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Effect of tillage and nutrient levels on nutrient uptake and protein yield of Lathyrus in rice fallow cultivation

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Abstract
A field study on "Effect of tillage and nutrient levels on nutrient uptake and protein yield of lathyrus in rice fallow cultivation" was conducted during *rabi* season of 2022-23 and 2023-24 at Agriculture farm, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, in Red and Lateritic zone of West Bengal, India. The experiment comprised of 12 treatment combinations laid out in a split–plot design with three replications. The main–plot treatments included two different tillage practices Zero tillage and Conventional tillage. Sub–plot treatments included six nutrient levels *viz*. soil application of 100% RDF N: P: K @ 20-40- 20 kg ha^{-1}, foliar spray of DAP @ 2% at 30 and 45 DAS, N: P: K (19:19:19) @ 2% at 30 and 45 DAS, N: P: K (19:19:19) @ 2% at 30 and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS, N: P: K (19:19:19) @ 2% at 30 and 45 DAS+ $ZnSO_4$ @ 0.5% at 40 DAS+ Boron @ 0.1% at 50 DAS.
Results revealed that conventional tillage outperformed zero tillage in enhancing nitrogen (N), phosphorus (P), potassium (K), zinc (Zn), and boron (B) content and uptake and protein yield in seed and straw. Among the nutrient treatments, the combined foliar application of N: P: K (19:19:19) @ 2% at 30 and 45 DAS+ $ZnSO_4$ @0.5% at 40 DAS+ Boron @0.1% at 50 DAS consistently recorded the highest nutrient content and uptake, as well as the maximum protein yield in both seed and straw. Conventional tillage improved aeration and mineralization under tilled soil conditions, facilitating better nutrient retention and utilization, while combined foliar application of nutrients further enhanced nutrient assimilation and use efficiency in crops. The interaction between tillage and nutrient treatments was found to be non-significant, suggesting that nutrient application strategies were equally effective under both tillage systems.

Keywords: Lathyrus, rice fallow, zero tillage, conventional tillage, foliar spray, nutrient uptake and protein yield

1. Introduction
Lathyrus (*Lathyrus sativus* L.), commonly known as grass pea, has been cultivated for centuries, particularly in Asia, Africa, and parts of Europe. Valued for its drought tolerance and minimal input requirements chickling pea has become an important crop in resource-poor farming systems. In India, lathyrus is recognized as a multifunctional crop providing grain, fodder, biomass, and green manure making it a vital component of agricultural systems (Campbell, 1997; Mikić *et al*., 2010; Basaran *et al*., 2011) [5, 18, 2]. Lathyrus is rich in protein (28%) and minerals especially calcium, phosphorus and iron (Bhagat *et al*., 2014, Navaz *et al*., 2018) [3, 19]. Besides, it's a really good source of essential amino acids like arginine (7.8 g), lysine (7.4 g), isoleucine (6.7 g), leucine (6.6 g), valine (4.7 g) per 100 g of protein (Parihar and Gupta 2016) [21]. Despite of its benefits pulse cultivation, including lathyrus remains limited in many regions, particularly in the Eastern Gangetic plains of India, where rice is the predominant crop. Factors such as long-duration rice cultivars, erratic rainfall, and poor irrigation practices contribute to the dominance of rice monocropping systems, often leaving land as a fallow after the *kharif* rice cultivation. In India, around 12 million hectares of land remain fallow after the kharif rice harvest, with 80% of this area located in eastern India. States such as Assam, West Bengal, Bihar, Jharkhand, Chhattisgarh, and Odisha are among the regions where rice-fallow lands are abundant. Among the pulses, Lathyrus stands out as a drought-tolerant crop that requires minimal external inputs and offers great potential for improving the productivity of rice-fallow

areas (Gusmao *et al*., 2012; Kalita and Chakrabarty, 2017; Nazrul and Shaheb, 2015) [12, 14, 20].

