Application Progress of Microbial Fertilizers in Flue-Cured Tobacco Production in China

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Abstract: The followings were overviewed: the application of microbial fertilizers in China’s tobacco production; the influences of microbial fertilizers on the nutrients, microbial biomass and enzymatic activity in tobacco-planting soil; the influences of microbial fertilizers on flue-cured tobacco root system, tobacco yield as well as chemical properties and disease resistance of cured tobacco leaves; the influence of microbial fertilizers on continuous cropping obstacles of flue-cured tobacco, and their fertilizer saving effect. The problems in the existing researches were analyzed, and the future development direction of microbial fertilizers in tobacco production was discussed.

1.Introduction
As an important economic crop in China, tobacco accounts for an extremely high proportion in both fiscal revenue and local economic sources in China [1]. However, the multiple crop index is high in most tobacco planting areas across China, along with even more obvious continuous cropping obstacles of flue-cured tobacco; moreover, tobacco growers have applied a great amount of chemical fertilizers for a long time while neglecting the input of organic fertilizers in the pursuit of high yield, which have triggered a series of environmental degradation problems of tobacco-planting soil, such as soil salinization, soil hardening, soil microbial activity decline and heavy metal pollution. This is also the primary cause for dramatic decrease of utilization rate of soil nutrients, thus directly impacting the tobacco quality and yield. As a kind of functional fertilizers harmless to soil environment with stable and enduring fertilizer efficiency [2 , 3], microbial fertilizers have potential application values in strengthening the fertility of tobacco-planting soil, improving the growth environment for rhizosphere soil microorganisms, overcoming continuous cropping obstacle, elevating the quality of flue-cured tobacco, saving the cost and enhancing the efficiency, and they are also the important future development direction for sustainable tobacco production. Based on a summary of predecessors’ researches on fertilizer saving effect of microbial fertilizers, the physicochemical properties of tobacco-planting soil, soil micro-ecological environment, soil enzymatic activity, disease resistance of flue-cured tobacco, yield and intrinsic quality of tobacco plants, and their continuous cropping
obstacles, the problems embodied in the existing researches were analyzed, expecting to provide a reference for the follow-up research.

2. Overview of Microbial Fertilizers

Microbial fertilizer is a kind of functional fertilizer also called bacterial fertilizer [4]. To be specific, products containing specific living microorganisms are applied to agricultural production, and the vital activities of the microorganisms can be used to increase the quantity of plant nutrients delivered, facilitate the plant growth, stabilize the crop yield, and improve the agricultural product quality and agroecological environment. Microbial fertilizers can be divided into three types: microbial agents, compound microbial fertilizers and bio-organic fertilizers [5, 6]. The current action mechanisms of the microbial fertilizers include: functional bacteria induce crop resistance against the attack of fungi, bacteria, viruses and nematodes; induce crop tolerance of more abiotic stress factors, such as drought and lack of fertility [7, 8].

2.1. Applied research progress of microbial fertilizers in domestic (Chinese) and foreign tobacco production

Though having a relatively early start, the foreign applied researches on microbial fertilizers are mainly concentrated on grain crops like soybean, corn and wheat, while there are few applied researches on tobacco. Except that the azotobacter agent developed by an Indian scholar can save the nitrogen fertilizer by 30 kg/hm² after being applied to tobacco field; when applied to tobacco field, aspergillus flavus agent can increase the potassium content in tobacco plant by 0.1%-0.4%, but others are not reported [9]. The domestic (Chinese) applied researches on microbial fertilizers in tobacco production have experienced several special periods. At the end of the 1960s, actinomycetes 5406, and phosphorus and potassium-dissolving agents developed in China started being used in tobacco production [10], following the 1990s, the R & D of compound bacterial fertilizers for flue-cured tobacco achieved amazing progress. In 1995, the State Tobacco Monopoly Bureau founded the “R & D of compound microbial fertilizers for tobacco” program, where two microbial fertilizers—Baode and Tianlibao—were extensively promoted and applied [11]; further researches show that the production increase and efficiency improvement of flue-cured tobacco applied with compound microbial fertilizers were superior to those of flue-cured tobacco applied with single bacterial fertilizer or conventional chemical fertilizer [10]. Although the researches on microbial fertilizers for tobacco have developed for dozens of years in China, there is not any microbial fertilizer which can be promoted and used on a national scale for a long time. To figure out why, the application methods are not scientific, product quality is not satisfying, the related knowledge is ineffectively propagated, and moreover, the credibility of microbial fertilizers falls due to chaotic market management, etc.

