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EFFECTS OF MIXED CROPPING AND INOCULANTS ON YIELD AND QUALITY OF FORAGE UNDER DIFFERENT INTER CROPPING RATIOS OF OAT AND FIELD PEA

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Abstract

Using forage oat and field pea, this study was conducted to explore the effects of sole and mixed cropping patterns at varying ratios, and microbial inoculant application. The aim was to reveal the comprehensive effects of mixed cropping patterns and microbial inoculation on the above-ground biomass, forage yield, and nutritional quality. The results indicated that mixed cropping significantly increased the above-ground biomass of both oats and field peas. With microbial inoculation, mixed cropping increased dry hay yield by 21.81, 18.31, 13.33 and 10.05%; crude protein by 9.4, 16.44, 14.98 and 4.18%, and crude fat by 8.22, 2.9, 14.81 and 5.59%, respectively, compared to sole cropping. Additionally, neutral and acid detergent fiber contents decreased by 2.94 and 1.89% on average in mixed crops. These findings suggest that mixed cropping with microbial inoculants can significantly increase forage nutritional quality and yield, offering a scientific basis for efficient forage crop utilization.

Introduction

In recent years, the continuous growth in demand for livestock products has provided a strong impetus for the implementation of integrated crop-livestock systems, while also exacerbating the shortage of feed resources (Broderick 2018). As a traditional integrated agricultural and pastoral economic belt, the Inner Mongolia region plays a crucial role in actively developing and utilizing feed resources and diversifying the supply of high-quality forage to ensure the stable supply of livestock products (Tian *et al.* 2022). The construction of artificial grasslands is considered as an effective measure to enhance the forage yield in the region (She *et al.* 2024). Common vetch (*Vicia sativa* L.), an annual semi-vining leguminous forage, contains rich crude protein and low fiber content (Ma *et al.* 2020). Oats (*Avena sativa* L.), an annual grass, although high-yielding, have lower crude protein content, which often fails to meet the nutritional needs of most livestock when grown alone; intercropping with common vetch can effectively supplement this deficiency (Xu *et al.* 2022). During intercropping, oats provide necessary support for common vetch, facilitating the absorption of water and nutrients and enhancing photosynthetic efficiency, thereby increasing dry matter accumulation, and improving the overall quality of the forage. It is noteworthy that the yield and quality of legume-grass mixed crops largely depend on the choice of species and their proportions in the mix (Fischer *et al.* 2020). Additionally, low soil fertility is a key factor limiting crop yield enhancement, scientific fertilization can effectively improve crop yield and the availability of nutrients (Mahmoodreza *et al.* 2018). Research on intercropping oats and common vetch has mainly focused on the aspects such as intercropping ratios (Roohi *et al.* 2022), harvesting times (Huang *et al.* 2020), variety combinations (Liu *et al.* 2020), and water and fertilizer management (Prasad *et al.* 2015). While studies on fertilization measures, especially the application of microbial agents, are relatively scarce. Therefore, the combination of mixed forage

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cropping with microbial agent application is of undeniable importance in addressing the shortage of forage resources and the issue of crop homogeneity in the region. This study aims to explore the effects of adding microbial agents on the yield and quality of forage under different intercropping ratios of oats and common vetch, aiming to establish suitable grass-legume intercropping techniques for the western regions of Inner Mongolia to address the local shortage of fodder for herbivores during the winter and spring seasons. The study highlights the combined impact of variety, fertilization level, and environmental factors on the growth and yield of oats, as well as the economic feasibility of fertilization strategies.

Materials and Methods

This experiment was conducted at the Hailiu Campus of Inner Mongolia Agricultural University, located in Hailiu Village, Beishizhou Town, Tumote Left Banner, Hohhot. The geographical coordinates of the experimental area range from 40°26′N to 40°54′N latitude and from 110°48′E to 111°48′E longitude, forming an integral part of the Tumochuan Plain. The area experiences an average annual temperature of 5.8℃ and an average annual precipitation of 417.5 mm, with a frost-free period ranging from 90 to 120 days. The predominant soil type is typical saline-alkali soil.

