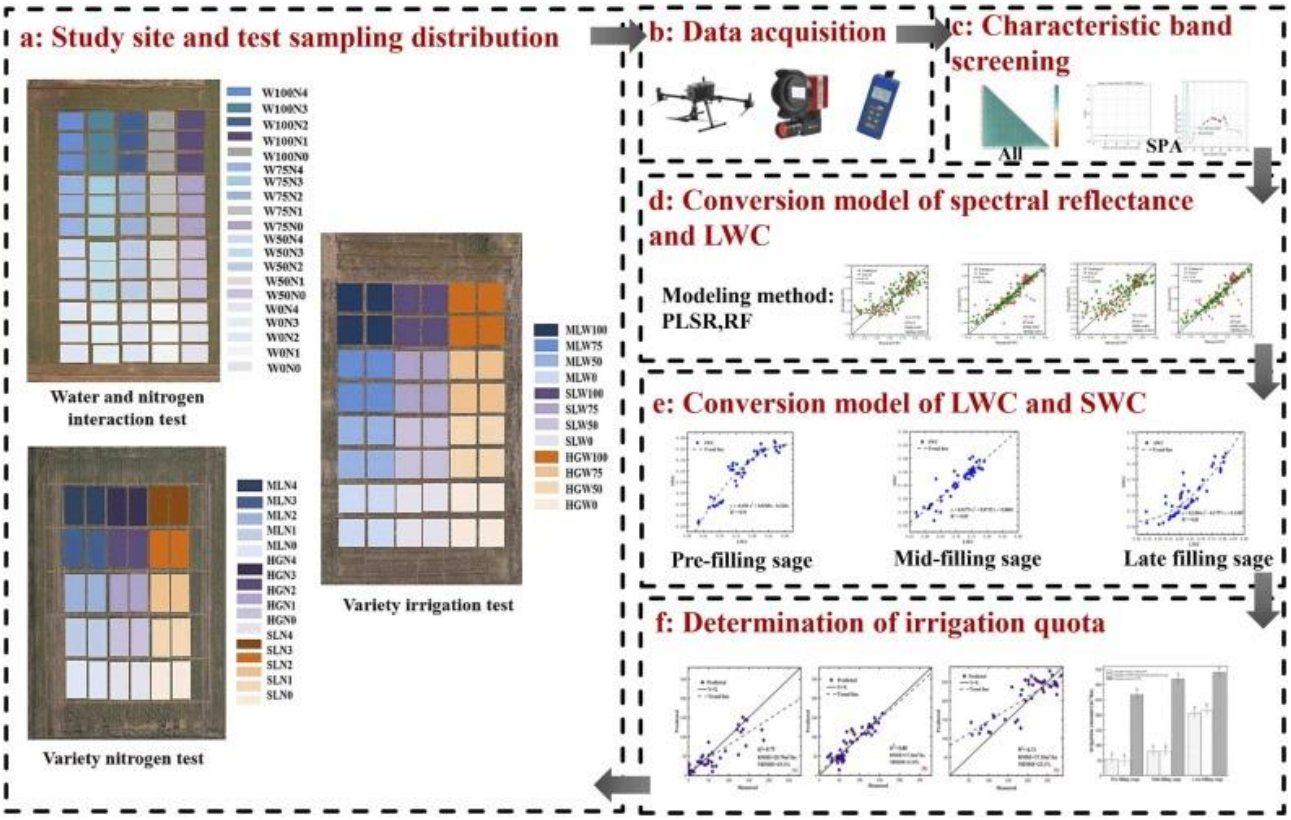

Figure 2 Test distribution and technical roadmap. Note: LWC, leaf water content; SWC, soil water content; PLSR, partial least squares regression; RF, random forest; ALL, hyperspectral band; SPA, successive projections algorithm (Adopted from Sun et al., 2024)

In dryland and semi-arid wheat systems, straw mulching can help retain more rainfall or irrigation water in the tillage layer and reduce evaporation losses from bare soil. Dong et al. (2025) studied the effects of long-term rotary tillage and straw mulching in a rainfed wheat-soybean rotation system. The results showed that appropriate tillage combined with straw management promoted dry matter accumulation, increased grain yield, and improved water use efficiency. Under unstable rainfall conditions, the role of straw mulching is not only to conserve soil moisture but also to influence final yield through improving crop growth and dry matter production.

Qiang et al. (2022) conducted field experiments in Xinxiang, Henan Province, comparing no-tillage, rotary tillage, and subsoiling combined with straw return in terms of tillage layer structure, grain yield, and WUE. Compared with no-tillage, subsoiling significantly reduced soil bulk density in the 20~40 cm layer, increased soil porosity, and reduced soil compaction in the 0~40 cm layer. Subsoiling combined with straw return also increased soil organic carbon in the tillage layer. More importantly, subsoiling promoted the downward movement of irrigation water and rainfall, creating a better soil environment for root growth. Compared with no-tillage, subsoiling increased winter wheat yield by 34.48%~38.10% and improved WUE by 19.57%~21.96%.

4.4 Integrated water and fertilizer management

Water and nutrients do not function independently. Water shortage limits nitrogen transport to the root zone and root absorption, while insufficient nitrogen supply weakens leaf area development, photosynthate accumulation, and root activity. Under water-saving conditions, reducing irrigation without adjusting fertilization can easily result in either “less water but excessive fertilizer” or “insufficient fertilizer efficiency.” On the other hand, simply increasing nitrogen fertilizer without improving water supply may increase the risk of nitrogen residue and leaching.

Wu et al. (2025) studied the effects of regulated deficit irrigation on winter wheat yield formation, water use efficiency, and nitrogen use efficiency under different soil fertility conditions. Regulated deficit irrigation was not