3. Influence of Microbial Fertilizers on Tobacco-planting Soil

3.1. Influence of microbial fertilizers on nutrients in tobacco-planting soil

Generally speaking, the effective contents of alkali-hydrolyzable nitrogen, rapidly available phosphorus, rapidly available potassium and organic matters serve as the main indexes used to evaluate the fertility of soil, which is the basic medium for crop growth [12]. Researches show that [13] applied to tobacco field, microbial fertilizers can improve the loosening degree of arable layer, strengthen soil water retention and fertilizer maintenance abilities, so as to improve its physicochemical properties. The reason is that the microbial fertilizer applied into the tobacco field will form a kind of carbohydrates, bind to humic acids in soil and crop root exudates, and thus a well-coordinated granular structure is formed in the soil [14].

DENG Zhao-quan et al. [15] found that bacterial fertilizers, when blended with water-soluble fertilizers and then applied to the tobacco field, could significantly elevate the contents of available nitrogen, rapidly available phosphorus, rapidly available potassium and organic matters in soil, and exerted a certain promoting effect on the growth and development of tobacco plants. ZHANG Lu et al.
investigated the influences of organic materials such as grass peat, peanut shell, steam-exploded tobacco stem and steam-exploded corn straw on the nutrients in the tobacco-planting soil, and found that the applied organic materials could remarkably increase the contents of organic carbon, rapidly available nitrogen, rapidly available phosphorus and rapidly available potassium in soil, and the best effect was embodied on steam-exploded corn straw. FAN Jun et al. [17] pointed out that composting organic fertilizer could increase the contents of rapidly available potassium, organic carbon, available zinc, available magnesium and available boron in soil better than straw returning to field, and moreover, it was more conducive to the growth and development of flue-cured tobacco.

3.2. Influence of microbial fertilizers on soil enzymes and microbial biomass

Microorganisms are important constituent parts of soil, and important factors participating in the organic matter decomposition and promoting the circulation and energy transformation of nutritive elements needed by plants. Their categories and quantity are significant evaluation indexes for soil fertility [18]. Soil enzymes are mainly generated by the vital activities of soil microorganisms and plant root exudates, while most of the biochemical reactions are completed under the catalytic action of soil enzymes [19]. Therefore, the enzyme activity in soil also indirectly reflects the microbial activity [20]. In recent years, many researches manifest that the enzymatic activity can be one of the measuring and evaluation indexes for soil fertility [19 ~ 23]. The application of microbial fertilizers in tobacco field is of a certain facilitating effect on microbial biomass and enzymatic activity in soil. The possible reason is that the specific functional microorganisms of microbial fertilizers, a kind of living microorganism-type fertilizers, can maintain or promote the beneficial microflora formed by tobacco plant roots in the soil, resist the pest invasion, and create a suitable growth environment for flue-cured tobacco.

According to the research of CAO Ming-feng [24], the Baode microbial fertilizers applied in the tobacco field could change the quantity of bacteria and actinomycetes in soil, facilitate the organic matter decomposition and generate antibiotics and hormones; improve the soil micro-ecological environment, promote the growth of tobacco plants, and enhance the early-stage dry matter accumulation in flue-cured tobacco. The research carried out by GOU Xiao-mei et al. [25] indicated that the mixture of EM fertilizer and bacillus mucilaginosus fertilizer applied in seedbed could evidently increase the carbon-nitrogen contents in the rhizosphere soil microorganisms of Honghuadajinyuan and Yunyan 85, and maintain the soil under high microbial activity and fertility level, so it was good for sustainable and efficient production of flue-cured tobacco. WU En-biao [4] concluded that the application of compound microbial fertilizers could boost the mass reproduction of bacillus, azotobacter and other bacterial populations, and furthermore, when the microbial fertilizers were applied in squaring period and mature period of flue-cured tobacco, both bacterial diversity and uniformity in soil were significantly higher than those in the treatment with chemical fertilizers.

