**Growth performance of mustard and chickpea under different intercropping patterns and nitrogen fertilizer levels in North-western India**

**ABSTRACT**

Agriculture is a vital economic activity in India’s economy, vital to India’s economy, benefits from intercropping techniques like mustard and chickpea cultivation. This method enhances soil fertility through chickpea’s nitrogen fixation and reduces fertilizer needs. Effective crop management involves optimizing plant growth parameters, which significantly influences yield and economic returns. This experiment employed a Randomized Block Design with 8 treatments having 3 replications to evaluate intercropping strategies between mustard and chickpea. The treatments included sole crops with recommended rates of fertilizers (RDF), and various intercropping ratios and nitrogen levels: Mustard sole (T1), Chickpea sole (T2), Mustard + Chickpea (3:1) with 100 kg/ha (T3), 75 kg/ha (T4), and 50 kg/ha (T5), as well as Mustard + Chickpea (4:2) with 100 kg/ha (T6), 75 kg/ha (T7), and 50 kg/ha (T8). Exactly after 90 days of sowing, mustard plant heights ranged from a maximum of 198 cm in T6 to a minimum of 175.13 cm in T8. For chickpea, T3 achieved the highest height of 41.37 cm, while T5 had the lowest at 34.49 cm. The highest dry matter yield for mustard and chickpea was recorded in T3, showing improvements of 11.83% and 51.18%, respectively, compared to sole crops. The T6 and T3 also achieved the highest chlorophyll indices for mustard and chickpea, respectively. Yield results shows that the 3:1 ratio with 100 kg N/ha produced the highest mustard equivalent yield of 19.26 q/ha, whereas lower nitrogen levels reduced both yields and benefit-cost ratios. Overall, intercropping treatments, particularly with optimal nitrogen levels, enhanced both crop productivity and profitability compared to sole crops.

**Keywords:** Chickpea; dry matter; intercropping; Mustard; nitrogen.

**INTRODUCTION**

Agriculture is the backbone of India's economy, with about 70% of the population reliant on it. The country's diverse climatic conditions allow for a wide variety of crops. Among these, mustard (*Brassica juncea* L.) and chickpea (*Cicer arietinum* L.) stand out for their nutritional value and role in the agricultural system (Rajput and Kushwaha, 2021). India is the third-largest mustard producer globally, after China and Canada. The global area under rapeseed cultivation is approximately 35.19 million hectares, yielding 64.09 million metric tons, with an average productivity of 1,840 kg/ha (Agricultural Statistics at a Glance, 2018; Kumar *et al.,* 2018). India contributes 19.29% of the world's mustard cultivation area and 10.07% of its production. Mustard is crucial for India’s edible oil supply, given its substantial oil content and nutritional value. Chickpea is another vital crop, being the main source of protein for many vegetarians in India. It is grown on approximately 10.56 million hectares, producing 11.23 million tonnes annually, with an average productivity of 1,063 kg/ha (Agricultural Statistics at a Glance, 2018; Mhaske e*t al.,* 2019). Chickpea is valued for its high protein and mineral content, making it key to food and nutritional security. In India, growing mustard and chickpea intercropped is a productive agricultural technique. Growing two or more crops side by side in different row configurations on the same piece of land is known as intercropping (Kaparwan *et al.,* 2020). As a result of the leguminous chickpea's biological nitrogen fixation, this method improves soil fertility and reduces the need for fertilizer. It also saves space. Although mustard has a high nitrogen, phosphorus, and potassium requirement (N:P:K = 90:75:0), intercropping chickpea can cut that requirement by roughly 25 to 30 percent. (Khaitov and Abdiev, 2018) Various row ratios, including 1:2, 1:4, and 1:6 (mustard to chickpea), have been investigated and found to be most advantageous for the development and growth of both crops. By utilizing environmental resources more efficiently and lowering the need for chemical pesticides and fertilizers, the intercropping system increases production and productivity per unit area (Maitra *et al.,* 2021). Intercropping improves soil moisture retention and crop resistance to lodging, while reducing agriculture's environmental impact by minimizing synthetic inputs (Rahman *et al.,* 2022). It offers greater economic stability, crucial given challenges like soil degradation, resource scarcity, and the need for higher productivity to meet population demands. Current practices have led to stagnant production due to excessive fertilizer and pesticide use, degrading soil health. Intercropping maximizes productivity per unit area by using land and resources efficiently. Compatible crop selection and proper planting geometry are key. Research shows intercropping increases land productivity with lower inputs, providing yield stability against adverse conditions. In India, intercropping mustard and chickpea boosts soil health, reduces costs, and enhances sustainability through biological nitrogen fixation.

