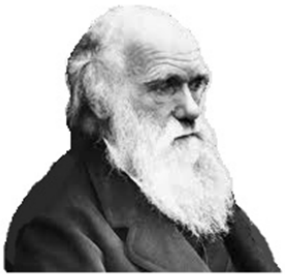
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Effects of planting spacing and potassium fertilizer rates on the growth, development and seed yield of *Atractylodes macrocephala* Koidz. in Sa Pa, Vietnam

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ABSTRACT

Atractylodes macrocephala Koidz. is a valuable medicinal plant widely used in traditional East Asian medicine, particularly for digestive disorders, diarrhea, abdominal distension, edema, night sweats and threatened miscarriage. This study was conducted in Sa Pa, Lao Cai Province, Vietnam, to identify suitable planting spacing and potassium fertilizer rates for the growth, development and seed yield of *A. macrocephala*. The experiment comprised four potassium treatments (0, 110, 135, and 160 kg K_2O ha^{-1}) and three planting spacings (30 × 20 cm, 30 × 30 cm, and 30 × 40 cm). The results indicated that planting spacing and potassium application affected plant height, canopy diameter, the number of primary branches and seed-yield components. The most suitable treatment for seed production comprised 15 t ha^{-1} farmyard manure, 5 t ha^{-1} wood ash, 86 kg P_2O_5 ha^{-1}, 186 kg N ha^{-1} and 160 kg K_2O ha^{-1}, combined with a planting spacing of 30 × 30 cm. The harvested seed yield under this treatment was 210.52 kg ha^{-1}.

Keywords: *Atractylodes macrocephala*, planting density, potassium fertilizer rate, seed yield, seed quality

1. INTRODUCTION

Atractylodes macrocephala Koidz. is a member of the family Asteraceae. The species is native to China and is naturally distributed in mountainous areas above approximately 800 m

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elevation [1]. It was introduced into Vietnam around the 1960s and trialled in Lao Cai Province, including Sa Pa and Bac Ha, before being cultivated in other mountainous areas and parts of the Red River Delta, such as Hung Yen, Hanoi and Hai Duong [2].

In traditional Chinese medicine, *A. macrocephala* has been used for more than 2,000 years. Its rhizome is traditionally used to strengthen the spleen, replenish qi and promote diuresis [3].

In Japanese traditional medicine, it has also been used as a diuretic for conditions including reduced or painful urination, seminal emission and dizziness [2].

Atractylodes macrocephala Koidz. is a cross-pollinated species [4] that is commonly propagated by seeds [5]. Pham Van Dan et al. (2024) investigated agronomic practices for cultivating *A. macrocephala* in Bac Ha District, Lao Cai Province, Vietnam. Field experiments examining the effects of fertilizer application and bed-covering materials on the medicinal yield and quality of *A. macrocephala* were conducted in 2022-2023. The experiments were arranged in a randomized complete block design (RCBD) with three replications [6].

The fertilizer experiment identified an application rate of 2,000 kg ha^{-1} of microbial organic fertilizer, 180 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, 150 kg K_2O ha^{-1} and 830 kg ha^{-1} of powdered lime as the most effective treatment. This treatment produced a dry medicinal-material yield of 2.85-2.89 t ha^{-1} and the highest atractylenolide III content, at 0.062-0.063% [7]. In the bed covering experiment, plastic mulch resulted in the highest dry medicinal material yield, at 2.87-2.90 t ha^{-1}, with an atractylenolide III content of 0.056-0.058% [8].

In 2021, Tran Van Thang et al. published a study evaluating the growth and development of the VDL-BT1 accession of *Atractylodes macrocephala* Koidz [4] in Lao Cai Province, Vietnam. The VDL-BT1 Atractylodes accession was selected over a two year period, from 2018 to 2019, from a local Atractylodes accession collected in Sa Pa, Lao Cai Province. In 2020, the growth and development of VDL-BT1 were evaluated in Sa Pa [9]. The results showed that VDL-BT1 exhibited good growth and development, with an actual seed yield of 1.57 quintals ha^{-1} and an actual medicinal material yield of 2.96 t ha^{-1} [10].

