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Interactive effect of Gibberellic Acid and Nitrogen Sources on Quality and Yield of Wheat under Different Tillage Systems

Farad Farad[1], Abdul Basir[1], Fazli Wahid[1], Muhammad Adnan[1], Mushtaq Ahmad Khan [1], Farahat S. Moghanm[2] and **Adel M. Ghoneim[3]**

[1]Department of Agriculture, University of Swabi, Anbar-23561, Swabi Khyber Pakhtunkhwa, Pakistan
[2] Soil and Water Department, Faculty of Agriculture, Kafr Elsheikh University, Kafr El-Sheikh 33516, Egypt.
[3] Agricultural Research Center, Field Crops Research Institute, Giza 12112, Egypt

THE INJUDICIOUS application of synthetic nitrogen (N) fertilizer has adversely affected soil quality and the overall ecosystem. In this scenario, a two year field experiments was carried out at the Agriculture Research Station (ARS) Swabi to evaluate the role of various sources of nitrogen (120 kg N ha^{-1}) together with gibberellic acid (GA applied at the rate of100 mg L^{-1} as foliar spray) for achieving quality wheat production under different tillage systems (conventional and deep tillage system).The maximum thousand-grain weight (53.2 g), grain yield (3915 kg ha^{-1}), biological yield (11668 kg ha^{-1}), and harvest index (32.3%), were observed in plots where N was applied 50% each as farmyard and poultry manure along with gibberellic acid (FYM+PM+GR). Similarly, plots treated with FYM+PM+GR resulted highest grain and straw N content, and grain protein which were 61.1, 51.9 and 39.8% higher than control, respectively. Deep tillage system was found better than conventional tillage with respect to all tested traits. The integrated application of organic manures along with gibberellic acid improved wheat yield and quality under deep tillage system (once in five years) and should be adopted by farmers for obtaining quality yield of wheat.

Keywords: Chemical fertilizers, Grain yield, Gibberellic acid, Poultry manure, Tillage system.

1. Introduction

Wheat (*Triticum aestivum*L.) is a member of the Poaceae family and is widely consumed in Pakistan and worldwide. Wheat is an important cereal crop in terms of protein sources. Its straw is mostly used as premium animal feed and, to some extent, as a raw material for the paper industry (Chondie, 2015; Khan et al., 2022a). In Pakistan, the wheat crop is grown on approximately 9039 thousand hectares, with a total production of 26.8 million tonnes (MNFSR, 2021-22). Compared to other developed nations, Pakistan's wheat yield is still quite low (Kalhoro et al., 2016; Leghari et al., 2016). One of the major factors contributing to low wheat productivity in Pakistan is the poor fertility status of our soils (Zahoor et al., 2016; Bhanger et al., 2021). Furthermore, poor nutrient and fertilizer management is the greatest obstacle to wheat production and has caused a dramatic decline in wheat output (Wahid et al., 2019; Amanullah et al., 2021). The consistent and injudicious application has caused the organic matter depletion Pakistani soil, consequently the soil has the organic matter content of less that 1% (Akhtar et al., 2019). The integrated management of nutrients from both organic and inorganic sources is currently the focus of improving soil health and crop production (Ibrahim et al., 2020; Khan et al., 2022b).

Nitrogen is an essential nutrient and plays a vital role in plants healthy growth and productivty. It is a fundamental component of proteins that accelerates the production of carbohydrates as a result of an increase in leaf area. Nitrogen utilization efficiency is crucial for receiving its full benefits (Singh et al., 2018). Good crop yields with significant and profitable outcomes can be achieved by applying a sufficient quantity of N at an

*Corresponding author e-mail: adelrrtc.ghoneim@gmail.com
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appropriate growth stage (Chondie, 2015; Rekaby et al., 2024). The application of nitrogen at an optimum rate accelerates the internal processes inside the plant, resulting in more protoplasm formation owing to the conversion n of sugar into protein (Zhang et al., 2021). However, the continued and overuse of chemical fertilizers degrades soil conditions, which lowers crop yields (Shambhavi et al., 2017; Alam et al., 2022; Elsaied et al., 2024). The use of organic manure or some organic wastes alone is thought to be beneficial, but the combined use of inorganic and organic wastes has demonstrated excellent efficiency (Roba et al., 2018 and Wahid et al., 2020).