**MATERIAL AND METHODS**

The experimental work was conducted at Lovely Professional University, Phagwara, Punjab, during the *Rabi* season of 2020-21. The farm is located at 31°22’31.81”N latitude, 252 meters above mean sea level, and 75°23’03.02”E longitude, as per Google Maps. The region experiences summer temperatures exceeding 45°C, while winter temperatures can drop below 20°C, often accompanied by frost. Annual rainfall ranges from 550 to 750 mm, primarily occurring during the monsoon season from July to September. Winter months (December, January, February) receive scanty rainfall, but the overall rainfall and temperature conditions were adequate for mustard and chickpea cultivation.

The experiment was designed using a "Randomized Block Design" with 8 treatment having 3 replications combinations are Mustard sole (RDF) (T1), Chickpea sole (RDF) (T2), Mustard + Chickpea (3:1) (100 kg/ha) (T3), Mustard + Chickpea (3:1) (75 kg/ha) (T4), Mustard + Chickpea (3:1) (50 kg/ha) (T5), Mustard + Chickpea (4:2) (100 kg/ha) (T6), Mustard + Chickpea (4:2) (75 kg/ha) (T7), and Mustard + Chickpea (4:2) (50 kg/ha) (T8).

Observations for the experiment included measurements of plant height, leaf area index, dry weight, and chlorophyll content. The height of the main shoot was recorded in centimeters for five randomly selected plants from each plot, measuring from the base to the uppermost growing tip. Leaf area was assessed using a leaf area meter, and the leaf area index was calculated by dividing this measurement by the ground area. Dry weight was determined by selecting five plants from each plot, cutting them at ground level, and drying them in an oven at 60 ± 5°C until a constant weight was achieved, with the dry weight of chickpea recorded separately. Chlorophyll content was measured using a SPAD meter on tagged plants from each plot. These observations provided essential data on the growth and development of mustard and chickpea under different treatment combinations, contributing to the evaluation of their intercropping efficiency.

**RESULTS AND DISCUSSION**

**Plant Height**

## At 90 days after sowing, the maximum and minimum plant heights of mustard were recorded in T6 (198 cm) and T8 (175.13 cm), respectively. For chickpea, the highest plant height was in T3 (41.37 cm) and the lowest in T5 (34.49 cm) (Table 1). In T3, mustard height increased by 0.98% and chickpea by 7.28% compared to their respective sole crops. T4 saw slight increases of 0.05% in mustard and 2.93% in chickpea. However, T5 resulted in decreased heights for both crops, with mustard down by 2.38% and chickpea by 10.5%. T6 showed significant increases, with mustard by 5.96% and chickpea by 4.64%. In T7, mustard height remained unchanged, while chickpea decreased by 3.21%. T8 saw reductions of 6.27% in mustard and 5.31% in chickpea. Overall, T6 significantly (*p* < 0.05) superior in the maximum plant height for mustard, while T3 was superior for chickpea than other treatments.

