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Nitrogen Fertilization Strategies for Sustainable Winter Wheat Production in a Growing World

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The escalating global human population, projected to reach nine billion by 2050, necessitates proactive measures to address the impending food gap. Crop yield augmentation and the expansion of arable land emerge as primary strategies to ensure food security. Winter wheat, a vital cereal crop, holds the potential to bridge this gap. However, global wheat yield averages remain suboptimal, emphasizing the underexplored potential of this critical crop. Nitrogen, a pivotal nutrient for wheat, significantly influences grain yield and quality. Efficient nitrogen management is crucial for maximizing profitability while minimizing environmental impact. Nitrogen deficiency poses limitations to winter wheat production, impacting growth and yield positively, while excess nitrogen leads to undesirable consequences such as lodging and susceptibility to diseases. Despite its potential, a decline in winter wheat grain production in 2021 underscores the need to evaluate the role of nitrogen fertilizers in enhancing production sustainability. Encouraging farmers to judiciously apply nitrogen fertilizers emerges as a key strategy to enhance winter wheat sustainability, supported by a three-year study conducted by the State Agricultural University. China, as the world's largest wheat-producing country, also emphasizes the importance of nitrogen fertilization in optimizing yields. However, excessive nitrogen application poses environmental risks and requires careful consideration to balance crop productivity and environmental sustainability. This comprehensive review highlights the intricate relationship between nitrogen fertilization and winter wheat productivity, considering factors such as planting dates, nitrogen rates, and environmental conditions. The research underscores the need for optimal nitrogen application to enhance grain yield while minimizing environmental impact. The study's results, drawn from multiple sources and field experiments, demonstrate that nitrogen fertilization plays a crucial role in winter wheat growth and development. The findings emphasize the importance of considering specific factors such as nitrogen dosage, planting dates, and regional conditions for effective nitrogen management. Overall, this research provides valuable insights into the multifaceted impact of nitrogen fertilization on winter wheat, offering guidance for sustainable agricultural practices to ensure food security and environmental preservation.

Keywords: Arable Land, Nitrogen Deficiency, Susceptibility to Diseases, Effective Nitrogen Management.

Introduction:

Human population growth is on a continual rise and is projected to reach a staggering nine billion by the year 2050. Addressing the impending food gap necessitates various actions, with the primary and most impactful strategies being the augmentation of crop yields and the expansion of arable land [1]. Historically, the former factor has contributed significantly, accounting for a 55%-60% increase in food production. Wheat (Triticumaestivum L.) stands out as a crucial global cereal crop and a staple food source for humans, holding the potential to bridge the food gap. In Russia, winter wheat plays a vital role in agricultural production, contributing significantly to the overall agricultural system, with its grain serving as a staple ingredient for bread production. Despite its high-yielding potential, the global average wheat yield is considerably low, standing at only 3.2 t/ha (FAOSTAT, 2021), highlighting the inadequate exploration of wheat's potential on a global scale [2].

Among fertilizers, Nitrogen (N) takes precedence as the most critical nutrient for wheat, playing a pivotal role in enhancing both grain yield and quality. Managing nitrogen inputs in wheat production becomes imperative to achieve maximum profitability with minimal negative environmental impact. Nitrogen deficiency poses a significant limitation to winter wheat production, impacting plant growth and yield positively. Insufficient nitrogen severely affects wheat's sensitivity and responsiveness, hindering its optimal growth [3]. Nitrogen's primary role in plants lies in its presence in protein structures, the essential building blocks constituting the living material or protoplasm of every cell. Additionally, nitrogen is a key component of chlorophyll, the green pigment in leaves responsible for photosynthesis. Consequently, the plant's nitrogen supply influences protein, protoplasm, and chlorophyll formation, subsequently impacting cell size, leaf area, and photosynthetic activity [4].

Optimal nitrogen supply results in vigorous plant growth, vibrant dark green coloration, and enhanced leaf and stem development. Conversely, insufficient nitrogen leads to a lighter green color, reduced tillering, abnormal cell growth, and diminished protein synthesis, potentially resulting in significantly reduced crop yields. Excessive nitrogen can cause overly lush growth, increasing the risk of lodging, delayed maturity, and susceptibility to diseases [5]. As plants absorb more nitrogen than any other essential elements from the soil, effective nitrogen management becomes crucial for maximizing grain yield in winter wheat production. Therefore, maintaining an appropriate nitrogen fertilizer management strategy is essential for sustainable crop yield improvement while mitigating environmental risks. Achieving an optimal basal-topdressing ratio in nitrogen application emerges as a critical component of effective nitrogen fertilizer management [6].