Plant growth regulators (PGRs) are critical tools in enhancing wheat yield and quality by modulating various physiological processes such as germination, root development, photosynthesis, and grain filling (Espindula et al., 2009; Rekaby et al., 2023). PGRs like gibberellins (GAs), cytokinins, auxins, and abscisic acid (ABA) can influence wheat growth patterns, improve stress tolerance, and increase yield potential (Koprna et al., 2016; Elsherpiny et al., 2023). Gibberellic acid (GA) is a plant growth regulator which plays a significant role in improving wheat quality and yield by enhancing key physiological processes such as germination, seedling growth, and tillering. It promotes cell elongation, stimulates shoot development, and accelerates flowering, which in turn can lead to earlier and more uniform maturity. In wheat, GA application has been found to increase plant height, spike length, and number of grains per spike, thus improving overall yield potential (Hussain et al., 2019; Mian et al., 2019). Furthermore, GA can enhance photosynthetic efficiency, increase biomass production, and improve grain filling, which contributes to better grain quality, including higher protein content and larger grain size (Zhao et al., 2020; Awwad et al., 2022). However, the effectiveness of GA depends on factors such as the timing and dosage of application, environmental conditions, and wheat variety. Limited research information has been documented on the use of only organic and inorganic fertilizers in wheat crop improvement, but their application along with growth regulators under different tillage systems has never been documented. We hypothesized that, the proper use of GA along with N application through the integration of organic and mineral fertilizers can therefore lead to significant agronomic benefits, improving both the quantity and quality of wheat production. Thus, the current study aimed to evaluate the role of various sources of nitrogen (organic and inorganic), together with a growth regulator (gibberellic acid), to enhance wheat productivity and improve soil health under different tillage systems.

1. Materials and Methods

2.1.Experimental material

The Wheat (*Triticumaestivum* L.) variety Swabi-1 was obtained from the Agriculture Research Station (ARS) Swabi, Khyber Pakhtunkhwa Pakistan. The analytical grade gibbrilc acid (GA) was obtained from the soil sciences Lab, University of Swabi. The Farmyard and poultry manures were obtained from the local dairy and poultry farm respectively. The N, P, and K contents were 0.91, 0.29, and 0.54% in FYM and 1.42, 0.83, and 0.77 % in PM, respectively.

2.2.Experimental site description

The field experiments were conducted during the rabi season in year 2021-22 and 2022-2023 at the Agriculture Research Station Swabi. The experimental site is situated 331 m above sea level at latitude 34.0130 North and longitude 72.39270 East. The location has a mean annual rainfall of 639 mm and a moderate to hot, semi-arid, subtropical, continental climate. Rainfall throughout the winter months is often higher than that during the summer as shown in Fig.1. The soil of the experimental site was non-saline, alkaline and silty clay loam in texture and deficient in NPK and organic matter as shown in Table 1.

Table 1. Physico-chemical properties of the experimental soil.

Properties	Values
pH	8.10
Electrical conductivity (dS m^{-1})	0.88
Bulk density (g^{-1} cm^3)	1.59
Sand (%)	7.49
Silt (%)	61.7
Clay (%)	37.5
Textural class	Silty clay loam
Nitrogen (%)	0.002
Phosphorus (mg kg^{-1})	4.60
Potassium (mg kg^{-1})	66.0
Organic matter (%)	0.53

