# Impact of Different Nitrogen and Phosphorus Combinations Along with Naphthalene Acetic Acid on Growth and Yield of Late-Sown Wheat (*Triticum aestivum L.*)

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## Abstract

Significant efforts have been made over the past decade to enhance wheat productivity. The application of synthetic plant growth regulators, in combination with nitrogen fertilization, has shown promising results in this regard. This study aimed to evaluate the effects of different nitrogen (N) and phosphorus ($P_2O_5$) levels, along with the exogenous application of naphthalene acetic acid (NAA), on late-sown wheat under the agro-climatic conditions of Dera Ismail Khan, KP, Pakistan. Data were collected on various agronomic traits, including plant height (cm), spike weight (g), spike length (cm), number of tillers, thousand-grain weight (g), grains per spike, biological yield (kg $ha^{-1}$), grain yield (kg $ha^{-1}$), straw yield (kg $ha^{-1}$), productivity score, and harvest index. Significant differences were observed across different fertilizer and NAA treatment levels. Additionally, physiological parameters such as leaf area index (LAI) at 49 and 98 days after emergence, leaf area duration (LAD) at 49 and 98 days, crop growth rate (CGR), and net assimilation rate (NAR) were also significantly influenced by NAA and fertilizer application. The highest grain yield and yield-related parameters were obtained from the fertilizer treatment of 180 kg N and 120 kg $P_2O_5$ $ha^{-1}$ combined with the $PGR_2$ level (50 ml NAA $ha^{-1}$). Based on this one-year study, applying 50 ml NAA $ha^{-1}$ alongside an optimal dose of nitrogen and phosphorus resulted in maximum net returns for wheat production under the agro-ecological conditions of Dera Ismail Khan.

## Keywords

Wheat Productivity, Plant Growth Regulators, NAA, Yield Improvement, Nitrogen and Phosphorus Fertilization

## 1.Introduction

Wheat is the most widely cultivated cereal crop, serving as a staple food for one-third of the global population. It accounts for about 30% of total cereal production and is grown in 43 countries [1].Wheat adapts to diverse environments, thriving from sea level to altitudes above 4,500 meters. It is cultivated year-round in different parts of the world, ensuring continuous global production [2]. In 2017-18, global wheat production reached 757.92 million tons, with Pakistan contributing 26.3 million tons over 8.73 million hectares. Wheat contributes 10.3% to agriculture and 2.2% to Pakistan's GDP. Its productivity largely depends on fertilizers, especially nitrogen [3]. Balanced fertilization optimizes yield while reducing environmental impact. Growth regulators like naphthalene acetic acid (NAA) further enhance wheat production by promoting growth and development. Wheat originates from the Triticeae tribe, which includes rye and barley. The Fertile Crescent, spanning West Asia and North Africa, is considered the center of wheat domestication. Wild einkorn (*Triticum monococcum*) and emmer (*Triticum dicoccoides*), known for 75,000 years, were among the first domesticated wheat varieties. Transitioning from gathering to cultivation about 10,000 years ago marked a turning point in human civilization, enabling settled agriculture and trade. Systematic wheat germplasm collection began in Japan in the early 1900s. Since the 1960s, wheat research centers have been established worldwide [4]. Wheat has been a staple in Europe, North Africa, and Western Asia for over 8,000 years. Many developing nations prioritize wheat self-sufficiency for food security. According to [2] wheat is cultivated on nearly one-sixth of the world's arable land. In Pakistan, wheat production has progressed through three phases: the pre-Green Revolution era (1947-1965) with traditional wheat varieties, the Green Revolution (1966-1976) with the introduction of high-yielding varieties (HYVs) and synthetic fertilizers, and the post-Green Revolution period (1977-present) focusing on disease-resistant HYVs and national expansion of wheat cultivation [2]. Late sowing due to delayed harvesting of kharif crops like cotton, rice, and sugarcane reduces wheat productivity. A key agricultural challenge is sustainably increasing yield while maintaining soil fertility. If nutrients removed during harvesting are not replenished, soil fertility declines, affecting crop growth. This issue persists across many regions of Pakistan, where wheat yield has stagnated in recent years. Enhancing yield, particularly in late-sown wheat, requires strategic fertilization and growth regulation. Wheat plays a vital role in global food security. In Pakistan, unbalanced fertilizer use, favoring nitrogen over phosphorus, limits productivity. Phosphorus application is crucial for maximizing cereal crop yields. The use of plant growth regulators (PGRs) is an emerging approach to improving crop performance. These organic compounds regulate growth, development, and yield while preventing premature fruit and flower drop [5]. Naphthalene acetic acid (NAA), a synthetic growth promoter, enhances crop growth and physiological processes [3]. However, its effect on nutrient uptake and cereal productivity remains underexplored [6]. Combining NAA with nitrogen fertilizers may reduce production costs and enhance nutrient efficiency, yielding economic and environmental benefits. Water scarcity is another major challenge in arid regions, affecting crop productivity. Climate change and erratic rainfall patterns increase vulnerability to pests and diseases, necessitating efficient agronomic practices. In dry regions like Dera Ismail Khan, maintaining optimal wheat-growing conditions is crucial for securing stable yields.