The Russian Federation prioritizes food security in its domestic agriculture agenda, emphasizing the need to increase agricultural crop production by leveraging all influencing factors, with a focus on the judicious use of mineral fertilizers. Winter wheat production remains integral to Russia's agricultural landscape, with substantial land dedicated to its cultivation. Notably, Russia has the potential to achieve winter wheat yields averaging around 30 t/ha, with the possibility of reaching 60 t/ha depending on agricultural practices [7]. Winter wheat grain holds a prominent position as a major cash crop in Russia, constituting at least 70% of the country's cash crop production. Despite its potential, a decline in winter wheat grain production was observed in 2021 compared to 2020. This reduction underscores the importance of evaluating the role of nitrogen fertilizers in enhancing winter wheat production [8].

Encouraging farmers to apply nitrogen fertilizers to winter wheat plantations stands out as a key strategy to enhance grain production sustainability, particularly for winter wheat grain [15]. Nitrogen fertilizers emerged as cost-effective techniques to boost winter wheat production in Russia, supported by a three-year study conducted by the State Agricultural University, as detailed in the journal article "Influence of Mineral Fertilizers on Winter Wheat Yield" authored by [9]. China holds the position of the world's largest wheat-producing country, with wheat ranking as the third most significant crop after maize and rice within China. Noteworthy progress has been achieved in both the overall wheat production and average crop yield per hectare since the establishment of China. Among the crucial factors influencing the yield and quality of wheat, nitrogen fertilization plays a pivotal role. Recent years have seen a shift in agricultural practices towards optimizing yields through the judicious use of nitrogen fertilization [10]. While fields often receive substantial nitrogen fertilization, plants typically utilize only 5% to 50% of the applied fertilizer. Upon application to agricultural fields, nitrogenous fertilizers are either directly absorbed by plants or converted into various forms through oxidation. Farmers globally tend to apply excess nitrogen to achieve higher yields. However, this excessive application can lead to reduced grain yield and increased nitrogen loss in the soil ecosystem, potentially causing nutritional disorders in wheat and limiting crop yield. Conversely, insufficient nitrogen results in smaller leaves, lower chlorophyll content, reduced biomass production, and subsequently, diminished grain yield and quality. Therefore, it is crucial to apply nitrogen fertilizers in the right quantities and according to crop requirements. A pressing need exists to adopt a suitable strategy that ensures higher grain yield while minimizing environmental pollution [11].

Nitrogen, a key component of protein, chlorophyll, and amino acids, significantly contributes to wheat productivity. Augmenting wheat grain yield involves increasing biomass and improving the harvest index of wheat. While the wheat harvest index may have plateaued, achieving further improvements in yield requires an increase in profitable biomass. Substantial biomass accumulation in photosynthetic areas ultimately leads to an increase in grain yield potential. The positive and significant correlation between grain yield, total dry biomass production, and nutrient uptake in crops has been well-established [12]. Dry matter development and nutrient accumulation vary with the growing stages of crops. Nitrogen use efficiency is commonly defined as the dry matter yield per unit of available nitrogen. Leaf photosynthetic capacity, a crucial trait quantifying crop yield, may not fully represent photosynthetic features throughout all grain-filling stages, particularly in the later stages. Optimal nitrogen rates and timing play a vital role in improving crop yield and nitrogen use efficiency (NUE). Previous studies indicate a linear increase in grain yield with nitrogen rates up to 200 kg ha^{-1}, particularly with a split application of 50% at sowing time and 50% at the tillering stage, enhancing nitrogen uptake and efficiency [13].

Some studies have revealed a positive correlation between nitrogen content and chlorophyll content in leaves. Consequently, measuring chlorophyll content can indirectly determine the nitrogen status. A growing interest in maximizing wheat grain yields has prompted growers to adopt more demanding management practices. High nitrogen application has been linked to increased vegetative growth and canopy structure, hindering light interception and leading to lodging and yield loss. Conversely, excessive nitrogen use can degrade soil properties through nitrogen leaching and volatilization, impacting nutrient uptake and crop balance [14].

