Amini et al. (2023) investigated drought stress memory in common wheat and synthetic wheat germplasm. Treatments included normal irrigation, secondary drought stress after seed priming, drought at jointing followed by severe drought at flowering, and single drought stress at flowering. A total of 27 wheat genotypes were evaluated. Plants exposed to moderate drought during jointing and then severe drought during flowering showed a more effective enzymatic antioxidant system, which reduced later yield loss. Clear differences in stress memory responses were found among genotypes, and synthetic wheat generally performed better than common wheat in grain yield, yield components, and drought resistance index. Changes in proline, soluble sugars, peroxidase, catalase, and ascorbate peroxidase under secondary stress indicated that osmotic adjustment and antioxidant defense are important physiological bases for stress memory formation in winter wheat.

3.4 Source-sink coordination during grain filling

The grain filling stage is the final critical period for yield formation in winter wheat and also the stage most vulnerable to yield risk under water-saving cultivation. The “source” mainly refers to assimilate-producing organs such as the flag leaf, the second leaf below the flag leaf, stems, and spikes, while the “sink” mainly refers to the grains.

Fang et al. (2024) quantitatively analyzed source-sink relationships using 13 years of semi-controlled field experiment data involving six bread wheat genotypes under combinations of high temperature, water deficit, and nitrogen deficiency. Across different environments and genotypes, grain biomass was on average about 10% higher than newly produced aboveground biomass after flowering. This indicates that grain filling does not rely entirely on newly formed photosynthates after anthesis, but also depends on remobilization of assimilates stored before flowering. More importantly, as stress intensity increased, the relative contribution of pre-anthesis assimilates to grain biomass increased from nearly 0 to 100%. This contribution was more strongly affected by water and nitrogen conditions than by temperature. Under drought or nitrogen deficiency, the ability of winter wheat to effectively transport previously accumulated carbohydrates into grains becomes the key factor determining grain filling stability.

On the Huang-Huai-Hai Plain of China, optimized irrigation can also improve source-sink relationships by delaying flag leaf senescence. Yan et al. (2023) reported in a two-year experiment that under traditional border irrigation, a border length of 40 m achieved a good balance between water saving and high yield. Compared with other border lengths, the L40 treatment enhanced antioxidant enzyme activity and sucrose metabolism in the flag leaf after flowering, delayed declines in SPAD value and chlorophyll fluorescence parameters, and promoted grain filling rate and thousand-kernel weight. In contrast, excessively short borders reduced yield, while excessively long borders lowered water productivity.

4 Advances in Water-Saving Cultivation Technology

4.1 Deficit irrigation strategies

Deficit irrigation (DI) is not simply reducing irrigation water input. Instead, it is a targeted regulation of irrigation timing, irrigation amount, and the lower limit of soil moisture according to the sensitivity of winter wheat to water deficit at different growth stages. From the regreening stage to jointing, winter wheat enters a period of rapid vegetative growth, with rapid expansion of leaf area and increased transpiration water consumption. The booting stage, flowering stage, and early grain-filling stage are directly related to spikelet number, grain formation, and dry matter transport to grains, so these stages require the greatest water guarantee in water-saving irrigation. In contrast, moderate water deficit during the overwintering stage, early regreening stage, or late maturity stage has relatively limited effects on final yield. Based on this, the concept of deficit irrigation has gradually formed: “moderate water control during non-critical periods and precise water supply during critical periods.”

From the perspective of regional irrigation systems, water-saving irrigation for winter wheat in the North China Plain emphasizes coordination with interannual precipitation differences. Optimal irrigation strategies differ among years with different rainfall conditions. In wet years, irrigation frequency can be reduced, and sometimes only one supplemental irrigation at flowering is enough. In normal rainfall years and dry years, two irrigations are generally required to balance water supply before and after flowering. The irrigation demand of winter wheat