**Objectives**

To assess the efficiency of nitrogen and phosphorus application in late-sown wheat.

To improve late-sown wheat productivity through foliar application of NAA.

## 2.Materials and Methods

### 2.1 Experimental Site and Facilities

The study on the integrated application of nitrogen, phosphorus, and naphthalene acetic acid (NAA) in late-sown wheat was conducted at the Research Farm, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Pakistan. The experiment followed a split-plot arrangement under a randomized complete block design (RCBD). The seedbed was prepared by deep plowing followed by planking to ensure a uniform and well-moisturized soil surface. Wheat variety Hashim-08 was sown at a seed rate of 140 kg $ha^{-1}$. Each plot measured 3m × 1.8m, comprising six rows spaced 30 cm apart. Treatments were replicated three times. Nitrogen and phosphorus fertilizers were applied at four levels (0:0, 60:40, 120:80, and 180:120 kg $ha^{-1}$) at sowing, with nitrogen split into two doses. Potassium was uniformly applied at 60 kg $ha^{-1}$. NAA was sprayed at booting stage at three levels (0-, 50-, and 100-ml $ha^{-1}$).

### 2.2 Studied Parameters

**Soil Analysis**
Soil properties, including pH, EC, organic matter, nitrogen, and phosphorus, were analyzed following standard methods [7].

**Measured Variables**

**Plant emergence (%) Determined using:**
Germination % = (Emerged seedlings / Total plot area) × 100

**Days to germination**

Recorded after sowing.

**Leaf area index (LAI)**

Leaf area index is Measured at 49 and 98 DAS using:

LAI = Total leaf area / Ground area

**Leaf area duration (LAD)**

Leaf area calculated as: LAD = LAI × Weeks

**Crop growth rate (CGR g $m^{-2}$ $day^{-1}$)**

Estimated by: $CGR = (W_2 - W_1) / (t_2 - t_1)$

**Net assimilation rate (NAR mg $m^{-2}$ $day^{-1}$)**

The Net assimilation is measured by using: $NAR = (W_2 - W_1) \times (\ln(LA_2) - \ln(LA_1)) / (t_2 - t_1) \times (LA_2 - LA_1)$

**Plant height (cm)**

Plant height was Recorded from ten randomly selected plants per plot.

**Number of tillers**

Counted within a randomly selected 1$m^2$ area per plot.

**Spike weight (g)**

Determined from ten randomly selected spikes per plot.

**Spike length (cm)**

Measured from ten randomly selected spikes per plot.

**Grains per spike**

Counted from ten randomly selected spikes after threshing.

**Thousand-grain weight (g)**

Measured by weighing 1000 grains from each subplot.

**Biological yield (kg ha$^{-1}$)**

Harvested from a 1m² area and converted using: Biological yield = Biomass (kg m$^{-2}$) × 10,000

**Economic yield (kg ha$^{-1}$)**

Grains from a harvested 1m² area were dried, weighed, and converted to kg ha$^{-1}$ using:

Economic yield = Yield (kg m$^{-2}$) × 10,000

**Straw yield (kg ha$^{-1}$)**

Calculated as: Straw yield = Total biomass - Economic yield

**Harvest index (%)**

Computed using: HI = (Economic yield / Biological yield) × 100

**Productivity score**

Summation of grain yield, biological yield, and harvest index (Stoskopf, 1981).

**Fertilizer use efficiency (FUE)**

Assessed using = (Net yield with fertilizer - Yield in control) / Fertilizer applied (kg)

**Data Collection Methods**

Each parameter was recorded following standard experimental procedures.

**Sampling Technique**

Appropriate sampling methods were used for accurate data collection.

**Research Design**

The study followed a randomized complete block design with a split-plot arrangement.

**Layout Plan**

The experiment was arranged systematically, including replications (R1, R2, R3), footpaths, and water channels for irrigation management.

**Statistical Analysis**

Data were analyzed using ANOVA as per Steel et al. (1997), utilizing Statistix 8.1 software.

## 3. Results and Discussion

### 3.1 Plant Emergence Percentage (%)

Table 1 data showed no significant differences among varying N, P, and NAA levels or their interactions, though visual variations were noted. The Maximum germination was observed in $T_1$ (80.70%), followed by $T_2$ (77.48%), while among NAA levels, $GR_1$ (79.58%) had the highest germination, followed by $GR_3$ (75.09%). The highest interaction value (85.46%) was recorded in T × GR, with the lowest in the control. These variations may be due to the use of a single wheat variety (Hashim-08), similar germination conditions, and no foliar NAA application at that stage. Minor differences could be attributed to soil heterogeneity, while N and P levels had no significant impact on germination.

