Effects of Fertilization on the Yield and Quality of *Scutellaria baicalensis* in Field Conditions

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Abstract [**Objectives**] To investigate the effects of various fertilization patterns on the growth, yield, and active component content of *Scutellaria baicalensis* in field conditions and to identify high-quality and efficient fertilization strategies. [**Methods**] One-year-old *S. baicalensis* plants served as the experimental material. The treatments comprised a control with no fertilization (CK), application of chemical fertilizer alone (H), organic fertilizer alone (Y0), and several gradients of organic fertilizer combined with compound fertilizer (Y5-Y25). Parameters measured included the branch number, bud number, root length, rhizome neck diameter, yield per unit area, and both the content and accumulation of five flavonoids. [**Results**] All fertilization treatments enhanced the growth and yield of *S. baicalensis*. The combined application of organic and compound fertilizers generally outperformed the sole application of chemical fertilizer. Treatment Y15 (1 000 kg/667 m^2 of organic fertilizer + 15 kg/667 m^2 of compound fertilizer) resulted in the highest dry root yield (92.93 kg/667 m^2). The baicalin content reached 12.26 g/100 g, representing a 32.45% increase compared to CK. Consequently, the accumulation of active components per unit area was maintained at a relatively high level. [**Conclusions**] Treatment Y15 can enhance both the yield and quality of *S. baicalensis*. Under the conditions of this experiment, it is a superior fertilization model and may serve as a valuable reference for the high-quality and efficient cultivation of *S. baicalensis*.

Key words *Scutellaria baicalensis*, Fertilization, Yield, Quality

1 Introduction

Scutellaria baicalensis Georgi, a traditional and widely utilized Chinese medicinal herb, is primarily harvested for its root, which serves medicinal purposes. The yield and quality of this root significantly influence the production efficiency of the medicinal material. With the ongoing expansion of the artificial cultivation area of *S. baicalensis*, enhancing the yield and promoting the accumulation of active components through appropriate cultivation and management practices has become a critical issue to address in the standardized production of this herb. Fertilization is a critical agricultural practice that influences the growth, development, and yield formation of medicinal plants. It significantly contributes to the yield of medicinal materials by regulating soil nutrient availability, enhancing vegetative growth, and improving root development. An adequate supply of essential mineral elements, including nitrogen, phosphorus, and potassium, promotes photosynthesis and the accumulation of dry matter in plants, thereby increasing root biomass[1]. Currently, chemical fertilizers are extensively utilized in agricultural production owing to their high nutrient content and rapid efficacy. However, prolonged exclusive use of chemical fertilizers may result in an imbalance of soil nutrient supply and adversely affect the quality enhancement of medicinal materials[2]. Organic fertilizers, which are abundant in organic matter and diverse nutrients, can improve soil conditions and increase soil fertility. The rational application of organic and compound fertilizers can ensure a sustained nutrient supply and enhance fertilizer use efficiency[3-4]. Therefore, investigating an appropriate combined application pattern of organic fertilizers is of considerable importance for optimizing the cultivation techniques of *S. baicalensis* and achieving high-yield, high-quality production. This study utilized one-year-old *S. baicalensis* as the experimental material and established various treatments combining organic fertilizer with compound fertilizer to examine the effects of different fertilization patterns on the growth, yield, and quality of *S. baicalensis*. The objective was to identify suitable fertilization schemes and provide a theoretical foundation and technical guidance for the efficient cultivation and production of *S. baicalensis*.

2 Materials and methods

2.1 Test materials and fertilization treatments This study focused on one-year-old *S. baicalensis* and involved a plot experiment. Each plot measured 10 m^2 (10 m × 1 m). Prior to transplanting, base fertilizer was applied and thoroughly mixed with the soil, followed by land preparation and the formation of raised beds. Eight fertilization treatments were established: CK, serving as the control with no fertilization; H, involving the application of chemical fertilizer (compound fertilizer, $N : P_2O_5 : K_2O = 15 : 6 : 24$, Zhongcang Ecological Agriculture Co., Ltd.) at a rate of 40 kg/667 m^2; Y0, consisting of a single application of organic fertilizer at 1 000 kg/667 m^2; and treatments Y5, Y10, Y15, Y20, and Y25, which combined organic fertilizer at 1 000 kg/667 m^2 with varying amounts of compound fertilizer at 5, 10, 15, 20, and 25 kg/667 m^2, respectively. Each treatment was replicated three times, resulting in a total of 24 plots arranged in a randomized block design. Both the organic and compound fertilizers used in this experiment were developed by the Institute of Traditional Chinese Medicine at Chengde Medical University.