The global significance of common wheat lies in its ability to serve as animal feed and ensure food security for humans. In pursuit of consistent and higher grain yields, ongoing agricultural research continually refines the cultivation methods and varieties of this plant. Studies by [15] have indicated that climate change may lead to decreased agricultural production, especially in regions with low rainfall levels. [16] propose that climate change could result in reduced grain yields, necessitating adjustments to agronomic recommendations, particularly concerning planting dates and densities, especially for winter wheat. The researchers emphasize the crucial role of selecting the optimal planting date to aid in the species' adaptation and mitigation of climate change impacts. [17] notes that despite the well-established understanding that winter wheat should be promptly seeded, significant delays in crop planting occur in certain regions, often associated with delayed harvesting of previous crops, such as grain maize or sugar beets, in Poland. [18] have found that the timing of planting significantly influences plants' responses to photoperiodism and vernalization, impacting the growth of their reproductive organs [19]. Delays in planting have a detrimental effect on plant development and maturity, as observed in the study conducted by [20], which revealed that postponing the sowing of winter wheat significantly affects the crop's yield, protein composition, and other characteristics. The study reported that a further two-week delay in planting resulted in increased overall crop production and a larger number of grains per spike. However, due to the limited capacity of plants to assimilate nitrogen, the protein content of the grain decreased. Contrarily, the study conducted by [21] demonstrated a notable increase in the protein composition of wheat grains due to delayed planting. The study found that crop production in the tested region decreased by approximately 1% for each day that winter wheat was planted after the optimal date. Diminished yield components, delayed plant growth, and reduced nitrogen absorption from fertilizers were the primary factors contributing to the fall in productivity. Due to the postponed sowing procedure, the plants encountered suboptimal temperatures during the period of vegetative development, abbreviated growing seasons, and excessive temperatures during the grain-filling stage. [22] suggest that adjusting wheat production in dry regions to climate change may require shifting the planting date to an earlier time and ensuring sufficient fertilizer application. [23] found that winter wheat had a higher capacity to assimilate nitrogen from the soil compared to spring wheat, carrying substantial ecological and economic consequences. [24] propose that increasing the quantity of cultivated grain might compensate for these declines. However, postponing wheat planting dates leads to decreased optimal water and nitrogen utilization. [25] demonstrates that both the timing of planting and the use of nitrogen fertilizers have a substantial influence on wheat grain yield. The authors' findings, particularly regarding nitrogen fertilization, were dependent on the precise weather conditions of each season. According to [26], delaying the planting of winter wheat beyond the scheduled time might result in a decrease in yield of up to 13.7%. Nevertheless, increasing the utilization of nitrogen fertilizers can counterbalance the decrease in crop productivity. [27] investigation discovered that intentionally postponing the planting of wheat led to a decrease in grain yield. Nevertheless, the application of a nitrogen treatment at a rate of 100 kg ha^{-1} resulted in improved plant growth, yield components, and overall yield. Utilizing more than 100 kg ha^{-1} of nitrogen fertilizer was deemed unwarranted, regardless of the timing of plant cultivation. According to the research by [28], the escalating use of NPK fertilization notably influenced the nitrogen content of the grain, while the delayed planting of wheat remained unaffected. [29] unveiled that delaying the planting of wheat significantly diminished the visible characteristics of the plants, excluding the thousand-grain weight. However, all other indicators exhibited improvement as the nitrogen fertilization rate increased from 75 to 125 kg ha^{-1}. [30] recommended a nitrogen rate of 240 kg ha^{-1} to optimize wheat grain and protein yield, cautioning against excessive nitrogen utilization due to environmental repercussions and limited economic benefits. [31] shared a similar perspective, emphasizing that excessive nitrogen application, coupled with a significantly delayed planting schedule, was economically unjustifiable. Previous studies underscored the critical role of nitrogen fertilization in winter wheat production, impacting both yield and quality. [32] determined that the optimal nitrogen application rate for winter wheat is 217 kg N ha^{-1}, resulting in a peak grain yield of 8.25 metric tonnes per hectare. [33] suggested a nitrogen rate of 140 kg N ha^{-1}, to be applied in three equal increments prior to planting, during the tillering and shooting stages. Contrarily, [34] demonstrated a significant increase in wheat yields with an elevated nitrogen dosage of 180 kg ha^{-1}. All grain quality indices, except starch content, exhibited improvement when the nitrogen treatment rate increased to 210 kg ha^{-1}. [35] revealed that adding 140 kg N ha−1 of nitrogen fertilizer enhanced yields of crude protein and wet gluten, with urea solution as the nitrogen source showing the most substantial increase. Researchers [36] advocated for modern measurement methods to comprehensively assess plant health and predict crop production for crops like wheat. [37] emphasized the importance of employing SPAD measurement to precisely evaluate the nutritional state of plants during the development phase. Studies by [38] highlighted the significant impact of the geographic region and experimental site selection on the optimal timing of agronomic approaches, particularly planting dates. Consequently, they suggested that field research was generally necessary to generate reliable results and useful recommendations.

