcohol (PEA). The increase in phenylalanine-derived volatile substances in the experiment was possibly due to the use of potassium fertilizers, which stimulate sugar accumulation and the absorption of nitrogen in the tea plant to ultimately increase the content of phenylalanine [18]. Zhou et al. [19] found that a higher level of potassium activates the activity of recombinant theanine synthetase (CsTSI) and raises the ethylamine content (a precursor to L-theanine), and thus improves the production of L-theanine at the roots of the tea plant.

3. Effect of Potassium on Tea Quality

Tea produced from potassium-deficient soil lacks the intoxicating flavors of tea grown in well-balanced soils [4]. Potassium deficiency in mature tea plants decreases amino acids, caffeine, water extract, and EGCG in tea leaves, while greatly increasing tea polyphenols, catechins, epigallocatechin (EGC), and epicatechin (EC), as well as the phenol/ammonia ratio. Given the lower content of aromatic alcohols, aldehydes, and esters and the weaker diversity of aromatics, such teas lack quality. Some scholars insist that exogenous application of potassium would influence the levels of polyphenols and theaflavins in the tea plant, which would reverse this situation [20].

On the other hand, in young tea plants, potassium has little direct effect on the content of free amino acids and caffeine, and has a positive effect on the content of water extract, catechins, and tea polyphenols [21]. After using potassium fertilizers, the concentration of total free amino acids and extract from tea infusion rises dramatically, while the concentration of polyphenols in autumn tea increases correspondingly [1].

Wei [22] performed experiments to prove that different concentrations of potassium affect the amino acids and aroma contents of different types of tea. Longjing #43 leaves had the highest arginine content when potassium in soil was 20 mg/kg. Arginine declined as the potassium concentration further increased; however, it was still higher than in potassium-deficient conditions. The shuchazao cultivar had outstanding amounts of arginine when potassium was 100 mg/kg in soil. Venkatesan et al. [23] observed that the polyphenol and free amino acid contents increased with increasing potassium concentration. At nitrogen levels of 0 or 50 kg/ha, caffeine content positively correlated with the dose of potassium fertilizers. When nitrogen stabilized at 300 kg/ha/y, the caffeine content increased with the increase in potassium fertilizers, and peaked at a ratio of 1:0.83 [10].

The content of aroma components in tea changes most obviously when potassium is applied as a chloride salt (i.e., potassium chloride). More specifically, fragrant compounds, such as linalool, linalool oxides, benzyl alcohol, β-PEA, nonanal, and 1-octanol, increase significantly, while aroma components with low boiling points and grassy smells (heptanal, leaf alcohol, etc.) decrease. In other words, grassy smells become lighter, while refreshing floral scents become stronger and persist for longer [16]. Wei [22] also found that when the extra amount of exogenous potassium is 40~60 mg/kg in soil, typical terpene fragrances, including trans-linalool oxide, linalool oxide, linalool, geraniol, and nerolidol, reach the maximum value in leaves of Longjing #43 and shuchazao. Venkatesan et al. [10] found that more nitrogen and potassium (NK) fertilizer causes higher concentrations of Group II compounds, which produce pleasant scents. Three of them—linalool, methyl salicylate and benzaldehyde—contribute to the flavor index (FI) in tea.

Given the long interval of time between the use of phosphorus and potassium fertilizers, the concentrations of available phosphorus and potassium in soils during summer and autumn harvests may be lower than in spring time. In order to raise the quality of summer and autumn tea, the timing of fertilizer application, especially that of phosphorus and potassium, should be based on the specific nutrient needs of the tea plant at that time period [24].