3.3. Fertilizer saving effect of microbial fertilizers

Microbial fertilizers are capable of effectively improving the soil fertility and boosting the growth and development of flue-cured tobacco; the beneficial bacteria and antagonistic bacteria they contain can effectively inhibit the activity of pathogenic bacteria, and strengthen the disease resistance of tobacco plants [14]. The effect is not unideal when the microbial fertilizers are independently used, however, when they are reasonably mixed with chemical fertilizers and organic fertilizers, the fertilizer efficiency of microbial fertilizers can be exerted to the greatest extent, and moreover, the use amount of chemical fertilizers can also be reduced, so can the production cost, and the good ecological environment can be maintained.

YANG Xu-chu et al. [1] applied two microbial fertilizers, “Jinlong Feizhongfei” and “Degenbei”, at fertilizer saving levels of 0%, 10%, 20% and 30%, and found that the fertilizer saving level was suitable at 10% and the saving effect of “Degenbei” was better. ZHANG Huan-ju et al. [26] replaced chemical fertilizers with the same amount bio-organic fertilizers at levels of 15%, 30%, 45% and 60%, and pointed out that the bio-organic fertilizers could reduce the use amount of chemical fertilizers,
with the optimal proportion of 30%. LI-Jie et al. [27] believed that the reasonable combined application of chemical fertilizers and bio-organic fertilizers could effectively promote the growth and development of tobacco plants, elevate the tobacco yield and improve the tobacco quality, and the optimal proportion in the combined application was 40 kg of chemical fertilizers/667 m² + 60 kg of bio-organic fertilizers/667 m². According to the research of CAI Qiu-hua et al. [28], although the two treatments—combined application of organic fertilizers and chemical fertilizers, and independent application of chemical fertilizers—showed no significant differences in yield and quality of flue-cured tobacco, the former could regulate the microbial community structure in soil, enhance the stability and disease resistance of its microbial ecosystem, and reduce the incidence rate of bacterial wilt triggered by soil microorganisms to flue-cured tobacco.

The fertilizer saving effect of microbial fertilizers is also manifested in the production of other economic crops. For instance, CHEN Long et al. [29] found that replacing 15% of the chemical fertilizers, the microbial fertilizers could not only improve the agronomic traits and increase the yield of corn during the harvesting time but also could improve the soil microorganism environment. As stated by HE Bing et al. [30], the combined application of microbial agent and chemical fertilizers could boost the growth of overground part of tomato seedlings, increase the volume, fresh weight and dry weight of roots, but moreover, it could elevate the contents of soluble sugar in seedling leaves and rapidly available nitrogen in soil.

4. Influence of Microbial Fertilizers on Tobacco

4.1. Influences of microbial fertilizers on the root development and yield of flue-cured tobacco

The tobacco plant root is an important organ absorbing water and mineral nutritive elements, and also a significant place for nicotine synthesis [31]. Besides, the root activity has a direct bearing on the growth, nutritional status and yield of overground part of flue-cured tobacco, but moreover, it is one of important physiological indexes for tobacco plants [32]. Studies show that [33] the distribution of tobacco root is closely related to the chemical compounds contained in its leaves, that is, the more developed the root, the larger the leaves, and the higher the nicotine content in leaves will be.

The research of GAO Jia-he et al. [34] indicated that the organic fertilizers could facilitate the growth and development of primary and secondary lateral roots of flue-cured tobacco, and the length, quantity and activity of tobacco roots were apparently higher than those in the control group. XU Wen-bing et al. [35] found that when applied to the root zone of tobacco plant, the Sanbingheyi (three cake-like fertilizers integrated into one) bio-organic fertilizer could increase the root length, volume, diameter and branch number, improve the root activity, and increase the dry matter content in flue-cured tobacco. According to LI Yan-ping et al. [36], the organic fertilizer made of tobacco stalks could considerably increase the biomass and improve the physiological activity of flue-cured tobacco root, which was the most evident at the vigorous growing stage and doming stage, and the treatment effect was the optimal by 500g of organic fertilizer/pot. ZHU-Yi et al. [37] studied the application effects of different microbial fertilizers on the yield and quality of flue-cured tobacco, and the results showed that in comparison with the control group, the yield of flue-cured tobacco applied with Engelan microbial agent was increased by 115.50 kg/hm², the output value by RMB 4,806.45/hm², and the proportion of middle and first-class tobaccos by 2.73%. DING Can et al. [38] found that the additional application of bio-potassium fertilizer could shorten the seedling returning stage by 3 d, and the growth stage of the whole field by 5 d, and the cured tobacco yield, output value and proportion of middle and first-class tobacco were elevated by 3.6%, 7.7% and 10%, respectively.