Crucial Role of Nitrogen Fertilizer on the Yield and Quality of Winter Wheat:

Nitrogen stands out as a vital nutrient for achieving substantial biomass and, consequently, high yield due to its fundamental role in protein formation and its impact on key enzymes regulating photosynthesis. Despite being abundantly available in the atmosphere, nitrogen assumes a limiting role for plants globally since its atmospheric form is unusable. The advent of synthetic nitrogen fertilizer, produced through industrial fixation, has proven instrumental in nourishing plants, enhancing yields, and improving harvest quality. The expected yield outcomes from a specific quantity of N fertilizer depend on various factors, including the plant's total N uptake, the efficiency of the variety in constructing and maintaining photosynthetic machinery, genetic biomass potential, and the proportion of total assimilates allocated to grains.

Research by [39] showcased that a fertilizer treatment combining 50% basal and 50% dressing significantly increased post-anthesis nitrogen accumulation, nitrogen translocation to grains, free amino acid levels in flag leaves, nitrate reductase and glutamine synthetase activities, and the accumulation rate, active accumulation period, and 1000-grain nitrogen accumulation. This comprehensive improvement led to increased grain and protein yields, highlighting a positive correlation with nitrogen transport parameters, enzyme activity, and grain nitrogen filling parameters. Similarly, [40] demonstrated a significant increase in grain yield with escalating N fertilizer application rates, with a linear trend indicating that the maximum rate (200 kg N ha^{-1}) may not have been sufficient to achieve the biological maximum yield. Experiments conducted by [41] revealed that nitrogen fertilizer rates significantly affected winter wheat yield, with the highest average grain yield obtained at a 110 kg ha^{-1} nitrogen rate, utilizing a combination of nitrogen application to the frozen soil surface and foliar feeding. This approach resulted in an increased grain protein content less dependent on weather conditions.

Research by [42] emphasized the critical role of nitrogen nutrition in optimizing natural nitrogen reserves, preserving soil fertility, and mitigating the adverse effects of improper nitrogen fertilizer use. Studies by [43] evaluated the impact of different organic and mineral fertilizers on winter wheat grain parameters, revealing that nitrogen in mineral form led to the highest grain yield and bulk density. [44] investigation into the doses and methods of nitrogen fertilizer application demonstrated an increase in winter wheat yield and grain protein content. Findings from [45] indicated that N fertilizer application significantly increased grain yield, straw yield, aboveground biomass, N uptake, and N concentration of wheat. [40] supported the significance of nitrogen application in successful wheat production systems, while [15] and others highlighted the impact of nitrogen fertilizer rate on winter wheat yield and quality indices.

Given the prevalent characteristics of sod-podzolic soils in the non-Chernozem Zone, characterized by low fertility, low humus content, and poor nutrient levels, studies affirm a positive correlation between nitrogen fertilizer application and increased productivity in winter wheat. The potential impact of appropriate nitrogen application on wheat yield in Moscow, as per the Ministry of Agriculture recommendations, further underscores the significance of nitrogen fertilizers for substantial yield increases [46]. The application of nitrogen fertilizers emerges as a potential solution for enhancing winter wheat productivity and quality in the Central part of the non-Chernozem Zone. Mineral fertilizers, containing essential nutrients like nitrogen, when applied judiciously, enhance soil nitrogen content, contributing to increased productivity and improved quality of winter wheat in the region. [20] stress the importance of nitrogen nutrition in optimizing winter wheat production in the non-Chernozem soils of Central Russia. Nitrogen fertilizers, when appropriately applied, enhance glassiness and gluten content in winter wheat, ultimately elevating grain quality. Research findings indicate that increasing fertilizer doses positively impact grain quality indicators, with a 1.5-fold increase in fertilizer dose resulting in a 0.7 to 0.9 times increase in grain quality. [29] underscore the need to boost winter wheat yield and quality, particularly in the Russian agricultural and economic systems, advocating for the judicious use of nitrogen fertilizers under suitable conditions. The substantial nitrogen content in winter wheat emphasizes its critical role in the crop's development. Large-scale winter wheat plantations in regions with nitrogen deficiencies highlight the special requirement for nitrogen nutrition in wheat crops. Recent research points to an increase in fibrin content in winter wheat following nitrogen fertilizer application. [30] associates increased fibrin content with mineral fertilizer application, underscoring the positive impact of nitrogen fertilizers on winter wheat in leached chernozem soils.