The cultivation of Lathyrus in rice-fallow areas offers a promising strategy for improving resource use efficiency. However, several challenges such as biotic, abiotic, and social constraints must be addressed to unlock the full potential of this crop (Anonymous, 2013; Gumma *et al*., 2016; Chowdhury *et al*., 2020; Deka *et al*., 2020) [1, 10, 7, 8]. Addressing these constraints through the adoption of appropriate crop management practices, such as conservation tillage, nutrient management, and water use optimization, can contribute to improving the sustainability and profitability of rice-based cropping systems.

Micronutrient deficiencies, especially zinc (Zn) and boron (B), can significantly impact the growth and productivity of pulse crops like Lathyrus (Gupta *et al*., 2021; Prasad and Shivay, 2019) [11, 23]. Foliar sprays of micronutrients such as zinc and boron can enhance carbohydrate metabolism, protein synthesis, and flower production, leading to increased yield and improved uptake of nutrients (Hafeez *et al*., 2013; Karmakar *et al*., 2021) [13, 15].

In the context of rice-fallow areas, this research aims to evaluate effect of tillage and nutrient levels on the nutrient content, nutrient uptake and protein yield of lathyrus in rice fallow cultivation. The findings will provide valuable insights into optimizing crop management practices and improving the sustainability of rice-fallow cultivation in West Bengal's red and lateritic soils.

2. Material and Methods

A two-year field experiment was carried out on sandy loam soil during *Rabi* seasons (October– March) of 2022–23 and 2023–24 at Agriculture farm, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, in Red and Lateritic zone of West Bengal, India. The farm was situated at 23°39´ North latitude and 87°42´ East longitude with an average altitude of 58.90 m above mean sea level. During the crop growing season, the maximum temperature has been ranged from 22.19°C to 33.69 °C and minimum temperature has been varied from 9.6°C to 19.74°C respectively. The investigation involved different combination of tillage practices (main plot) *i.e.*, Zero tillage and Conventional tillage and nutrient levels (sub plot) *i.e.*, soil application of 100% RDF N: P: K, foliar spray of DAP @ 2% at 30 DAS and 45 DAS, foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS, foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS, foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS+ Boron (20%) @ 0.1% at 50 DAS, foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS. In total twelve treatment combinations were laid out with three replications in split plot design. The lathyrus variety BioL 212 (Ratan) was sown on 6th November and 8th November during 2022 and 2023, respectively and harvested on 6th March and 10th March during 2023 and 2024, respectively. Preparatory tillage was done as per treatments and seeds were sown @ 60 kg ha^{-1} with a spacing of 30 cm×10 cm. Data were pooled and standard statistical methods were followed for analyzing the experimental data (Gomez and Gomez, 1984) [9].

3. Results and Discussion

3.1 Nutrient Uptake and Content

3.1.1 Nitrogen Uptake and Content

During 2023 and 2024, nitrogen (N) content and uptake in seed and straw were evaluated across different crop establishment methods and nutrient treatments, with the mean values pooled over the two years (Table 1).

3.1.1.1 Nitrogen Content in Seed and Straw

Among the crop establishment methods, conventional tillage recorded higher nitrogen content in both seed (4.55%) and straw (1.37%) which was statistically at par with zero tillage, with nitrogen content of 4.47% in seed and 1.33% in straw. The enhanced nitrogen content in conventional tillage could be attributed to better aeration and mineralization under tilled soil conditions. Similar observations were reported by Singh *et al*. (2020) [28] in maize systems, highlighting improved nutrient availability under conventional tillage practices.

Among the nutrient treatments, the foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS exhibited the highest nitrogen content in seed (4.82%) and straw (1.49%), followed by the foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + Boron (20%) @ 0.1% at 50 DAS with seed content of 4.67% and straw content of 1.40%. foliar spray of DAP @ 2% at 30 and 45 DAS recorded the lowest nitrogen content in seed (4.08%), and as well as in straw (1.12%). The increased nitrogen content was due to efficient foliar nutrient application, which improved nutrient assimilation, aligning with findings by Patel *et al*. (2021) [22] in cereal crops under foliar feeding.

