High-yield and High-efficiency Cultivation Technology with Delayed Nitrogen Application for Wheat in the Huang – Huai Region

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Abstract The delayed nitrogen application technology is a crucial method for achieving high yield and efficiency in wheat cultivation. Specifically, more nitrogen is supplied to the middle and late growth stages of wheat by adjusting the application time and proportion of nitrogen fertilizer. This approach helps improve the tiller-bearing percentage and increase the number of grains per ear and the thousand-grain weight, while also reducing nitrogen loss and enhancing fertilizer use efficiency. This paper systematically elaborated on the high-yield and high-efficiency cultivation technology system with delayed nitrogen application for wheat, covering variety selection, soil management, sowing technology, the principle and implementation methods of delayed nitrogen application, integrated water and fertilizer management, field management, and comprehensive pest and disease control. Considering the ecological characteristics of major wheat-growing regions in China, tailored technical solutions were proposed, and operational key points of critical technological steps were introduced in detail. Through scientific variety distribution, precise nitrogen management, and integrated pest control, wheat yield and quality can be enhanced while achieving cost saving, improved efficiency, and ecological environmental protection. This paper provides systematic theoretical guidance and practical references for promoting thedelayed nitrogen application technology in wheat, thereby supporting the sustainable development of China's wheat industry.

Key words Wheat; Delayed nitrogen application; High yield and efficiency; Cultivation technology; Pest and disease control; Water and fertilizer management

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Wheat is a primary grain crop in China, playing an irreplaceable role in ensuring national food security. As one of the most essential nutrients for wheat growth and development, nitrogen has a decisive impact on yield formation and quality improvement. However, in traditional nitrogen fertilization, the majority of nitrogen is applied as the basal fertilizer or topdressing during the regreening stage, which often leads to excessive nitrogen supply in the early growth stages and deficiency in the later stages, resulting in issues such as increased ineffective tillers, higher lodging risks, and reduced fertilizer use efficiency. The delayed nitrogen application technology optimizes the time of fertilizer application by allocating a larger proportion of nitrogen to the jointing and booting stages. It ensures sufficient nitrogen supply during critical growth phases, facilitating the formation of an optimal plant structure, enhancing photosynthetic efficiency, and increasing both grain number per ear and thousand-grain weight. Meanwhile, this approach reduces nitrogen loss and volatilization, mitigates environmental pollution risks, and achieves a synergistic improvement in yield, quality, efficiency, and ecological sustainability. In response to the current status of wheat cultivation in the Huang – Huai region, this paper conducted a comprehensive analysis covering multiple aspects, including the principles and advantages of delayed nitrogen application, variety selection, seed treatment, pre-sowing land preparation, implementation of delayed nitrogen technology, precision sowing, field management, pest and disease control, and timely harvesting, aiming to offer technical guidance for achieving high-quality and high-yield wheat cultivation through delayed nitrogen application in the Huang – Huai region.

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Principles and Advantages of Delayed Nitrogen Application Technology

Technical principles of delayed nitrogen application

Wheat exhibits distinct stage-specific characteristics in nitrogen absorption and utilization. During the tillering stage, nitrogen demand is relatively low, and excessive nitrogen can lead to increased ineffective tillers. In contrast, from the jointing to booting stages, wheat enters a rapid growth phase, and nitrogen demand increases sharply. Adequate nitrogen supply during this period promotes floret differentiation and increases the number of grains per spike. During the filling stage, appropriate nitrogen application delays leaf senescence, enhances photosynthetic efficiency, and increases the thousand-grain weight[1]. The delayed nitrogen application technology is designed based on the nutritional requirements of wheat at different growth stages. It shifts the traditional fertilization strategy of "heavy basal fertilizer and early topdressing" to a new approach of "stabilizing base fertilizer, controlling regreening topdressing, emphasizing jointing topdressing, and supplementing grain-filling topdressing". Such adjustment ensures a better alignment between nitrogen supply and wheat demand in terms of time and quantity.

Advantages of delayed nitrogen application

The technique optimizes population structure by reducing ineffective tillers and improving the rate and uniformity of productive tillers. It promotes grain development, increases grains per ear and thousand-grain weight, and establishes a rational yield composition. Additionally, it enhances processing quality through higher grain protein content, wet gluten content, and improved dough elasticity. Supplying nitrogen according to growth law of wheat aligns nitrogen availability with peak absorption periods, minimizing waste. It reduces fertilizer loss and enables higher yields with equivalent or reduced nitrogen input, thereby lowering nitrogen consumption per unit of yield.