4.2. Influence of microbial fertilizers on chemical components of flue-cured tobacco

Chemical components form the material basis for the intrinsic quality of tobacco, where the contents of total sugar, reducing sugar, total nitrogen, nicotine, chlorine and potassium in tobacco are important manifestations for the tobacco quality improvement, and important detection indexes for high-quality tobacco in the tobacco industry [39]. According to research findings [40], the potassium-dissolving
agent applied in the tobacco field could coordinate the chemical components in tobacco leaves, elevate the yellowing rate, improve the maturity and increase the potassium content in the cured tobacco. According to the research of HUO Guang et al. [41], in comparison with the conventional fertilizer application, the contents of reducing sugar, total sugar and starch in the tobacco leaves additionally applied with bio-organic fertilizers were more approximate to the standard for high-quality tobacco, and the nicotine content was also more suitable. CHANG Jian-bo et al. [42] concluded that the bio-organic fertilizers dedicated for flue-cured tobacco could effectively regulate the chemical components in tobacco, and increase the content of aroma substances in cured tobacco; the contents of total sugar, reducing sugar and aroma substances, and potassium to chlorine ratio in the cured tobacco were all higher than those in the conventional fertilizer application. WEI Zhong et al. [43] explored the application effect of compound bio-potassium fertilizer on the tobacco quality in Baise area, and found that at the application amount of 45 kg/hm2, the contents of total sugar and reducing sugar in tobacco were higher than those in the control group by 18%-22% and 16%-20%, respectively, with nitrogen/nicotine ratio and sugar/nicotine ratio of 0.75 and 12.36, respectively, both of which were within the suitable range. Furthermore, LI Zu-ying also found that the application of organic fertilizers produced by Chuangfeng Biotechnology in the tobacco field could not only elevate the contents of rapidly available nitrogen, rapidly available phosphorus and rapidly available potassium in soil, but also could increase the contents of proteins and total nitrogen in tobacco, and keep the nitrogen/nicotine ratio and reducing sugar content in tobacco at moderate levels [44].

4.3 Influence of microbial fertilizers on disease resistance of tobacco plants

ZHANG Yun-wei et al. [45] indicated the obvious inhibitory effect of bio-organic fertilizers on black shank of flue-cured tobacco, where the effect was the best under combined application of 80% NPK chemical fertilizer and 0.3 kg/m2 bio-organic fertilizer. DONG Yan et al. [46] deemed that the microbial fertilizers could relieve the incidence rate and disease index of wildfire disease, anthracnose and brown spot of flue-cured tobacco to different degrees, the disease index could be well repressed by the application of Baode soil inoculant and leaf synergist, but the inhibitory effect on tobacco mosaic virus was unapparent. CHEN Yu-guo et al. [47] found that the preventive efficiencies of HYT microbial fertilizers for virus disease, black shank and root-knot nematode disease of tobacco could reach 47.13%, 36.06% and 65.62%, respectively. According to the research findings of XIAO Xiang-zheng et al. [48], the functional microorganisms were colonized in tobacco rhizosphere soil through the application of bio-organic fertilizers, which could inhibit the harmful pathogenic microorganism—ralstonia solanacearum, improve the early-stage activity of defensive enzymes in flue-cured tobacco, and strengthen the resistance of tobacco plants against pathogenic microorganisms. ZHAO Li-guang et al. [49] thought that the combined application of chemical fertilizers and bio-organic fertilizers exerted a certain inhibitory effect on the bacterial wilt of flue-cured tobacco, and the pathogenic ralstonia solanacearum in flue-cured tobacco was reduced by 53.41% and 57.04% under the combined application of chemical fertilizers (10% decrement) and 100 kg of bio-organic fertilizers, and combined application of chemical fertilizers (20% decrement) and 200 kg of bio-organic fertilizers, respectively.