The experimental materials consisted of forage oats (Mongolian Feed Oats No. 1) and common vetch (Lan Jian No. 2), with seeds provided by Inner Mongolia Agricultural University and the Inner Mongolia Academy of Agricultural and Animal Husbandry Sciences, respectively. The microbial inoculant used in the trial was provided by Nanjing Cuijingyuan Biotechnology Co., Ltd. The inoculant contains the arbuscular mycorrhizal fungus (AMF) *Rhizophagus intraradices*, with a concentration of 50 spores per gram of inoculant. Based on the conventional sole cropping rates in the Inner Mongolia region, which are 165 kg/ha for oats and 75 kg/ha for common vetch, ten treatment methods were designed for this experiment. The intercropping ratios were determined based on the sole cropping amounts of oats and common vetch and their respective proportions. Each treatment was arranged in a randomized complete block design, with specific values, detailed given in Table 1.

Table 1. Ratios and Seeding Rates of Mixed Cropping for Oats and Peas.

Treatments		Seeding Rate（kg/hm^2）	
		Oats	Field Pea
Oat monoculture	DB	165	
Oat monoculture + microbial inoculant	DB+V	165	
Oats: Peas = 2 : 3	H1-2:3	66	45
Oats: Peas = 2 : 3+ microbial inoculant	HV1-2:3	66	45
Oats: Peas = 1: 1	H2-1:1	82.5	37.5
Oats: Peas = 1 : 1+ microbial inoculant	HV2-1:1	82.5	37.5
Oats: Peas = 3 : 2	H3-3:2	99	30
Oats: Peas = 3 : 2+ microbial inoculant	HV3-3:2	99	30
Oats: Peas = 4 : 1	H4-4:1	132	15
Oats: Peas = 4 : 1+ microbial inoculant	HV4-4:1	132	15

After entering and organizing the raw data using Excel software, data analysis was conducted with SPSS software version 22.0. The data were analyzed using one-way analysis of variance (ANOVA), with a significance level set at $P<0.05$.

During the growth cycle of oats, at key developmental stages - milk ripeness (85 days post-sowing), wax ripeness (92 days post-sowing), and full ripeness (99 days post-sowing) - 15 representative plants of oats and common vetch each were randomly selected from each treatment plot for the measurement of plant height and stem thickness. Plant height was measured using a measuring tape, while stem thickness was determined precisely using a caliper.

At these three critical growth periods, three $1m^2$ quadrats were randomly selected within each treatment plot for ground cutting. The fresh weight of oats and common vetch was weighed separately, and the samples were then air-dried to constant weight for the determination of dry weight. Subsequently, the 500g air-dried samples were randomly selected, grind ground and sieved through a 0.4 mm mesh to analyze their nutritional components, including crude protein (CP), crude fat (CF), acid detergent fiber (ADF), and neutral detergent fiber (NDF).

Table 2. Plant Height of Oats and Field Peas under Different Treatments.

Treatments		Oats/cm		Pea/cm
	85 d	92 d	99 d	85 d
DB	90.33±9.12b	92.47±5.71ef	89.40±6.70de	
DB+V	91.20±7.78b	101.20±5.00bc	91.20±5.85e	
H1-2:3	101.47±4.67a	97.80±8.27cde	98.53±10.13c	60.27±4.67a
HV1-2:3	104.13±5.73a	99.20±8.08ab	99.60±6.53c	62.47±4.98a
H2-1:1	102.13±5.15a	94.07±10.24def	92.20±4.81de	57.33±7.78a
HV2-1:1	102.33±5.33a	105.20±8.08ab	95.60±8.02cd	58.40±5.70a
H3-3:2	90.47±7.03b	89.73±11.14f	91.53±5.01de	43.47±5.36c
HV3-3:2	105.47±5.04a	109.53±5.68a	96.73±7.91cd	62.47±7.89a
H4-4:1	93.80±6.64b	90.60±9.53f	91.86±6.82de	49.27±9.65b
HV4-4:1	102.20±8.58a	100.07±8.59bcd	92.20±5.33de	57.60±4.73a

Different lowercase letters following data in the same column indicate significant differences between treatments ($P<0.05$).

Results and Discussion

The effects of various treatments on the plant height of oats and peas are summarized in Table 2. In mixed cropping systems, the height of oats declined as the proportion of peas decreased, while the height of peas diminished with an increase in the oat ratio. During the milk ripening stage, the tallest oat plants were recorded in the DB+V treatment, reaching 91.2 cm. Conversely, the tallest oat plants in the HV3 treatment measured 105.47 cm, significantly taller than those in the H3 and H4 treatments. The tallest pea plants in the HV1 treatment reached 62.47 cm, which was significantly greater than the heights observed in the H3 and H4 treatments. By the wax ripening stage, the tallest oat plants in the DB+V treatment reached 101.2 cm, while those in the HV3 treatment achieved a height of 109.53 cm, significantly surpassing the heights of plants in the DB, DB+V, H1, H2, H3, H4, and HV4 treatments. At the full ripening stage, the tallest oat plants in the monoculture DB+V treatment measured 91.2 cm, whereas the tallest oat plants in the HV1 mixed cropping treatment reached 99.6 cm. This height was significantly greater than that of plants in the DB, DB+V, H1, H2, H3, H4, and HV4 treatments, although it was not significantly different from the heights observed in the H1, HV2, and HV3 treatments. The tallest pea plants in the HV3 treatment reached 62.47 cm, with no significant differences in pea height noted among the mixed cropping treatments during this period.

