

Effects of Combined Application of Chinese Milk Vetch and Nitrogen Fertilizer on Dry Matter Production and Nitrogen Uptake and Utilization in Early-Season Rice (Postprint)

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Abstract

To comprehensively evaluate the effects of combined milk vetch and nitrogen fertilizer application on dry matter production and nitrogen uptake and utilization in early rice and to identify optimal nitrogen application rates under conditions of equal milk vetch incorporation, a winter fallow conventional nitrogen application [150 kg(N) · hm²] treatment was used as the control. With milk vetch incorporated at 22 500 kg · hm², four nitrogen application rates of 90 kg(N) · hm², 120 kg(N) · hm², 150 kg(N) · hm², and 180 kg(N) · hm² were established to investigate the effects of milk vetch and nitrogen application rate on dry matter production and nitrogen uptake and utilization in early rice. The results showed that the dry matter accumulation of all treatments with combined milk vetch and nitrogen fertilizer application was higher than that of the control, with the treatments of milk vetch combined with nitrogen fertilizer at 90 kg(N) · hm² and 120 kg(N) · hm² having the highest dry matter accumulation, reaching 9.65 t · hm² and 9.97 t · hm², respectively, which represented increases of 11.18% and 14.86% compared with the control. For all treatments, dry matter accumulation was substantial during the rice sowing–tillering and heading–grain filling stages, accounting for 19.26%–24.77% and 45.23%–52.75% of the dry matter at maturity, respectively, indicating that these two growth stages were the main periods of dry matter accumulation. The nitrogen accumulation of all treatments with combined milk vetch and nitrogen fertilizer application was higher than that of the control, with increases ranging from 6.95% to 18.68%. Both nitrogen dry matter production efficiency and nitrogen harvest index were highest under the treatment of milk vetch combined with 90 kg(N) · hm², increasing by 3.94%~14.08% and 6.65%~14.90% compared with other treatments, respectively. Combined application of milk vetch and nitrogen fertilizer was beneficial for increasing dry matter accumulation and ni-

nitrogen utilization efficiency in early rice, with the combination of milk vetch and nitrogen fertilizer at $90 \text{ kg(N)} \cdot \text{hm}^{-2}$ and $120 \text{ kg(N)} \cdot \text{hm}^{-2}$ showing superior effects, achieving the goal of reducing nitrogen while increasing efficiency, and representing an ideal fertilization model.

Full Text

Title and Authors

Effect of Combined Application of Chinese Milk Vetch and Nitrogen Fertilizer on Nitrogen Uptake, Utilization and Dry Matter Accumulation in Early Rice

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Abstract: This study evaluated the effects of combined application of Chinese milk vetch (*Astragalus sinicus* L.) and different nitrogen (N) fertilizer levels on dry matter accumulation and N use efficiency in early rice to determine the optimal N rate under Chinese milk vetch incorporation. Using a winter fallow field with conventional N application [$150 \text{ kg(N)} \cdot \text{hm}^{-2}$] as the control, four N levels were established under Chinese milk vetch incorporation at $22,500 \text{ kg} \cdot \text{hm}^{-2}$: $90 \text{ kg(N)} \cdot \text{hm}^{-2}$, $120 \text{ kg(N)} \cdot \text{hm}^{-2}$, $150 \text{ kg(N)} \cdot \text{hm}^{-2}$, and $180 \text{ kg(N)} \cdot \text{hm}^{-2}$. The results showed that all treatments combining Chinese milk vetch with N fertilizer achieved higher dry matter accumulation than the control, with the $90 \text{ kg(N)} \cdot \text{hm}^{-2}$ and $120 \text{ kg(N)} \cdot \text{hm}^{-2}$ treatments producing the highest dry matter accumulation at $9.65 \text{ t} \cdot \text{hm}^{-2}$ and $9.97 \text{ t} \cdot \text{hm}^{-2}$, respectively—representing increases of 11.18% and 14.86% over the control. Dry matter accumulation was most pronounced during the sowing-tillering and heading-filling stages, accounting for 19.26%–24.77% and 45.23%–52.75% of mature-stage dry matter, respectively. These two growth phases represented the primary periods of dry matter accumulation. All Chinese milk vetch plus N fertilizer treatments also showed higher N accumulation than the control, with increases ranging from 6.95% to 18.68%. Both nitrogen dry matter production efficiency (NDMPE) and nitrogen harvest index (NHI) were highest under the Chinese milk vetch + $90 \text{ kg(N)} \cdot \text{hm}^{-2}$ treatment, exceeding other treatments by 3.94%–14.08% and 6.65%–14.90%, respectively. The combined application of Chinese milk vetch with N fertilizer enhanced dry matter accumulation and N use efficiency in early rice, with the $90 \text{ kg(N)} \cdot \text{hm}^{-2}$ and $120 \text{ kg(N)} \cdot \text{hm}^{-2}$ treatments proving most effective for reducing N input while increasing efficiency—representing an ideal fertilization model.