4. Effects of Potassium on Tea’s Abiotic and Biotic Stress Response

4.1. Drought Resistance

Drought stress is among the main factors limiting tea yield. Potassium exists in plant cells in ionic states, and keeping the potassium in balance is an important strategy for the tea plant to cope with drought stress. When plants are subjected to drought stress, proteins on the cell membrane immediately respond to the stress signal, letting the intracellular potassium ion (K^+) rapidly leak out for several minutes or even hours. It is evident that plants’ responses and subsequent water supplementation are crucial for drought tolerance, both of which are related to the regulated activity of the plasma membrane proton-pump ATPase (H^+-ATPase) [23]. Potassium fertilizers bring more K^+ to tea plant cells, and these ions can increase the osmotic pressure of the sap of plant cells, increasing water absorption by roots, stomatal closure, and the stability of biofilms. As a result, the tea plant’s drought resistance is greatly enhanced with proper amounts of available potassium [8][9][25][26][27][28][29].

K^+ retention is indispensable for reducing drought-induced damage to the tea plant, and exogenous potassium (i.e., application of potassium fertilizer) is necessary to retain K^+. Comparison between two cultivars, drought-tolerant Zhongcha #108 and drought-sensitive Ruanzhi oolong, revealed that a stronger ability to remove reactive oxygen species (ROS), increase plasma membrane H^+- ATPase activity, and a negative membrane potential were the major factors that led to better K^+ retention in Zhongcha #108 [30]. In a drought-tolerant tea cultivar called Taicha #12, the effect of outwardly rectifying potassium levels on K^+ retention in mesophyll was relatively small, and non-selective cation channels (NSCC), which are activated by ROS, may have been the main path of K^+ leakage in mesophyll under drought conditions [31].

The research of Chen Linmu [32] also showed that stronger drought resistance correlates with higher K^+ content in tea leaves and better K^+ retention in mesophyll. Transcriptome analysis revealed that under drought stress, the tea plant controls K^+ retention in mesophyll cells by regulating gene expression of potassium channels and potassium transporters. Considerable studies have proved that the high-affinity K^+ (HAK)/K^+ transporter (KT)/K^+ uptake (KUP) transporters, which are potassium transporters (CsHAKs), dominate K^+ acquisition and long-distance transport, especially under K^+ constraints. Analysis of specific problems and expression patterns induced by multiple stress types implied that CsHAKs participate in K^+ uptake and stress response in roots [33].

There is a mechanism behind K^+’s ability to alleviate drought stress in the tea plant: external supplementation of potassium, in association with chlorides and amino acids, relieves drought stress [34]. After further exploration, Xianchen

[32] found that under drought conditions, the supply of K^+ causes lower Cl^- outflow, which benefits osmotic balance in mesophyll cells.

4.2. Pest and Disease Resistance

Potassium deficiency results in increased susceptibility to infection, especially by fungi, which can be attributed to the role of potassium in primary metabolism and transport in the phloem of plants [35]. An adequate supply of potassium helps with pathogen tolerance, but in some cases, insects and necrotrophic pathogens are less likely to attack plants with potassium deficiency [36] , which may be caused by low potassium induced increases in jasmonic acid and its derivatives, which act as a trigger in the system to defend against animals and insects [37].

Tea plants lacking potassium grow slowly, and are susceptible to Exobasidium vexans, anthrax, tea brown blight, etc. [38]. Increasing the application of potassium fertilizer can reduce the incidence of anthrax, Pestalotia theae and tea brown blight, and improve overall disease resistance. As for the reason behind improved resistance, it may be that a higher level of potassium facilitates the formation of organic substances such as phenolic compounds and peroxidases, which serve as phytotoxins in the tea plant to inhibit the growth, reproduction and spread of pathogens [39].

Sudoi [40] found that nitrogen–phosphorous–potassium (NPK) fertilizers can induce the tea plant’s tolerance to mites. In the control of root-knot nematode in tea, Kamunya et al. [41] observed that the number of irregularly rounded roots decreased by 44% after two years of potassium treatment. Pruning combined with nitrogen and potassium application in a 1:2 ratio can greatly protect the tea plant from wormhole attack [42].

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