3.1.1.2 Nitrogen Uptake in Seed and Straw

Regarding nitrogen uptake, conventional tillage demonstrated higher nitrogen uptake in seed (60.03 kg ha^{-1}) and straw (21.74 kg ha^{-1}) compared to zero tillage, which showed nitrogen uptake of 55.14 kg ha^{-1} in seed and 19.09 kg ha^{-1} in straw. The increased nitrogen uptake under conventional tillage is primarily due to higher crop yields associated with this tillage method, which allowed for greater nitrogen accumulation in plant biomass similar to the findings of Kumar *et al*. (2022) [17], under conventional tillage in wheat.

Among the nutrient treatments, foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS exhibited the highest nitrogen uptake in seed (69.00 kg ha^{-1}) and straw (25.24 kg ha^{-1}), followed by N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + Boron (20%) @ 0.1% at 50 DAS with seed nitrogen uptake of 62.35 kg ha^{-1} and straw nitrogen uptake of 22.62 kg ha^{-1}. The lowest nitrogen uptake was observed in foliar spray of DAP @ 2% at 30 and 45 DAS, with seed uptake of 44.94 kg ha^{-1} and straw uptake of 15.15 kg ha^{-1}. The superior performance of foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS is likely due to the combined foliar application of macro and micronutrients, enhancing nitrogen use efficiency, consistent with the results of Sharma *et al*. (2023) [26] in rice systems.

Interaction Effect

The interaction effect between tillage and nutrient levels on nitrogen content and uptake was found to be non-significant, indicating that the impact of nutrient treatments was consistent across both conventional and zero tillage methods.

3.1.2 Phosphorus Uptake and Content

During 2023 and 2024, phosphorus (P) content and uptake in seed and straw were evaluated across different crop establishment methods and nutrient treatments, with the mean values pooled over the two years (Table 2).

3.1.2.1 Phosphorus Content in Seed and Straw
Among the crop establishment methods, zero tillage recorded phosphorus content in seed (0.93%) and straw (0.70%), which was statistically at par with conventional tillage, showing phosphorus content of 0.91% in seed and 0.69% in straw. This suggests that the tillage method did not significantly affect the phosphorus content in seed or straw. These results are consistent with findings by Chaudhary *et al*. (2021) [6], who noted minimal differences in phosphorus content across tillage systems under well-managed nutrient conditions.

Among the nutrient treatments, the foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS exhibited the highest phosphorus content in seed (0.96%) and straw (0.77%), followed by N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + Boron (20%) @ 0.1% at 50 DAS with seed content of 0.93% and straw content of 0.75%. The lowest phosphorus content in seed (0.89%) and straw (0.62%) was recorded in the foliar spray of DAP @ 2% at 30 and 45 DAS. The superior performance of foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS can be attributed to effective nutrient application strategies that enhance phosphorus uptake and assimilation.

3.1.2.2 Phosphorus Uptake in Seed and Straw
Phosphorus uptake under conventional tillage in seed (11.95 kg ha^{-1}) and straw (11.06 kg ha^{-1}) showed a significant difference with that under zero tillage, which showed phosphorus uptake of 11.43 kg ha^{-1} in seed and 10.06 kg ha^{-1} in straw. The increased phosphorus uptake under conventional tillage is primarily due to higher crop yields associated with this tillage method, which allowed for greater phosphorus accumulation in plant biomass similar to the findings of Reddy *et al*. (2022) [25].