Table 3 revealed that during the milk ripening stage, the stem thickness of oats in mixed cropping increased as the pea ratio decreased, while the stem thickness of peas in mixed cropping decreased as the oat ratio increased. In the monoculture treatment in DB+V, the oats exhibited the thickest stems, measuring 4.6 mm; among mixed cropping treatments, the thickest oat stems were found in HV4, measuring 6.21 mm, which was found statistically significant compared to DB, DB+V, H1, H2, HV2, H3, and HV3 treatments. In mixed cropping, the thickest pea stems in the HV1 treatment measured 2.94 mm which was significantly thicker than those in H2 and HV2 treatments. By the wax ripening stage, the oats in the monoculture DB+V treatment still had the thickest stems, measuring 5.2 mm; the thickest oat stems in the mixed cropping in HV3 treatment measured 5.6 mm and significantly thicker than all other treatments except DB+V. At the full ripening stage, the oats in the monoculture DB+V treatment had the thickest stems, measuring 4.82 mm which was the thickest oat stems in the mixed cropping in HV2 treatment measured 4.7 mm, significantly thicker than those in DB and H3 treatments.

Table 3. Stem Thickness of Oats and Field Peas under Different Treatments.

Treatments	Oats/mm			Pea/mm
	85 d	92 d	99 d	85 d
DB	3.91±0.38b	4.60±0.51bc	3.35±0.93d	
DB+V	4.60±0.51b	5.20±0.43ab	4.82±0.46a	
H1-2:3	4.63±0.89b	4.25±0.51cd	3.89±0.62bcd	2.79±1.31b
HV1-2:3	5.66±0.75a	4.25±0.52cd	4.59±0.61abc	2.94±1.23b
H2-1:1	4.31±0.24b	3.83±0.38d	4.64±0.61ab	1.56±0.39a
HV2-1:1	4.01±0.32b	4.59±0.55bc	4.70±0.74ab	1.70±0.36a
H3-3:2	4.32±0.46b	4.17±0.46cd	3.74±0.55cd	1.54±0.30b
HV3-3:2	4.68±0.66b	5.60±0.71a	4.37±0.35abc	2.10±0.37ab
H4-4:1	5.58±0.77a	4.19±0.55cd	3.94±0.65bcd	1.94±0.29ab
HV4-4:1	6.21±1.33a	4.89±0.35bc	4.29±0.75a	2.21±0.29ab

Different lowercase letters following data in the same column indicate significant differences between treatments ($P<0.05$).

In Table 4 indicated that as the growth period progressed, the dry forage yield of both oats and peas showed a general declining trend under all treatment conditions. Specifically, the fresh forage yield of mixed oats initially increased and then decreased as the pea ratio decreased, while the fresh forage yield of mixed peas decreased as the oat ratio increased. During the milk ripening stage, the highest fresh forage yield of oats in the monoculture DB+V treatment reached 24.3 t/ha; the highest values in the mixed cropping HV3 treatment was 31.03 t/ha, but the differences in fresh forage yield of oats among all mixed cropping treatments were not significant. In the wax ripening stage, the highest fresh forage yield of oats in the monoculture DB+V treatment remained the highest at 23.47 t/ha; the highest in the mixed cropping HV2 treatment was 31.17 t/ha, significantly higher than DB, H1, H3, and H4 treatments. The highest fresh forage yield of peas in the mixed cropping HV1 treatment was 1.77 t/ha, only significantly different from the H4 treatment.

At the full ripening stage, the highest fresh forage yield of oats in the monoculture DB+V treatment was 15.6 t/ha; the highest in the mixed cropping HV2 treatment was 20.9 t/ha, significantly higher than DB and H1 treatments.

Table 4. The Impact of Different Treatments on Fresh Forage Yield.