## The nutrient management theory emphasizes the crucial role of nitrogen in plant growth, as it is a key component of amino acids, proteins, and chlorophyll, which are essential for photosynthesis and overall plant development. The results suggest that there is an optimal range of nitrogen application, as seen in treatments like T3 and T6, which led to significant increases in plant height for both crops. However, excessive nitrogen application, as observed in T5 and T8, resulted in reduced plant height, illustrating the concept of diminishing returns. The positive growth responses in certain intercropping treatments may reflect the synergistic benefits of intercropping, where the two species can complement each other's nutrient uptake and growth conditions. The increase in plant height in response to optimal nitrogen levels can also be attributed to enhanced physiological processes, including increased chlorophyll production, improved photosynthetic efficiency, and better root development, all of which contribute to overall plant vigor. These findings highlight the importance of careful management of nitrogen inputs and tailored fertilization strategies in sustainable agriculture to achieve optimal growth outcomes in mustard and chickpea crops.

## Higher intercrop density boosts sunlight interception, promoting rapid mustard growth through enhanced photosynthetic activity and greater dry matter accumulation during both vegetative and reproductive stages (Tripathy *et al.,* 2023). The complementary growth habits of mustard and chickpea lead to more efficient nutrient use, further supporting mustard growth (Dhaliwal *et al.,* 2022; Lal *et al.,* 2019). However, intercropping does not significantly affect plant height at maturity, likely due to species-specific growth traits or resource limitations. Thus, while intercropping enhances productivity through better light capture and resource use, it doesn't result in taller mature plants.

## Table 1: Effect of various N levels and intercropping patterns on plant height of mustard and chickpea.

|  |  |  |
| --- | --- | --- |
| **Treatment** | **Plant height (cm)** | |
|  | **Mustard** | **Chickpea** |
| Mustard sole (RDF) | 186.86 ± 0.84 | 0.00 ± 0.00 |
| Chickpea sole (RDF) | 0.00 ± 0.00 | 38.56 ± 0.52 |
| Mustard + Chickpea (3:1) (100kg/ha) | 188.70 ± 0.67 | 41.37 ± 0.64 |
| Mustard + Chickpea (3:1) (75 kg/ha) | 186.96 ± 0.70 | 39.69 ± 0.32 |
| Mustard + Chickpea (3:1) (50 kg/ha) | 182.40 ± 0.85 | 34.49 ± 0.62 |
| Mustard + Chickpea (4:2) (100kg/ha) | 198.00 ± 1.73 | 40.35 ± 0.55 |
| Mustard + Chickpea (4:2) (75 kg/ha) | 186.86 ± 0.32 | 37.32 ± 0.61 |
| Mustard + Chickpea (4:2) (50 kg/ha) | 175.13 ± 0.76 | 36.51 ± 0.61 |
| **SE (m) ±** | 0.92 | 0.53 |
| **C.D at 5%** | 2.82 | 1.65 |

## Dry Matter Accumulation

At 90 days after sowing, the maximum dry matter accumulation in mustard was recorded in T3 (84.13 g) which was significantly higher than other treatments, and the minimum in T8 (71.70 g) (Table 2). For chickpea, the highest accumulation was in T3 (14.06 g) and the lowest in T8 (8.26 g). T3 showed an 11.83% increase in mustard and a 51.18% increase in chickpea dry matter compared to their sole crops. T4 increased dry matter by 9.87% in mustard and 41.93% in chickpea. T5 decreased dry matter by 3.36% in mustard and 9.03% in chickpea. T6 resulted in a 9.87% increase in mustard and a 43.33% increase in chickpea. T7 saw a 9.70% increase in mustard and a 38.70% increase in chickpea. T8 reduced dry matter by 4.69% in mustard and 11.18% in chickpea. Overall, T3 significantly (*p* < 0.05) superior in the maximum dry matter accumulation for both mustard and chickpea.

