**Original Research Article**

**Optimization of Nitrogen Requirement of Indian Mustard (*Brassica juncea* L.) Genotypes under *Populus deltoides-*Based Agroforestry System**

**ABSTRACT**

Agroforestry systems incorporating woody perennials such as *Populus deltoides* offer promising solutions for sustainable land use and enhanced agricultural productivity. This study evaluated the performance of three Indian mustard genotypes (RCH 1, PHR 126, and PBR 357) under four nitrogen (N) levels (0, 100, 125, and 150 kg ha-1) within a poplar-based agroforestry system over two consecutive years (2020-21 and 2021-22) at PAU, Ludhiana. The experiment was laid out in a randomized complete block design. Results showed that increasing nitrogen levels significantly improved growth parameters, number of seeds per siliqua, and productivity. Among the genotypes, PBR 357 recorded the highest plant height, dry matter accumulation, and chlorophyll index. Interaction effects between genotypes and nitrogen levels were significant for seed yield, stover yield, and number of seeds per siliqua. Genotype PBR 357 with application of 150 kg N ha-1 recorded highest seed yield (19.17 and 17.30 q ha-1), and stover yield (68.82 and 61.78 q ha-1). Physiological efficiency and partial factor productivity were highest at 100-125 kg N ha-1, indicating efficient nutrient utilization at moderate N levels. The study highlights PBR 357 as a suitable mustard genotype for integration into poplar-based agroforestry, with 150 kg N ha-1 identified as the optimum dose for maximizing productivity under such systems.

***Keywords:*** *Agroforestry; Indian mustard; physiological efficiency; partial factor productivity; nitrogen levels.*

1. **INTRODUCTION**

The developing world is facing an escalating threat in the form of unsustainable land use practices, leading to severe food insecurity, especially among underprivileged communities. Major driving forces behind this challenge include rapid population growth, urbanization, land degradation, and climate change. Among the potential solutions, woody perennial-based production systems such as agroforestry hold considerable promise for promoting sustainable land use.

Agroforestry integrates trees, crops, and livestock in a scientifically sound, ecologically viable, and socially acceptable manner (Nair, 1979). Such systems enhance soil fertility, increase biodiversity, provide regular income through diversified produce, and improve land sustainability. Particularly in the irrigated agro-ecosystems of the Indo-Gangetic plains, poplar (*Populus deltoides*) has emerged as a dominant tree species in agroforestry due to its fast growth, deciduous nature, pruning tolerance, and compatibility with various intercrops (Kaur et al., 2025).

Poplar’s leafless period during winter allows adequate sunlight penetration, making it ideal for *rabi* crops such as wheat, mustard, and spinach. However, as trees mature, increased canopy shade can reduce intercrop yields - though this is often offset by the economic value of harvested wood (Artru et al., 2017). The selection of suitable tree-crop combinations and effective management practices are therefore crucial to maximize overall system productivity (Chauhan et al., 2013).

Indian mustard (*Brassica juncea* L.), a vital oilseed crop of the Brassicaceae family, plays a significant role in Indian agriculture, particularly in northern states where mustard oil is a staple cooking medium (Pradhan et al., 2021). It is known for its stress tolerance, short duration, and adaptability to partial shade, making it a promising intercrop under poplar plantations (Swami and Puri, 2005). Additionally, mustard contributes to crop diversification and helps in meeting the increasing demand for edible oils.

One of the key factors influencing mustard productivity is nitrogen (N) management, as nitrogen is fundamental for vegetative growth, photosynthesis, and reproductive development (Yasari and Patwardhan, 2006; Al-Barrak, 2006). In agroforestry systems, competition between tree and crop components for nutrients necessitates optimized nutrient management strategies to achieve maximum yields (Joshi et al., 1991). Despite well-established mustard production practices in sole cropping systems, its performance under tree-based systems, especially in relation to nitrogen requirements, remains underexplored. Considering the above, the present investigation was undertaken to evaluate the growth and productivity of Indian mustard genotypes under varying nitrogen levels within a poplar-based agroforestry system. The study aims to determine optimal nitrogen doses to enhance yield potential while ensuring ecological and economic sustainability in integrated farming systems.

