at the institutional level (Bregaglio et al., 2022). In grape production, these thresholds are usually combined with field observations and model outputs, such as downy mildew risk levels and pest phenology models, to help growers move away from fixed-calendar spray programs and adopt risk-based precision management strategies that balance control efficacy with environmental impact (Figure 2).

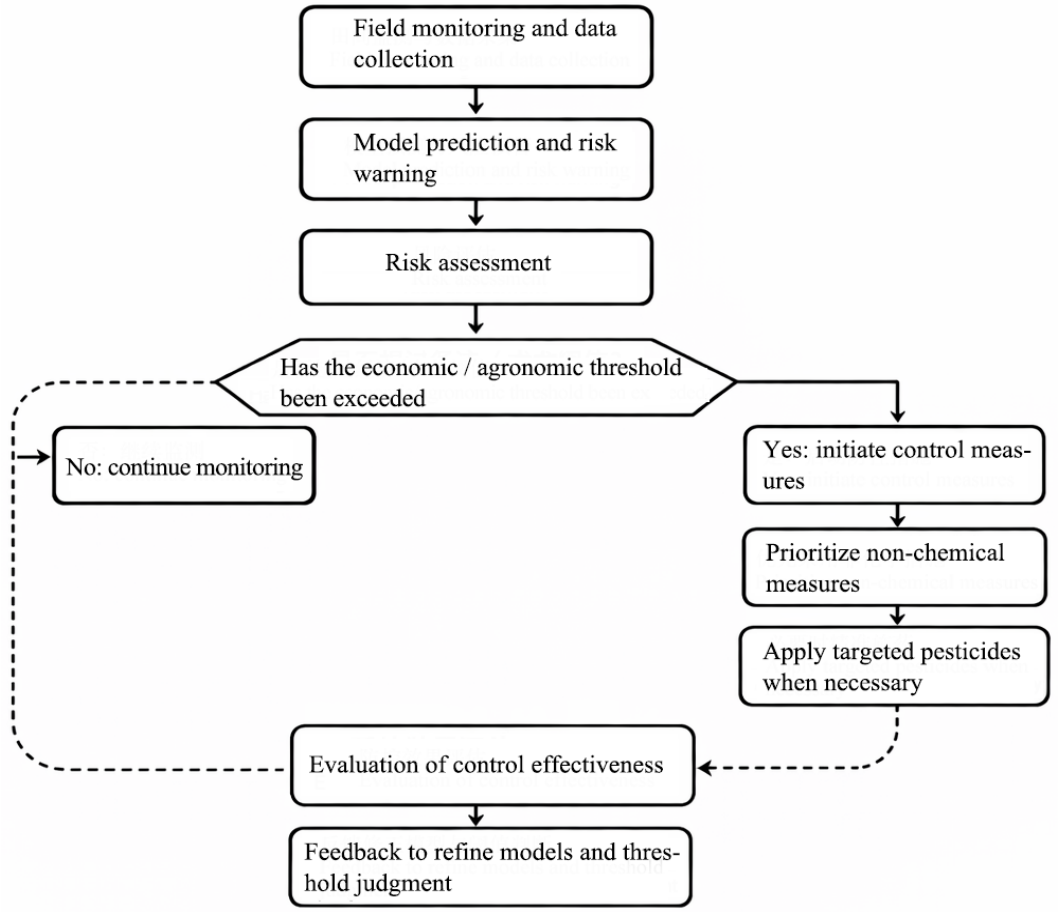

Figure 2 IPM decision flowchart based on economic thresholds

5.2 Monitoring and early warning systems

Field surveys remain the foundation of grape IPM, as they provide direct information for assessing pest and disease occurrence, crop growth stages, and the activity of natural enemies. Through standardized and regular monitoring—including sampling surveys of insects and mites as well as standardized disease assessment methods—it is possible to accurately determine pest and disease status and provide a basis for threshold application and DSS-based decision-making (Lessio and Alma, 2021; Bashyal et al., 2022). For leafhoppers, grape moths, and vector insects that transmit yellows diseases or Pierce's disease, monitoring usually combines trap surveillance with visual inspection of leaves and clusters, supported by predictive models to analyze their population dynamics (Pavan et al., 2026). In many IPM systems, plant protection services or grower organizations establish regional monitoring networks to integrate data from multiple farms and issue risk warnings and management recommendations, thereby enabling area-wide coordinated control and reducing unnecessary pesticide applications.

In recent years, monitoring technologies have evolved into warning systems that integrate field surveys, model analysis, and digital platforms. For example, in the management of grape downy mildew, the MISFITS system developed in Italy combines meteorological data, infection process models, grape phenology simulation, and machine-learning classification algorithms to divide infection risk into five levels, thereby achieving