dependence on insecticides, particularly in the control of pests such as Lobesia botrana (Pertot et al., 2017; Korányi et al., 2025).

Comparative studies of organic and IPM vineyards in Europe further indicate that integrated management can maintain effective control of diseases and weeds while reducing overall toxic load and avoiding some of the limitations associated with strictly organic systems. In Swiss vineyards, long-term use of herbicides and copper-based fungicides has been shown to alter the structure of soil bacterial, fungal, and protist communities and to reduce soil microbial respiration, highlighting the ecological costs of intensive pesticide use (Steiner et al., 2024). In contrast, IPM systems based on limited and targeted pesticide applications are more likely to prevent severe disease outbreaks while reducing these unintended ecological impacts. Research in Hungarian vineyards has also shown that when IPM is combined with surrounding forest cover, which promotes the activity of natural enemies such as birds and bats, strong pest suppression can still be maintained even at lower levels of insecticide input, keeping moth damage to fruit at relatively low levels (Korányi et al., 2025). These studies indicate that integrated management strategies can reduce pesticide dependence while improving the overall functioning of vineyard ecosystems.

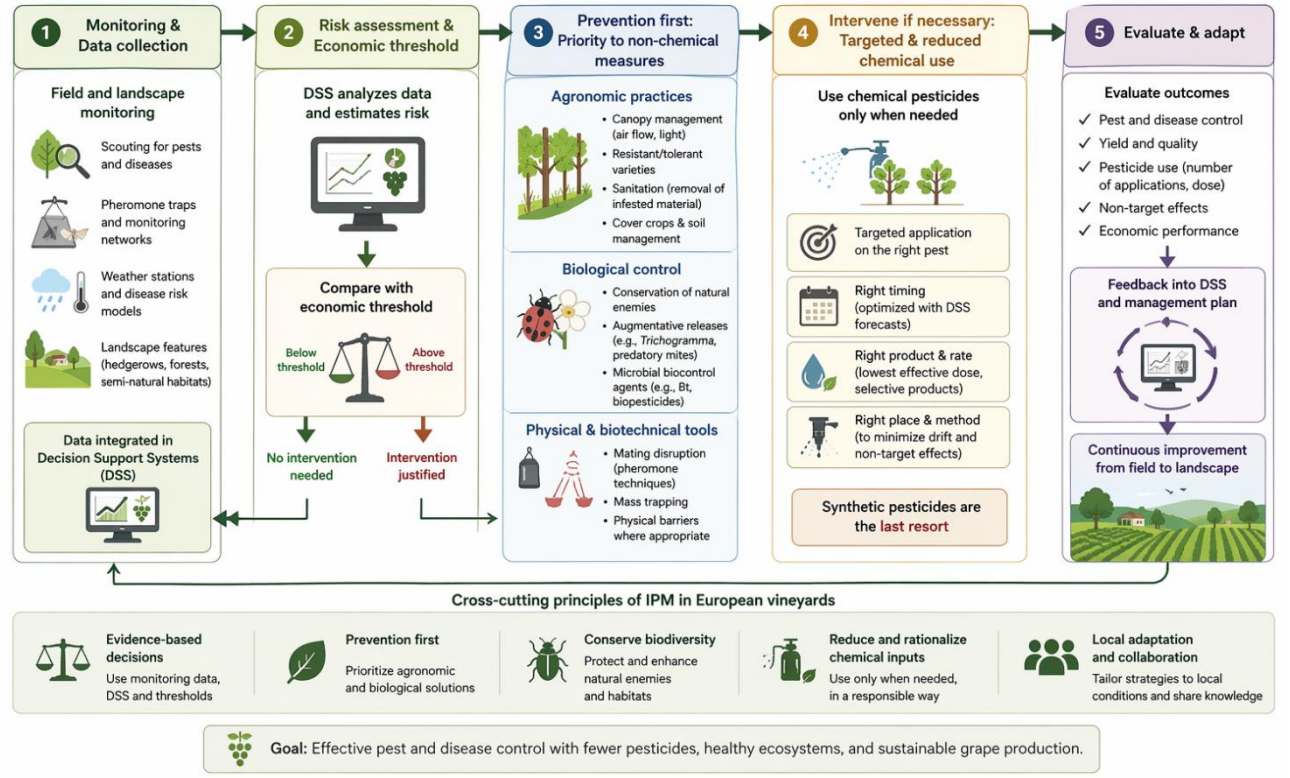

Figure 3 IPM implementation framework in European vineyards

Image caption: This figure outlines the IPM workflow in European vineyards, including monitoring, threshold-based decisions, prevention-first measures, necessary intervention, and evaluation, highlighting the roles of DSS, biological control, and targeted pesticide use in reducing chemical inputs

6.2 Smart vineyard management systems

Smart vineyard management systems are gradually becoming an important complement to traditional IPM, especially in precision viticulture, where they show clear advantages. IoT-based sensors, wireless networks, and remote sensing platforms can now provide real-time, high-spatial-resolution data on microclimate, soil moisture, plant status, and pest and disease indicators (Fuentes-Peñailillo et al., 2024; Mansoor et al., 2025). In a case study of precision viticulture in southern Italy, researchers combined IoT-based monitoring of weather and soil parameters with machine learning models to predict grape diseases, optimize water management, and reduce frost damage, demonstrating that this technology is not only feasible but also brings significant agronomic benefits