The VDL-BT1 accession was characterized by green stems, green leaves, purple corollas, rhizomes with yellowish-grey outer skin and seeds covered with white hairs [10,11]. The plant had a raspberry shaped canopy, while the rhizomes were frog-thigh-shaped. Plant height ranged from 40 to 60 cm [12], stem diameter from 0.3 to 0.5 cm, leaf blade width from 2 to 4 cm and leaf blade length from 6 to 10 cm [13,14]. Seed length ranged from 0.8 to 1.0 cm, seed width from 0.2 to 0.4 cm [15] and the weight of 1,000 seeds from 30 to 40 g [14]. The theoretical seed yield ranged from 1.43 to 2.55 quintals ha^{-1}, while the actual seed yield ranged from 0.84 to 1.6 quintals ha^{-1} [16]. Rhizome length ranged from 4.93 to 6.17 cm and rhizome diameter from 2.87 to 3.49 cm [17]. Individual plant yield ranged from 13.26 to 17.22 g $plant^{-1}$, the theoretical medicinal material yield from 3.17 to 4.31 t ha^{-1} and the actual medicinal material yield from 2.33 to 3.09 t ha^{-1} [18].

The incidence of diseases, including root collar rot, Fusarium wilt, ring spot, brown spot, black spot, basal rot with white mold and stem and leaf desiccation was low. The ethanol-soluble extractive content of Atractylodes medicinal material, determined using 60% ethanol, must not be less than 35.0% on an anhydrous basis [19]. *Atractylodes macrocephala* Koidz. is a valuable medicinal plant widely used in traditional medicine [20]. However, its susceptibility to pests and diseases has limited the availability of high-quality seeds. Therefore, developing a technical protocol for cultivating *A. macrocephala* for seed production is necessary to meet current development needs.

2. MATERIAL AND METHODS

2. 1. Plant material

The experimental material consisted of *A. macrocephala* seeds maintained by the Sa Pa Medicinal Plant Research Center, National Institute of Medicinal Materials.



Fig. 1. *Atractylodes macrocephala* seeds.



Fig. 2. *Atractylodes macrocephala* fruit.

2. 2. Location anh period research

The field experiment was conducted in Sa Pa, Lao Cai Province, from November 2021 to November 2024.

2. 3. Research contents

Task 1. Effects of planting spacing and potassium fertilizer application rates on the growth and development of *Atractylodes macrocephala* Koidz.

Task 2. Effects of planting spacing and potassium fertilizer application rates on the yield and quality of *Atractylodes macrocephala* medicinal materials.

2. 4. Experimental treatments and design

Experimental design: A two-factor experiment was conducted.

The main factor was potassium fertilizer application rate with four levels:

P1: No potassium fertilizer application
P2: 110 kg K_2O ha^{-1}
P3: 135 kg K_2O ha^{-1}
P4: 160 kg K_2O ha^{-1}

Basal fertilizer application per hectare: 15 tonnes of farmyard manure ha^{-1} + 5 tonnes of wood ash ha^{-1} + 86 kg P_2O_5 ha^{-1} + 186 kg N ha^{-1}.

The secondary factor was planting spacing with three levels:

K1: 30 × 20 cm
K2: 30 × 30 cm
K3: 30 × 40 cm

The distance between the two closest rows in adjacent beds was 30 cm.

Experimental layout: The two factor experiment was arranged in a split plot design with three replications. Each replication was divided into four main plots corresponding to the different planting spacings. Each main plot was further divided into four subplots corresponding to the four fertilizer application rates. The experiment comprised a total of 36 experimental plots, with each subplot measuring 5 m^2. The total experimental area was 180 m^2, excluding furrows and pathways [8].