Variety Selection

Variety selection serves as the foundation for achieving high-quality and high-yield wheat production. Based on the climatic characteristics and soil conditions of different ecological zones in the Huang – Huai region, varieties should be chosen for their superior quality, high yield potential, strong tillering ability, and high ear-bearing percentage. Meanwhile, resistance traits such as tolerance to cold, drought, and dry hot winds, as well as disease resistance, must be considered. Suitable wheat varieties for the Huang – Huai region include Jimai 22, Zhengmai 366, Zhoumai 22, and Yannong 19[2].

Seed Treatment

Seed treatment is a critical measure to ensure uniform, complete, and robust seedlings, effectively preventing pests and diseases, enhancing stress tolerance, and promoting early and stable growth. Typically, seeds should be sun-dried for 1 – 2 d before sowing, avoiding exposure to intense sunlight. Disinfection treatment is essential for controlling seed-borne and soil-borne diseases. Hot water treatment adopted elevated temperatures to eliminate surface pathogens. For instance, soaking seeds in water maintained at 55 ℃ for 15 min effectively controls diseases such as bunt. Chemical treatment includes seed dressing, coating, and soaking. Commonly used fungicides such as triadimefon, tebuconazole and fludioxonil can control sheath blight and root rot, while insecticides like imidacloprid and thiamethoxam help manage aphids and soil pests.

Pre-sowing Land Preparation

Land preparation before sowing is a critical step to ensure seeding quality and cultivate strong seedlings. When the preceding crop is corn, straw should be crushed to less than 5 cm, evenly spread, and plowed into the soil. Application of nitrogen fertilizer is recommended to accelerate decomposition and prevent nutrient competition between straw decomposition and young seedlings. Deep plowing is the core of land preparation. Generally, the plowing depth should be 25 – 30 cm to break the plow pan, enhancing soil aeration and water permeability. After deep plowing, timely harrowing and compaction are essential to create a soil structure that is loose on the top and firm underneath, preventing issues related to sowing depth. For clay soils, rotary tillage combined with compaction can improve the surface structure, while sandy soils require moderate compaction to reduce moisture evaporation. Before sowing, the field surface should be flat with a slope not exceeding 0.5%, and free of large clods and residues to facilitate mechanical seeding. Meanwhile, irrigation should be performed at the right time according to soil moisture conditions to maintain the water content in the 0 – 20 cm soil layer at 60% – 70% of the field capacity, thereby guaranteeing successful seed germination.

Implementation of Delayed Nitrogen Application

The delayed nitrogen application technology in wheat shifts the traditional fertilization approach of "heavy base fertilizer and early topdressing" to a strategy of "stabilizing base fertilizer, controlling regreening topdressing, emphasizing jointing topdressing, and supplementing grain-filling topdressing". The technology ensures precise alignment of nitrogen supply with the mid-to-late growth demands of wheat[3]. This technology significantly enhances yield, improves grain quality, increases fertilizer use efficiency, and strengthens stress resistance.

Control of total nitrogen application

The total nitrogen application rate should be determined based on soil fertility and target yield. In specific, the total application rate is 180 – 225 kg/hm^2 of pure nitrogen for high-yield fields, 135 – 180 kg/hm^2 for medium-yield fields, and 90 – 135 kg/hm^2 for low-yield fields.

Nitrogen allocation proportion

The basal fertilizer accounts for 30% – 40% of the total nitrogen application. The application rate at the regreening stage accounts for 10% – 20%, which may be appropriately increased in weak seedling fields. At the jointing stage as the critical fertilization period, the application rate accounts for 30% – 40%. The application rate from the booting to heading stages accounts for 10% – 20% to prevent floret degeneration. Additionally, a 1% – 2% urea solution should be sprayed on the leaves during the filling stage based on seedling condition.

Precision time control of fertilization

Nitrogen fertilizer should be applied at different growth stages of wheat. The basal fertilizer is applied before sowing during land preparation. The regreening fertilizer is applied from the regreening to setting stages. The jointing fertilizer is applied when the population leaf color begins to fade. The booting fertilizer is applied from the emergence of flag leaf tip to full expansion. The foliar fertilizer is applied during the mid filling stage.

Accurate and Quantitative Sowing

The optimal sowing period in the Huang – Huai region is generally from early October to mid-October, ensuring the development of strong seedlings before winter and laying a foundation for high yields in the following year. For semi-winter varieties, the target basic seedling number is 1 800 000 – 1 950 000 per hectare, with a seeding rate of 6 – 8 kg[4]. Using a wide-width precision seeder with row spacing of 25 – 30 cm and sowing depth of 3 – 5 cm ensures uniform sowing and high emergence rates.