2.2 Methods The roots of *S. baicalensis* were harvested in the

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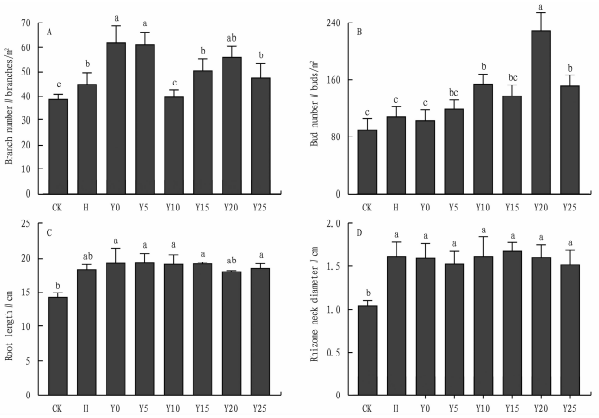
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autumn of the transplanting year. A 1 m^2 sample plot was randomly selected from each experimental plot for analysis. The total number of branches and buds of *S. baicalensis* per unit area were counted, and the average root length and rhizome neck diameter of individual plants were measured. All root systems within the sample plot were collected to determine the fresh yield per unit area. Following drying to a constant weight, the dry yield per unit area was also measured. The concentrations of baicalin, wogonoside, baicalein, wogonin, and oroxylin A were quantified using high-performance liquid chromatography[5].

2.3 Data processing Data were compiled using Microsoft Excel 2010, and analysis of variance and significance tests were conducted using GraphPad Prism 10 software.

3 Results and analysis

3.1 Effects on the growth of medicinal materials The research findings indicated that, compared to CK, the application of fertilizer resulted in an increase in the number of branches and buds of *S. baicalensis*. Treatment Y10 did not significantly enhance branch number, and treatments H and Y0 did not significantly increase bud number; however, all other treatments produced a significant increase in both branches and buds ($P < 0.05$), with treatment Y20 exhibiting the most pronounced effect (Fig. 1A – B). As illustrated in Fig. 1C, all fertilization treatments significantly increased root length relative to CK, with growth rates ranging from 25.79% to 34.56%. Nevertheless, differences in root length among the fertilization treatments were not statistically significant. A similar pattern was observed for rhizome neck diameter: fertilization significantly increased this parameter, with growth rates between 45.22% and 61.46%, yet no significant differences were detected among the various fertilization treatments (Fig. 1D).



NOTE A. Branch number; B. Bud number; C. Root length; D. Rhizome neck diameter.

Fig. 1 Effects of fertilization on the growth of *Scutellaria baicalensis*

3.2 Effects on root biomass and yield per unit area The yield per unit area under each fertilization treatment increased significantly compared to CK (Fig. 2). Regarding dry weight yield per unit area, the most pronounced increase was observed in treatment Y15, which exhibited a 39.18% increase, corresponding to a dry root yield of 92.93 kg/667 m^2. The effects on dry weight yield for the other treatments followed the order: Y10 (38.45%) > Y20 (33.35%) > Y0 (31.45%) > Y25 (26.27%) > H (25.64%) > Y5 (14.45%) (Fig. 2). The yield-enhancing effects on fresh weight per unit area differed from those observed for dry weight. Specifically, the greatest increases in fresh weight were recorded for treatments Y15 and Y0, with yield increases of 30.86% and 30.13%, respectively, whereas treatment Y25 exhibited the smallest increase, at only 10.27% (Fig. 2). Overall, based on the effect of various fertilization treatments on the unit area yield of *S. baicalensis*, treatment Y15 demonstrated the most effective yield enhancement, maintaining relatively high levels of both fresh and dry weight yields.