2.3 Experimental Procedure

A two-year field experiment was conducted during the rabi season in year 2021-2022 and 2022-2023 at the Agriculture Research Station Swabi to investigate the effect of various sources of nitrogen sources (organic and inorganic) with gibberellic acid (GA) and their combinations to enhance wheat quality and productivity under different tillage systems. The experiment was laid out in factorial randomize complete block design with split plot arrangement with three (3) replications. The two different tillage system Conventional tillage (Cultivator + Rotavator), and Deep tillage (Chisel Plow +Cultivator + Rotavator) were assigned to main plot while fourteen (14) Sources and GA combinations includingT1: Control, T2: Nitrogen, T3: Farmyard manure (FYM), T4: Poultry manure (PM), T5: N + FYM, T6: N + PM, T7: FYM + PM, T8: gibberellic acid (GA), T9: N+ GA, T10: FYM+ GA, T11: PM+ GA, T12: N+ FYM+ GA, T13: N+ PM +GA and T14: FYM+PM+GA, were assigned to sub plot The Wheat variety Swabi-1 was grown at the seed rate of 100 kg ha^{-1} with a row to row distance of 30 cm in subplot (4 x 4.5 m^{-2}). Farm yard manure (FYM) and poultry manure (PM) were used as organic sources while urea fertilizer as an inorganic source of nitrogen for supplementing 120 kg N ha^{-1} as 100% recommended dose. The organic sources of nitrogen were applied during soil preparation after the layout of sub plots while the inorganic nitrogen was applied in three split applications: first 20 days after sowing (DAS), Second 40 DAS and third 60 DAS. Gibberellic acid was applied as a foliar spray with the concentration of 200 mg L^{-1} at early tillering stage. As base dose, Single super phosphate (SSP, 18%P), at a rate of 60 kg ha^1 was used to apply phosphorus to the field. All agronomic and cultural procedures, including irrigation, weeding, and hoeing, should be performed consistently for each replication treatment. The following year, the same experiment was repeated using the same procedure and methodology. The wheat crop was harvested with a sickle when the spikes turned a golden-brown color. The crop was cut after three days of sun drying in the field so that further data could be collected.