1. **MATERIAL AND METHODS**

**2.1 Climate and soil properties of the site**

The research was carried out at research area of Department of Forestry & Natural Resources, PAU, Ludhiana (30° 90' N, 75° 80' E; 247 m above mean sea level) for two years (2020-21 and 2021-22). The region is characterized by a sub-tropical and semi-arid type of climate with hot and dry weather from April to June, hot and humid from July to September and cold from November to January. The soil at the experimental field was sandy loam and had neutral pH, normal electrical conductivity, medium organic carbon, low available nitrogen and medium in available phosphorus and potassium.

**2.2 Experimental details**

The present investigation was conducted in a poplar-based agroforestry system established with *Populus deltoides* clone L-47/88. The trees were planted at a spacing of 5 m × 4 m, arranged in north–south oriented block plantations, comprising 10 trees per row. The poplar plantation was 4 years old in 2020 and 5 years old in 2021. During the initial three years, wheat (*rabi*) and fodder crops (*kharif*) were cultivated under the plantation to utilize the interspaces effectively.

The experiment was laid out in a Randomized Complete Block Design (RCBD) with twelve treatment combinations, consisting of three Indian mustard genotypes (RCH 1, PHR 126, and PBR 357) intercropped with poplar under four nitrogen levels [N1- 0 (No Nitrogen); N2- 100 kg ha-1; N3- 125 kg ha-1 (Recommended dose of nitrogen); N4- 150 kg ha-1]. A uniform basal dose of 30 kg P2O5 ha-1 and 15 kg K2O ha-1 was applied to all plots before sowing. The field was prepared by disc harrowing followed by planking to ensure a fine tilth. Manual sowing of mustard was carried out in the alleys between the tree rows on 15th October 2020 and 17th October 2021 using a seed rate of 3.75 kg ha-1. A row spacing of 30 cm was maintained, and thinning at 21 days after sowing (DAS) ensured an intra-row spacing of 10-15 cm. Nitrogen was applied in two equal splits: 50% at sowing and the remaining 50% as top-dressing at 30 DAS. Weed control was managed through manual weeding at 30 and 45 DAS. To ensure proper crop establishment, one pre-sowing irrigation was provided, followed by three post-sowing irrigations at 35, 75, and 115 DAS, respectively. The crop was harvested in late March to early April, coinciding with physiological maturity, when more than 80% of the siliquae had turned yellow.

**2.3 Collection of data**

The assessment of various Indian mustard growth parameters, such as plant height, dry matter accumulation, chlorophyll index and number of seeds per siliqua was done at 120 days after sowing (DAS). The chlorophyll index of leaves was measured with the help of Chlorophyll content meter at 120 DAS. Indian mustard was harvested and threshed separately from each plot, and seed yield was estimated.

**Physiological efficiency (PE), and Partial factor productivity (PFP) were calculated by using standard methods (Fageria and Baligar 2005) as:**

PE (kg biological yield/kg nutrient uptake) = (biological yield of fertilized crop - biological yield of unfertilized crop)/(nutrients taken up by fertilized crop- nutrients taken up by unfertilized crop)

PFP = seed yield of fertilized crop/quantity of N applied

**2.3 Statistical analysis**

The standard analysis of variance (Gomez and Gomez, 1984) technique prescribed for the randomized block design with factorial concept was performed to compare the treatment means at 5% level of significance using least significant difference (LSD).