Deficiencies in nutrient content in non-Chernozem soils validate the need for nitrogen fertilizer application to enhance winter wheat quality and productivity. Prioritizing various quality indicators, including physical, biological, chemical, and consumer characteristics, demonstrates the multifaceted benefits of nitrogen fertilizer application in the non-Chernozem soils of Central Russia. Optimal nitrogen fertilizer application is deemed critical for achieving high-quality winter wheat, and its potential to increase gluten and crude protein content further supports its role in enhancing grain quality across all soils. [47] emphasis on the importance of applying nitrogen fertilizers in appropriate quantities for optimal yields and enhanced quality aligns with the broader findings reviewed in this study. The research aimed to assess the impact on winter wheat growth and development of three nitrogen doses (100, 150, and 200 N kg ha^{-1}) and two recommended and delayed planting dates. The study hypothesis posited that increasing the nitrogen dose is essential to mitigate the adverse effects of delayed planting on production.

Results and Discussion:

Meteorological conditions occasionally exert a significant impact on the characteristics of the crops under study. The variations in these traits observed across several years of research can substantially influence the outcomes of long-term field studies. The correlation between the variables under investigation and specific years of experimentation may potentially explain the observed variations across numerous seasons. [48] highlight the importance of June for Poland as it marks the commencement of the winter wheat grain-filling season, often associated with insufficient rainfall. Air temperatures, as emphasized by [49], significantly influence the growth and development of field crops, with adverse temperature patterns having an impact comparable to insufficient rainfall. [50] stress the threats posed by drought and global warming to wheat production worldwide, underscoring the need for innovative wheat varieties and advancements in agricultural technology. [50] attribute the decline in wheat production to heat stress, emphasizing the superior adaptability of hexaploidy species in contrast to tetraploid or diploid species to such conditions. Notably, the treatment involving a nitrogen injection of 100 kg ha^{-1} and delayed planting resulted in the lowest Leaf Area Index (LAI). The investigation revealed a distinct correlation between the studied variables, indicating that the effects of various nitrogen fertilization methods were contingent on the planting date. An increased nitrogen dosage was predicted to elevate the SPAD index, with significant improvements observed only in treatments receiving 200 kg ha^{-1} of nitrogen and 100 kg ha^{-1} of nitrogen with delayed planting.

Consistent monitoring of a plant's Soil-Plant Analysis Development (SPAD) throughout its complete development season, as advocated by [51], expands the available data pool and enables the evaluation of the impacts of studied variables in experiments. The findings of my independent investigation align with this assertion. According to [51], plant biomass and the Leaf Area Index (LAI) decrease when winter wheat is planted later than planned, suggesting a recurring pattern, in my interpretation. [52] demonstrated the utilization of field measurements, such as SPAD and LAI, to assess the impact of winter wheat fertilization and the plants' responses to applied fertilizers. They proposed that indicators of plant growth and grain production could be obtained from the winter wheat SPAD and LAI. [53] found that under diverse abiotic stressors, simultaneous application of sulfur and nitrogen fertilization benefited plant physiology, nitrogen accumulation, and the SPAD index. However, they observed increased vulnerability to high temperatures, especially under additional environmental stressors.