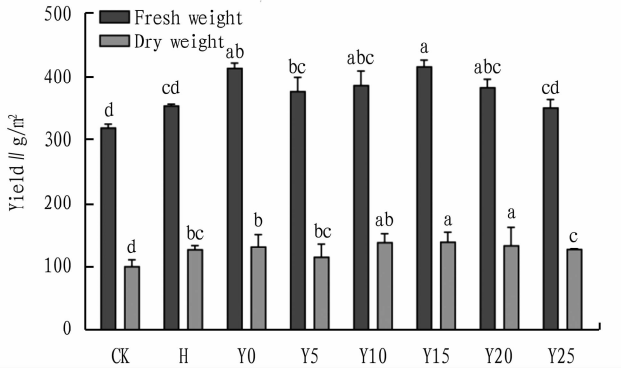
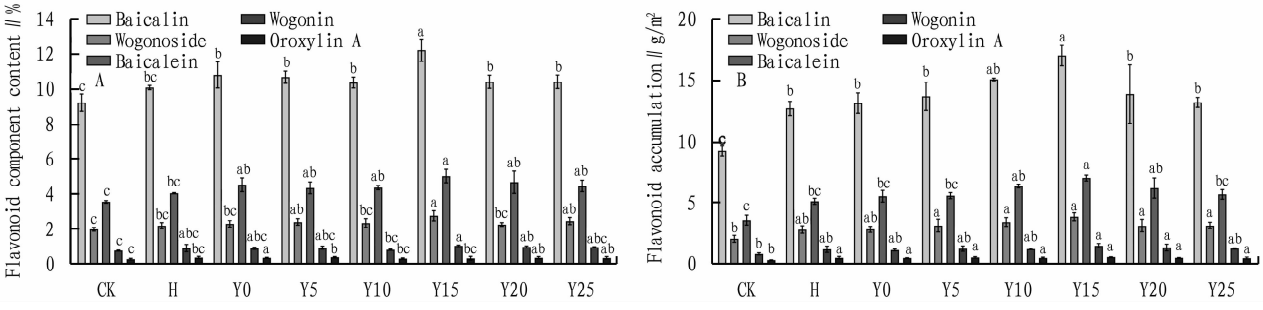


Fig. 2 Effects of fertilization on the yield of *Scutellaria baicalensis* per unit area

3.3 Effects on active component content and accumulation per unit area Different fertilization treatments exerted varying effects on the concentrations of five major flavonoid components in the roots of *S. baicalensis* (Fig. 3). As a critical indicator for assessing the medicinal material quality of *S. baicalensis*, baicalin content exhibited significant differences across treatments. Compared to CK, all fertilization treatments resulted in increased baicalin levels. Treatment Y15 produced the most pronounced enhancement, with baicalin content reaching 12.26 g/100 g, representing a 32.45% increase relative to CK and significantly exceeding the levels observed in other fertilization treatments. Compared to treatment H (single application of chemical fertilizer at 10.11 g/100 g), the combined application of organic and compound fertilizers generally led to higher baicalin content, and treatment Y15 demonstrated a 21.31% increase relative to treatment H. The baicalin content in other combined organic and compound fertilizer treatments ranged from 10.40 to 10.83 g/100 g, which was consistently higher than that observed in both treatment H and CK (Fig. 3A). Different fertilization treatments exhibited notable enhancing effects on various flavonoid components, including wogonoside, baicalein, wogonin, and oroxylin A (Fig. 3A). In treatment Y15, the concentrations of wogonoside, baicalein, and wogonin reached 2.79%, 5.04%, and 1.04%, respectively, representing relatively elevated levels. In contrast, the variation in oroxylin A content across treatments was comparatively minimal.

Overall, the application of an appropriate quantity of organic and compound fertilizer effectively increases the content of principal flavonoids in *S. baicalensis*, thereby contributing to the quality enhancement of medicinal materials.

The effects of various fertilization treatments on the accumulation of active components in *S. baicalensis* were further analyzed in conjunction with dry matter yield per unit area (Fig. 3B). The results indicated that all fertilization treatments enhanced the accumulation of flavonoids per unit area in *S. baicalensis*. The combined application of organic and compound fertilizers demonstrated superior efficacy compared to the sole application of chemical fertilizers. Treatment Y15 exhibited the most favorable overall performance. The accumulation levels of baicalin, wogonoside, baicalein, wogonin, and oroxylin A reached 17.03, 3.87, 6.99, 1.45, and 0.52 g/m^2, respectively, representing relatively high levels among the treatments. Although other fertilization treatments also increased the accumulation of active components per unit area, their effects were consistently lower than those observed in treatment Y15.



NOTE A. Flavonoids content; B. Accumulation of flavonoid components per unit area.

Fig. 3 Effects of fertilization on the active component content in *Scutellaria baicalensis*

4 Discussion

Fertilization is a critical agronomic practice aimed at enhancing the growth and development of medicinal plants. An appropriate supply of nutrients can improve the plants' nutritional status and facilitate the coordinated development of both aerial and subterranean organs. This study demonstrated that, compared to CK, all fertilization treatments resulted in varying degrees of increase in the number of branches and buds of *S. baicalensis*. These findings suggest that suitable fertilization promotes lateral bud germination and branch formation, thereby benefiting the morphogenesis of the plant's aerial parts[6]. Meanwhile, all fertilization treatments significantly enhanced root length and rhizome neck diameter, indicating that fertilization effectively improves the root system's growth environment and stimulates root elongation and swelling[7-8].