**Table 1. Effect of N:P and NAA application on germination percentage (%) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 65.07$^{NS}$ | 70.62 | 81.99 | 72.49$^{NS}$ |
| $T_2$(60:40) | 76.39 | 85.05 | 71.00 | 77.48 |
| $T_3$(120:80) | 77.52 | 77.34 | 67.59 | 74.14 |
| $T_4$(180:12) | 76.76 | 85.45 | 79.97 | 80.70 |
| Means | 73.93$^{NS}$ | 79.59 | 75.09 | |

### 3.2 Number of Days to Germination

Table 2 data showed that nitrogen (N), phosphorus (P), and naphthalene acetic acid (NAA) levels, along with their interactions, had no significant effect on germination days. The ANOVA table is provided in Appendix 2. The longest germination period was recorded in N and P levels for $T_1$ (11.89 days), followed by $T_5$ (11.78 days). Among NAA levels,

$GR_1$ had the highest germination time (12.58 days), followed by $GR_3$ (11.50 days). The interaction T × GR recorded the maximum value of 13.00 days. The shortest germination time was observed in $T_4$ (11.33 days) and $GR_2$ (10.83 days), with the lowest interaction value (10.00 days) in T × GR. This variation may be due to the use of a single cultivar (Hashim-08) and its genetic potential. N and P levels had no significant impact on germination days, and the foliar application of NAA at the booting stage had minimal influence.

**Table 2. Effect of N:P and NAA application on No. of days to germination of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | **$GR_1$ (Control)** | **$GR_2$ (50)** | **$GR_3$ (100)** | |
| **$T_1$(control)** | $13.00^{NS}$ | 10.68 | 11.00 | $11.56^{NS}$ |
| **$T_2$(60:40)** | 12.33 | 10.00 | 11.67 | 11.33 |
| **$T_3$(120:80)** | 12.00 | 11.33 | 12.00 | 11.78 |
| **$T_4$(180:12)** | 13.00 | 11.35 | 11.33 | 11.89 |
| **Means** | $12.58^{NS}$ | 10.83 | 11.50 | |

### 3.3 Plant Height (cm)

Table 3 data indicated that plant height was significantly influenced by the application and interactions of different nitrogen (N), phosphorus (P), and naphthalene acetic acid (NAA) levels. The ANOVA table is provided in Appendix 3. Among NP levels, $T_1$ (180:120) resulted in the tallest plants (89.42 cm), while in interaction T × GR, the maximum height was recorded at 94.13 cm. Plants treated with $GR_1$ (50 ml NAA $ha^{-1}$) exhibited greater height (89.42 cm) than other treatments. $T_2$ (80.51 cm) and $T_3$ (82.79 cm) showed no significant difference. The shortest plants were recorded in the control (72.19 cm) and $GR_3$ (75.10 cm), with the lowest interaction value (67.20 cm) in T × GR. This reduction in plant height may be due to high plant density, leading to competition for light and nutrients. [8] reported that foliar NAA application improved tiller development compared to the control, while observed taller plants with higher NP fertilizer levels.

**Table 3. Effect of N:P and NAA application on Plant Height (cm) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | **$GR_1$ (Control)** | **$GR_2$ (50)** | **$GR_3$ (100)** | |
| **$T_1$(control)** | 67.20 g | 77.33ef | 72.03g | 72.19c |
| **$T_2$(60:40)** | 72.50 fg | 86.63bc | 82.40.cde | 80.51b |
| **$T_3$(120:80)** | 79.37de | 88.13abc | 83.87cd | 83.79b |
| **$T_4$(180:120)** | 833.73 cd | 94.14a | 90.40ab | 89a |
| **Means** | 75.70 c | 86.56a | 82.17b | |

### 3.4 Number of Tillers at Maturity

Table 4 analysis showed that different levels of nitrogen (N), phosphorus (P), and naphthalene acetic acid (NAA), along with their interactions, had a significant effect on the number of mature tillers. The ANOVA table is provided in Appendix 4. Among fertilizer treatments, $T_4$ (180:120) produced the highest number of tillers at maturity (215.22), followed by $T_3$ (184.67). In NAA treatments, $GR_1$ (50 ml $ha^{-1}$) recorded the maximum tillers (186.92), followed by $GR_3$ (179.67). The interaction $T_4$ (180:120 kg $ha^{-1}$) × $GR_1$ (50 ml $ha^{-1}$) resulted in the highest number of tillers. The lowest tiller count was observed in the control treatment $T_0$ (150.11), $GR_2$ (170.83), and the interaction T × GR (141.00). The increase in tillers may be due to the optimal availability of nutrients at the tillering stage and the role of NAA in stimulating meristematic activity at the plant base. Similar findings were reported by [3], who stated that foliar application of NAA enhanced nitrogen and phosphorus uptake, leading to improved tillering

**Table 4. Effect of N:P and NAA application on No. of Tillers at Maturity of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | **$GR_1$ (Control)** | **$GR_2$ (50)** | **$GR_3$ (100)** | |
| **$T_1$(control)** | 141.00 j | 157.67 i | 151.67 i | 150.11 d |
| **$T_2$(60:40)** | 160.67 h | 171.67 fg | 167.33 g | 166.56 c |
| **$T_3$(120:80)** | 178.67 c | 192.00 d | 184.00 e | 184.67 b |
| **$T_4$(180:120)** | 203.67 c | 226.33 a | 215.67 b | 215.22 a |
| **Means** | 170.83 c | 186.92 a | 179.67 b | |