Among the nutrient treatments, foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS exhibited the highest phosphorus uptake in seed (13.67 kg ha^{-1}) and straw (12.98 kg ha^{-1}), followed by N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + Boron (20%) @ 0.1% at 50 DAS with seed phosphorus uptake of 12.45 kg ha^{-1} and straw phosphorus uptake of 12.01 kg ha^{-1}. The lowest phosphorus uptake was observed in foliar spray of DAP @ 2% at 30 and 45 DAS, with seed uptake of 9.78 kg ha^{-1} and straw uptake of 8.42 kg ha^{-1}. The superior performance of foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS is attributed to the foliar application of macronutrients, which improved phosphorus use efficiency, corroborating findings by Singh *et al*. (2023) [27] in maize systems.

Interaction Effect
The interaction effect between tillage and nutrient levels on phosphorus content and uptake was found to be non-significant, suggesting that the nutrient treatments were equally effective under both conventional and zero tillage systems.

3.1.3 Potassium Uptake and Content
During 2023 and 2024, potassium (K) content and uptake in seed and straw were evaluated across different crop establishment methods and nutrient treatments, with the mean values pooled over the two years (Table 3).

3.1.3.1 Potassium Content in Seed and Straw
Among the crop establishment methods, zero tillage recorded potassium content in seed (1.42%) and straw (2.11%), which was statistically at par with conventional tillage, showing phosphorus content of 1.41% in seed and 2.13% in straw. This suggests that the tillage method did not significantly affect the phosphorus content in seed or straw. These results are consistent with findings by Chaudhary *et al*. (2021) [6].

Among the nutrient treatments, the foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS exhibited the highest potassium content in seed (1.49%) and straw (2.38%), followed by N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + Boron (20%) @ 0.1% at 50 DAS with seed content of 1.47% and straw content of 2.23%. The lowest potassium content in seed (1.26%) and straw (1.76%) was recorded in the foliar spray of DAP @ 2% at 30 and 45 DAS. The superior performance of foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + ZnSO4 @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS can be attributed to effective nutrient application strategies that enhance potassium uptake and assimilation, corroborating findings by Karthika *et al*. (2018) [16].

3.1.3.2 Potassium Uptake in Seed and Straw
Potassium uptake under conventional tillage in seed (18.57 kg ha^{-1}) and straw (33.95 kg ha^{-1}) was significantly differed with that of zero tillage, which showed phosphorus uptake of 17.44 kg ha^{-1} in seed and 30.20 kg ha^{-1} in straw. The increased potassium uptake under conventional tillage is primarily due to higher crop yields associated with this tillage method, which allowed for greater potassium accumulation in plant biomass. Such observations align with by Ramesh *et al*. (2014) [24], who reported significant differences in potassium uptake between tillage systems in similar agroecological conditions.

Among the nutrient treatments, foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS exhibited the highest potassium uptake in seed (21.37 kg ha^{-1}) and straw (40.37 kg ha^{-1}), followed closely by N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + Boron (20%) @ 0.1% at 50 DAS with seed uptake of 19.64 kg ha^{-1} and straw uptake of 35.80 kg ha^{-1}. The lowest potassium uptake in seed (13.86 kg ha^{-1}) and straw (23.69 kg ha^{-1}) was recorded in the foliar spray of DAP @ 2% at 30 and 45 DAS. The superior performance of foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS is attributed to targeted potassium applications, significantly improving potassium use efficiency, supporting findings by Ali *et al*. (2022).

Interaction Effect
The interaction effect between tillage and nutrient levels on potassium content and uptake was found to be non-significant, suggesting that the nutrient treatments were equally effective under both conventional and zero tillage systems.

3.1.4 Zinc Uptake and Content
During 2023 and 2024, zinc (Zn) content and uptake in seed and straw were evaluated across different crop establishment methods and nutrient treatments, with the mean values pooled over the two years (Table 3).

3.1.4.1 Zinc Content in Seed and Straw
Among the crop establishment methods, conventional tillage recorded a zinc content in seed of 0.038% and in straw of 0.027%, which was consistent with zero tillage that also showed

0.038% in seed and 0.027% in straw. This indicates that both tillage methods maintained similar levels of zinc content.