1. **RESULTS AND DISCUSSION**

**3.1 Growth attributes of Indian mustard**

The genotype PBR 357 exhibited significantly highest plant height, dry matter accumulation and chlorophyll index values during both experimental years (Table 1, p < 0.05). Key growth attributes of Indian mustard, including plant height, dry matter accumulation and chlorophyll index, increased significantly with higher N fertilizer doses during both years of the study. The application of 150 kg N ha-1 resulted in the highest plant height (187.0 and 179.8 cm), and dry matter accumulation (905.8 and 886.1 g m-2) during 4th and 5th years of poplar plantation. The chlorophyll index reached its maximum with the application of 150 kg N ha-1, recording values of 37.7 and 35.0 at 120 days after sowing (DAS) during two growing seasons. Among the genotypes, PBR 357 produced the highest number of primary and secondary branches during both experimental years under the poplar plantation. The results for the number of primary branches per plant were non-significant. A significantly higher number of secondary branches (14.2 and 12.5) were observed with the application of 150 kg N ha-1 compared to lower doses under the poplar plantation during both growing seasons. Nitrogen, being a key component of amino acids, proteins, chlorophyll, and protoplasts, directly influences growth and yield characteristics through better utilization of photosynthates. Additionally, increased nitrogen supply boosts protein production, thereby increasing protoplasm. This, in turn, results in larger cell size, more cell division, and a greater leaf area, ultimately leading to improved growth parameters of Indian mustard (Dhaliwal et al., 2022; Ullah et al., 2018). The variations in growth attributes among three genotypes may be due to heterogeneity in genetic constitution of each genotype (Kumar and Yadav, 2007).

Interaction effect of Indian mustard genotypes and nitrogen levels on number of seeds per siliqua beneath poplar plantation was found significant during both experimental years (Table 2). Significantly higher number of seeds per siliqua was recorded in genotype PBR 357 applied with 150 kg N ha-1 under poplar (15.5 and 14.0) during both experimental years, respectively.

**3.2 Seed and stover yield**

Indian mustard yield under poplar plantation was significantly influenced by interaction effect of genotypes and varying N levels during both growing seasons (Table 3, p < 0.05). The interactive effect of genotypes and nitrogen levels indicated that the application of 150 kg N ha-1 significantly increased seed yield in all genotypes compared to the application of 100 kg and 125 kg N ha-1 during 2020-21. The highest seed yield was recorded with the PBR 357 genotype (19.17 and 17.30 q ha-1) with the application of 150 kg N ha-1 during both experimental years. The PHR 126 genotype with the application of 150 kg N ha-1 behaved statistically similar to PBR 357 with the application of 125 kg N ha-1 during both growing seasons. The application of 150 kg N ha-1 increased seed yield by 19.1 and 15.5% in RCH 1, by 12.8 and 10.6% in PHR 126, and by 11.3 and 11.5% in the PBR 357 genotype over the application of 125 kg N ha-1 during 2020-21 and 2021-22, respectively.

The interactive effect of genotypes and nitrogen levels indicated that genotype PBR 357 (68.82, 61.78 q ha-1) with application of 150 kg N ha-1 recorded significantly higher stover yield during both the years, respectively (Table 4, p < 0.05). Application of 150 kg N ha-1 increased stover yield by 21.2 and 14.8% in RCH 1, 14.7 and 11.9% in PHR 126 and 13.1 and 9.9% in PBR 357 genotype over application of 125 kg N ha-1 during 2020-21 and 2021-22, respectively.

Application of 150 kg N ha-1 beneath poplar canopy significantly increased seed and stover yield by producing more vigorous growth and development as reflected via higher number of seeds per siliqua, increased plant height, highest dry matter accumulation and higher number of branches per plant. The application of more N enhances growth and number of seeds per siliquathat led to more seed yield (Kalita et al., 2017; Singh and Kumar, 2014). This could be ascribed due to more availability of nutrients in soil with increasing levels of nutrients must have enhanced the proportion of nutrients in the plant which ultimately led to contribute higher yield. Similar increase in yield due to increasing nutrient levels has also been reported by Ghimire and Bana (2011) and Jat et al. (2017). In this study, the fact that the soil of the experimental field at both sites was low in nitrogen can be seen as a key factor for the response of Indian mustard to higher dose of nitrogen fertilizer.