Keywords: Chinese milk vetch; nitrogen fertilizer; early rice; dry matter; ni-

trogen uptake

Introduction

Chinese milk vetch (*Astragalus sinicus* L.) is a traditional winter green manure in southern China's rice-growing regions. When incorporated into soil, it increases soil nutrients, improves soil physical and chemical properties, enhances plant NPK content, and reduces chemical fertilizer requirements [1-3]. However, with intensified agricultural practices in recent decades, chemical fertilizers—valued for their convenience and rapid effectiveness—have become the primary means for increasing crop yields. This has led to widespread neglect of green manure application and excessive reliance on chemical fertilizers, particularly nitrogen. China's average rice N application rate reaches $180 \text{ kg} \cdot \text{hm}^{-2}$, 75% higher than the global average, with some regions exceeding $300 \text{ kg} \cdot \text{hm}^{-2}$ [4-5]. Excessive N application reduces N use efficiency [6], causes delayed crop maturity, and triggers environmental problems [7]. Therefore, utilizing winter fallow periods to plant Chinese milk vetch combined with rational nutrient management is crucial for maintaining high rice yields while improving N use efficiency, achieving high-quality, high-yield, and efficient rice production while reducing fertilizer losses.

Numerous studies have reported on the synergistic effects of green manure and chemical fertilizer on rice yield. Most research indicates that Chinese milk vetch, through biological N fixation combined with appropriate chemical fertilizer, improves soil fertility and yield [8-9]. Xie et al. [10] found that incorporating Chinese milk vetch with 60%-80% of conventional fertilizer rates (N $150 \text{ kg} \cdot \text{hm}^{-2}$, P O $75 \text{ kg} \cdot \text{hm}^{-2}$, K O $120 \text{ kg} \cdot \text{hm}^{-2}$) increased soil alkali-hydrolyzable N and available K by 10%-59%. Wang et al. [11] reported that Chinese milk vetch incorporation with chemical fertilizer increased single-crop late rice yield by 8.5%-17.4% compared to no fertilizer. Hou et al. [12] conducted a 25-year field experiment in Jiangxi's double-rice cropping area, finding that organic-inorganic fertilizer combinations increased early and late rice yields by 3.9%-7.8% compared to chemical fertilizer alone. Xu et al. [13] demonstrated that reducing early rice fertilizer by 20% effectively promoted N, P, and K uptake and accumulation.

While many studies have addressed rational fertilization for crops, few have investigated optimal N rates for environmentally friendly rice cultivation systems that reduce chemical fertilizer through green manure incorporation. Most green manure research focuses on Chinese milk vetch combined with complete chemical fertilizers (or organic-inorganic mixtures), with less systematic investigation of Chinese milk vetch paired specifically with N fertilizer. This study utilized winter fallow periods for Chinese milk vetch cultivation, comparing dry matter production characteristics and N uptake/utilization under different N application rates to determine optimal N rates for rice production with Chinese milk vetch incorporation, providing a theoretical basis for sustainable rice production and conservation tillage.

Materials and Methods

1.1 Study Site

The experiment was conducted from October 2014 to July 2015 at the rice experimental field of Jiangxi Agricultural University Science and Technology Park (28°46' N, 115°55' E). The study area features a subtropical monsoon humid climate with annual total solar radiation of $4.79 \times 10^{13} \text{ J} \cdot \text{hm}^{-2}$, annual sunshine hours of 1,852 h, accumulated temperature $^{\circ}\text{C}$ of 6,450 $^{\circ}\text{C}$, mean annual temperature of 17.1–17.8 $^{\circ}\text{C}$, and annual precipitation of 1,624 mm. The soil was developed from Quaternary red clay, typical of subtropical red soil regions. Before Chinese milk vetch planting, the topsoil had pH 5.59, organic matter 29.48 $\text{g} \cdot \text{kg}^{-1}$, total N 2.17 $\text{g} \cdot \text{kg}^{-1}$, alkali-hydrolyzable N 38.69 $\text{mg} \cdot \text{kg}^{-1}$, available P 12.22 $\text{mg} \cdot \text{kg}^{-1}$, and available K 30.31 $\text{mg} \cdot \text{kg}^{-1}$.