2. 5. Observed Parameters

Growth and developmental duration:

- Seed germination rate under field conditions in the experimental treatments (%): The period from sowing until 50% of the plants in each plot have emerged and developed two cotyledons.
- Time from sowing/planting to the onset of germination (days): The number of days from sowing/planting until 50% of the plants have germinated.
- Time from sowing/planting to the onset of branching (days): The number of days from sowing/planting until 50% of the plants have developed branches.
- Time from sowing/planting to fruit harvest (days): The number of days from sowing/planting until fruits have been harvested from 50% of the plants.

Growth parameters:

- Plant height (cm): Measured from the point at which the plant emerges from the soil surface to the tip of the highest leaf.
- Canopy diameter: Measured in two perpendicular directions through the center of the canopy and the average value was calculated.
- Number of primary branches per plant: The total number of primary branches per plant was counted.

Seed yield parameters:

- Number of fruits per plant: The total number of fruits on each plant was counted.
- Number of filled seeds per fruit: The total number of filled seeds in each fruit was counted.
- 1,000 seed weight (g): A sample of 1,000 seeds was counted and weighed in each of the three replications, and the mean weight was calculated.
- Individual plant yield (g): The seed yield of each individual plant was weighed.
- Actual seed yield (kg ha^{-1}): The seed yield harvested from the experimental plots was measured and converted to yield per hectare.

2. 6. Data Analysis Methods

The data collected during the experiment were compiled and statistically analyzed using IRRISTAT 5.0 and Microsoft Excel.

3. RESULTS AND DISCUSSION

3. 1. Effects of planting spacing and potassium fertilizer application rates on the duration of growth stages of *Atractylodes macrocephala* Koidz.

The results of the study on the effects of planting spacing and potassium fertilizer application rates on the growth duration of *Atractylodes macrocephala* are presented in Table 1.

Table 1. Effects of planting spacing and potassium fertilizer application rates on the duration of growth stages of *Atractylodes macrocephala* Koidz.

K treatment	Spacing	Time from sowing to … (days)			Field emergence (%)
		Days to emergence	Days to branching	Days to harvest	
P1	K1	21	125	315	76.67
P1	K2	21	125	316	80
P1	K3	22	127	318	76.67
P2	K1	20	125	315	83.33
P2	K2	21	126	315	83.33
P2	K3	21	127	317	80
P3	K1	20	125	316	76.67
P3	K2	21	125	315	80
P3	K3	22	126	316	80
P4	K1	21	126	315	83.33
P4	K2	20	126	315	83.33
P4	K3	21	127	316	80

Note: P1: no potassium fertilizer application; P2: 110 kg K_2O ha^{-1}; P3: 135 kg K_2O ha^{-1}; P4: basal fertilizer treatment with 160 kg K_2O ha^{-1}; K1: planting spacing of 30 × 20 cm; K2: planting spacing of 30 × 30 cm; K3: planting spacing of 30 × 40 cm.

The growth period of *Atractylodes macrocephala* Koidz. was defined as the period from seed germination to harvest. The monitoring results presented in Table 1 show no clear differences in the duration of the growth stages among the different planting spacings and potassium fertilizer application rates. Period from sowing to seedling emergence: Atractylodes macrocephala seeds germinated approximately 20-22 days after sowing. No differences were observed among the planting spacings and potassium fertilizer application rates.

Period from sowing to branching: The monitoring results showed that differences in planting spacing and potassium fertilizer application rate did not significantly affect the timing of branching. *Atractylodes macrocephala* plants began branching approximately 125-127 days after sowing.

Period from sowing to seed harvest: Planting spacing and potassium fertilizer application rate had little effect on the growth and development period of *Atractylodes macrocephala*. The period from sowing to seed harvest ranged from 315 to 318 days.

The field germination rate in the experimental treatments was not affected by planting spacing or potassium fertilizer application rate, but was mainly influenced by external environmental factors and growing season. The seed germination rate exceeded 70% in all treatments, ranging from 76.67% to 83.33%.

3. 2. Effects of planting spacing and potassium fertilizer application rates on the growth and development of *Atractylodes macrocephala* Koidz.