4.4 Influence of microbial fertilizers on continuous cropping obstacles of flue-cured tobacco

Under normal cultivation and management conditions, the weakening plant growth vigor, production decline and quality deterioration due to continuous crop tillage are jointly called continuous cropping obstacles, which are one of the key factors restricting the yield and quality of flue-cured tobacco [50]. According to the existing researches, the continuous cropping obstacles of flue-cured tobacco are mainly induced by soil nutrient imbalance, poor soil physical and chemical properties, soil microbial community structural imbalance, and autotoxicity of plant allelopathy [50 ~ 52]. It is pointed out in some recent researches that the microbial fertilizers can improve the continuous cropping obstacles of flue-cured tobacco to a certain extent. For instance, LIU Hong-jie [53] investigated the influence of continuous cropping enzyme activity in tobacco-planting soil, and the results showed that the
microbial compound fertilizer and glomus mosseae had the best improving effect on soil enzyme activity, followed by glomus etunicatum and glomus intraradices. After applying conventional chemical fertilizers and biological fertilizers in continuous tobacco-planting soil in different periods, LU Yan-hong [54] found that the growth & development, quality and soil microbial activity of tobacco plants were all improved, suggesting that the combined application of microbial fertilizers and conventional chemical fertilizers could relieve the continuous cropping obstacles of flue-cured tobacco. Some researches show that [55, 56] some arbuscular mycorrhizal fungi (AMF), pseudomonas fluorescens and streptomyces exert certain inhibitory effects on pathogenic bacteria. It is suggested that these bacteria should be applied to tobacco field after culturing to decompose hazardous substances, control the growth of pathogenic bacteria, and relieve the continuous cropping problem of flue-cured tobacco. However, the effects of microbial fertilizers on soil continuous cropping obstacles are scarcely probed, and their practicality and action mechanism remain to be further investigated and verified.

5. Research Prospects
The researches on the microbial fertilizers will be of great importance for improving the tobacco quality and mitigating the impact of chemical fertilizers on the soil structure in tobacco field. Based on predecessors’ researches, it is already confirmed that the microbial fertilizers have potential values for improving the soil rhizosphere micro-ecological environment, the fertility of tobacco-planting soil and quality of flue-cured tobacco, increasing the soil microbial biomass, and enhancing the enzyme activity, etc. In addition, the microbial fertilizers can also reduce the application amount of chemical fertilizers, strengthen the tobacco resistance against plant diseases and insect pests, and improve the continuous cropping obstacles of tobacco-planting soil. Nevertheless, the application effects of chemical fertilizers on flue-cured tobacco vary with the fertilizer variety, application area and application method to a certain degree. The microbial fertilizers have gradually aroused high attention with their extensive application in tobacco production in recent years, but the core problem always lies in the fertilizer efficiency. Hence, the applied researches of microbial fertilizers on different flue-cured tobacco production areas should be further carried out from the two following aspects:

1) The suitable microbial fertilizer varieties should be screened out for different flue-cured tobacco production areas. As the tobacco growth environment varies from area to area, and the application effect of the same microbial fertilizer through the same application method is not necessarily good, it is essential to select the microbial fertilizers adaptable to different tobacco production areas.

2) The effect is not ideal if the microbial fertilizers are independently applied. However, the efficiency of the microbial fertilizers can be exerted to the greatest extent if combined with inorganic and organic fertilizers. It is suggested that the optimal mixing ratio of microbial fertilizers and chemical fertilizers or organic fertilizers should be figured out, thus giving full play to the fertilizer saving effect of the microbial fertilizers.

Fund program
Scientific Research Fund Program of Yunnan Provincial Department of Education (2020Y0478); General Science and Technology Planning Project of Yunnan Company of China National Tobacco Corporation (2018530000242011); Special Joint Fundamental Research Project of Local Universities and Colleges in Yunnan Province (2017FH001 - 041); National Natural Science Foundation of China (42067009).

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