1.2 Experimental Design

A single-factor randomized block design was employed with five treatments: a control (Treatment A) of winter fallow with conventional N application [$150 \text{ kg(N)} \cdot \text{hm}^{-2}$], and four treatments with Chinese milk vetch incorporation at 22,500 $\text{kg} \cdot \text{hm}^{-2}$ (dry matter nutrient content: total N 26.7 $\text{g} \cdot \text{kg}^{-1}$, total P 2.1 $\text{g} \cdot \text{kg}^{-1}$, total K 20.1 $\text{g} \cdot \text{kg}^{-1}$) combined with N rates of 90 $\text{kg(N)} \cdot \text{hm}^{-2}$ (B), 120 $\text{kg(N)} \cdot \text{hm}^{-2}$ (C), 150 $\text{kg(N)} \cdot \text{hm}^{-2}$ (D), and 180 $\text{kg(N)} \cdot \text{hm}^{-2}$ (E). Each treatment had three replications, totaling 15 plots of 16.5 m^2 (5.5 m \times 3 m) separated by cement ridges to prevent water and fertilizer movement between plots.

The Chinese milk vetch cultivar ‘Yujiang Large Leaf’ was sown on October 4, 2014, and incorporated at full bloom on April 3, 2015. Early rice cultivar ‘Jinyou 458’ was sown on March 27, 2015, transplanted on April 29, and harvested on July 28. Planting density was three seedlings per hill with 325 hills per plot. Nitrogen was applied as urea (46% N), phosphorus as calcium magnesium phosphate (12% P₂O₅), and potassium as potassium chloride (60% K₂O). All plots received identical P (P₂O₅ 50 $\text{kg} \cdot \text{hm}^{-2}$) and K (K₂O 120 $\text{kg} \cdot \text{hm}^{-2}$) as basal fertilizers. Nitrogen was applied in a 5:3:2 ratio as basal, tillering, and panicle fertilizer. Tillering fertilizer was applied 5–7 days after transplanting, and panicle fertilizer was applied when the main stem panicle reached 1–2 cm. Field management followed standard local practices.

1.3.1 Dry Matter Determination

At tillering (June 1, 2015), booting (June 14), heading (June 25), filling (July 6), and maturity (July 25) stages, five representative hills per plot (excluding border rows) were sampled according to average tiller numbers. Plants were separated into leaves, stem-sheaths, and panicles (post-heading), oven-dried at 105 $^{\circ}\text{C}$ for 30 minutes, then at 80 $^{\circ}\text{C}$ to constant weight. Dry matter translocation indices were calculated as follows [14]:

Stem-leaf dry matter export = Stem-leaf dry weight at heading – Stem-leaf dry

weight at maturity

Stem-leaf dry matter export rate = (Stem-leaf dry matter export / Stem-leaf dry weight at heading) \times 100%

Apparent conversion rate = (Stem-leaf dry matter export / Dry matter accumulation in panicle from heading to maturity) \times 100%

1.3.2 Plant Nitrogen Determination

After dry matter determination, plant samples were ground and digested with H₂SO₄-H₂O₂, and total N content was measured by semi-micro Kjeldahl method. Related indices were calculated as follows [15]:

N accumulation = Aboveground dry matter weight \times N content

Nitrogen dry matter production efficiency (NDMPE) = Dry matter accumulation per unit area / Plant N accumulation

Nitrogen harvest index (NHI) = Grain N accumulation / Plant N accumulation

1.4 Data Processing

All data were processed using Microsoft Excel 2010 for basic statistics and SPSS 17.0 for statistical analysis.