The formation of medicinal plant yield is influenced not only by the growth and developmental status of the plant but also closely associated with biomass accumulation and assimilate allocation within the medicinal parts[9]. This study demonstrated that, compared to CK, all fertilization treatments significantly increased both the fresh and dry weight yields per unit area of *S. baicalensis*, indicating that appropriate fertilization can enhance plant biomass accumulation. Different fertilization patterns resulted in significant variations in yield formation. Among these, treatment Y15 produced the highest yield, suggesting that the application of a suitable combination of organic and compound fertilizers can effectively coordinate nutrient supply and promote biomass formation in the roots of *S. baicalensis*. However, further increases in compound fertilizer application, as observed in treatments Y20 and Y25, did not lead to continued yield improvements, indicating that excessive nutrient input does not sustain yield enhancement. These findings are consistent with the results reported by Gan[10]. The analysis of growth indicators revealed that, although treatment Y20 enhanced branch and bud formation in *S. baicalensis*, its yield per unit area was lower than that observed in treatment Y15. This finding suggests that the yield formation of *S. baicalensis* depends not only on the vegetative growth of the aerial parts, but is also closely associated with the supply of assimilates within these parts and the accumulation of medicinal organs in the roots. An appropriate fertilization pattern may optimize the source-sink relationship in the plant, thereby facilitating the transport of assimilates to the root medicinal organs and ultimately increasing the yield of medicinal materials[9,11].

The accumulation of bioactive compounds in *S. baicalensis* is a critical indicator for assessing its quality formation. Miao Huifeng *et al.*[1] demonstrated that the rational application of nitrogen, phosphorus, and potassium fertilizers can enhance both the yield of *S. baicalensis* and the accumulation of key active components such as baicalin and baicalein. This finding underscores the significant role of appropriate nutrient management in optimizing yield and improving the quality of *S. baicalensis*. The present study revealed that, relative to CK, all fertilization treatments increased the flavonoid content in *S. baicalensis* to varying extents, suggesting that rational fertilization promotes the accumulation of bioactive components and enhances the quality of medicinal materials. Furthermore, compared to the sole application of chemical

fertilizers, the combined use of organic and compound fertilizers yielded superior effects on quality formation, indicating that an integrated fertilization strategy is more effective in facilitating the accumulation of active components. Adequate nutrient supply establishes a foundation for the biosynthesis of these compounds. The synergistic application of organic and compound fertilizers ensures a sustained and balanced nutrient supply, improves the plant growth environment, and satisfies the mineral element requirements throughout the developmental stages of *S. baicalensis*, thereby contributing to the quality enhancement of medicinal materials[8,12]. Furthermore, this study demonstrated that increasing the application rate of compound fertilizer did not result in a continuous increase in the content of flavonoid components, suggesting the existence of an optimal nutrient supply range for the accumulation of bioactive compounds in *S. baicalensis*. Excessive nutrient input failed to consistently enhance quality[13]. Analysis of the accumulation of active components per unit area further revealed that treatment Y15 not only elevated the concentration of active components per unit mass of the medicinal material, but also, due to increased root biomass, achieved a synergistic improvement in both yield and quality. Therefore, under the experimental conditions, the application of an appropriate amount of organic and compound fertilizer can promote the high-yield and high-quality production of *S. baicalensis*, with treatment Y15 exhibiting the most favorable overall effect.

5 Conclusions

The findings of this study demonstrate that the combined application of organic fertilizer and compound fertilizer significantly enhances the growth and development of *S. baicalensis*, promotes root biomass accumulation, and facilitates the accumulation of flavonoid bioactive components. Notably, the most effective treatment involved the application of 1 000 kg/667 m^2 organic fertilizer in combination with 15 kg/667 m^2 compound fertilizer (Y15), resulting in a dry weight yield of 92.93 kg/667 m^2. Additionally, the baicalin content in this treatment reached 12.26 g/100 g, representing a 32.45% increase compared to CK, thereby achieving a relatively high accumulation of active components per unit area. Within the parameters of this experiment, the application of 1 000 kg/667 m^2 organic fertilizer combined with 15 kg/667 m^2 compound fertilizer effectively balances yield and quality improvements in *S. baicalensis* and is recommended as a suitable fertilization pattern for high-yield and high-quality field cultivation of this species.

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