Nitrogen is a critical nutrient that plays a vital role in plant growth and development, primarily as a key component of amino acids, proteins, and chlorophyll. In this study, treatment T3 (3:1, 100 kg N/ha) resulted in the highest dry matter accumulation for both mustard and chickpea, indicating that this nitrogen level was optimal for maximizing growth. The significant increases in dry matter for mustard and for chickpea compared to their respective sole crops demonstrate the positive impact of adequate nitrogen supply on biomass production. Conversely, lower nitrogen applications in treatments such as T5 and T8 led to reductions in dry matter accumulation, highlighting the importance of sufficient nitrogen for achieving optimal growth. The results also suggest that intercropping may enhance nutrient uptake efficiency, as evidenced by the substantial increases in dry matter in intercropped treatments (T4 and T6). Overall, these findings underscore the significance of tailored nitrogen management strategies in promoting dry matter accumulation and improving the productivity of both mustard and chickpea crops, ultimately contributing to more sustainable agricultural practices.

Among nutrient management strategies, the combined application of organic manures, which offer ample macro and micronutrients, resulted in notably higher dry matter accumulation at maturity during both seasons (Tripathy *et al.,* 2023; Chandranath *et al.,* 2020). The maximum seed and stover yield of mustard achieved in plots enriched with a mixture of farmyard manure, leaf manure, and microbial consortia, which enhanced nutrient uptake and increased dry matter accumulation. This efficacy is due to organic manures delivering essential nutrients in balanced proportions, fostering optimal plant growth and development (Saren, 2023). Furthermore, organic manures boost the population of beneficial soil microbes, which produce organic acids that aid in the rapid decomposition, mineralization, and solubilization of nutrients, making them more available to plants.

## Leaf Area Index

## The leaf area index (LAI) data reveals notable differences in leaf growth for mustard and chickpea across various treatments. The maximum LAI for mustard was observed in the sole mustard treatment with RDF, which registered a value of 3.71, significantly greater than all other treatments. This indicates optimal leaf development under sole cropping conditions. In contrast, the minimum LAI for mustard was recorded in the treatment with a 4:2 row ratio and 50 kg N/ha, showing a reduced value of 2.63 (Table 3). For chickpea, the maximum LAI of 1.75 was achieved in both the sole chickpea treatment with RDF and the mustard-chickpea (4:2) ratio with 100 kg N/ha, suggesting these treatments are highly effective for enhancing leaf growth in chickpea. The minimum LAI for chickpea was found in the treatment with a 4:2 row ratio and 50 kg N/ha, which had a value of 1.59. Overall, the data indicates that while the sole mustard treatment achieved the highest LAI for mustard and specific intercropping configurations were beneficial for chickpea, lower nitrogen levels and certain row ratios generally resulted in reduced leaf area indices for both crops.

**Table 2: Effect of various N levels and intercropping patterns on Dry matter content of mustard and chickpea.**

|  |  |  |
| --- | --- | --- |
| **Treatment** | **Dry matter (g/plant)** | |
|  | **Mustard** | **Chickpea** |
| Mustard sole (RDF) | 75.23 ± 0.58 | 0.00 ± 0.00 |
| Chickpea sole (RDF) | 0.00 ± 0.00 | 9.30 ± 0.35 |
| Mustard + Chickpea (3:1) (100kg/ha) | 84.13 ± 1.01 | 14.06 ± 0.41 |
| Mustard + Chickpea (3:1) (75 kg/ha) | 82.66 ± 0.86 | 13.20 ± 0.35 |
| Mustard + Chickpea (3:1) (50 kg/ha) | 72.70 ± 0.85 | 8.46 ± 0.34 |
| Mustard + Chickpea (4:2) (100kg/ha) | 82.66 ± 0.90 | 13.33 ± 0.33 |
| Mustard + Chickpea (4:2) (75 kg/ha) | 82.53 ± 0.95 | 12.90 ± 0.17 |
| Mustard + Chickpea (4:2) (50 kg/ha) | 71.70 ± 0.84 | 8.26 ± 0.23 |
| **SE (m) ±** | 0.80 | 0.31 |
| **C.D at 5%** | 2.46 | 0.95 |