Treatments	Dry Hay Yield(t/ha)		
	85 d	92 d	99 d
DB	22.87±0.50a	18.53±0.26cd	13.20±0.21b
X DB+V	24.30±0.36a	23.47±0.08abc	15.60±0.20ab
H1-2:3	28.27±1.09a	22.93±0.27abc	13.73±0.34b
HV1-2:3	31.17±0.50a	21.47±0.25bc	20.03±0.34a
H2-1:1	28.3±0.48a	22.23±0.13abc	18.30±0.35ab
HV2-1:1	31.17±1.12a	27.07±0.06a	20.90±0.24a
H3-3:2	30.10±1.06a	18.90±0.17cd	17.7±0.27ab
HV3-3:2	31.03±0.09a	24.43±0.59ab	19.90±0.50a
H4-4:1	22.73±0.47a	15.87±0.17d	15.97±0.25ab
HV4-4:1	26.03±0.68a	25.33±0.43ab	18.33±0.23ab

Different lowercase letters following data in the same column indicate significant differences between treatments (P<0.05).

As shown in Table 5, with the extension of the growth cycle, the dry hay yield of both oats and peas under all treatment conditions exhibited a continuous declining trend. The dry hay yield of mixed oats initially increased as the pea ratio decreased and then gradually declined, reflecting a pattern of initial rise followed by a reduction; simultaneously, the dry hay yield of mixed peas decreased as the oat ratio increased. During the milk ripening stage, the highest dry hay yield of oats in the monoculture DB+V treatment was 9.0 t/ha, while the maximum yield in the mixed cropping HV2 treatment reached 11.73 t/ha. However, no significant differences were observed in the dry hay yield of oats among all treatments. In the wax ripening stage, the highest dry hay yield of oats in the monoculture DB+V treatment remained the highest at 7.93 t/ha. The dry hay yield in the mixed cropping HV2 treatment was 9.23 t/ha, only significantly higher than the H4 treatment, with no significant differences from other treatments. In the full ripening stage, the highest dry hay yield of oats in the monoculture DB+V treatment was still the highest at 6.8 t/ha. In the mixed cropping treatments, the highest yield was observed in HV2, at 9.1 t/ha, significantly higher than DB and H1 treatments.

As shown in Tables 6 and 7, during the milk ripening stage, the highest crude fat content in oats under the monoculture DB+V treatment was 2.94%, and it also had the highest crude protein content at 10.95%, with the lowest neutral detergent fiber (NDF) content at 54.02%, and the lowest acid detergent fiber (ADF) content at 32.42%. In mixed cropping treatments, the highest crude fat content in oats was found in the H4 treatment at 2.92%, while the highest crude protein content was in the HV3 treatment at 12.59%, and the lowest contents of NDF and ADF were in the HV4 treatment at 52.98 and 32.26%, respectively. Among all treatments, differences in crude fat, NDF, and ADF contents were not significant (P>0.05), but the crude protein content in HV2 and HV4 treatments significantly higher than other treatments (P<0.05).

Table 5. The impact of different treatments on dry hay yield.

Treatments	Dry Hay Yield(t/ha)		
	85 d	92 d	99 d
DB	8.43±0.13a	7.63±0.08ab	5.83±0.08c
DB+V	9.00±0.10a	7.93±0.06ab	6.80±0.05bc
H1-2:3	9.77±0.04a	7.03±0.08ab	6.93±0.17ab
HV1-2:3	10.97±0.07a	8.57±0.13ab	8.73±0.13abc
H2-1:1	9.53±0.25a	7.83±0.07ab	8.40±0.12ab
HV2-1:1	11.73±0.06a	9.23±0.07a	9.10±0.07a
H3-3:2	8.33±0.07a	7.50±0.02ab	7.83±0.09abc
HV3-3:2	9.07±0.24a	8.50±0.14ab	8.53±0.17ab
H4-4:1	9.77±0.19a	6.20±0.04b	7.47±0.09abc
HV4-4:1	10.13±0.37a	6.93±0.38ab	8.60±0.07ab

Different lowercase letters following data in the same column indicate significant differences between treatments (P<0.05).

Table 6. Effect of Different Treatments on Quality (Crude fat and Crude protein) of Oats at Different Periods.