Among the nutrient treatments, the foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS exhibited the highest zinc content in seed (0.050%) and straw (0.036%), followed by N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS with seed content of 0.048% and straw content of 0.033%. The lowest zinc content in seed (0.028%) and straw (0.021%) was recorded in the foliar spray of DAP @ 2% at 30 and 45 DAS. The superior performance of foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS can be attributed to effective nutrient application strategies that enhance zinc uptake and assimilation, corroborating findings by Cakmak (2008) [4].

3.1.4.2 Zinc Uptake in Seed and Straw

Regarding zinc uptake under conventional tillage in seed (0.513 kg ha^{-1}) and straw (0.439 kg ha^{-1}) was significantly differed with that of zero tillage, which showed zinc uptake of 0.479 kg ha^{-1} in seed and 0.384 kg ha^{-1} in straw. However, this observed difference in zinc uptake is largely due to the higher yields associated with conventional tillage, which supports greater biomass production and consequently higher total nutrient uptake.

Among the nutrient treatments, foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS exhibited the highest zinc uptake in seed (0.716 kg ha^{-1}) and straw (0.608 kg ha^{-1}), followed by N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS with seed uptake of 0.626 kg ha^{-1} and straw uptake of 0.537 kg ha^{-1}. The lowest zinc uptake in seed (0.311 kg ha^{-1}) and straw (0.284 kg ha^{-1}) was recorded in the foliar spray of DAP @ 2% at 30 and 45 DAS. The superior performance of foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS is attributed to the targeted application of zinc, significantly improving zinc use efficiency, supporting findings by Zeng *et al*. (2021) [29].

Interaction Effect

The interaction effect between tillage and nutrient levels on zinc content and uptake was found to be non-significant, suggesting that the nutrient treatments were equally effective under both conventional and zero tillage systems.

3.1.5 Boron Uptake and Content

During 2023 and 2024, boron (B) content and uptake in seed and straw were evaluated across different crop establishment methods and nutrient treatments, with mean values pooled over the two years.

3.1.5.1 Boron Content in Seed and Straw

Among the crop establishment methods, zero tillage recorded a boron content in seed of 0.043% and in straw of 0.020%, while conventional tillage showed boron content of 0.042% in seed and 0.019% in straw. These results suggest that both tillage methods maintained similar boron levels in seed as well as in straw.

Among the nutrient treatments, the foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS exhibited the highest boron content in seed (0.048%) and straw (0.025%), followed by N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS with seed content of 0.048% and straw content of 0.025%. The lowest boron content in seed (0.039%) and straw (0.016%) was recorded in the foliar spray of DAP @ 2% at 30 and 45 DAS. The superior performance of foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS can be attributed to effective nutrient application strategies that enhance boron uptake and assimilation, corroborating findings by Cakmak (2008) [4].

3.1.5.2 Boron Uptake in Seed and Straw

Regarding boron uptake, conventional tillage demonstrated higher boron uptake in seed (0.530 kg ha^{-1}) compared to zero tillage, which showed boron uptake of 0.556 kg ha^{-1}. In straw, conventional tillage also had a higher uptake (0.292 kg ha^{-1}) than zero tillage (0.310 kg ha^{-1}). The enhanced boron uptake under zero tillage may be linked to improved root development and better nutrient absorption, as noted by Yang *et al*. (2020).

Among the nutrient treatments, foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS exhibited the highest boron uptake in seed (0.684 kg ha^{-1}) and straw (0.425 kg ha^{-1}), followed by N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + Boron (20%) @ 0.1% at 50 DAS with seed uptake of 0.639 kg ha^{-1} and straw uptake of 0.409 kg ha^{-1}. The lowest boron uptake was observed in foliar spray of DAP @ 2% at 30 and 45 DAS, with seed uptake of 0.426 kg ha^{-1} and straw uptake of 0.211 kg ha^{-1}. The superior performance of foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS is attributed to targeted boron applications, significantly improving boron use efficiency, supporting findings by Zeng *et al*. (2021) [29].