Different planting spacings and potassium fertilizer application rates affected the growth characteristics of *Atractylodes macrocephala*.

Table 2. Effects of planting spacing and potassium fertilizer application rates on selected growth and development parameters of *Atractylodes macrocephala* Koidz.

Treatment		Final plant height (cm)	Canopy diameter (cm)	Primary branches (plant^{-1})
P1	K1	68.9	36.0	4.2
	K2	67.5	36.5	4.5
	K3	66.7	37.2	5.0
P2	K1	74.7	40.4	5.3
	K2	73.4	41.2	5.4
	K3	72.5	42.1	5.8
P3	K1	77.6	42.0	5.5
	K2	76.5	43.5	5.7
	K3	75.2	44.7	6.2
P4	K1	79.7	45.5	6.0
	K2	78.1	46.3	6.1
	K3	76.5	47.7	6.5

Trung binh P	P1	67.7	36.6	4.6
	P2	73.5	41.2	5.5
	P3	76.4	43.4	5.8
	P4	78.1	46.5	6.2
Trung binh K	K1	75.2	40.9	5.3
	K2	73.9	41.9	5.4
	K3	72.7	42.9	5.9
$LSD_{0,05}P$		3.49	3.13	0.30
$LSD_{0,05}K$		3.59	1.99	0.44
$LSD_{0,05}P\times K$		7.18	3.98	0.88
CV%		5.6	5.5	9.3

Note: P1: no potassium fertilizer application; P2: 110 kg K_2O ha^{-1}; P3: 135 kg K_2O ha^{-1}; P4: basal fertilizer treatment with 160 kg K_2O ha^{-1}; K1: planting spacing of 30 × 20 cm; K2: planting spacing of 30 × 30 cm; K3: planting spacing of 30 × 40 cm.

The results presented in Table 2 on the effects of planting spacing and potassium fertilizer application rates on selected growth characteristics of *Atractylodes macrocephala* Koidz. showed the following:

- Plant height: Final plant height across the treatments ranged from 66.7 to 79.7 cm. A comparison of the mean values among potassium fertilizer application rates showed that the highest mean plant height was recorded at P4 (78.1 cm), which was comparable to that at P3 (76.4 cm). The P1 and P2 treatments were comparable to each other and had significantly lower plant heights than P3 and P4. A comparison of the mean values among planting spacings showed that mean plant heights were 75.2, 73.9 and 72.7 cm. Analysis of the interaction between planting spacing and potassium fertilizer application rate indicated an interaction effect on plant height. The P4K1 (79.7 cm) and P4K2 (78.1 cm) treatments produced the greatest plant heights, which were significantly higher than those obtained at the P1 fertilizer rate across the planting spacings. The differences were statistically significant at the 95% confidence level.
- Canopy diameter: Canopy diameter across the treatments ranged from 36.0 to 47.7 cm. The P3 and P4 fertilizer treatments produced comparable canopy diameters, both of which were significantly greater than those obtained with P1 and P2. The K2 and K3 planting spacings resulted in larger canopy diameters than K1. These differences were statistically significant at the 95% confidence level.
- Number of primary branches per plant: Monitoring the number of primary branches at different fertilizer application rates showed an increasing trend with increasing fertilizer

application. A comparison of the mean values among fertilizer treatments showed that P4 produced the highest number of primary branches, at 6.2 branches per plant, significantly exceeding the values recorded for the other treatments. A comparison of the mean values among planting spacings indicated that the number of primary branches tended to decrease as planting density increased. The K3 spacing produced the highest number of primary branches, significantly exceeding the values obtained at the other spacings at the 95% confidence level. An interaction effect between fertilizer application rate and planting spacing was also observed, with P4K3 producing the highest number of primary branches, at 6.5 branches per plant.

The experimental results indicate that planting spacing and potassium fertilizer application rate affected plant height, canopy diameter and the number of primary branches per plant in *Atractylodes macrocephala* Koidz.