Treatments	Crude fat(CF, %)			Crude protein(CP, %)		
	85 d	92 d	99 d	85 d	92 d	99 d
DB	2.45±0.45a	3.05±0.14a	2.81±0.11a	10.27±0.55ab	7.87±1.32a	7.87±1.32c
DB+V	2.94±0.26a	3.06±0.44a	3.04±0.58a	10.95±1.07b	9.14±1.018a	7.92±1.57c
H1-2:3	2.73±0.35a	2.95±0.19a	3.01±0.39a	11.98±0.66ab	9.54±1.24a	8.67±0.55bc
HV1-2:3	2.62±0.26a	3.20±0.53a	3.29±0.50a	10.77±0.71ab	10.82±1.58a	9.01±0.41bc
H2-1:1	2.8±1.09a	2.90±0.45a	2.80±0.31a	11.29±0.40ab	10.74±0.85a	8.48±1.33bc
HV2-1:1	2.78±0.69a	2.89±0.39a	3.13±0.23a	12.75±3.35a	11.39±3.25a	11.11±0.81ab
H3-3:2	2.81±0.29a	3.07±0.35a	2.91±0.25a	10.58±1.26ab	8.53±1.81a	9.61±0.62abc
HV3-3:2	2.86±0.17a	3.10±0.25a	3.01±0.85a	12.59±2.14b	10.64±3.29a	12.01±2.51a
H4-4:1	2.92±0.09a	3.03±0.44a	3.72±0.63a	10.32±1.10ab	9.30±1.25a	9.11±2.02bc
HV4-4:1	2.56±0.07a	2.80±0.15a	3.21±0.35a	10.51±0.78a	11.66±1.55a	8.41±1.25bc

Different lowercase letters following data in the same column indicate significant differences between treatments (P<0.05).

In the wax ripening stage, oats in the monoculture DB+V treatment continued to show the highest crude fat content at 3.06% and the highest crude protein content at 9.14%, with the lowest NDF content at 53.06% and the lowest ADF content at 31.22%. The highest crude fat content in mixed cropping was in the HV1 treatment at 3.2%, while the highest crude protein content was in the HV4 treatment at 11.66%, and the lowest contents of NDF and ADF were in the HV3 treatment at 51.64 and 32.20%, respectively. During this ripening stage, there were no significant differences in the contents of crude fat, crude protein, NDF, and ADF among all treatments (P>0.05).

Table 7. Effect of Different Treatments on Quality (Detergent Fiber) of Oats at Different Periods.

Treat-ments	Neutral Detergent Fiber (NDF, %)			Acid Detergent Fiber (ADF, %)		
	85 d	92 d	99 d	85 d	92 d	99 d
DB	55.30±0.94a	55.84±3.03a	57.58±0.46a	33.97±0.61a	34.48±2.93a	35.98±0.92bc
DB+V	54.02±1.91a	53.06±1.36a	55.71±2.68ab	32.42±1.61a	31.22±1.15a	34.26±2.23c
H1-2:3	53.77±0.570a	54.84±1.16a	55.24±2.09ab	33.47±0.82a	33.56±1.53a	34.13±2.65bc
HV1-2:3	55.43±1.11a	52.84±1.75a	51.61±5.85ab	34.33±1.41a	32.54±1.67a	31.36±5.14bc
H2-1:1	53.52±5.52a	54.78±3.34a	55.04±2.34ab	33.26±5.20a	34.32±4.24a	33.67±2.23bc
HV2-1:1	52.36±1.68a	53.00±3.88a	53.76±0.70ab	34.15±2.22a	33.16±2.23a	33.18±0.93ab
H3-3:2	54.46±1.71a	54.66±0.73a	54.58±1.44ab	32.98±1.45a	33.39±1.15a	33.40±1.21abc
HV3-3:2	53.9±0.71a	51.64±1.64a	50.68±3.71b	33.07±1.27a	32.20±1.99a	31.00±5.22ab
H4-4:1	54.27±0.62a	55.20±1.65a	55.12±2.011ab	33.15±0.87a	35.23±1.96a	33.55±1.27bc
HV4-4:1	52.98±1.09a	54.54±4.48a	55.58±3.13ab	32.26±2.57a	33.78±3.49a	33.74±2.30bc

Different lowercase letters following data in the same column indicate significant differences between treatments (P<0.05).

At the full ripening stage, oats in the monoculture DB+V treatment again exhibited the higher crude fat content at 3.04% and the higher crude protein content at 7.92%, with the lower NDF content at 55.71% and the lower ADF content at 34.26% than the DB treatment. In mixed cropping, the highest crude fat content in oats was in the H4 treatment at 3.72%, while the highest crude protein content was in the HV3 treatment at 12.01%, with the lowest contents of NDF and ADF at 50.68 and 31.0%, respectively. Among all treatments, differences in crude fat content were not significant (P>0.05), with only the crude protein content in the HV3 treatment significantly higher than other treatments (P<0.05), and differences in NDF and ADF contents were not significant among all treatments (P>0.05).