**Table 1: Effect of nitrogen levels on growth attributes of Indian mustard genotypes under poplar plantation**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Plant height (cm)** | | **Dry matter accumulation (g m-2)** | | **Chlorophyll index** | | **Primary branches (no.)** | | **Secondary branches (no.)** | |
|  | **2020-21** | **2021-22** | **2020-21** | **2021-22** | **2020-21** | **2021-22** | **2020-21** | **2021-22** | **2020-21** | **2021-22** |
| **Indian mustard genotypes** | | | | | | | | | | |
| **RCH 1** | 158.4 | 146.0 | 730.3 | 707.1 | 29.8 | 27.7 | 5.2 | 4.9 | 10.9 | 9.1 |
| **PHR 126** | 168.5 | 159.6 | 786.2 | 764.7 | 31.7 | 29.3 | 5.3 | 5.1 | 12.4 | 10.5 |
| **PBR 357** | 178.6 | 172.0 | 843.2 | 821.6 | 33.5 | 31.3 | 5.5 | 5.5 | 13.6 | 11.9 |
| **CD (p=0.05)** | 10.0 | 11.3 | 53.9 | 54.5 | 1.7 | 1.4 | NS | NS | 0.9 | 1.2 |
| **Nitrogen levels (kg ha-1)** | | | | | | | | | | |
| **0** | 150.3 | 138.0 | 625.4 | 598.7 | 20.9 | 22.0 | 5.0 | 4.7 | 10.4 | 8.6 |
| **100** | 162.4 | 152.8 | 773.1 | 751.0 | 32.7 | 29.0 | 5.2 | 5.1 | 11.7 | 9.9 |
| **125** | 174.4 | 166.3 | 842.1 | 821.9 | 35.3 | 31.7 | 5.4 | 5.3 | 12.9 | 11.1 |
| **150** | 187.0 | 179.8 | 905.8 | 886.1 | 37.7 | 35.0 | 5.7 | 5.5 | 14.2 | 12.5 |
| **CD (p=0.05)** | 11.6 | 13.0 | 62.2 | 62.9 | 1.9 | 1.6 | NS | NS | 1.1 | 1.3 |

**Table 2: Mean effect of Indian mustard genotypes and nitrogen levels on number of seeds per siliqua under poplar plantation**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Genotypes** | **Nitrogen levels (kg ha-1)** | | | |
| **0** | **100** | **125** | **150** |
| **2020-21** | | | | |
| **RCH 1** | 8.1 | 10.0 | 11.6 | 11.9 |
| **PHR 126** | 8.3 | 10.2 | 11.6 | 13.0 |
| **PBR 357** | 8.8 | 11.8 | 12.9 | 15.5 |
| **CD (p=0.05)** | Genotypes × Nitrogen levels = 1.2 | | | |
| **2021-22** | | | | |
| **RCH 1** | 7.7 | 8.5 | 10.5 | 11.3 |
| **PHR 126** | 8.0 | 9.7 | 11.1 | 11.8 |
| **PBR 357** | 8.3 | 12.2 | 13.5 | 14.0 |
| **CD (p=0.05)** | Genotypes × Nitrogen levels = 1.3 | | | |

**Table 3: Mean effect of Indian mustard genotypes and nitrogen levels on seed yield (q ha-1) under poplar plantation**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Genotypes** | **Nitrogen levels (kg ha-1)** | | | |
| **0** | **100** | **125** | **150** |
| **2020-21** | | | | |
| **RCH 1** | 8.16 | 10.03 | 12.03 | 14.33 |
| **PHR 126** | 8.81 | 12.77 | 15.60 | 17.60 |
| **PBR 357** | 9.26 | 15.20 | 17.23 | 19.17 |
| **CD (p=0.05)** | Genotypes × Nitrogen levels = 1.87 | | | |
| **2021-22** | | | | |
| **RCH 1** | 6.37 | 8.72 | 10.65 | 12.30 |
| **PHR 126** | 6.67 | 9.85 | 13.77 | 15.23 |
| **PBR 357** | 6.99 | 12.28 | 15.51 | 17.30 |
| **CD (p=0.05)** | Genotypes × Nitrogen levels = 1.69 | | | |