## The maximum and minimum leaf area indices (LAI) for mustard were recorded in T1 (3.71) and T8 (2.63), respectively at 90 days after sowing (Table 3). For chickpea, the highest and lowest LAI were in T2 (1.75) and T8 (1.59). T3 (3:1, 100kg N/ha) showed a 1.34% decrease in mustard and a 0.57% decrease in chickpea LAI compared to their sole crops. T4 (3:1, 75kg N/ha) resulted in a 12.93% decrease in mustard and a 3.42% decrease in chickpea. T5 (3:1, 50kg N/ha) saw LAI reductions of 26.95% in mustard and 8% in chickpea. T6 (4:2, 100kg N/ha) showed a 9.97% decrease in mustard with no change in chickpea. T7 (4:2, 75kg N/ha) had decreases of 19.40% in mustard and 2.28% in chickpea. T8 showed significant reductions of 29.11% in mustard and 9.14% in chickpea. Therefore, T3 had the highest LAI for mustard and T6 for chickpea at 90 DAS and significantly higher than other treatments.

## LAI is a crucial indicator of plant growth and photosynthetic capacity, as it reflects the amount of leaf area available for light interception and photosynthesis. In this study, the maximum LAI for mustard was recorded in treatment T1, while chickpea reached its peak in T2. The decrease in LAI observed in treatments like T3 and T4 indicates that while these nitrogen levels initially supported growth, they may not have been optimal for maximizing leaf area development. The significant reductions in LAI in treatments T5 and T8 suggest that insufficient nitrogen availability can severely limit leaf expansion, thereby reducing the plant's photosynthetic potential. Additionally, the physiological stress from lower nitrogen levels may lead to reduced chlorophyll production and leaf expansion, further contributing to the observed decreases in LAI. The findings emphasize the importance of optimizing nitrogen application to enhance leaf area development, which is critical for improving overall crop productivity and ensuring effective light capture for photosynthesis in both mustard and chickpea crops.

## The leaf area index (LAI) was significantly affected by different nitrogen levels and intercropping patterns, with sole mustard showing the highest LAI compared to intercropped systems. This is due to its denser foliage and more efficient sunlight use, enhancing light interception and thus increasing LAI (Singh *et al.,* 2019; Rameshbhai, 2021). The thick canopy supports more effective photosynthesis, leading to improved growth and higher biomass accumulation. Furthermore, the absence of competition for light and space in sole cropping allows mustard plants to fully optimize their growth potential, resulting in a larger leaf area (Laishram and Jaswal, 2023). Additionally, mustard's specific growth habits, including a tendency for vertical growth, also contribute to a higher LAI in sole crops.

## Table 3. Effect of various N levels and intercropping patterns on leaf area index of mustard and chickpea.

|  |  |  |
| --- | --- | --- |
| **Treatment** | **Leaf area index** | |
|  | **Mustard** | **Chickpea** |
| Mustard sole (RDF) | 3.71 ± 0.02 | 0.00 ± 0.00 |
| Chickpea sole (RDF) | 0.00 ± 0.00 | 1.75 ± 0.01 |
| Mustard + Chickpea (3:1) (100kg/ha) | 3.66 ± 0.02 | 1.74 ± 0.01 |
| Mustard + Chickpea (3:1) (75 kg/ha) | 3.23 ± 0.12 | 1.69 ± 0.01 |
| Mustard + Chickpea (3:1) (50 kg/ha) | 2.71 ± 0.11 | 1.61 ± 0.01 |
| Mustard + Chickpea (4:2) (100kg/ha) | 3.34 ± 0.08 | 1.75 ± 0.02 |
| Mustard + Chickpea (4:2) (75 kg/ha) | 2.99 ± 0.14 | 1.71 ± 0.02 |
| Mustard + Chickpea (4:2) (50 kg/ha) | 2.63 ± 0.10 | 1.59 ± 0.01 |
| **SE (m) ±** | 0.07 | 0.01 |
| **C.D at 5%** | 0.22 | 0.03 |