3. 3. Effects of planting spacing and potassium fertilizer application rates on seed yield of *Atractylodes macrocephala* Koidz.

Yield is an important factor in crop production, determining the economic efficiency of a crop. Seed yield in Atractylodes macrocephala is determined by several yield components including the number of fruits per plant, the number of filled seeds per fruit and the 1,000-seed weight. The monitoring results are presented in Table 3.

Table 3. Effects of planting spacing and potassium fertilizer application rates on seed yield of *Atractylodes macrocephala* Koidz.

Treatment		Fruits plant^{-1}	Filled seeds fruit^{-1}	1,000-seed weight (g)	Seed yield (g plant^{-1})	Harvested yield (kg ha^{-1})	Germination (%)
P1	K1	7.4	23.1	24.1	4.12	153.78	90.0
	K2	8.0	25.2	24.5	4.93	154.82	90.0
	K3	9.5	25.8	24.5	6.0	146.12	93.33
P2	K1	8.2	28.2	25.1	5.8	180.13	90.0
	K2	9.5	29.5	25.5	7.14	182.9	90.0
	K3	10.1	29.6	25.3	7.56	170.5	93.33
P3	K1	8.7	31.5	25.1	6.88	192.75	93.33
	K2	9.9	32.7	25.6	8.28	194.52	93.33
	K3	10.8	32.8	25.7	9.1	182.34	93.33
P4	K1	9.6	32.8	25.2	7.93	207.75	90.0
	K2	10.5	34.7	26.1	9.5	210.52	93.33

	K3	11.1	34.8	25.6	9.89	191.9	93.33
Trung bình P	P1	8.3	24.7	24.4	5.02	151.57	91.11
	P2	9.3	29.1	25.3	6.83	177.84	91.11
	P3	9.8	32.3	25.5	8.09	189.87	93.33
	P4	10.4	34.1	25.6	9.12	203.39	92.22
Trung bình K	K1	8.48	28.9	24.9	6.18	183.60	90.83
	K2	9.48	30.53	25.4	7.46	185.69	91.67
	K3	10.38	30.75	25.3	8.14	172.72	93.33
$LSD_{0,05}P$		0.36	0.41	0.59	0.83	5.66	-
$LSD_{0,05}K$		0.64	0.72	0.44	0.58	6.13	-
$LSD_{0,05}P\times K$		1.28	1.45	0.89	1.17	12.25	-
CV%		7.8	8.9	4.0	9.3	4.5	-

(Note: P1: no potassium fertilizer application; P2: 110 kg K_2O ha^{-1}; P3: 135 kg K_2O ha^{-1}; P4: basal fertilizer treatment with 160 kg K_2O ha^{-1}; K1: planting spacing of 30 × 20 cm; K2: planting spacing of 30 × 30 cm; K3: planting spacing of 30 × 40 cm.)

Number of fruits per plant: Significant differences were observed among potassium fertilizer application rates, planting spacings and the interaction between potassium fertilizer application rate and planting spacing. A comparison of the mean values among fertilizer treatments showed that P4 produced the highest average number of fruits per plant, at 10.4 fruits, which was significantly higher than those obtained with the other fertilizer treatments. A comparison of the mean values among planting spacings showed that K3 produced an average of 10.38 fruits per plant, clearly exceeding the values recorded at K1 and K2. An analysis of the interaction between potassium fertilizer application rates and planting spacings showed that the P3 and P4 treatments combined with the K2 and K3 spacings produced clearly higher numbers of fruits per plant than the other treatment combinations. Among these, P4K3 produced the highest number of fruits per plant, at 11.1. These differences were statistically significant at the 95% confidence level.

Number of filled seeds per fruit: The number of filled seeds per fruit showed a clear increasing trend as the potassium fertilizer application rate increased. Across the treatments, the number of filled seeds per fruit ranged from 23.1 seeds in P1K1 to 34.8 seeds in P4K3. A comparison of the interactions between different potassium fertilizer application rates and planting spacings showed that P4K2 and P4K3 produced the highest numbers of filled seeds per fruit, clearly exceeding those of the remaining treatment combinations at the 95% confidence level.