Interaction Effect

The interaction effect between tillage and nutrient levels on boron content and uptake was found to be non-significant, suggesting that the nutrient treatments were effective under both conventional and zero tillage systems.

3.1.6 Protein Yield and Content

During 2023 and 2024, protein content and yield in seed and straw were evaluated across different crop establishment methods and nutrient treatments, with mean values pooled over the two years. The results revealed significant differences based on tillage methods and nutrient management strategies applied.

3.1.6.1 Protein Content in Seed and Straw

Among the crop establishment methods, conventional tillage recorded a highest protein content in seed of 28.466% and in straw of 8.536%, while zero tillage showed protein content of 27.935% in seed and 8.322% in straw. These results suggest that both tillage methods maintained similar protein levels in seed as well as in straw.

Among the nutrient treatments, the foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS exhibited the highest protein content in seed (30.105%) and straw (9.337%), followed by N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS with seed content of 29.201% and straw content of 8.774%. The lowest protein content in seed (25.477%) and straw (6.978%) was recorded in the foliar spray of DAP @ 2% at 30 and 45 DAS. The superior performance of foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS

+ $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS can be attributed to effective nutrient application strategies that enhance protein synthesis, supporting findings by Karthika *et al.* (2018) [16].

3.1.6.2 Protein Yield in Seed and Straw

Regarding boron uptake, conventional tillage demonstrated higher protein yield in seed (375.209 kg ha^{-1}) compared to zero tillage, which showed protein yield of 344.614 kg ha^{-1}. In straw, conventional tillage also had a higher yield (135.882 kg ha^{-1}) than zero tillage (119.293 kg ha^{-1}). The enhanced protein yield under conventional tillage may be attributed to better soil aeration and nutrient availability, which facilitate efficient nutrient uptake and utilization, as highlighted by Ramesh *et al.* (2014) [24].

Among the nutrient treatments, foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS exhibited the highest protein yield in seed (431.276 kg ha^{-1}) and straw (157.738 kg ha^{-1}), followed closely by N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + Boron (20%) @ 0.1% at 50 DAS with seed yield of 389.662 kg ha^{-1} and straw yield of 141.356 kg ha^{-1}. The lowest protein yield was observed in foliar spray of DAP @ 2% at 30 and 45 DAS, with seed yield of 280.860 kg ha^{-1} and straw yield of 94.667 kg ha^{-1}. The superior performance of foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS is attributed to targeted protein-enhancing applications, significantly improving protein yield efficiency, supporting findings by Zeng *et al.* (2021) [29].

Interaction Effect

The interaction effect between tillage and nutrient levels on protein content and yield was found to be significant for straw yield, suggesting that the nutrient treatments were effective under both conventional and zero tillage systems.

Table 1: Effect of tillage practices and nutrient levels on Nutrient content of lathyrus in rice fallows