### 3.5 Spike Length (cm)

Spike length is a key factor influencing grain yield, affecting the number of grains per spike, spike weight, and thousand-grain weight. Table 5 data indicated significant differences in spike length among different combinations of nitrogen (N) and phosphorus ($P_2O_5$) with naphthalene acetic acid (NAA) application in late-sown wheat. The ANOVA table is provided in Appendix 5. The longest spike (11.87 cm) was recorded in $T_1$ (180:120 kg $ha^{-1}$ N:P), followed by $T_3$ (11.31 cm). Among NAA treatments, $GR_1$ (50 ml $ha^{-1}$) produced the longest spike (11.89 cm), followed by $GR_3$ (11.31 cm). In interaction, T × GR recorded the highest spike length (12.33 cm). Treatments $T_2$ and $T_5$ showed no significant difference. The shortest spike length was observed in the control $T_0$ (10.31 cm) and $GR_2$ (10.22 cm), while the lowest interaction value was recorded in $T_1 \times GR_2$ (8.98 cm). [9] reported similar findings, stating that fertilizer application along with NAA significantly improved spike growth by enhancing nutrient uptake.

**Table 5. Effect of N:P and NAA application on Spike Length (cm) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 8.98 f | 11.50 bc | 10.43 de | 10.31 c |
| $T_2$(60:40) | 10.27 e | 11.46 bc | 11.23 cd | 10.99 b |
| $T_3$(120:80) | 10.42 e | 11.98 abc | 11.52 bc | 11.31 b |
| $T_4$(180:12) | 11.23 cd | 12.33 a | 12.06 ab | 11.87 a |
| Means | 10.22 c | 11.89 a | 11.87 a | |

### 3.6 Spike Weight (g)

The spike is a crucial component of the wheat plant as it produces grains and significantly contributes to yield. Table 6 data showed that different combinations of nitrogen (N), phosphorus (P), and naphthalene acetic acid (NAA) had a significant impact on spike weight in late-sown wheat. The ANOVA table is provided in Appendix 6. The highest spike weight (3.08 g) was observed in $T_1$ (180:120 kg ha$^{-1}$ N:P), followed by $T_3$ (2.58 g). Among NAA treatments, $GR_1$ (50 ml ha$^{-1}$) recorded the highest spike weight (2.89 g), followed by $GR_3$ (2.63 g). In interaction, $T_1 \times GR_2$ showed the maximum spike weight (3.35 g). However, $T_2$ and $T_3$ exhibited no statistical difference. The lowest spike weight was recorded in the control $T_0$ (2.37 g), $GR_2$ (2.42 g), and in interaction $T_0 \times GR$ (2.13 g). Spike weight is influenced by environmental conditions, genotype, soil fertility, and sowing time. In late sowing conditions, the foliar application of NAA positively affected spike development, as reported by [8] The $T_1 \times GR_2$ treatment also produced longer spikes with more grains, contributing to heavier spikes.

**Table 6. Effect of N:P and NAA application on Spike Weight (g) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 2.13 h | 2.60 cde | 2.37 fg | 2.37 c |
| $T_2$(60:40) | 2.38 efg | 2.78 bed | 2.55 dg | 2.57 b |
| $T_3$(120:80) | 2.30 gh | 2.84 bc | 2.60 def | 2.58 b |
| $T_4$(180:120) | 2.89 b | 3.35 a | 3.01 b | 3.08 a |
| Means | 2.42 c | 2.89 a | 2.63 b | |

### 3.7 1000-Grain Weight (g)

Thousand-grain weight directly correlates with grain yield and requires careful consideration. Table 7 data indicated that NP levels and NAA doses significantly affected 1000-grain weight. The ANOVA table is provided in Appendix 7. The highest 1000-grain weight (46.95 g) was recorded in $T_1$ (180:120 kg ha$^{-1}$ N:P), followed by $T_5$ (42.09 g). Among NAA treatments, $GR_1$ (50 ml ha$^{-1}$) resulted in the maximum 1000-grain weight (43.01 g), followed by $GR_2$ (39.48 g). The highest interaction value (51.04 g) was observed in T × GR, though interaction values showed no significant differences. The lowest 1000-grain weight was recorded in the control $T_0$ (31.54 g) and $GR_1$ (36.26 g), while the lowest interaction value (29.30 g) was observed in $T_0 \times GR$. This increase in grain weight may be attributed to the exogenous application of NAA and improved NP uptake, enabling wheat to accumulate more assimilates and metabolites in grains, resulting in heavier seeds. Similar findings were confirmed by [3,10].