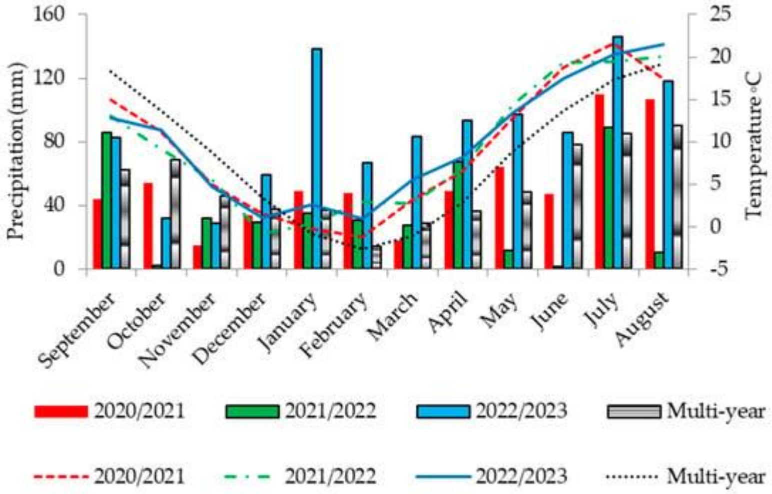

Figure 1: Weather conditions. The columns show the total precipitation, and the line shows the mean temperature [54].

In the present study, optimal ways to increase spikes per square meter and thousand-grain weight (TGW) were observed to be applying nitrogen at a rate of 150 or 200 N kg ha^{-1} and planting within the designated period. The recommended sowing date and a dosage of 200 N kg ha^{-1}, in comparison to delayed planting with a dosage of 100 N kg ha^−1, resulted in a significant difference in the number of grains per spike. Delayed planting led to fewer spikes and grains per square meter, aligning with [55]. However, there was no discernible change in the TGW index. [56] reported that delayed planting frequently decreased the number of spikes per square meter. [55] demonstrated significant impacts of planting dates on individual grain weight (TGW) but not on the number of grains per spike. Those who planted wheat in October had the lowest Thousand Grain Weights (TGW), approximately ten to twenty. It is crucial to acknowledge potential ambiguity or discrepancy between our findings and those of other investigators.

According to [56], wheat yield is primarily determined by spike density per square meter and the number of grains per spike. They found that the quantity of spikes per square meter decreased with delayed sowing. [57] established positive correlations between the quantity of nitrogen fertilizer used and various wheat characteristics, including grain yield, growth period, spike density per square meter, and thousand-grain weight. [58] discovered that, except for grain weight, increased nitrogen fertilization improved all parameters of wheat productivity, aligning with the present inquiry. The relationships between the investigated components significantly influenced winter wheat grain yield. Planting within the designated period and applying 200 or 150 kg ha^{-1} of nitrogen supplementation produced the best average crop yield, while winter wheat yields decreased significantly with delayed planting and 100 kg ha^{-1} of nitrogen. The results for 2021 and 2023 showed high consistency and significant differences in grain output were observed in 2022 when comparing approved and delayed sowing dates with nitrogen application rates of 200 kg ha^{-1} and 100 kg ha^{-1}, respectively. Wheat yields varied from 6.71 t ha^$^{-1}$ in 2021 to 7.45 t ha^$^{-1}$ in 2023. [59] reported a yield drop ranging from 6.14% to 13.72% with delayed planting, mitigated by nitrogen fertilizers. Increasing nitrogen application resulted in a significant increase in annual crop production and agricultural revenue, despite increased costs, aligning with the present investigation.

[60] reported a notable decrease in wheat yield when cultivars were planted in December without adequate nitrogen fertilization. [61] suggested that reducing nitrogen fertilizer usage significantly might lead to a decline in both crop output and soil fertility. [62] emphasized the importance of considering the specific needs of the cultivated plant, nitrogen utilization effectiveness, and potential negative environmental impacts for successful nitrogen fertilization. It's crucial to recognize that various factors, including environmental conditions, influence field

testing. A 30-day delay in the commencement of the grain planting schedule accompanied by the application of 100 kg/ha of nitrogen resulted in a drop in grain protein content. An increased level of protein was achieved with a nitrogen injection rate of 200 kg ha^{-1} for grain production, irrespective of the planting date.