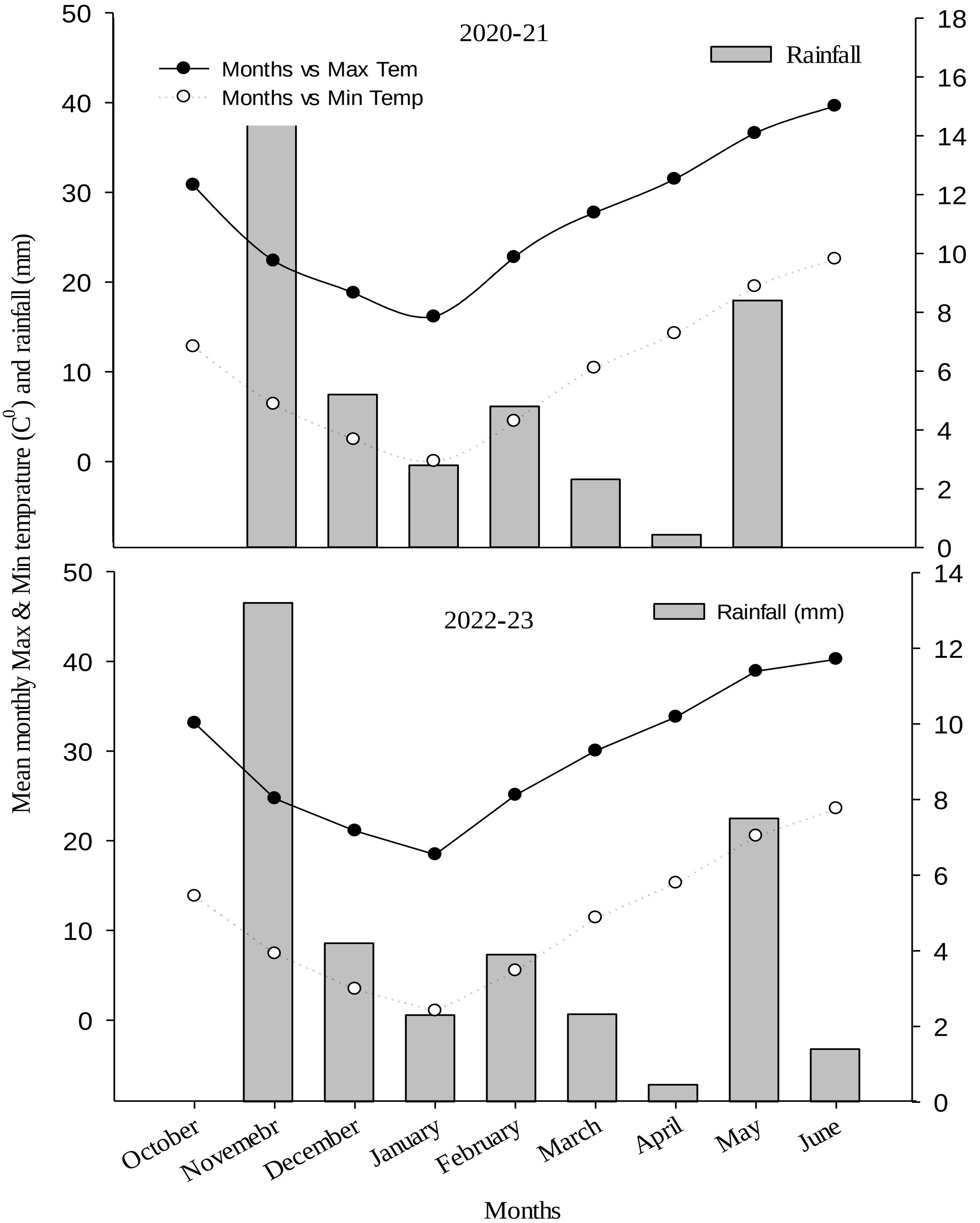

Fig. 1. Rainfall and temperature of the study area.

2.4. Protocol for recorded parameters

Plants were harvested from central two rows of each subplot at maturity stage. Five representative plants chosen at random and the height of each plant was measured using a tape meter from the ground to the spike's peak, and the average was then calculated. Five randomly chosen plant spikes from each plot were gathered and threshed. After that, the grains were tallied and averaged. For the data concerning grain and biological yield, the four central rows of each experimental subplot were harvested, air-dried, and weighed to determine biological yield and grain yield by the formulas of Khan et al. (2022) as follow:

$$\text{BY (kg ha}^{-1}\text{)} = \frac{\text{(straw + grain) weight of central 4 rows of each subplot}}{\text{Row to row distance} \times \text{row length} \times \text{No of rows harvested}} \times 10000\ \text{m}^2$$

$$\text{GY (kg ha}^{-1}\text{)} = \frac{\text{wt of grains of central 4 rows in each plot}}{\text{Row to row distance} \times \text{row length} \times \text{No of rows harvested}} \times 10000\ \text{m}^2$$

Grain and straw nitrogen content of wheat were calculated during both consecutive seasons by the Kjeldhal method (Westerman, 1990) by using the following formula:

$$\text{N \%} = \frac{\{\text{(Nitrogen blank) x (Normality of acids x Volume made x N mol. weight)}\}}{\text{Weight of dry sample}} \times 100$$

The grain protein content was quantified by adopting the formula used by Khan et al. (2022) as mentioned below:

$$\text{GP content (\%)} = \text{Grain N (\%)} \times 6.25$$

2.5. Statistical analyses

The collected replicated data was processed for analysis of variance (ANOVA) according to split-plot arrangement based on the randomized completer block design using statistical package Statistix 8.1. The data were further processed for least significant different (LSD) test to assess mean differences at P≤0.05, adhering to the protocol of Steel et al. (1997).

3. Results

3.1. Plant height

Integrated N management from organic and inorganic sources with gibrellic acid and various tillage systems significantly affected plant height (Table 2). Significantly taller plants (99.7 cm) were produced by conventional tillage (Cultivator + Rotavator), whereas shorter plants (94.6 cm) were produced by deep tillage (chisel plow + cultivator + rotavator). In the case of different N management, maximum plant height (105.2 cm) was obtained by application of FYM+PM+GA (farmyard manure, poultry manure, and gibrellic acid) which was statistically at par to FYM+PM+GA (nitrogen + poultry manure+ gibrellic acid) (101.6 cm). Dwarf-statured plants (88.7 cm) were obtained under control plots. Average mean data for years showed significant differences in plant height, the plant height observed in 2nd year (104.5 cm) was significantly higher than 1st year (95.6 cm).

3.2. Thousand grains weight

The two-year mean data demonstrated that tillage techniques, together with integrated nitrogen management from organic and inorganic sources, including gibbrellic acid, had a considerable impact on thousand-grain weight of wheat (Table 2). Among the different nitrogen fertilizer treatments, heavier grains (53.2 g) were obtained using farmyard manure, poultry manure, and gibbrellic acid (FYM + PM + GA), which was statistically similar to those obtained under nitrogen, poultry manure, and gibbrelic acid (Nitrogen + PM + GA). The control plots, which received no fertilizer treatment, had the minimum grain weight (37.9 g). Regarding different tillage practices, heavier grains (46.6 g) were obtained by deep tillage (chiesel plow + Cultivator+Rotavator), whereas the lowest thousand-grain weight (44.5 g) was recorded by conventional tillage (cultivator rotavator). Significantly heavier grains were obtained during the 2nd year (48.6 g) when compared to 1st year (2021-22).