**Table 7. Effect of N:P and NAA application on 1000 grains weight (gm) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 29.30 | 34.58 | 30.73 | 31.54 d |
| $T_2$(60:40) | 34.20 | 41.60 | 37.48 | 37.76 c |
| $T_3$(120:80) | 38.48 | 44.81 | 42.98 | 42.09 b |
| $T_4$(180:12) | 43.08 | 51.04 | 46.73 | 46.95 a |
| Means | 36.26 c | 43.01 a | 39.48 b | |

### 3.8 Number of Grains per Spike

The number of grains per spike is a crucial yield-determining factor, directly linked to overall grain production. Table 8 data showed that combining NP fertilizers with NAA significantly influenced grains per spike in late-sown wheat. The ANOVA table is provided in Appendix 8. The highest number of grains per spike (56.67) was recorded in $T_1$ (180:120 kg ha$^{-1}$ N:P), followed by $T_3$ (53.44). Among NAA applications, $GR_2$ (50 ml ha$^{-1}$) resulted in the highest number of grains per spike (54.08), followed by $GR_3$ (51.33). In interaction, T × GR recorded the maximum value (62.00 grains per spike). The lowest values were observed in the control $T_0$ (44.11), $GR_1$ (47.58), and interaction $T_0 \times GR$ (42.33). The increase in grains per spike was due to the foliar application of 50 ml NAA ha$^{-1}$ in combination with $T_4$ (180:120 kg ha$^{-1}$ N:P), which significantly enhanced this trait. However, applying 100 ml ha$^{-1}$ NAA ($GR_1$) with $T_1$ reduced the number of grains per spike.

**Table 8. Effect of N:P and NAA application on No. of grains spike$^{-1}$ of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 42.33 h | 46.33 g | 43.67 h | 44.11 d |
| $T_2$(60:40) | 48.00 fg | 51.00 d | 50.33 de | 49.78 c |
| $T_3$(120:80) | 49.00 ef | 57.00 b | 54.33 c | 53.44 b |
| $T_4$(180:120) | 51.00 d | 62.00 a | 57.00 b | 56.67 a |
| Means | 47.58 c | 54.08 a | 51.33 b | |

### 3.9 Leaf Area Index (49 DAS)

The leaf plays a crucial role in photosynthesis, while the Leaf Area Index (LAI) represents the ratio of leaf area to ground area. Increased leaf area enhances photosynthesis, leading to greater accumulation of photosynthates, which ultimately contribute to grain weight and yield. Table 9 data indicated that NP fertilizers and NAA application significantly influenced LAI in late-sown wheat. The ANOVA table is provided in Appendix 9. The highest LAI (0.18) was recorded in $T_1$ (180:120 kg ha$^{-1}$ N:P), followed by $T_3$ (0.16). Among NAA treatments, $GR_1$ (50 ml ha$^{-1}$) resulted in the highest LAI (0.21), followed by $GR_3$ (0.14). In interaction, T × $GR_2$ exhibited the maximum LAI (0.25).

**Table 9. Effect of N:P and NAA application on Leaf Area Index (49 DAS) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 0.08 h | 0.17 cd | 0.12 fgh | 0.12 b |
| $T_2$(60:40) | 0.08 gh | 0.19 bc | 0.13 def | 0.13 b |
| $T_3$(120:80) | 0.11 fgh | 0.23 ab | 0.13 df | 0.16 ab |
| $T_4$(180:120) | 0.13 dh | 0.25 a | 0.16 cde | 0.18 a |
| Means | 0.10c | 0.21 a | 0.14 b | |

### 3.10 Leaf Area Index (98 DAS)

Photosynthesis is the process by which inorganic carbon dioxide is converted into organic compounds using light and chlorophyll. Since the leaf contains over 90% of the plant's chlorophyll, leaf area and LAI are crucial physiological traits contributing to vegetative growth and grain yield. Enhancing LAI can improve photosynthesis efficiency, thereby increasing grain yield, biological yield, and harvest index. Table 10 data revealed that NP fertilizers with NAA application had no significant effect on LAI in late-sown wheat. The ANOVA table is provided in Appendix 10. The highest LAI (2.59) was recorded in $T_1$ (180:120 kg ha$^{-1}$ N:P), while among NAA treatments, $GR_1$ (50 ml ha$^{-1}$) resulted in the maximum LAI (2.47). In interaction, T × $GR_2$ recorded the highest LAI (3.52). [3] observed similar results, stating that exogenous foliar application of NAA at varying nitrogen levels significantly improved nutrient uptake, which enhanced leaf area development and photosynthate conversion into grain yield.

**Table 10. Effect of N:P and NAA application on Leaf Area Index (98 DAS) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 0.94 f | 1.70 d | 1.25 e | 1.30 c |
| $T_2$(60:40) | 1.06 ef | 2.04 c | 1.28 e | 1.46 c |
| $T_3$(120:80) | 1.17 ef | 2.63 b | 1.96 cd | 1.92 b |
| $T_4$(180:120) | 1.82 cd | 3.52 a | 2.41 b | 2.59 a |
| Means | 1.25 c | 2.47 a | 1.73 b | |

### 3.11 Leaf Area Duration (49 DAS)

Leaf Area Duration (LAD) reflects a plant's capacity to maintain green foliage over time per unit area. [11] highlighted that dry matter accumulation depends on photosynthesis, which is largely influenced by canopy characteristics. LAD and photosynthetic efficiency significantly affect yield potential. Nitrogen availability, leaf area, and LAD influence both short-term growth and overall productivity. The ANOVA table for LAD is provided in Appendix 11. Data in Table 11 indicate that $T_4$ (180:120 kg ha$^{-1}$ N:P) exhibited the highest LAD (1.25), while in interaction, T × GR recorded a maximum LAD of 1.74. Among NAA applications, $GR_1$ (50 ml ha$^{-1}$) resulted in the highest LAD (1.46).

