thousand-grain weight, grain uniformity, and protein content compared with reduced or no-tillage systems, partly via effects on soil structure, weed pressure, and nutrient dynamics (Ahmadi et al., 2024). Sowing method and organic nutrient management (e.g., raised beds, split farmyard manure with liquid organics) can also enhance spike number, grain yield, and soil biological activity (Sharma et al., 2024). Fertilizer form and biostimulants (e.g., phosphorus, humic acids, mycorrhizae) further influence grains per spike, thousand-grain weight, biological yield, and harvest index, demonstrating multiple pathways from management to yield components and then to total grain yield.

Despite abundant evidence on individual factors, comparatively fewer studies jointly quantify how different management practices reshape the correlation structure and direct versus indirect effects among yield components. This motivates a statistical analysis of yield components in wheat under contrasting management regimes. The central research questions can be framed as: (i) How do key yield components (spikes per area, grains per spike, thousand-grain weight, biological yield, harvest index) respond to different management practices? (ii) How do management-induced changes in these components translate, via correlation and path relationships, into changes in grain yield? (iii) Do specific management practices strengthen the contribution of particular components (e.g., grains per spike or harvest index) to yield?

Based on prior correlation and path-analysis work, the study can hypothesize that: (1) management practices that enhance biological yield, spike number, grains per spike, and harvest index will significantly increase grain yield; (2) the relative importance of numerical components (spikes per area, grains per spike, thousand-grain weight) in determining yield will differ across management regimes; and (3) integrated or optimized management will not only raise yield but also modify the strength and direction of correlations among yield components, revealing management-specific yield-formation pathways. Statistical tools such as correlation, path analysis, and multivariate methods offer an appropriate framework to test these hypotheses and to identify the most responsive and yield-determining components under different management practices.

## 2 Regulatory Effects of Different Management Practices on Wheat Growth and Development

### 2.1 Effects of fertilization intensity on vegetative and reproductive growth

Nitrogen fertilization strongly modifies the hierarchy and plasticity of wheat yield components, with early-formed traits such as tiller and spike number responding differently from later traits like grain number and grain weight (Paolo et al., 2022). Increasing N rate up to about 150-300 $kg{\cdot}N{\cdot}ha^{-1}$ enhances grain number, grain weight, straw biomass, and plant height, although responses are curvilinear and context dependent (Yokamo et al., 2023). The timing of N also matters: delaying N from early tillering to stem elongation or later tends to reduce total yield but can increase grain weight, reflecting a trade-off between grain number and grain size.

Vegetative photosynthetic capacity and biomass accumulation are also sensitive to N intensity. Moderate to high N rates increase leaf area index, chlorophyll content, and flag-leaf photosynthesis, which in turn support higher total dry matter and reproductive organ biomass (Noor et al., 2023). Under partial shading, appropriate N can compensate for reduced light by boosting photosynthetic efficiency and dry matter transfer to ears, but under heavy shading, the regulatory effect of N on vegetative growth and yield formation becomes limited (Hongzhi et al., 2021). Meta-analysis shows that N use efficiency declines at high N and on fertile soils, implying that excessive fertilization may increase biomass but not proportionally increase grain yield.

### 2.2 Impacts of water availability on population structure regulation

Water supply around jointing and heading governs tiller survival and spike formation, thereby shaping population structure. Supplemental irrigation that wets the soil to 0-20 cm at jointing reduces tiller mortality, increases productive spike number, and improves leaf photosynthesis of both main stems and tillers, while deeper irrigation layers mainly increase transpiration and reduce water-use efficiency without clear yield gains (Shang et al., 2020). Deficit irrigation schemes that combine moderate water inputs with suitable planting patterns can raise tiller number, spikelets per spike, grains per spike, and radiation use efficiency, particularly when water is applied at both jointing and heading (Zhou et al., 2020).