3.3. Biological yield

The analysis of the variance (ANOVA) revealed that the integrated management of nitrogen from organic and inorganic sources, together with gibbrellic acid and varying tillage techniques, had a substantial impact on the biological yield of wheat crops as shown in Table 2.

Nitrogen application from organic sources considerably influences the biological yield of wheat crops. Plots treated with farmyard manure, poultry manure, and gibbrellic acid (FYM+PM+GR) produced the highest biological yield (11668 kg ha^{-1}), followed by application of nitrogen, poultry manure, and gibbrellic acid (N + FYM + GA) with a yield of 11058 kg ha^{-1}. The control plots, which received no fertilizer treatment, had the lowest biological yield (7840 kg ha-1). Various tillage practices considerably increased the wheat's biological yield. Deep tillage (chisel plow +Cultivator + Rotavator) produced the significantly higher biomass (10392 kg ha-1) compared to conventional tillage (8966 kg ha^{-1}). The biomass (9761 kg ha^{-1}) observed in 2nd year was significantly higher than 1st year.

3.4. Grain yield

The results indicated that the grain yield of wheat crops was also significantly influenced by integrated nitrogen management and the different tillage practices are shown in Table 2. Tillage practices considerably increased the wheat grain yield. During the 2nd year (2022-23) of treatments application significantly higher grain yield (3128 kg ha^{-1}) was observed in comparison with 1st year (2021-22) with a yield of 3018 kg ha^{-1}. A higher grain yield (3316 kg ha^{-1}) was achieved by using deep tillage practices (Chisel Plow +Cultivator + Rotavator), whereas a lowest grain yield (2830 kg ha^{-1}) was observed by conventional tillage practices (Cultivator + Rotavator). Nitrogen application from organic and organic sources noticeably influenced the grain yield of wheat crops. Plots treated with farmyard manure, poultry manure and gibbrellic acid (FYM+PM+GA) produced higher grain yield (3915 kg ha^{-1}) which followed by application of nitrogen, poultry manure and gibbrellic acid (N + FYM + GA) with yield of 3806 kg ha^{-1}while the lowest grain yield (2417 kg ha^{-1}) was observed under control.

3.5. Harvest index

The mean data in the table show that the harvest index of wheat was considerably influenced by integrated N management from organic and inorganic sources with gibbrelllic acid, and tillage practices are shown in Table 2. Tillage practices considerably influence the harvest indices of wheat crops. The maximum harvest index (32.3%) was recorded for deep tillage (chisel plow +Cultivator + Rotavator) compared to conventional tillage (cultivator + rotavator) (31.4%). Among the different fertilizer treatments, plots treated with nitrogen, farmyard manure, and gibbrellic acid (N+FYM+GA) produced a considerably higher harvest index (37.8%), followed by treatment with nitrogen + farmyard manure + gibbrellic acid (33.2% harvest index). The lowest harvest index (27.3%) was observed in plots where only poultry manure was applied. When averaged across the years, the harvest index was higher during 1st year (32.3%) compared to 2nd year.

Table 2. Plant height (cm), thousand grains weight eight (g), biological yield (kg ha^{-1}), grain yield (kg ha^{-1}) and harvest index of wheat crop as influenced by integrated nitrogen management under different tillage system.

Nitrogen Sources	Plant height	Thousand grains weight	Biological yield	Grain yield	Harvest index
Control	88.7 f	37.9 e	7840 d	2417 f	31.4 bcd
Nitrogen (N)	91.2 ef	43.2 d	7913 d	2449 f	31.3 bcd
Farmyard manure (FYM)	92.1 def	45.0 cd	7983 d	2528 ef	30.9 cde
Poultry manure (PM)	93.8 cde	45.6 cd	9378 c	2534 ef	27.3 e
N + FYM	94.6 cde	46.2 cd	9684 c	2830 de	29.3 de
N + PM	95.4 cd	46.3 cd	9339 c	2930 cd	32.5 bcd
FYM + PM	95.6 c	46.3 cd	9849 c	3104 bcd	31.6 bcd
Gibberellic acid (GA)	99.7 b	45.8 cd	9704 c	3137 bc	32.8 bcd
N+ GA	100.3 b	46.6 d	9808 c	3184 bc	34.9 ab
FYM+ GA	100.7 b	47.1 bcd	9952 c	3232 bc	32.3 bcd
PM+ GA	100.9 b	48.3 bc	10587 b	3277 b	31.0 b-e
N+FYM+ GA	101.0 a	48 bc	10741 b	3682 ab	37.8 a
N+ PM +GA	101.6 a	51.3 ab	11058 a	3806 a	31.0 b-e
FYM+PM+GA	105.2 a	53.2 a	11668 a	3915 a	33.6 bc
Tillage Practices					
Conventional tillage	99.7a	44.5 a	8966b	2830b	31.4b
Deep tillage	94.6b	46.6 b	10392a	3316a	32.3a
Years					
2021-2022	95.6b	44.5 b	9597b	3018b	31.7b
2022-2023	104.5a	48.6 a	9761a	3128a	32.3a
LSD (0.05)					
LSD for N sources	2.37	32.92	617.6	138.06	4.08
LSD for Tillage practices	3.35	12.41	409.9	305.8	1.57
LSD for Years	3.43	14.32	398.4	304.2	1.87

