

inoculation, and density management (Karavidas et al., 2022). In a sword bean case study, measurements of seed protein, crude fiber, and nutrient concentration would therefore be as informative as yield alone for assessing treatment value.

The sustainability case for integrated management is stronger than the yield case alone because it includes soil health, resource efficiency, and environmental protection. Balanced organic-inorganic fertilization is widely described as the most logical strategy for sustaining long-term soil health and productivity, and integrated systems can increase crop yields by up to 15%~30% while also improving soil organic carbon and broader ecosystem services (Liang et al., 2025). In sword bean production, this means the most desirable treatment may not be the one with the absolute highest short-term yield, but the one that maintains soil function and resource-use efficiency while producing stable biomass and seed output. System-level sustainability also depends on how integrated management uses legumes to reduce external inputs and strengthen agroecosystem resilience. Legume-based systems improve soil health by reducing bulk density, increasing soil organic matter, fixing substantial atmospheric nitrogen, and reducing the need for inorganic N fertilizer, while legumes more broadly are valued because they support crop diversity, conserve resources, and fit low-input and conservation systems (Akchaya et al., 2025). Overall, a sword bean case study should evaluate integrated management not only by growth and yield, but by its capacity to deliver stable productivity, better seed quality, and more sustainable use of soil, water, and nutrient resources.

7 Advances and Future Perspectives in Sword Bean Production Management

7.1 Application of precision agriculture technologies in sword bean cultivation

Precision agriculture offers a practical pathway for improving sword bean management because it uses data-driven tools to optimize inputs while reducing resource waste and environmental impact (Mansoor et al., 2025). Across field crops, remote sensing, IoT, GIS, GPS, big-data analytics, and AI are increasingly used to monitor crop status, characterize spatial variability, and support site-specific management decisions that improve production efficiency. For sword bean, these tools are especially relevant where growth varies across fields because of uneven soil moisture, nutrient supply, or pest pressure. Recent sensor platforms suggest that sword bean cultivation could benefit from real-time monitoring of soil, canopy, and weather conditions linked to automated responses. IoT-enabled systems can integrate soil-moisture sensing, air sensing, automatic watering, pesticide application, and crop-health diagnostics, while bean-specific AI models have already shown accurate real-time discrimination between healthy and diseased leaves with lower computation time (Devi et al., 2023). More broadly, soil-moisture sensors, automated irrigation, and predictive analytics can improve water management and help forecast yield, pest outbreaks, and disease occurrence before losses become severe.

Remote sensing is likely to become one of the most useful precision tools for sword bean because it can monitor crop status across space and time without destructive sampling. Multispectral and hyperspectral imaging already support crop-health monitoring and spatially variable input application, and the fusion of spectral data with LiDAR can detect changes even within different parts of individual plants. Proximal sensing and UAV-based sensing also improve the fidelity of structural and physiological measurements by reducing environmental noise and increasing spatial resolution, which is valuable for detecting subtle stress responses in legumes (Berlingeri et al., 2025). The main future challenge is not the lack of digital tools, but their adaptation to real farm conditions and smallholder systems. Reviews of smart agriculture emphasize that broader adoption still depends on solving problems of startup cost, connectivity, data integration, real-time decision support, and farmer-friendly interfaces. For sword bean, future research should therefore move beyond technology demonstration and develop affordable, field-validated decision systems that translate sensor data into clear management recommendations for irrigation, fertilization, disease control, and planting windows.

7.2 Integration of physiological, molecular and ecological approaches

Future sword bean improvement will depend on integrating physiological understanding with molecular tools rather than treating them as separate research domains. In legumes, integrated frameworks that combine genomics, systems biology, physiology, breeding, and crop modeling are proposed as the most effective way to improve