Research by [63] indicated that delaying wheat planting led to poorer yield, lower thousand-grain weight, and fewer grains per spike. However, the total grain protein content was higher. [64] also demonstrated that later-grown winter wheat exhibited higher protein content. Grain quality, as shown by [65], remained unaffected by variations in planting dates, with genotype and harvest year being the primary factors influencing the chemical makeup of winter wheat grain. My own research confirmed that seeds sown at the ideal moment showed minimal impact. [66] emphasized that weather has the most influence on wheat grain quality. [66] stated that agronomic practices, weather patterns, soil quality, and genetic characteristics all significantly impact the technical and nutritional value of grain. While increasing nitrogen fertilizers to wheat at a rate of 200 kg per hectare had favorable outcomes, not all aspects of grain quality showed positive impacts. The research indicated that adding nitrogen fertilizer to grain increased its protein content, but this effect was more pronounced when the grain was sown at a later period.

Economic studies suggested that applying 150 or 200 kg of nitrogen per hectare is beneficial, especially on the ideal planting date. However, if the sowing date is postponed, the cost-effectiveness of nitrogen fertilization declines in all scenarios, particularly with a dose of 100 kg ha^{-1}. Calculations were based on 2023 pricing, with a tonne of grain priced at EUR 210 and EUR 1.5 for nitrogen expenditures per kilogram. Maximizing nitrogen fertilization was shown to reduce environmental risks, increase financial returns, and yield large wheat crops with excellent grain quality. Higher concentrations of nitrogen fertilizers, compared to lower concentrations, significantly improved the economic performance of wheat farming in both humid and dry regions, as indicated by studies conducted by [67]. Excessive nitrogen doses negatively impact the natural ecosystem. [67] found that, except for the top 20 cm of soil, the application of nitrogen fertilization to wheat and maize had no effect on the concentration of ammonium nitrogen (NH_4–N) in the soil profile, but the quantity of nitrate nitrogen (NO_3–N) varied significantly. Further research revealed a significant tendency for NO_3-N to migrate from the topmost soil layer to the lower soil layers (20–100 cm) following the application of 240 and 360 kg N ha^{-1} doses. [68] asserted that the economic effects of nitrogen fertilization depend on the cost of the nitrogen fertilizer and the grain's market value. Therefore, data correction is crucial for modifying economic analyses, a conclusion supported by the results of my inquiry.

The yield of wheat is intricately influenced by the combined impacts of fertilizer and soil moisture. Inadequate soil moisture diminishes the positive effects of soil nitrogen on wheat production. Conversely, excessive precipitation or irrigation can lead to the leaching loss of soil nitrogen, adversely affecting yield. Soil water deficit during tillering tends to increase grain harvest index but decreases biomass, particularly impacting spike number. If this deficit occurs during the booting to the flowering stage, it significantly affects wheat's grain number per spike. Higher soil nitrogen levels accelerate plant growth, depleting soil water reserves. While wheat may produce more grains, they may not be fully developed due to soil water accumulation. To achieve advanced grain yield and efficient crop water production, nitrogen fertilizer input must be adjusted based on precipitation. Scientific fertilization should consider both water accumulation and utilization. For instance, N fertilizer rate N210 kg ha^{-1}, compared to N150 kg ha^{-1}, significantly increased crop water use efficiency by 6.1%. Precipitation fallow use efficiency (PFUR) is equivalent to fallow soil water storage ratio (SWSR), indicating that fallow precipitation stored in the soil can only meet part of the subsequent crops' water demand. The soil water accumulated during the fallow period can satisfy the water consumption before the jointing stage in dryland wheat. Throughout the year, this accumulated soil water can meet the water demand before the anthesis of dryland wheat. Research on the spatio-temporal dynamics of water in dryland wheat fields in

Shanxi showed that N fertilizer rate N210 kg ha^{-1} significantly improved soil water consumption in the 80/240 cm soil layer from jointing to flowering by 36.6% compared to N180 kg ha^{-1}. There was a significant positive correlation between soil water intake and spike number in the same period ($a = 1.7$, $R2 = 0.45$, $P < 0.001$). N210 compared to soil water consumption of N180 kg ha−1 significantly increased by 22.7% in the 80–240 cm soil layer, with a significant positive correlation between soil water consumption and spike number ($a = 2.9$, $R2 = 0.47$, $P < 0.001$). N240 kg ha−1 significantly increased the water consumption of jointing to flowering soil in dryland, promoting tiller spike creation and improving yield.