## Chlorophyll Index

## The table 4 presents chlorophyll indices for mustard and chickpea under various treatments. Chlorophyll index measures the concentration of chlorophyll in plant tissues, indicating plant health and photosynthetic efficiency. For mustard, the chlorophyll index ranged from 38.22 in the sole crop with recommended doses of fertilizers (RDF) to 40.56 in the mustard-chickpea (4:2) ratio with 100 kg N/ha. The highest chlorophyll index for chickpea was 40.37 in the sole crop with RDF, and the lowest was 37.50 in the mustard-chickpea (3:1) ratio with 75 kg N/ha. The treatment with the 4:2 ratio at 100 kg N/ha resulted in the highest chlorophyll index for mustard (40.56), which was significantly superior to other treatments. For chickpea, the highest index was observed in the sole crop (40.37), although the 3:1 ratio with 50 kg N/ha (39.90) and the 4:2 ratio with 75 kg N/ha (39.53) also showed high values. Overall, the 4:2 ratio with 100 kg N/ha was significantly superior for mustard chlorophyll index, while sole chickpea maintained the highest index for chickpea.

## The maximum and minimum chlorophyll indices for mustard were recorded in T6 (40.56) and T8 (38.22), respectively, while chickpea showed the highest and lowest indices in T6 (40.37) and T8 (38.40) (Table 4). In T3 (3:1, 100kg N/ha), mustard's chlorophyll index increased by 0.39%, whereas chickpea's index decreased by 2.72%. T4 (3:1, 75kg N/ha) led to a 4.39% increase in mustard but a 7.10% decrease in chickpea. T5 (3:1, 50kg N/ha) saw a 1.33% increase in mustard and a 1.16% decrease in chickpea. T6 (4:2, 100kg N/ha) resulted in a 6.12% increase in mustard and a 4.87% decrease in chickpea. T7 (4:2, 75kg N/ha) had a 2.45% increase in mustard and a 2.08% decrease in chickpea. T8 (4:2, 50kg N/ha) showed a 1.22% increase in mustard but a 4.45% decrease in chickpea. Thus, T6 achieved the highest chlorophyll index for mustard, and T5 was the most effective for chickpea at 90 days after sowing.

## The variations in chlorophyll index observed in mustard and chickpea crops at 90 days after sowing can be explained through the principles of plant nutrition and the role of nitrogen in chlorophyll synthesis. Nitrogen is a key component of chlorophyll molecules, and its availability directly influences the chlorophyll content in plants. In this study, treatment T6 resulted in the highest chlorophyll index for both mustard and chickpea, indicating that this nitrogen level was optimal for maximizing chlorophyll production. The significant increases in chlorophyll index in T6 compared to the sole crop treatments (T1 for mustard and T2 for chickpea) demonstrate the positive impact of adequate nitrogen supply on chlorophyll synthesis. Conversely, lower nitrogen applications in treatments such as T4 and T8 led to reductions in chlorophyll index, highlighting the importance of sufficient nitrogen for maintaining optimal chlorophyll levels.

## The chlorophyll index, which is directly linked to chlorophyll content, was significantly influenced by nitrogen levels and intercropping patterns in both mustard and chickpea crops. In chickpea, the chlorophyll index peaked due to optimal nitrogen levels, as chickpeas are legumes that fix atmospheric nitrogen through their symbiotic relationship with Rhizobium bacteria (Zayed *et al.,* 2023). This nitrogen-fixing ability reduces the need for external nitrogen application, allowing efficient use of available nitrogen for chlorophyll synthesis and photosynthesis. The application of nitrogen fertilizers positively impacted the chlorophyll content in both mustard and chickpea crops (Dhaliwal *et al.,* 2021; Layek *et al.,* 2018). Nitrogen availability directly affects chlorophyll synthesis and accumulation in plant tissues, ensuring sufficient nutrient supply for chlorophyll production, which enhances the green color and photosynthetic capacity of the leaves (Mengesha, 2021).