**Table 11. Effect of N:P and NAA application on Leaf Area Duration (49 DAS) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 0.53 g | 1.19 cd | 0.86 defg | 0.86 b |
| $T_2$(60:40) | 0.57 fg | 1.31 bc | 0.93 de | 0.93 b |
| $T_3$(120:80) | 0.72 efg | 1.62 ab | 0.90 def | 1.08 ab |
| $T_4$(180:120) | 0.88 defg | 1.74 a | 1.13 cd | 1.25 a |
| Means | 0.67 c | 1.46 a | 0.95 b | |

### 3.12 Leaf Area Duration (98 DAS)

Table 12 data indicated that LAD was not significantly affected by NP fertilizer and NAA application in late-sown wheat. The ANOVA table for LAD (98 DAS) is in Appendix 12. The highest LAD (18.10) was recorded in $T_4$ (180:120 kg $ha^{-1}$ N:P), while $GR_1$ (50 ml $ha^{-1}$) resulted in the maximum LAD (17.30). In interaction, T × $GR_2$ exhibited the highest LAD (24.68).

**Table 12. Effect of N:P and NAA application on Leaf Area Duration (49 DAS) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 6.59 f | 11.87 d | 8.77 e | 9.08 c |
| $T_2$(60:40) | 7.39 ef | 14.27 c | 8.99 e | 10.21 c |
| $T_3$(120:80) | 8.16 ef | 18.38 b | 13.68 cd | 13.41 b |
| $T_4$(180:120) | 12.73 cd | 24.68 a | 16.90 b | 18.10 a |
| Means | 8.72 c | 17.30 a | 12.08 b | |

### 3.13 Crop Growth Rate (g $m^{-2}$ $day^{-1}$)

Crop Growth Rate (CGR) is a fundamental indicator of plant development. While plants naturally synthesize growth regulators, exogenous application enhances growth. NP fertilizers also contribute to increased growth rates. Table 13 data revealed significant differences among fertilizer levels, foliar-applied NAA, and their interactions. The ANOVA table for CGR is in Appendix 13. The highest CGR (1.29 g $m^{-2}$ $day^{-1}$) was recorded in $T_4$ (180:120 kg $ha^{-1}$ N:P), while $GR_1$ (50 ml $ha^{-1}$) produced a maximum CGR of 1.15 g $m^{-2}$ $day^{-1}$. In interaction, $T_4$ × $GR_2$ exhibited the highest CGR (1.40 g $m^{-2}$ $day^{-1}$). [10] reported that NAA plays a key role in plant growth, regulating tiller count, spike development, grain weight, and overall yield.

**Table 13. Effect of N:P and NAA application on CGR (g $m^{-2}$ $day^{-1}$) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 0.66 e | 0.91 d | 0.73 e | 0.76 d |
| $T_2$(60:40) | 0.87 d | 1.12 c | 0.92 d | 0.97 c |
| $T_3$(120:80) | 0.96 d | 1.17 bc | 1.11 c | 1.08 b |
| $T_4$(180:120) | 1.21 bc | 1.40 a | 1.27 b | 1.29 a |
| Means | 0.93 c | 1.15 a | 1.01 b | |

### 3.14 Net Assimilation Rate (mg $m^{-2}$ $day^{-1}$)

Net Assimilation Rate (NAR) measures dry matter accumulation per unit leaf area over time. Higher NAR during the reproductive phase may result from increased photosynthetic efficiency to meet grain demand. Table 14 data showed no significant differences among treatments. The ANOVA table for NAR is in Appendix 14. The highest NAR (0.19 mg $m^{-2}$ $day^{-1}$) was observed in $T_2$ (60:40 kg $ha^{-1}$ N:P), while $GR_1$ (50 ml $ha^{-1}$) recorded the maximum NAR (0.21 mg $m^{-2}$ $day^{-1}$). In interaction, $T_2$ × $GR_1$ exhibited the highest NAR (0.23 mg $m^{-2}$ $day^{-1}$).