Mean with different lower-case alphabets in each column are significantly different at $\alpha = 0.05$. Conventional tillage (Cultivator +Rotavator) and Deep tillage (chisel plow + cultivator+ rotavator).

3.6. Nitrogen content in grains.

Data revealed that the integrated nitrogen management from organic and inorganic sources with gibbrellic acid and tillage practices had significant impact the grain nitrogen content (Table 3).

The year as a source of variance was also found to be significant. Significantly higher nitrogen content in grains (0.24%) was observed in 2nd year in comparison with 1st year (0.19%). Similarly, significantly higher nitrogen content in grains (0.25) was obtained under deep tillage (Chisel Plow +Cultivator + Rotavator), compared to

conventional tillage (0.18%) (Cultivator + Rotavator). Plots treated with farmyard manure, poultry manure, and gibbrellic acid (FYM+PM+GA) produced higher nitrogen content in grains (0.29%), followed by the application of nitrogen, poultry manure, and gibbrellic acid (N + FYM + GA) with nitrogen content in grains of wheat 0.27%, which, statistically, was comparable to one another. In the control plots, where no fertilizer was administered, the lowest nitrogen level (0.18) was found in the grains.

3.7. Nitrogen content in straw

The amount of nitrogen in straw was significantly impacted by different tillage practices and integrated N management as appears in Table 3. It was also shown that years were a substantial source of fluctuation for the content of nitrogen in straw. Nitrogen application from organic sources noticeably influenced the nitrogen content in the straw of wheat crops. Plots treated with farmyard manure, poultry manure, and gibbrellic acid (FYM+PM+GA) produced higher nitrogen content in straw (1.61%), which was statistically at par to 1.63% N observed under nitrogen, poultry manure, and gibbrellic acid (N + FYM + GA), The lowest straw nitrogen content (1.06%) was recorded under control plots that received no fertilizer treatment. Tillage practices considerably increased the nitrogen content in the straw of wheat. Higher nitrogen content in grains (1.54%) was observed by deep tillage (Chisel Plow +Cultivator + Rotavator), whereas the lower nitrogen content in wheat straw (1.52%) was obtained by conventional tillage (Cultivator + Rotavator). The straw N content was higher in 2nd year (1.82%) was signifcantly higher than 1st year (1.24%).

3.8. Grains protein content

Data concerning the grain protein content of wheat crops influenced by integrated nitrogen management and tillage practices are shown in Table 3. The two-year mean showed that the combination of gibbrellic acid, tillage techniques, and integrated nitrogen management from organic and inorganic sources had a considerable impact on grain protein content (%). The maximum grain protein content (13.2%) was recorded under deep tillage (Chisel Plow +Cultivator + Rotavator), while the minimum grain protein content (11.8%) was obtained by conventional tillage (Cultivator + Rotavator). Plots treated with farmyard manure, poultry manure, and gibbrellic acid (FYM+PM+GA) produced the highest grain protein content (14.3%), that was at par to nitrogen, poultry manure, and gibbrellic acid (N + FYM + GA) and N+PM+ GA. The control plots, which received no fertilizer treatment, had the lowest grain protein level (10.3%). The protein content in grains (12.9%) was higher in 2nd year compared to 1st year (11.8%).

Table 3. Nitrogen content in grains, and straw and grains protein content of wheat as influenced by integrated nitrogen management under different tillage system.