Results

2.1.1 Dry Matter Weight at Main Growth Stages

As shown in , aboveground population dry matter weight varied among treatments and growth stages. No significant differences were observed among treatments at the tillering stage ($P > 0.05$). Differences became apparent from the booting stage onward. Treatment C (Chinese milk vetch + 120 kg(N) \cdot hm⁻²) achieved the highest dry matter accumulation at all stages except tillering, with significant differences from other treatments at booting ($P < 0.05$). At heading, treatments B, C, and D showed significantly higher dry matter accumulation than treatments A and E ($P < 0.05$). During the filling stage, treatments B and C exhibited significantly higher accumulation than treatment A ($P < 0.05$), with increases of 16.77% and 17.02%, respectively. At maturity, treatments B, C, and D had significantly higher dry matter accumulation than treatment A ($P < 0.05$), with treatment C differing significantly from treatments A and E ($P < 0.05$).

2.1.2 Dry Matter Accumulation and Ratio at Main Growth Stages

Analysis of dry matter accumulation across growth stages () revealed that the sowing-tillering and heading-filling stages were the primary periods of dry matter accumulation, accounting for 19.26%-24.77% and 45.23%-52.75% of mature-stage dry matter, respectively, though differences were not statistically significant ($P > 0.05$). During tillering-booting, treatment C showed the highest dry matter accumulation, significantly greater than treatments A, D, and E ($P < 0.05$). During booting-heading, treatment D accumulated the most dry

matter, significantly exceeding treatments C and E ($P < 0.05$) by 38.89%. No significant differences were observed among treatments during filling-maturity ($P > 0.05$).

2.1.3 Dry Matter Distribution in Stem-Sheath, Leaf, and Panicle

Analysis of dry matter distribution () showed that the stem-sheath ratio peaked at heading and declined thereafter. Treatment C achieved the highest stem-sheath ratio at heading (46.50%), significantly higher than treatments A and E ($P < 0.05$) by 7.83 and 4.75 percentage points, respectively. Leaf ratio followed a similar trend, peaking at heading with significant differences among treatments ($P < 0.05$), where treatment A reached 41.33%. At maturity, treatment D had the highest leaf ratio (14.00%), significantly different from treatments A, B, and E ($P < 0.05$). Panicle ratio increased progressively throughout growth, reaching maximum values of 64.50%-68.67% at maturity from 18.50%-23.50% at heading. Treatment D had the highest panicle ratio at heading, significantly different from treatment C ($P < 0.05$), while treatment B differed significantly from A, C, and D at maturity ($P < 0.05$).

2.1.4 Dry Matter Translocation

As shown in , treatment B exhibited the highest values for stem-leaf dry matter export amount, export rate, and apparent conversion rate, followed by treatment C, while treatment E showed the lowest. Treatment D's values were higher than treatment A's but not significantly different ($P > 0.05$). These results indicate that reduced N application under full Chinese milk vetch incorporation promoted dry matter translocation from vegetative organs to grains. At equivalent N rates, Chinese milk vetch incorporation showed no significant effect on translocation, while excessive N application inhibited dry matter transfer.

2.2.1 Nitrogen Accumulation at Main Growth Stages

[Figure 1: see original paper] illustrates that N accumulation under Chinese milk vetch plus N fertilizer increased gradually throughout growth stages, reaching maximum values at maturity. No significant differences were observed among treatments at tillering ($P > 0.05$). While treatment D showed the highest N accumulation at heading, treatment C achieved the highest values at booting, filling, and maturity stages, significantly exceeding treatment A and, at filling and maturity, treatment B ($P < 0.05$).

2.2.2 Nitrogen Content and Uptake in Stem, Leaf, and Panicle at Maturity

At maturity, N content and uptake in stems, leaves, and panicles varied among treatments (). Stem N content in treatments C, D, and E was significantly higher than in treatment B ($P < 0.05$), likely because higher N rates promoted N accumulation in stems under Chinese milk vetch incorporation, or because

treatment B received less total N. No significant differences were observed in leaf N content among treatments. Panicle N content was significantly higher in treatment E than in other treatments ($P < 0.05$). Stem N uptake was significantly higher in treatment C than in treatment B ($P < 0.05$), while leaf N uptake was significantly higher in treatment D than in treatment B ($P < 0.05$). All four Chinese milk vetch plus N treatments showed significantly higher panicle N uptake than treatment A ($P < 0.05$).