**Table 14. Effect of N:P and NAA application on Net Assimilation Rate (mg $m^{-2}$ $day^{-1}$) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 0.14 efg | 0.19 bc | 0.15 ef | 0.16 b |
| $T_2$(60:40) | 0.15 ef | 0.23 a | 0.18 cd | 0.19 a |
| $T_3$(120:80) | 0.12 fg | 0.22 ab | 0.17 cde | 0.17 ab |
| $T_4$(180:120) | 0.11 g | 0.19 bc | 0.15 de | 0.15 b |
| Means | 0.13 c | 0.21 a | 0.16 b | |

### 3.15 Grain Yield (kg $ha^{-1}$)

Grain yield depends on multiple factors, including tiller count, grains per spike, and thousand-grain weight. Table 15 data showed the impact of NP fertilizer and NAA on wheat yield. The ANOVA table is in Appendix 15. The highest grain yield (4381.37 kg $ha^{-1}$) was achieved in $T_4$ (180:120 kg $ha^{-1}$ N:P), followed by $T_3$ (3800.03 kg $ha^{-1}$). Among NAA treatments, $GR_1$ (50 ml $ha^{-1}$) recorded the highest yield (4102.70 kg $ha^{-1}$), followed by $GR_3$ (3693.17 kg $ha^{-1}$). While interactions were statistically non-significant, visual differences were noted. The lowest yield was observed in the control. NAA application improved fertilizer efficiency by enhancing photosynthate conversion into grain yield. The 50 ml $ha^{-1}$ NAA treatment produced the best results. [10,3] reported similar findings.

**Table 15. Effect of N:P and NAA application on Grain Yield (kg ha⁻¹) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 2168.38 | 3625.54 | 3234.01 | 3009.31 d |
| $T_2$(60:40) | 3227.00 | 3859.84 | 3514.62 | 3533.82 c |
| $T_3$(120:80) | 3525.13 | 4166.53 | 3708.44 | 3800.03 b |
| $T_4$(180:120) | 4069.62 | 4758.89 | 4315.59 | 4381.37 a |
| Means | 3247.53 c | 4102.70 a | 3693.17 b | |

### 3.16 Biological Yield (kg $ha^{-1}$)

Biological yield is influenced by plant height and tiller count. Table 16 data indicated the effects of NP and NAA on biological yield in late-sown wheat. The ANOVA table is in Appendix 16. The highest biological yield (9826.82 kg $ha^{-1}$) was observed in $T_4$, followed by $T_3$ (8314.86 kg $ha^{-1}$). Among NAA applications, $GR_1$ (50 ml $ha^{-1}$) resulted in the maximum biological yield (8845.72 kg $ha^{-1}$), followed by $GR_3$ (8316.03 kg $ha^{-1}$). Interaction $T_4 \times GR_2$ produced the highest yield (10486.19 kg $ha^{-1}$). The lowest yield was in the control ($T_0$: 6261.19 kg $ha^{-1}$, $GR_2$: 6860.27 kg $ha^{-1}$).

**Table 16. Effect of N:P and NAA application on Biological Yield (kg ha⁻¹) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 4054.46 h | 7652.82 e | 7076.30 fg | 6261.19 d |
| $T_2$(60:40) | 6806.88 g | 8238.56 d | 7833.95 de | 7626.47 c |
| $T_3$(120:80) | 7582.02 ef | 9005.28 c | 8357.27 d | 8314.86 b |
| $T_4$(180:120) | 8997.69 c | 10486.19 a | 9996.58 b | 9826.82 a |
| Means | 6860.27 | 8845.72 a | 8316.03 | |

### 3.17 Straw Yield (kg $ha^{-1}$)

Table 17 data indicated significant effects of NP and NAA application on straw yield in late-sown wheat. The ANOVA table is in Appendix 17. The highest straw yield (5445.45 kg $ha^{-1}$) was recorded in $T_4$ (180:120 kg $ha^{-1}$ N:P), followed by $T_3$ (4514.83 kg $ha^{-1}$). Among NAA treatments, $GR_1$ (50 ml $ha^{-1}$) recorded the highest straw yield (4743.01 kg $ha^{-1}$), followed by $GR_3$ (4622.86 kg $ha^{-1}$). In interaction, $T_4 \times GR_2$ resulted in the highest straw yield (5727.30 kg $ha^{-1}$). The lowest values were recorded in the control ($T_0$: 3251.88 kg $ha^{-1}$, $GR_1$: 3612.73 kg $ha^{-1}$, $T_0 \times$ GR: 1886.09 kg $ha^{-1}$).

**Table 17. Effect of N:P and NAA application on Straw Yield (kg ha⁻¹) of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 1886.09 h | 4027.27 | 3842.29 fg | 3251.88 d |
| $T_2$(60:40) | 3579.88 g | 4378.72 | 4319.34 de | 4092.65 c |
| $T_3$(120:80) | 40.56.89 def | 4838.76 b | 4648.83 bc | 4514.83 b |
| $T_4$(180:120) | 4928.07 b | 5727.30 a | 5680.99 a | 5445.45 a |
| Means | 3612.73 | 4743.01 a | 4622.86 b | |

Mean values of different letter in respective groups are significant at ($p<0.05$)

### 3.18 Productivity Score

Productivity score measures economic yield per unit area, incorporating grain and biological yield. Table 18 data indicated significant differences due to NP and NAA application. The ANOVA table is in Appendix 18. The highest productivity score (14252.79) was recorded in $T_4$ (180:120 kg $ha^{-1}$ N:P), followed by $T_3$ (12160.61). Among NAA treatments, $GR_1$ (50 ml $ha^{-1}$) recorded the highest score (12994.90). In interaction, $T_4 \times GR_2$ produced the highest score (15290.47), while the lowest was observed in the control.