Nitrogen Sources	**N (%) in grains**	**N (%) in straw**	**Grains protein (%)**
Control	0.18f	1.06c	10.3e
Nitrogen (N)	0.18e	1.39b	10.6e
Farmyard manure (FYM)	0.18e	1.42b	11.7d
Poultry manure (PM)	0.19e	1.57a	11.8d
N + FYM	0.19ef	1.57 bc	11.9de
N + PM	0.20e	1.58 bc	11.9cde
FYM + PM	0.20e	1.59b	11.9d
Gibberellic acid (GA)	0.21cde	1.59b	12.9 bc
N+ GA	0.21cd	1.60 bc	13.0 bc
FYM+ GA	0.22cde	1.61a	13.1c
PM+ GA	0.23 bcd	1.61ab	13.5ab
N+FYM+ GA	0.25 bc	1.60c	14.3ab
N+ PM +GA	0.27ab	1.63a	14.3a
FYM+PM+GA	0.29a	1.61a	14.4a
Tillage Practices			
Conventional tillage	0.18b	1.54	11.8b
Deep tillage	0.25a	1.52	13.2a
Years			
2021-2022	0.19b	1.24b	12.2a
2022-2023	0.24a	1.82a	12.9b
LSD (0.05)			
LSD for N sources	0.043	0.12	0.42
LSD for Tillage practices	0.027	0.12	0.81
LSD for Years	0.54	0.21	0.79

Mean with different lower-case alphabets in each column are significantly different at $\alpha = 0.05$. Conventional tillage (Cultivator + Rotavator) and Deep tillage (chisel plow + cultivator + rotavator).

4. Discussion

We observed that plant height, thousand grain weight, grain and biological yield, grain and straw N content and grain protein content of wheat were significantly improved by using gibberellic acid and nitrogen sources, where the performance of FYM+PM+GA (farmyard manure, poultry manure, and gibrellic acid) and N+PM+GA (Nitrogen, poultry manure, and gibrellic acid) were the best compared to the rest of treatment combinations. This could be because poultry manure contains high quantities of plant nutrients, and farmyard manure improves soil physical and chemical status and enhances nitrogen uptake. Similar outcomes were mentioned by Mussarat et al. (2021) and Khan et al. (2020), who observed that the biological yield of crops was enhanced by the application of organic manures like FYM and poultry manure. Our findings are consistent with Khan et al.'s (2022), who pointed out that nitrogen from organic sources, such as poultry manure, in combination with chemical nitrogen increased the yield and quality of wheat. The addition of inorganic fertilizer and mineralization organic manure did not expose the plant to nutrient stress, resulting in increased biological yield (Wahid et al., 2016; Ibrar et al., 2022). This could possibly be due to the positive impact of organic manures on soil physical health like porosity, aeration, water and nutrient holding capacity and microbial activity as reported by Basir et al. (2019). Furthermore, the high cost and limited efficiency of mineral nitrogen fertilizers have led farmers to increasingly adopt organic farming practices. Research has shown that a combination of organic and inorganic nitrogen sources can positively impact crop yield (Yang et al., 2007). Several studies have demonstrated that the integrated use of both organic and inorganic fertilizers enhances crop growth, increases yields, and improves soil fertility compared to the sole use of either chemical fertilizers or organic matter (Khan et al., 2008). Wahid et al. (2021) also noted that nitrogen incorporation from organic and inorganic sources increased grain yield. Similarly, the harvest index was enhanced by organic nitrogen sources in combination with growth regulators. This might be because an increase in grain yield relative to biomass may enhance the harvest index of the crop. Khan et al. (2018) reported that organic manure and nitrogen fertilizer application increased the harvest index. Islam and Mehraj (2014) reported that growth regulators enhanced the harvest index of wheat crops because they improved assimilate translocation from source to sink. The grain and straw nitrogen content of wheat was significantly affected by farmyard manure + poultry manure, growth regulators, and deep tillage. Data analysis showed that the straw N content increased with the application of farmyard manure, poultry manure, and growth regulators. The reason might be that decomposition of organic manure in addition to chemical fertilizer results in the incorporation of macronutrients in soil and becomes available for plant uptake. Our outcomes were confirmed by Dhaliwal et al. (2023), who found that integrated nitrogen application increased the availability of macronutrients as a result of increased straw N content.