Treatment	SEED					STRAW				
	N %	P %	K %	Zn %	B %	N %	P %	K %	Zn %	B %
	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled
Tillage practices (T)										
Zero tillage	4.470	0.928	1.415	0.038	0.043	1.331	0.704	2.112	0.027	0.020
Conventional tillage	4.555	0.908	1.409	0.038	0.042	1.366	0.695	2.130	0.027	0.019
Sem ±	0.01	0.01	0.03	0.00	0.00	0.03	0.02	0.02	0.00	0.00
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV %	1.32	3.47	9.84	8.03	4.71	1.32	3.47	9.84	8.03	4.71
Nutrient levels (FS)										
100% RDF N:P:K (20:40:20) basal	4.479	0.888	1.406	0.029	0.040	1.290	0.656	2.156	0.022	0.018
2% DAP foliar spray twice at 30 and 45 DAS	4.076	0.888	1.258	0.028	0.039	1.117	0.622	1.756	0.021	0.016
2% N:P:K (19:19:19) foliar spray twice at 30 and 45 DAS	4.451	0.917	1.417	0.035	0.039	1.344	0.695	2.086	0.024	0.016
2% N:P:K (19:19:19) foliar spray twice at 30 and 45 DAS + 0.5%$ZnSO_4$ at 40 DAS	4.577	0.927	1.424	0.048	0.042	1.443	0.706	2.116	0.035	0.018
2% N:P:K (19:19:19) foliar spray twice at 30 and 45 DAS + 0.1% Boron at 50 DAS	4.672	0.934	1.473	0.040	0.048	1.404	0.747	2.226	0.024	0.025
2% N:P:K (19:19:19) foliar spray twice at 30 and 45 DAS + 0.5% $ZnSO_4$ at 40 DAS + 0.1% Boron at 50 DAS	4.817	0.955	1.493	0.050	0.048	1.494	0.768	2.384	0.036	0.025
Sem ±	0.08	0.02	0.04	0.00	0.00	0.07	0.02	0.10	0.00	0.00
CD (p=0.05)	0.227	NS	0.107	0.005	0.004	0.198	0.047	0.288	0.003	0.003
CV %	4.19	5.06	6.31	11.10	6.92	12.17	5.60	11.27	9.55	11.23
Interaction (T×FS)										
Sem ±	0.11	0.03	0.06	0.00	0.00	0.10	0.03	0.14	0.00	0.00
T*FS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (FS×T)										
Sem ±	0.11	0.03	0.05	0.00	0.00	0.09	0.02	0.14	0.00	0.00
FS*T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NS: Not significant; DAS: Days after sowing; S: significant										

Table 2: Effect of tillage practices and nutrient levels on Nutrient Uptake of lathyrus in rice fallows

Treatment	SEED					STRAW				
	N Kg/ha	P Kg/ha	K Kg/ha	Zn Kg/ha	B Kg/ha	N Kg/ha	P Kg/ha	K Kg/ha	Zn Kg/ha	B Kg/ha
	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled
Tillage practices (T)										
Zero tillage	55.138	11.427	17.438	0.479	0.530	19.087	10.058	30.200	0.384	0.292
Conventional tillage	60.033	11.948	18.566	0.513	0.556	21.741	11.062	33.951	0.439	0.310
Sem ±	0.43	0.15	0.33	0.01	0.00	0.24	0.13	0.69	0.01	0.01
CD (p=0.05)	2.588	NS	NS	NS	0.024	1.456	0.781	NS	0.035	NS
CV %	3.13	5.40	7.67	6.39	3.11	4.97	5.16	9.12	6.01	12.21
Nutrient levels (FS)										
100% RDF N:P:K (20:40:20) basal	54.811	10.838	17.186	0.353	0.486	18.005	9.161	30.133	0.314	0.246
2% DAP foliar spray twice at 30 and 45 DAS	44.936	9.782	13.863	0.311	0.426	15.147	8.419	23.689	0.284	0.211
2% N:P:K (19:19:19) foliar spray twice at 30 and 45 DAS	55.265	11.389	17.573	0.438	0.488	19.445	10.040	30.238	0.349	0.236
2% N:P:K (19:19:19) foliar spray twice at 30 and 45 DAS + 0.5%$ZnSO_4$ at 40 DAS	59.152	11.992	18.387	0.626	0.537	22.032	10.757	32.232	0.537	0.277
2% N:P:K (19:19:19) foliar spray twice at 30 and	62.346	12.451	19.638	0.534	0.639	22.617	12.005	35.796	0.377	0.409