Oats are a nutrient-rich cereal abundant in dietary fiber, plant proteins, minerals, and antioxidants, making them an ideal choice for high-energy consumers and health-conscious eaters (Fox *et al.* 2016). They are not only popular as a breakfast food but also play a significant role in animal feed, where their cholesterol-lowering and blood sugar-regulating benefits are increasingly recognized. Their cholesterol-lowering effects have received FDA certification (Getaneh *et al.* 2021), and their cultivation supports sustainable agriculture. Future research on oats will focus on enhancing yield and quality.

Oats contribute significantly to sustainable agriculture due to their adaptability, short growth cycle, resilience, and diverse cultivation methods (Wang *et al.* 2024). Their high protein content adds economic value, supporting a stable and growing market demand. In sustainable practices, oats help to reduce pests and diseases, improve soil quality, and significantly boost economic benefits and biodiversity (Jiao *et al.* 2024). Mixed cropping offers advantages in land utilization and crop yield quality but requires complex management strategies. It is particularly suitable for arid regions and small farms, where crop combinations and management must be adapted to local conditions (Singh *et al.* 2024).

The application of microbial agents in agriculture is revolutionizing crop yield and quality enhancement. In oat fodder production, the synergistic effects of rhizobia, PGPB, antagonistic bacteria, mycorrhizal fungi, and cyanobacteria are favorable (Yang *et al.* 2020). These agents not only promote plant growth but also improve soil health, supporting sustainable agricultural development. Future research will explore deeper applications of microbial agents (Yakovleva 2023). The impact of mixed cropping on microbial communities remains a vital research area in agricultural ecology, with ongoing challenges in competitive effects and management complexity.

In mixed cropping systems, microbial agents intricately enhance oat fodder yield and quality through direct and indirect plant interactions, promoting disease protection, growth, and nutritional improvement. The diversity of these systems creates a rich microbial environment, enhancing plant health and disease resistance, which is crucial for sustainable agricultural progress. The integration of mixed cropping and microbial inoculants offers extensive opportunities for improving crop yield and quality.

Research on mixed cropping of oats and peas shows that optimal ratios, such as 3:2, significantly increase grain yield, utilizing both crops' growth traits for synergistic benefits (Lina *et al.* 2022). Studies have demonstrated that appropriate nitrogen fertilizer application enhances oats' competitiveness in mixed cropping, affecting overall yield (Neugschwandtner and Kaul 2014). Mixed-row intercropping with a 15 cm row spacing has shown yield advantages due to the dominance of oats over intercropped field peas, with enhanced biological nitrogen fixation and nitrogen transfer rates contributing to grassland nitrogen output (Lina *et al.* 2022). Additionally, a 3:1 intercropping pattern effectively utilizes interspecific complementarities for higher dry matter yields, influenced by the strategic arrangement of field band spacing and row ratios (Wang *et al.* 2021).

Forage yield is a key indicator reflecting the performance of forage production, closely related to plant height, stem thickness, fresh and dry weights. Mixed cropping of cereals and legumes can enhance the nutritional quality of forage to varying degrees, with CP content being a crucial determinant of nutritional quality, often used as the primary indicator for evaluating forage nutritional quality. The content of NDF is an important parameter for evaluating the palatability of forage, while the content of ADF affects its digestibility. Higher NDF content indicates poorer palatability; higher ADF content makes the forage more difficult to digest. Results from this study indicate that a cereal-legume ratio of 3:2 can achieve the maximum plant height for oats; while a ratio of 2:3 gives the maximum plant height for peas. The same 3:2 planting ratio also allows oats and peas to reach maximum stem thickness and yields the highest fresh and dry forage yields for oats, while a 2:3 ratio achieves the maximum yield for peas. Additionally, a 3:2 planting ratio also helps to enhance the CP content of oats and reduce ADF and NDF contents; a 4:1 ratio can increase the CF content of oat forage. Whether for oats or peas, the addition of microbial inoculant treatments enhances plant height, stem thickness, yield, and nutritional quality, indicating that microbial inoculants have a positive effect on forage production. In conclusion, the optimal cereal-legume mixed cropping ratio is determined to be 3:2, aligning with findings from previous studies that highlight the advantages of specific intercropping ratios.

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