

includes system productivity and resilience rather than sole-crop growth alone. Meta-analysis shows that intercropping often reduces legume grain and biomass yield relative to sole cropping but increases total land-equivalent productivity, with total LER values of 1.2-1.9, while broader review evidence shows that optimized row arrangement in legume intercrops can improve land productivity and resource-use efficiency. In a sword bean case study, this justifies comparing sole-crop sword bean with a carefully designed intercrop or rotational sequence if the aim is to assess integrated management at both crop and system level.

6.2 Effects of management practices on growth and physiological traits

Integrated management tends to improve vegetative growth and physiological vigor when balanced organic and inorganic nutrient sources are combined. In chickpea, the 50% organic plus 50% inorganic nitrogen treatment produced the highest plant height, dry matter accumulation, crop growth rate, relative growth rate, branch number, nodule number, and SPAD chlorophyll reading, outperforming both fully organic and 75: 25 treatments, and common bean reviews likewise conclude that reducing mineral nitrogen dependence through better biological fixation and stage-adjusted agronomy is central to optimizing crop performance. For sword bean, similar responses would be expected as improved nutrient synchrony promotes canopy development, chlorophyll retention, and nodulation without the inefficiencies of excessive single-source fertilization. Physiological improvements under integrated management are not limited to shoot growth, because belowground responses are equally important. Organic and inorganic nutrient combinations improve soil physical, chemical, and biological properties, which enhances nutrient availability and microbial conversion of less available forms, while biofertilizer inoculation can further stimulate nutrient supply and crop growth through rhizosphere colonization. In a sword bean experiment, these mechanisms would likely appear as stronger root development, more active nodulation, and improved nitrogen and phosphorus capture, especially where management includes microbial inoculants or residue-based amendments.

Water and soil management can further amplify these growth responses when integrated with nutrient treatments. Conservation tillage with crop-residue retention and organic manures improves macro-aggregation, soil-water storage, and bulk density, and legume intercropping systems can improve water-use efficiency by about 20-25% and nutrient-use efficiency by about 25%~30% across diverse environments (Choudhary et al., 2020; Akchaya et al., 2025). In sword bean, such conditions would be expected to support steadier physiological performance during vegetative and reproductive transition phases by buffering short-term water stress and maintaining more favorable root-zone conditions. Growth responses should still be interpreted cautiously because management effects vary with species, soil, and companion crop. A meta-analysis across smallholder legume systems found that inoculation and phosphorus application consistently increased grain and biomass yield, whereas minimum tillage showed no clear productivity effect and intercropping reduced legume biomass to varying extents depending on the associated non-legume crop. A sword bean case study should therefore analyze interactions carefully, since an integrated package that improves chlorophyll status and biomass in one soil or cropping context may not produce the same magnitude of response in another.

6.3 Impacts on yield, quality and agricultural sustainability

Integrated management usually improves yield most when nutrient supply is balanced and matched to crop demand over time. In the long-term maize-chickpea system, 75% soil-test-based NPK plus FYM at 5 Mg/ha increased mean grain yield by 20.9% in maize and 13.08% in chickpea over the general recommended dose, while broader INM evidence reports crop-yield gains ranging from 1.3% to 66.5% over conventional nutrient management across major cropping systems (Paramesh et al., 2023). For sword bean, this supports the expectation that integrated packages can improve pod and seed yield more reliably than either low-input or fully mineral-fertilizer strategies alone. Quality responses are also important because integrated nutrient supply can improve protein and nutrient accumulation rather than only total biomass. Reviews of pulse seed quality report that combining organic and inorganic nutrient sources with biofertilizer inoculation significantly increased phosphorus uptake, protein content, nitrogen, and potassium compared with other treatments, and integrated legume-management reviews identify yield and quality together as major targets of fertilization, irrigation,