1,000-seed weight: The 1,000-seed weight of Atractylodes macrocephala ranged from 24.1 to 26.1 g. Across the experimental treatments, the 1,000-seed weight tended to increase with

increasing potassium fertilizer application rates and under different planting spacings. In particular, at the P1 fertilizer rate, the 1,000-seed weight under the different planting spacings was clearly lower than that obtained with the other fertilizer application rates.

Individual plant yield: The individual plant yield of Atractylodes macrocephala differed among the potassium fertilizer application rates. A comparison of the mean values among fertilizer treatments showed that P4 produced the highest individual plant yield, which was statistically significantly higher than those obtained with the other fertilizer treatments at the 95% confidence level. A comparison of the mean values among the different planting spacings showed that K3 resulted in a clearly higher average individual plant yield than K1 and K2. An analysis of the interaction between potassium fertilizer application rates and planting spacings showed that the P4K3 treatment produced the highest individual plant yield (9.89 g), clearly exceeding that of the other treatment combinations. The high individual plant yield under this treatment was attributable to its substantially greater numbers of fruits per plant and filled seeds per fruit compared with the other treatments.

Potassium fertilization not only enhances the effectiveness of other fertilizers but also improves the photosynthetic capacity of plants and promotes the translocation of photosynthetic products from stems and leaves to fruits and seeds. This increases the seed-setting rate and the number of filled seeds per plant, thereby increasing seed yield.

Actual seed yield: Monitoring the actual seed yield across the experimental treatments showed that, when comparing the mean values among potassium fertilizer application rates, P4 produced an average actual seed yield of 203.39 kg ha^{-1}, which was clearly higher than those obtained with P1, P2, and P3, at 151.57, 177.84, and 189.87 kg ha^{-1}, respectively. A comparison of the mean values among the different planting spacings showed that, as planting density decreased from K1 to K3, actual seed yield declined from 185.69 to 172.72 kg ha^{-1}.



Fig. 3. Flowering *Atractylodes macrocephala* plants



Fig. 4. Seed production field of *Atractylodes macrocephala*

Although K1 and K2 resulted in lower individual plant yields, the greater number of plants per unit area led to higher actual yields per unit area. In contrast, although K3 produced a higher individual plant yield, the lower number of plants per unit area resulted in a lower

actual seed yield. An analysis of the interaction between potassium fertilizer application rates and planting spacings showed that the P4 treatment combined with K1 and K2 produced clearly higher actual seed yields than the other treatment combinations. Among these, P4K2 produced the highest yield, at 210.52 kg ha^{-1}.

The germination rate of Atractylodes macrocephala seeds harvested from all treatments exceeded 90%, indicating that the seeds met the required quality standards.

Monitoring the interactive effects of potassium fertilizer application rates and planting spacings on *Atractylodes macrocephala* seed yield showed that the P4 fertilizer rate combined with planting spacings K1 and K2 produced the highest actual seed yields, with comparable results. Therefore, in Sa Pa, *Atractylodes macrocephala* can be cultivated at either K1 (30 × 20 cm) or K2 (30 × 30 cm) with the P4 fertilizer treatment (160 kg K_2O ha^{-1}). However, K2 (30 × 30 cm) is preferred to promote good plant growth and reduce pest and disease incidence.

4. CONCLUSION

Planting spacing and potassium fertilizer application rate affected the growth, development and seed yield of *Atractylodes macrocephala*. The most suitable planting spacing and potassium fertilizer application rate for seed production of Atractylodes macrocephala were 15 tonnes of farmyard manure ha^{-1} + 5 tonnes of wood ash ha^{-1} + 86 kg P_2O_5 ha^{-1} + 186 kg N ha^{-1} + 160 kg K_2O ha^{-1}, combined with a planting spacing of 30 × 30 cm. The resulting seed yield was 210.52 kg ha^{-1}.

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