Field Management

Management of the seedling emergence stage

Before emergence, field inspection should be conducted. Within 2 – 3 d after sowing, soil moisture should be checked. If the surface layer is dry, a light "head-watering" irrigation is applied to ensure adequate moisture for seed germination. After emergence, it is necessary to promptly inspect and supplement seedlings. A comprehensive inspection should be carried out 5 – 7 d after emergence. If missing seedlings or broken ridges are found, seedlings should be replanted or transplanted in time to ensure the target basic seedling number is met. If soil surface compaction occurs due to rainfall, shallow hoeing or mechanical breaking should be performed promptly to improve soil aeration and promote root penetration.

Pre-winter management

Timely intertillage and soil loosening after seedling emergence help raise soil temperature and promote root development and the formation of effective tillers. When soil moisture content drops below 60% of field capacity, winter irrigation should be conducted promptly to prevent frost damage and reserve water for spring growth[5]. The pre-winter period is ideal for chemical weed control. Suitable herbicides should be selected based on weed species, with strict attention to dosage and application time. After sowing, 1 500 times dilution of 50% acetochlor emulsifiable concentrate or 2 000 times dilution of 90% acetochlor emulsifiable concentrate can be adopted before emergence, combined with uniform spraying of 3 000 times dilution of 25% thifensulfuron-methyl for soil sealing, with a spray volume of 450 – 600 kg/hm^2. During the 2 – 4 leaf stage of wheat and 1 – 3 leaf stage of weeds, broadleaf weeds are controlled using 1 500 times dilution of 75% tribenuron-methyl dry flowable formulation or 1 000 times dilution of 20% fluroxypyr emulsifiable concentrate, and grass weeds are managed with 800 times dilution of 6.9% fenoxaprop-P-ethyl aqueous emulsion or 1 200 times dilution of 15% clodinafop-propargyl microemulsion.

Management of the regreening stage

The regreening fertilizer is applied based on seedling condition, typically at a rate of 75 – 120 kg/hm^2 using urea, with appropriately increased amounts in fields with weak seedlings. Field drainage ditches are cleared promptly to prevent waterlogging caused by excessive spring rainfall, which could adversely affect root respiration. In fields exhibiting excessive plant populations and vigorous growth, growth regulators such as paclobutrazol are sprayed during the setting stage to control plant height and enhance lodging resistance.

Management of the jointing stage

This period represents the critical phase of nutrient demand in wheat. Typically, 120 – 180 kg/hm^2 of urea is applied, supplemented with an appropriate amount of potassium fertilizer to promote ear differentiation. As water demand increases significantly during the jointing stage, adequate moisture supply should be ensured to facilitate the development of larger ears and more grains. Key control measures target sheath blight, powdery mildew, and aphids, with timely application of specific pesticides based on the occurrence of pests and diseases.

Management of the heading and flowering stage

This period is highly sensitive to water stress, requiring maintained soil moisture to prevent impaired pollination and fertilization. To enhance seed setting rate and thousand-grain weight, foliar fertilization can be conducted with 0.25% potassium dihydrogen phosphate and 0.1% – 0.2% boron fertilizer. In case of rainy weather during this stage, fungicides such as carbendazim should be promptly sprayed to prevent *Fusarium* head blight.

Management of the filling stage

During the filling stage, soil moisture should be maintained without waterlogging to prevent late-stage drought and lodging. To delay leaf senescence and prolong the accumulation of photosynthetic products, 0.25% potassium dihydrogen phosphate can be sprayed uniformly in the field 1 – 2 times at intervals of 5 – 7 d. Irrigation or application of anti-adversity agents before the onset of dry hot winds can mitigate their adverse effects.

