under different water-N and cultivation modes further clarify thresholds for optimizing spike number and grains per spike. In the Huang-Huai Plain, yields below about 7.5 t ha^{-1} depend on jointly increasing spike number and grains per spike, while higher yields rely mainly on further increasing grains per spike through rapid pre-anthesis dry-matter accumulation. Both spike and non-spike dry matter and nitrogen before anthesis show strong positive relationships with grains per spike, whereas excessive N allocation to spikes reduces grain number, indicating that balanced N distribution between spike and vegetative organs is critical for optimizing the main yield component.

Water-nitrogen combinations create strong synergies in both production and resource-use traits. On the North China Plain, factorial irrigation-N experiments showed that both inputs increased total water use, but also intensified water consumption during grain filling and enhanced soil water use, with a clear positive synergy between crop water productivity and nitrogen-use efficiency across treatments. Decomposing nitrogen-use efficiency revealed that this synergy was driven mainly by higher nitrogen uptake efficiency rather than utilization efficiency, particularly where irrigation increased both pre- and post-anthesis N assimilation into grain. Similar interaction mechanisms appear under more complex management matrices that include planting pattern and density. In a semi-humid but drought-prone region, ridge-furrow planting with plastic film, moderate supplementary irrigation, and medium plant density significantly improved grain yield, water productivity, agronomic N-use efficiency and net income compared with flat planting or sub-optimal densities. These effects arose from interactive gains in soil water consumption, population N uptake and effective panicle number per unit area, demonstrating that coordinated adjustment of canopy structure and soil water capture can synchronize water and N supply with the formation of spikes and grains.

Long-term integrated management strategies illustrate how multiple levers can be combined into robust high-yield systems. In North China, integrated soil and crop system management that delayed sowing, increased seeding rate and optimized fertilization and irrigation achieved yields within about 4-5% of an input-intensive “high-yield” treatment, while markedly increasing nitrogen-use efficiency, water productivity and N balance. A related strategy using higher seeding rate, slightly delayed sowing and re-timed N topdressing similarly produced yields close to the maximum treatment but with much higher NUE and net profit, indicating that coordinated adjustment of sowing date, plant density and N partitioning can support both high yield and economic efficiency. At regional and systems scales, integrated crop management (ICM) and eco-friendly practices provide a broader template for stable high production. Global evidence shows that ICM can raise wheat yields by roughly 16-30% through site-specific nutrient management, conservation tillage, and complementary pest and disease control, while reducing excessive N use and environmental risk. Reviews of eco-friendly wheat systems further emphasize that stable high yields require normative strategies that jointly consider cultivar traits, crop rotation, reduced tillage, biological protection and soil agrochemical status, so that management buffers climatic variability while sustaining yield components across seasons.

Acknowledgments

The author expresses deep gratitude to Professor R.X. Cai from the Zhejiang Agronomist College for his thorough review of the manuscript and constructive suggestions.

Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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