**Table 18. Effect of N:P and NAA application on Productivity Score of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 6276.35 h | 11325.78 f | 10356.05 g | 9319.39 |
| $T_2$(60:40) | 10081.31 g | 12145.26 d | 11393.45 ef | 11206.67 c |
| $T_3$(120:80) | 11153.64 f | 13218.09 c | 12110.10 de | 12160.61 |
| $T_4$(180:120) | 13112.54 c | 15290.47 a | 14355.35 b | 14252.79 a |
| Means | 10155.96 c | 12994.90 a | 12053.74 b | |

### 3.19 Harvest Index

Harvest index represents the proportion of dry matter converted into grain yield. Table 19 data showed significant effects of NP and NAA on harvest index. The ANOVA table is in Appendix 19. The highest harvest index (48.89%) was observed in $T_0$, followed by $T_2$ (46.38%). Among NAA applications, $GR_1$ recorded the highest index (48.16%). In interaction, $T_0 \times GR_1$ had the highest value (53.51%), while the lowest was recorded in $T_4 \times GR_2$ (43.17%). [12] reported similar findings.

**Table 19. Effect of N:P and NAA application on Harvest Index of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 53.52 a | 48.41 bc | 45.75 ef | 48.89 a |
| $T_2$(60:40) | 47.52 b | 47.85 cd | 44.86 gh | 46.38 b |
| $T_3$(120:80) | 46.60 d | 46.27 de | 44.38 h | 45.71 c |
| $T_4$(180:120) | 46.23 fg | 45.38 fg | 43.27 i | 44.60 d |
| Means | 449.16 a | 46.48 b | 44.64 c | |

### 3.20 Nitrogen Use Efficiency

Nitrogen is a vital element for plant growth. Table 20 data showed that exogenous NAA application improved nitrogen use efficiency. The highest efficiency (19.74) was recorded with 50 ml $ha^{-1}$ NAA. Among NP levels, $T_2$ (60:40 kg $ha^{-1}$ N:P) showed the highest efficiency (22.76). In interaction, $T_2 \times GR_1$ exhibited the highest efficiency (28.19). [13] found similar results.

**Table 20. Effect of N:P and NAA application on Nitrogen Use Efficiency of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 0 | 0 | 0 | 0 |
| $T_2$(60:40) | 18.64 | 28.18 | 23.44 | 23.76 |
| $T_3$(120:80) | 12.31 | 16.85 | 13.38 | 14.60 |
| $T_4$(180:120) | 10.55 | 14.39 | 11.93 | 12.29 |
| Means | 13.27 | 20.74 | 15.83 | |

### 3.21 Phosphorus Use Efficiency

Phosphorus use efficiency measures economic output per unit of phosphorus applied. Table 21 data showed that exogenous NAA application improved phosphorus efficiency. The highest efficiency (29.26) was observed with 50 ml $ha^{-1}$ NAA, while among NP levels, $T_2$ (60:40 kg $ha^{-1}$) recorded the highest efficiency (34.14). In interaction, $T_2 \times GR_1$ had the highest efficiency (42.29). Similar findings were reported by [13].

**Table 21. Effect of N:P and NAA application on Phosphorus Use Efficiency of wheat**

| NP levels (kg/ha) | NAA levels (ml/ha) | | | Means |
|---|---|---|---|---|
| | $GR_1$ (Control) | $GR_2$ (50) | $GR_3$ (100) | |
| $T_1$(control) | 0.00 | 0.00 | 0.00 | 0.00 |
| $T_2$(60:40) | 26.27 | 42.27 | 33.56 | 34.13 |
| $T_3$(120:80) | 15.96 | 24.97 | 19.35 | 20.41 |
| $T_4$(180:120) | 14.84 | 21.69 | 18.89 | 18.54 |
| Means | 18.76 | 29.72 | 23.60 | |

## 4. Conclusion

This study demonstrates that the application of fertilizers and plant growth regulators (PGRs) significantly influences wheat yield and its components. The incorporation of naphthalene acetic acid (NAA) at a rate of 50 ml $ha^{-1}$, combined with 180 kg N and 120 kg $P_2O_5$ $ha^{-1}$, proved to be the most effective treatment for enhancing grain production in late-sown wheat. The findings highlight the potential of PGRs in optimizing crop performance under specific agro-climatic conditions. Based on this one-year study, it is recommended to apply 180 kg N and 120 kg $P_2O_5$ $ha^{-1}$ along with an exogenous foliar application of 50 ml NAA $ha^{-1}$ for achieving maximum grain yield and improving yield-related traits. Further research is needed to explore the long-term effects of this treatment under varying environmental conditions, particularly in the agro-climatic region of D.I. Khan, Khyber Pakhtunkhwa, Pakistan.

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