**Table 4: Mean effect of Indian mustard genotypes and nitrogen levels on stover yield (q** **ha-1) under poplar plantation**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Genotypes** | **Nitrogen levels (kg ha-1)** | | | |
| **0** | **100** | **125** | **150** |
| **2020-21** | | | | |
| **RCH 1** | 27.67 | 35.16 | 42.46 | 51.46 |
| **PHR 126** | 29.88 | 44.63 | 55.07 | 63.18 |
| **PBR 357** | 31.38 | 53.05 | 60.85 | 68.82 |
| **Mean** | 29.64 | 44.28 | 52.79 | 61.15 |
| **CD (p=0.05)** | Genotypes × Nitrogen levels = 6.53 | | | |
| **2021-22** | | | | |
| **RCH 1** | 26.49 | 28.32 | 37.89 | 43.48 |
| **PHR 126** | 28.17 | 37.87 | 48.86 | 54.66 |
| **PBR 357** | 30.29 | 46.33 | 56.21 | 61.78 |
| **Mean** | 28.32 | 37.50 | 47.65 | 53.31 |
| **CD (p=0.05)** | Genotypes × Nitrogen levels = 6.16 | | | |

**3.3 Efficiency indices**

Physiological efficiency (PE) was maximum with the application of 100 kg N ha**-1**, and the genotypes did not vary significantly regarding PE (Table 5). The maximum partial factor productivity (PFP) was observed with the application of 100 kg N ha**-1**, followed by 125 kg N ha**-1** during 2020-21. In the subsequent year, the highest PFP was observed with the application of 125 kg N ha**-1**, followed by 100 kg N ha**-1**. Genotype PBR 357 recorded significantly higher values for partial factor productivity during both growing seasons. This superior PFP in PBR 357 can be attributed to its higher grain yield compared to other genotypes (Kaur et al., 2021).

**Table 5: Effect of nitrogen levels on efficiency indices of Indian mustard genotypes under poplar plantation**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **Physiological efficiency (kg kg-1)** | | **Partial factor productivity (kg kg-1)** | |
| **2020-21** | **2021-22** | **2020-21** | **2021-22** |
| **Indian mustard genotypes** | | | | |
| **RCH 1** | 23.7 | 22.2 | 7.3 | 6.4 |
| **PHR 126** | 25.9 | 25.8 | 9.2 | 7.8 |
| **PBR 357** | 24.3 | 23.5 | 10.4 | 9.1 |
| **CD (p=0.05)** | NS | NS | 0.8 | 0.7 |
| **Nitrogen levels (kg ha-1)** | | | | |
| **0** | - | - | - | - |
| **100** | 38.0 | 32.5 | 12.7 | 10.3 |
| **125** | 32.1 | 32.2 | 12.0 | 10.6 |
| **150** | 28.4 | 30.7 | 11.4 | 10.0 |
| **CD (p=0.05)** | 6.0 | 5.9 | 1.0 | 0.8 |

1. **CONCLUSION**

The present investigation highlights the potential of poplar-based agroforestry systems for sustainable oilseed production in northern India. Indian mustard genotype PBR 357 demonstrated superior adaptability and performance under partial shade conditions and varied nitrogen levels. Nitrogen application at 150 kg ha-1 with genotype PBR 357 resulted in the highest seed and stover yields; however, maximum physiological efficiency and partial factor productivity were observed at 100-125 kg N ha-1, indicating the need for balanced nutrient management. This integrated approach offers an effective strategy to improve land-use efficiency, promote crop diversification, and contribute to food and livelihood security in agroforestry systems.

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**COMPETING INTERESTS**

Authors have declared that no competing interests exist.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that No generative AI technologies such as Large Language Models, ChatGPT etc. have been used during the writing or editing of manuscript.

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