

8 Conclusions

Sword bean shows broad agronomic potential because it combines favorable tropical adaptation with comparatively high yield potential among underutilized legumes. Its growth pattern is vigorous but relatively long, with a vegetative phase of about 4-5 months and pod maturation often extending another 5-6 months or more, so management effects accumulate across a long crop cycle. Nitrogen management improves quality more consistently than biomass, since urea treatments produced similar forage yields but altered crude protein and crude fiber, and the 50 kg/ha treatment was considered efficient while preserving rhizobial function. Phosphorus management is more decisive for reproduction, because P fertilization increased yield on acid upland soil, whereas crops without P formed pods but failed to produce seed.

Growth responses also depend strongly on biological and environmental management. VAM inoculation increased nitrogen uptake in sword bean leaves and interacted with rock phosphate to influence phosphorus uptake, showing that nutrient efficiency depends partly on symbiosis rather than fertilizer dose alone. Climatic adaptation is equally important, because under Western Poland conditions only the early cultivar produced viable seed, while the late cultivar remained immature, indicating strong sensitivity to temperature and season length. Field emergence above 60% under those conditions still showed that the crop can establish outside its usual range, but weather remained a crucial determinant of flowering and seed filling. Genotypic diversity adds another management opportunity, since evaluation of 20 native genotypes revealed variation in germination time, pod size, pod weight, and seed weight that breeders can exploit for local adaptation.

The main implication for productivity is that sword bean should be managed as a resource-efficient legume, not as a crop that simply requires high mineral inputs. Evidence from sword bean shows that moderate nitrogen can maintain forage quality efficiently, while broader legume evidence indicates that inclusion of legumes in cropping systems can reduce dependence on synthetic nitrogen through biological fixation. This makes phosphorus availability, root activity, and microbial functioning particularly important targets for management improvement on marginal or acidic soils. In practical terms, productivity gains are likely to come from combining moderate fertilization with inoculation, moisture support, and suitable cultivars rather than from maximizing one input alone.

Productivity improvement also depends on matching sword bean to systems where its ecological functions create added value. The crop grows well in poor or marginal soils and has potential as food, feed, and green-manure material, so its performance should be evaluated at both crop and system level. Reviews of legume intercropping show gains in land productivity, soil health, water-use efficiency, and nutrient-use efficiency, which suggests that sword bean can contribute more through diversified systems than through isolated monoculture evaluation alone. This system perspective is especially relevant for underutilized legumes, whose commercial value often depends on multiple outputs such as seed, forage, soil improvement, and resilience under low-input conditions. Accordingly, improving sword bean productivity means increasing not only yield per hectare, but also stability, nutritional value, and contribution to agroecosystem function.

Future work should focus first on locally adapted agronomic packages for sword bean, because available studies still show large knowledge gaps in cultivation technology, especially for marginal soils and nontraditional environments. Region-specific recommendations are needed for spacing, sowing time, water management, phosphorus strategy, and integrated nutrient use, since sustainability outcomes in legume systems depend strongly on local climate, soil conditions, and field management. Longer-term studies should also test sword bean in intercrops and rotations, because legume-based systems improve soil structure, microbial activity, nutrient cycling, and resilience, but adoption still depends on practical design and economic feasibility. In that context, sword bean is a strong candidate for sustainable intensification because it fits low-input production goals while contributing protein and soil-restorative functions.

A second priority is genetic and physiological improvement linked directly to management needs. Sword bean genotypes already differ substantially in germination and pod traits, and related *Canavalia* improvement studies