Our results regarding the positive impact of GA on yield and quality of wheat are in line with those of Islam and Mehraj (2014), who reported that growth regulators enhance the crop potential to efficiently utilize nutrients and water thus improve t yield of crops. Similar outcomes were reported by Islam and Mehraj (2014), who found that growth regulators increased grain yield. Gibberellic acid promotes cell elongation and division, leading to taller plants. This increased height can improve the plant’s ability to capture sunlight, which enhances photosynthetic activity and contributes to higher biomass accumulation. For example, Sharma et al. (2018) observed that the foliar application of GA_3 increased plant height and shoot biomass in wheat, particularly under water-stressed conditions. GA_3 can increase the size of the plant's grain-bearing structures, leading to larger and more uniform grains by enhancing cell division and elongation. According to a study by Zhang et al. (2019), the foliar application of GA resulted in significant increases in both grain number and grain weight in wheat. Moreover, the application of GA has been linked to improved grain quality, including increased protein content and better milling quality, which are important traits for wheat breeding programs (Mohammad et al., 2020; Sary et al., 2021). GA has been shown to improve nutrient uptake efficiency, particularly nitrogen, which is essential for protein synthesis and overall growth (Yaseen et al, 2020; Saeed et al., 2021).

Deep tillage practices performed better than shallow tillage with respect to crop growth and quality. A possible argument could be that deep or subsoil tillage reduced soil compaction and increased soil water content, proliferated more roots in deeper soil, and increased lodging resistance of the plant and biomass production. Compared to conventional tillage practices, deep tillage produces taller plants. This might be due to its large effect on root growth and nutrient availability, and deep tillage is frequently recommended over conventional tillage to increase plant height in wheat (Singh et al., 2014). By cultivating the soil at a greater depth, deep tillage practices assist in reducing soil compaction and developing a more beneficial soil structure. This makes it possible for wheat plants to develop strong, widespread root systems that may reach farther down the soil profile when searching for water and nutrients (Zhang et al., 2021; McFadden, 2023). Strong root systems enable plants to absorb nutrients more effectively, thereby fostering general growth and vitality. Wheat plants can experience stronger vegetative growth and stem elongation, resulting in an increase in plant height when nutrients are readily available (Adnan et al., 2016; HanumanthaRao et al., 2016; Burezq and Davidson, 2021; Mahmoud et al., 2023). However, conventional tillage can lead to compacted soil layers that prevent roots from penetrating and nutrients from being absorbed, thereby reducing the plant's capacity for vertical development. By using deep tillage, farmers create optimum conditions for better root development and nutrient uptake, allowing wheat plants to grow to greater plant heights, which boosts sunlight absorption and yield potential overall (Arif et al., 2015; Zhang et al., 2021; Mălinaş et al., 2022). Our results are also in line with those of Kahlon and Khurana (2017), who reported that deep tillage improved the soil infiltration rate and root length density, which improved grain yield. Our results are supported by Chu et al. (2016), who showed that deep tillage or subsoiling to 38 cm promoted post-anthesis dry biomass accumulation and remobilization to grain and increased the water use efficiency of winter wheat. Our findings concur with those reported by Fen et al. (2021), which revealed that harvest index was affected by deep tillage. Our results are supported by Cai et al. (2014), who revealed that deep tillage increases soil water content and proliferates more roots in deeper soil, resulting in enhanced biological yield. Similar outcomes were attained by Zhai et al. (2019), who reported that deep tillage improves yield and efficiency in many crops. Higher straw nitrogen content was recorded in the deep tillage practice. This might be because deep tillage incorporates organic manure in the subsoil layers, which mainly improves the enzyme activity of subsurface soil and accelerates the nutrient cycle of soil.

5. **Conclusion**

Our findings demonstrated that the supplementation of N (120 kg ha^{-1}) through integration of organic and mineral sources (50% each) along with application of gibberellic acid (as foliar spray) is the best remedy for improving yield and quality of wheat under deep tillage techniques (Chisel Plow + Cultivator + Rotavator once in five years)Hence, the integrated application of organic and inorganic N fertilizers along with growth regulators under a deep tillage system is recommended for obtaining optimum and quality yield of wheat crop.

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Author's Contribution

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

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The data supporting the findings of this study are available within the manuscript.

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No potential conflict of interest was reported by the author(s).

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