Pest and Disease Control Technology

Disease control technology

Wheat diseases mainly include sheath blight, powdery mildew, stripe rust, leaf rust, and *Fusarium* head blight[6]. Sheath blight manifests as brown cloud-like lesions on the leaf sheaths at the base of wheat plants. In severe cases, it spreads to the stems, leading to lodging or plant death. Occurrence regularity: The pathogen overwinters as sclerotia or mycelia in soil or infected plant debris, begins infection before winter and during the regreening stage, and rapidly spreads during the jointing stage. The control method is seed dressing with 2% tebuconazole at a rate of 0.1% – 0.15% of the seed weight. During the regreening to jointing stage, 2 000 – 3 000 times dilution of 24% thifluzamide suspension concentrate, 500 – 800 times dilution of 10% validamycin A aqueous solution or 2 000 – 3 000 times dilution of 30% difenoconazole propiconazole emulsifiable concentrate is sprayed in the entire field for control. The application is repeated every 7 – 10 d for 2 – 3 successive times. Powdery mildew initially appears as white powdery spots on leaf surfaces, which later turn grayish-white. In severe cases, the entire leaf surface becomes covered, impairing photosynthesis. Occurrence regularity: The pathogen overwinters as mycelia on infected plant residues and spreads rapidly in spring when temperatures rise and humidity increases. At the initial stage of disease occurrence, 1 000 – 1 500 times dilution of 25% triadimefon wettable powder, 2 000 – 3 000 times dilution of 12.5% diniconazole wettable powder or 3 000 – 4 000 times dilution of 40% kresoxim-methyl suspension concentrate is sprayed in the entire field. The application is repeated at intervals of 7 – 10 d for 2 – 3 successive times[7]. Stripe rust appears as yellow stripe-shaped pustules on leaves, arranged along the leaf veins. Occurrence regularity: It tends to prevail under low-temperature and high-humidity conditions, with spring being the primary outbreak period. At the initial stage of disease occurrence, 1 000 – 1 500 times dilution of 25% triadimefon wettable powder, 3 000 – 4 000 times dilution of 43% tebuconazole suspension concentrate or 2 000 – 3 000 times dilution of 25% propiconazole emulsifiable concentrate is sprayed in the entire field for control. In severe cases, the application is repeated once after 7 – 10 d. Leaf rust manifests as reddish-brown, circular or elliptical pustules scattered across the leaf surface. The disease tends to prevail under warm and rainy conditions, primarily affecting the leaves. At the initial stage of occurrence, 1 000 – 1 500 times dilution of 25% triadimefon wettable powder, 2 000 – 3 000 times dilution of 12.5% diniconazole wettable powder or 2 000 – 3 000 times dilution of 30% kresoxim-methyl · difenoconazole suspension concentrate is sprayed in the entire field for control. The application is repeated every 7 – 10 d for 2 – 3 successive times[8]. *Fusarium* head blight is characterized by the appearance of red mold on the ears, along with shriveled and discolored grains, leading to quality deterioration. Occurrence regularity: Outbreaks are likely to occur during the heading and flowering stages under rainy conditions, with the pathogen spreading via wind and rain. During the flowering period, 800 – 1 000 times dilution of 50% carbendazim wettable powder, 1 000 – 1 500 times dilution of 70% thiophanate-methyl wettable powder or 1 000 – 1 500 times dilution of 25% phenamacril suspension concentrate is sprayed in the entire field for control. The application is repeated for 1 – 2 times at intervals of 7 – 10 d.

Pest control technology

Common wheat pests include aphids, wheat midges, and wheat spider mites[9]. Aphid infestation causes leaf yellowing and curling, and they secrete honeydew, leading to sooty mold, and transmission of viral diseases. Occurrence regularity: Rapid reproduction occurs after spring temperatures rise, peaking during the heading stage. At the initial stage of aphid occurrence, 2 000 – 3 000 times dilution of 10% imidacloprid wettable powder, 3 000 – 4 000 times dilution of 25% thiamethoxam water-dispersible granules or 1 500 – 2 000 times dilution of 4.5% beta-cypermethrin emulsifiable concentrate is sprayed in the entire field. The application is repeated at intervals of 7 – 10 d for two successive times[10]. Wheat midge larvae often hide inside glumes to suck sap from grains, resulting in shriveled or empty grains. Occurrence regularity: Mature larvae overwinter in the soil and pupate the following spring, and adults emerge to lay eggs during the heading stage. The control methods include applying 3% phoxim granules at 45 – 75 kg/hm^2 during the pupal stage. During the adult stage, 1 500 – 2 000 times dilution of 4.5% beta-cypermethrin emulsifiable concentrate or 2 000 – 3 000 times dilution of 2.5% deltamethrin emulsifiable concentrate is sprayed in the entire field for control. Wheat spider mite infestation causes wheat leaves to turn chlorotic and whitish, and severe cases lead to withering and yellowing, thereby impairing photosynthesis. Occurrence regularity: Outbreaks are likely under dry and low-rainfall conditions, with spring being the main period of damage. At the initial stage of occurrence, 3 000 – 4 000 times dilution of 1.8% abamectin emulsifiable concentrate, 2 000 – 3 000 times dilution of 20% pyridaben wettable powder or 2 000 – 3 000 times dilution of 15% pyridaben emulsifiable concentrate is sprayed in the entire field for 1 – 2 times at intervals of 5 – 7 d.

Timely Harvesting

Wheat is optimally harvested from the late dough stage to the early full-maturity stage, when the grain moisture content ranges from 20% to 25% and dry matter accumulation peaks. Combine harvesters are used for timely harvesting. After harvesting, grains should be promptly cleaned, dried, and stored when moisture content drops below 13% to prevent mold and insect damage, ensuring both yield and quality.

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