The process of crop growth and yield creation involves the transformation of materials between crops and the environment, along with the accumulation and transformation of materials within crop organs. Smooth material accumulation and transport during key development periods are essential for crops to achieve high yields. Precipitation at various growth stages has a priority order in influencing wheat yield in dryland, with sowing emergence and jointing stages being the main limiting factors. The key growth period for tiller differentiation in dryland wheat is after the jointing stage, influencing spike numbers at the mature stage. Ineffective tillers can reduce the optimal effective population number of wheat, negatively impacting ear and grain weight. Therefore, studying the tillering polarization process is crucial, as it affects wheat growth, development, nutrient competition, and resource utilization, ultimately influencing yield and its components. Soil nitrogen and water conditions at the jointing stage significantly affect wheat fields. The N percentage of wheat significantly increased by 20.3% with an N application rate of 150 kg ha^{-1} compared to 210 kg ha^{-1}. Tiller count in dryland wheat significantly increased by 7% at N180 kg ha^{-1} compared to 210 kg ha^{-1}. An N150 kg ha^{-1} application rate significantly improved dry matter buildup from jointing to flowering in dryland wheat by 14.8% compared to 210 kg ha^{-1}.

Compared to 210 kg ha^{-1}, N180 kg ha^{-1} significantly increased the dry matter buildup of jointing to flowering wheat in dryland by 9%. Connection analysis showed that dry matter accumulation from jointing to flowering was significantly positively correlated with tiller percentage in dryland. A suitable nitrogen application rate can significantly increase dry matter accumulation from jointing to the flowering stage, increase tiller rate, promote the formation of effective tillers, and increase yield. The relationship between sources is the material basis for yield formation. The results presented show that grain profit decreased with the rise of dry matter buildup ($A = 11.1$, $R2 = 0.50$, $P < 0.05$; $A = 17.4$, $R2 = 0.65$, $P < 0.01$). The long-term experimental study in Changwu, Shanxi, over eight years, showed that the soil moisture before hand-sowing in dryland wheat was less than 200 mm, 200–250 mm, and >300 mm. The reasonable range of nitrogen application was 83–105 kg ha^{-1}, 98–120 kg ha^{-1}, and 105–135 kg ha^{-1}. The reasonable nitrogen application amounts of N180 kg ha^{-1} were similar to the effects of this study when the annual precipitation was normal (500–600 mm) and humid (600 mm). In the dry farming wheat region of the Loess Plateau, the annual types are divided according to the precipitation during the fallow period, which can be adjusted based on the local precipitation data in each region to be applicable to the local production reality. The results presented show that N150 kg ha^{-1} significantly reduced grain protein content of dryland wheat by 0.5% compared to N210 kg ha^{-1}. Compared to N210 kg ha^{-1}, N180 kg ha^{-1} significantly reduced the grain protein of dryland wheat by 0.6%. The results indicated that suitable nitrogen application based on fallow precipitation reduced grain protein content of dryland wheat, and further screening and exploring the potential of nitrogen utilization of dryland wheat varieties would be one of the effective directions [69].

Conclusion:

A 30-day delay in the winter wheat (RGT Kilimanjaro variety) planting date led to a decrease in grain yield by 0.89 t ha^{-1} in the experimental zone. The study revealed that both nitrogen fertilization and meteorological conditions significantly influenced wheat yields. Notably, there was a 0.74 kg ha^{-1} difference in grain yield between the years 2021 and 2023. Contrasting scenarios involving delayed planting and fertilization at a rate of 100 kg N ha^{-1} with those involving a nitrogen dosage of 200 kg ha^{-1} resulted in distinct outcomes. This led to a substantial increase in Soil Plant Analysis Development (SPAD) and Leaf Area Index (LAI). Optimal improvements in spike density per square meter and thousand-grain weight were observed when nitrogen was applied at rates of 150 or 200 kg per hectare, combined with grain seeding on the recommended date. Following the recommended planting schedule and applying a nitrogen dose of 200 kg, ha^{-1} resulted in the highest grain output per spike. The third iteration, with a nitrogen dose of 100 kg ha^{-1}, exhibited notably inferior results for the mentioned yield components. Greater nitrogen fertilization rates had a more significant impact on the grain's protein composition than differences in planting dates. Overall, the study demonstrates that planting winter wheat 30 days later reduces overall grain production, but this negative effect can be mitigated by increasing nitrogen application.

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