45 DAS + 0.1% Boron at 50 DAS										
2% N:P:K (19:19:19) foliar spray twice at 30 and 45 DAS + 0.5%$ZnSO_4$ at 40 DAS + 0.1% Boron at 50 DAS	69.004	13.672	21.366	0.716	0.684	25.238	12.978	40.366	0.608	0.425
Sem ±	1.44	0.30	0.46	0.02	0.02	1.09	0.28	1.57	0.02	0.02
CD (p=0.05)	4.262	0.897	1.364	0.071	0.058	3.222	0.834	4.619	0.046	0.046
CV %	6.15	6.38	6.29	11.83	7.01	13.11	6.56	11.96	10.69	12.82
Interaction (T×FS)										
Sem ±	2.09	0.46	0.73	0.03	0.02	1.56	0.42	2.32	0.03	0.02
T*FS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (FS×T)										
Sem ±	2.04	0.43	0.65	0.03	0.02	1.54	0.40	2.21	0.03	0.02
FS*T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NS: Not significant; DAS: Days after sowing; S: significant										

Table 3: Effect of tillage practices and nutrient levels on Nutrient Uptake of lathyrus in rice fallows

Treatment	**Protein content**		**Protein Yield**	
	SEED	**STRAW**	**SEED**	**STRAW**
	%	**%**	**Kg/ha**	**Kg/ha**
Tillage practices (T)				
Zero tillage	27.935	8.322	344.614	119.293
Conventional tillage	28.466	8.536	375.209	135.882
Sem ±	0.09	0.19	2.66	1.50
CD (p=0.05)	NS	NS	16.176	9.101
CV %	1.32	9.60	3.13	4.97
Nutrient levels (FS)				
100% RDF N:P:K (20:40:20) basal	27.994	8.065	342.566	112.530
2% DAP foliar spray twice at 30 and 45 DAS	25.477	6.978	280.860	94.667
2% N:P:K (19:19:19) foliar spray twice at 30 and 45 DAS	27.820	8.397	345.404	121.530
2% N:P:K (19:19:19) foliar spray twice at 30 and 45 DAS + 0.5%$ZnSO_4$ at 40 DAS	28.606	9.020	369.702	137.702
2% N:P:K (19:19:19) foliar spray twice at 30 and 45 DAS + 0.1% Boron at 50 DAS	29.201	8.774	389.662	141.356
2% N:P:K (19:19:19) foliar spray twice at 30 and 45 DAS + 0.5%$ZnSO_4$ at 40 DAS + 0.1% Boron at 50 DAS	30.105	9.337	431.276	157.738
Sem ±	0.48	0.42	9.03	6.83
CD (p=0.05)	1.421	1.235	26.637	20.138
CV %	4.19	12.17	6.15	13.11
Interaction (T×FS)				
Sem ±	0.69	0.62	13.05	9.77
T*FS	NS	NS	NS	NS
Interaction (FS×T)				
Sem ±	0.68	0.59	12.77	9.66
FS*T	NS	NS	NS	NS
NS: Not significant; DAS: Days after sowing; S: significant				

4. Conclusion

The results of the present study revealed that crop establishment methods and nutrient treatments significantly influenced the uptake and content of nitrogen, phosphorus, potassium, zinc, boron, and protein in both seed and straw. Conventional tillage generally exhibited higher nitrogen and phosphorus uptake due to improved aeration, mineralization, and crop yield, while zero tillage showed comparable potassium and micronutrient content, indicating its potential for sustainable nutrient management.

Among nutrient treatments, the foliar spray of N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS resulted in the highest nitrogen, phosphorus, potassium, zinc, boron, and protein content, as well as their uptake in both seed and straw. This highlights the importance of balanced foliar fertilization in enhancing nutrient assimilation, protein synthesis, and overall crop nutrition. The protein content was positively correlated with nitrogen availability, with the highest values observed in crops receiving N: P: K (19:19:19) @ 2% at 30 DAS and 45 DAS + $ZnSO_4$ @ 0.5% at 40 DAS + Boron (20%) @ 0.1% at 50 DAS, reinforcing the role of micronutrients in protein biosynthesis.

The interaction effect between tillage and nutrient treatments was non-significant, suggesting that the effectiveness of foliar fertilization strategies remained consistent under both conventional and zero tillage systems. These findings underscore the potential of integrated nutrient management through targeted foliar application to enhance nutrient use efficiency, improve crop productivity, and support sustainable agricultural practices.

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