2.2.3 Nitrogen Use Efficiency

Different fertilization treatments significantly affected N use efficiency (η). Nitrogen dry matter production efficiency (NDMPE) decreased with increasing N application rates. Treatment B achieved the highest NDMPE, exceeding other treatments by 3.94%–14.08%. Nitrogen harvest index (NHI), reflecting N distribution between vegetative and reproductive organs, ranged from 61.83% to 71.04% across treatments. Treatment B showed the highest NHI (71.04%), significantly greater than other treatments ($P < 0.05$), followed by treatment E. Thus, treatment B demonstrated superior NDMPE ($71.44 \text{ kg} \cdot \text{kg}^{-1}$) and NHI among all treatments.

Discussion and Conclusion

Previous research has shown that organic-inorganic fertilizer combinations promote dry matter accumulation [16]. Xu et al. [13] reported that incorporating $22,500 \text{ kg} \cdot \text{hm}^{-2}$ of Chinese milk vetch and reducing chemical fertilizer by 20% (compared to 100% chemical fertilizer: N $150 \text{ kg} \cdot \text{hm}^{-2}$, P O $75 \text{ kg} \cdot \text{hm}^{-2}$, K O $120 \text{ kg} \cdot \text{hm}^{-2}$) increased dry matter accumulation by 18.8%, while reductions to 40%–60% of conventional rates did not decrease accumulation. Yang et al. [17] found that organic-inorganic combinations enhanced dry matter accumulation during the grain-filling stage. Jiang et al. [18] reported that appropriate inorganic fertilizer ratios with equivalent organic manure increased total dry matter by 18.8%–26.9%. Our results similarly demonstrated that Chinese milk vetch plus N fertilizer increased early rice dry matter accumulation compared to the control, with the $120 \text{ kg} \cdot \text{hm}^{-2}$ N treatment achieving the highest accumulation. All treatments showed the highest dry matter accumulation proportion during heading-filling, with Chinese milk vetch plus N treatments averaging 10.01% higher than the winter fallow control. Nie et al. [19] reported that organic-chemical combinations increased dry matter accumulation from tillering to maturity, while our results showed advantages only from booting stage onward. At tillering, the control and higher N treatments (150 and $180 \text{ kg} \cdot \text{hm}^{-2}$) exceeded the 90 and $120 \text{ kg} \cdot \text{hm}^{-2}$ treatments, possibly because low spring temperatures slowed N release from Chinese milk vetch, making it less immediately available than the quick-release chemical N fertilizer [20]. Consequently, higher N rates promoted better early growth, while Chinese milk vetch plus N treatments performed better during mid-to-late growth stages. Regarding dry matter translocation, stem-leaf export amount, export rate, and apparent conversion

rate decreased with increasing N rates, consistent with findings by Zhu [21] and Zhao et al. [22].

Nutrient uptake forms the basis of dry matter production. Yang et al. [23] noted that under equivalent fertility conditions, soil N conversion efficiency initially increases then decreases with N application rate, suggesting that only appropriate N rates can coordinate soil N supply with crop demand. Unreasonable N application and asynchronous nutrient supply represent primary causes of low N use efficiency [24]. Chemical N fertilizers are quick-release, causing excessive early growth and insufficient late-stage supply in winter fallow systems, whereas Chinese milk vetch provides continuous nutrient release throughout the growth period. Yao et al. [25] found that organic-inorganic combinations improved rice nutrient use efficiency and promoted N absorption. Shang [26] reported that organic-inorganic N mixtures increased N recovery efficiency by 7%–18% compared to chemical fertilizer alone. Zhang et al. [27] similarly demonstrated higher N accumulation and use efficiency with organic-inorganic compound fertilizers. In our experiment, Chinese milk vetch plus N fertilizer increased rice N absorption by 6.95%–18.68% compared to the control, with the 120 kg · hm⁻² N treatment showing the highest accumulation—consistent with Li [28] and Meng [29]. Nitrogen dry matter production efficiency initially increased then decreased with N rate, indicating that moderate N application promotes N utilization, while excessive N causes luxury consumption [30] and reduces efficiency, aligning with previous research [11].

Under our experimental conditions, Chinese milk vetch plus N fertilizer increased rice dry matter accumulation, N uptake, and N use efficiency compared to the control. The treatments combining Chinese milk vetch with 90 kg · hm⁻² and 120 kg · hm⁻² N proved most effective, achieving the dual goals of N reduction and efficiency enhancement, representing an ideal fertilization model.

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