genotype × environment interactions. Multi-environment trials under irrigated, drought, and heat-stress conditions show significant variance for genotype, environment, and their interaction, and AMMI/GGE analyses identify specific genotypes that win in irrigated, drought, or heat environments, as well as a subset that combines high mean yield with broad stability across all stress scenarios (Ram et al., 2020). Similar AMMI/GGE analyses in irrigated versus terminal heat-stress environments indicate that some elite lines are specifically adapted to heat, while others show both above-average yield and high stability across contrasting moisture and temperature regimes.

Beyond individual trials, site conditions determine the magnitude of hydrothermal yield penalties. In Germany, combined heat-drought indices during the reproductive phase have the highest explanatory power for yield loss, with poor sites (low soil quality, lower precipitation) suffering two- to three-fold larger reductions than high-quality, high-rainfall locations under comparable stress (Riedesel et al., 2024). Meta-environment analyses of bread and durum wheat under normal, heat, and drought conditions also reveal complex genotype responses in quality traits and micronutrients, yet identify genotypes that maintain yield and nutritional stability across stress environments.

Across climatic zones, management responses in wheat are tightly conditioned by regional temperature, radiation, and precipitation regimes, with optimized water-nutrient-sowing strategies substantially narrowing yield gaps. Soil type and its physicochemical status regulate yield formation by controlling yield components and mediating the benefits of management inputs and organic amendments. Under varying hydrothermal conditions, both genotype choice and site quality govern yield stability, emphasizing the need to combine statistical G×E analysis with site-specific soil and climate information when designing management practices.

8 Case Study: Comparative Analysis of Typical Management Systems on Yield Structure

8.1 Characteristics of high-input intensive management systems

High-input intensive wheat systems are typically defined by full irrigation and relatively high nitrogen (N) rates, designed to maximize grain yield, grain protein and water productivity. Global and regional meta-analyses show that N addition generally increases grain yield by about 15% and water productivity by around 10%, with optimal responses often at 100-200 kg·N·ha^{-1} under humid or irrigated conditions (Wang et al., 2023). In arid zones with drip or micro-sprinkler irrigation, full evapotranspiration replacement combined with high N rates (e.g., 238 kg·N·ha^{-1}) increased grain yield, biological yield and seed index, and raised crop water productivity by more than 20% relative to lower N inputs (Figure 3) (Abdelrhman et al., 2025).

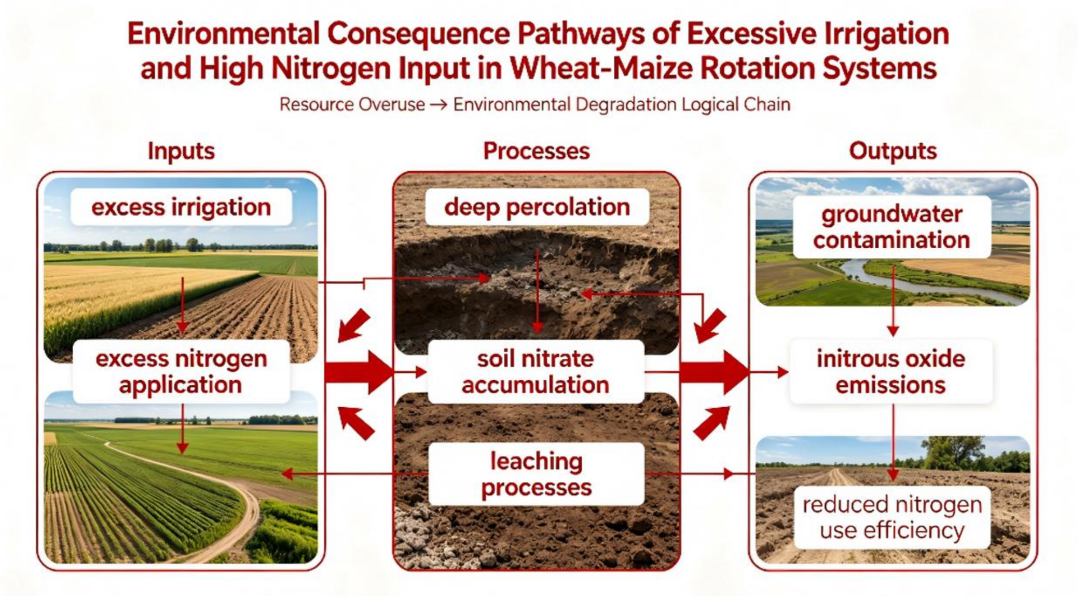

Figure 3 Environmental consequence pathways of excessive irrigation and nitrogen inputs in wheat-based cropping systems, highlighting leaching, groundwater depletion and greenhouse gas emissions