## Table 4. Effect of various N levels and intercropping patterns on chlorophyll index of mustard and chickpea at 90 DAS

|  |  |  |
| --- | --- | --- |
| **Treatment** | **Chlorophyll index** | |
|  | **Mustard** | **Chickpea** |
| Mustard sole (RDF) | 38.22 ± 0.53 | 0.00 ± 0.00 |
| Chickpea sole (RDF) | 0.00 ± 0.00 | 40.37 ± 0.29 |
| Mustard + Chickpea (3:1) (100kg/ha) | 38.37 ± 0.62 | 39.27 ± 1.04 |
| Mustard + Chickpea (3:1) (75 kg/ha) | 39.90 ± 0.70 | 37.50 ± 0.68 |
| Mustard + Chickpea (3:1) (50 kg/ha) | 38.73 ± 0.74 | 39.90 ± 1.37 |
| Mustard + Chickpea (4:2) (100kg/ha) | 40.56 ± 1.21 | 38.40 ± 0.99 |
| Mustard + Chickpea (4:2) (75 kg/ha) | 39.16 ± 0.35 | 39.53 ± 0.22 |
| Mustard + Chickpea (4:2) (50 kg/ha) | 38.69 ± 0.60 | 38.57 ± 1.52 |
| **SE (m) ±** | 0.70 | 0.94 |
| **C.D at 5%** | 2.15 | 2.89 |

**Mustard Equivalent Yield**

## The data shows that mustard equivalent yields varied significantly across treatments. Sole mustard yielded 11.81 q/ha, while sole chickpea achieved 14.29 q/ha. The highest mustard yield was observed with the 3:1 mustard-chickpea ratio at 100 kg N/ha, reaching 19.26 q/ha (Table 5). This was significantly superior than other treatments followed by the 4:2 ratio with 100 kg N/ha, which yielded 18.29 q/ha. Lower nitrogen levels reduced yields: 75 kg N/ha in the 3:1 ratio yielded 13.36 q/ha, while 50 kg N/ha led to only 7.90 q/ha. The 4:2 ratio with 75 kg N/ha yielded 12.52 q/ha, and 50 kg N/ha resulted in the lowest yield of 7.37 q/ha. The standard error and critical difference indicate the reliability of these findings, with the 3:1 ratio at 100 kg N/ha being the most effective for maximizing mustard yields.

## The variations in mustard equivalent yields across treatments can be attributed to nutrient management principles and the interaction between nitrogen application rates and cropping systems. Nitrogen is essential for plant growth, influencing the synthesis of proteins, nucleic acids, and chlorophyll. The highest yield of 19.26 q/ha was achieved with the 3:1 mustard-chickpea ratio at 100 kg N/ha, indicating optimal nitrogen levels for maximizing productivity in intercropping. This intercropping likely enhances resource use efficiency between mustard and chickpea. Conversely, lower nitrogen levels resulted in reduced yields, demonstrating that insufficient nitrogen limits growth potential. Overall, these findings emphasize the importance of tailored nitrogen management practices to enhance crop performance and sustainability.

## Table 5. Effect of various N levels and intercropping patterns on mustard equivalent yield (q/ha)

|  |  |
| --- | --- |
| **Treatment** | **Mustard equivalent yield (q/ha)** |
| Mustard sole (RDF) | 11.81 |
| Chickpea sole (RDF) | 14.29 |
| Mustard + Chickpea (3:1) (100kg/ha) | 19.26 |
| Mustard + Chickpea (3:1) (75 kg/ha) | 13.36 |
| Mustard + Chickpea (3:1) (50 kg/ha) | 7.90 |
| Mustard + Chickpea (4:2) (100kg/ha) | 18.29 |
| Mustard + Chickpea (4:2) (75 kg/ha) | 12.52 |
| Mustard + Chickpea (4:2) (50 kg/ha) | 7.37 |
| SE (m)± | 0.79 |
| C.D | 2.43 |

## The increase in mustard equivalent yield when intercropped with chickpea is due to several key factors related to nutrient dynamics and resource utilization. Firstly, the intercropping system enhances nitrogen uptake thanks to chickpea's nitrogen-fixing ability, which boosts soil nitrogen availability for both crops. This beneficial interaction allows mustard to benefit from the nitrogen fixed by chickpea, resulting in improved growth and yield (Tiwari and Singh, 2024). Additionally, intercropping promotes better light interception and resource sharing, as the different growth habits of mustard and chickpea enable them to occupy different niches in the same space. This complementary growth leads to higher overall productivity per unit area compared to monocultures (Zheng *et al.,* 2021). Furthermore, the presence of chickpea stimulates microbial activity in the rhizosphere, enhancing nutrient cycling and availability, which further supports mustard growth (Kushwaha and Mehta, 2023). Overall, the combination of nitrogen fixation, improved light capture, and enhanced soil nutrient dynamics contributes to the increased mustard equivalent yield observed in intercropping systems with chickpea.

**Benefit-Cost Ratio**

The observed differences in gross return, net return, and benefit-cost (B:C) ratios among the treatments can be attributed to the efficiency of resource utilization in intercropping systems. The 3:1 (100 kg N/ha) and 4:2 (100 kg N/ha) ratios maximized yields and returns due to optimal nitrogen application and complementary resource use between mustard and chickpea. In contrast, the lower nitrogen levels (50 kg N/ha) resulted in reduced yields and returns, leading to lower B:C ratios (Table 6). Overall, intercropping treatments generally outperformed sole crops by enhancing productivity and profitability through improved nutrient and light competition.

Intercropping treatments generally surpassed sole crops in terms of productivity and profitability by optimizing nutrient and light competition. This method allows for more efficient light interception and use, as different crop species occupy various canopy layers, minimizing mutual shading and enhancing overall light use efficiency. The complementary resource use in intercropping systems results in higher yields and better economic returns compared to sole cropping.

**Table 6: Economics of various N levels and intercropping patterns on mustard and chickpea**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatment** | **Gross return (Rs.)** | **Net return (Rs.)** | **B:C ratio** |
| Mustard sole (RDF) | 54339.80 | 41889.80 | 3.36 |
| Chickpea sole (RDF) | 66453.00 | 48326.00 | 2.67 |
| Mustard + Chickpea (3:1) (100kg/ha) | 89120.10 | 74228.10 | 4.98 |
| Mustard + Chickpea (3:1) (75 kg/ha) | 61837.70 | 46434.70 | 3.01 |
| Mustard + Chickpea (3:1) (50 kg/ha) | 36543.50 | 20750.50 | 1.31 |
| Mustard + Chickpea (4:2) (100kg/ha) | 84710.80 | 67954.45 | 4.93 |
| Mustard + Chickpea (4:2) (75 kg/ha) | 58010.10 | 43651.10 | 3.04 |
| Mustard + Chickpea (4:2) (50 kg/ha) | 34158.70 | 19376.70 | 1.31 |

**CONCLUSION**

It was concluded that at 90 days after sowing highlighted that specific intercropping treatments significantly influenced plant height, dry matter accumulation, and chlorophyll indices. The 3:1 ratio with 100 kg N/ha (T3) achieved the highest plant height, dry matter, and mustard equivalent yield, proving most effective for enhancing mustard productivity. For chickpea, the 4:2 ratio with 100 kg N/ha (T6) yielded the highest chlorophyll index. Overall, intercropping treatments generally surpassed sole crops in maximizing yields and returns, with T3 and T6 showing the most promising results. Lower nitrogen levels led to reduced yields and returns, emphasizing the critical role of optimal nitrogen application in intercropping systems. These findings demonstrate that strategic intercropping and nitrogen management can notably improve crop productivity and profitability.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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