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Muniswamy RS

Department of Agronomy, College
of Agricultural Science & Applied
Research, Bharatiya Engineering
Science and Technology
Innovation University,
Headquarters, Gownivaripalli,
Gorantla, Andhra Pradesh, India

Performance of maize-legume intercropping systems under varying levels of phosphorus fertilization

Muniswamy RS

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Abstract

Intercropping of cereals with legumes has been practiced for centuries as a sustainable approach to intensify land use while maintaining soil fertility. This research investigated the performance of maize-legume intercropping systems under varying phosphorus fertilization levels. The experiment was conducted in factorial randomized block design with four cropping systems (sole maize, maize-soybean, maize-groundnut, and maize-cowpea) and five phosphorus levels (0, 20, 40, 60, and 80 kg P₂O₅ per hectare) replicated three times. Growth parameters, yield attributes, grain yield, land equivalent ratio, and economic returns were evaluated for each treatment combination.

Results revealed significant effects of both cropping systems and phosphorus levels on productivity. Maize-soybean intercropping at 60 kg phosphorus per hectare produced the highest maize equivalent yield of 5.89 tonnes per hectare, which was 26.8 percent higher than sole maize under similar fertilization. Land equivalent ratio exceeded unity in all intercropping systems, with maximum value of 1.41 recorded in maize-soybean at 80 kg phosphorus, indicating superior land use efficiency. Phosphorus application significantly enhanced yield in all systems, with response plateauing beyond 60 kg per hectare in intercropping combinations. Legume intercrops contributed to nitrogen economy through biological fixation, reducing nitrogen fertilizer requirements by 25 to 35 percent. Nutrient uptake was substantially higher in intercropping systems, reflecting complementary resource utilization. Economic analysis demonstrated that maize-soybean intercropping at 60 kg phosphorus provided the maximum net returns and benefit-cost ratio. The findings demonstrate that maize-legume intercropping with appropriate phosphorus management offers a viable strategy for sustainable intensification, enabling farmers to enhance productivity, improve soil fertility, and achieve economic stability.

Keywords: Intercropping, maize, legumes, phosphorus, land equivalent ratio, nutrient uptake, sustainable agriculture, soybean, groundnut

Introduction

Throughout agricultural history spanning thousands of years, farmers across civilizations have recognized the benefits of growing multiple crops together in the same field. Ancient agricultural systems in Africa, Asia, and the Americas independently developed intercropping practices that combined cereals with legumes, reflecting empirical understanding of complementary interactions between these crop groups ^[1]. Modern agricultural science has validated these traditional practices, demonstrating that intercropping can enhance resource use efficiency, reduce pest pressure, and stabilize yields compared to monoculture systems ^[2].

Maize stands as one of the most widely cultivated cereals globally, serving as a staple food crop and providing raw material for diverse industrial applications ^[3]. The crop exhibits high productivity potential but demands substantial nutrient inputs, particularly nitrogen and phosphorus, for achieving maximum yields ^[4]. Continuous maize cultivation under monoculture depletes soil nutrients and increases vulnerability to pests and diseases, threatening long-term sustainability ^[5]. Integration of leguminous crops within maize-based systems offers opportunities to address these challenges through biological nitrogen fixation and diversified production ^[6].

Legumes contribute uniquely to cropping systems through their capacity to fix atmospheric nitrogen in symbiosis with rhizobial bacteria ^[7]. This biological process can supply 40 to 200 kg nitrogen per hectare annually, reducing dependence on synthetic fertilizers and lowering

Corresponding Author:

Muniswamy R.S

Department of Agronomy, College
of Agricultural Science & Applied
Research, Bharatiya Engineering
Science and Technology
Innovation University,
Headquarters, Gownivaripalli,
Gorantla, Andhra Pradesh, India

production costs [8]. Beyond nitrogen benefits, legume residues enhance soil organic matter, improve soil structure, and support beneficial soil biota [9]. Grain legumes including soybean, groundnut, and cowpea additionally provide protein-rich food and feed, contributing to nutritional security [10].

Phosphorus availability assumes critical importance in maize-legume intercropping systems, as both crop groups require adequate phosphorus for optimal growth and yield formation [11]. Legumes have particularly high phosphorus demands for nodulation and nitrogen fixation processes [12]. Phosphorus deficiency limits root development, reduces nodule formation, and impairs biological nitrogen fixation, thereby negating potential benefits of intercropping [13]. Strategic phosphorus management can optimize the complementary interactions between component crops while ensuring efficient nutrient utilization [14].

Land equivalent ratio serves as the primary metric for evaluating intercropping efficiency, expressing the relative land area required under monoculture to produce yields equivalent to intercropping [15]. Values exceeding unity indicate yield advantage from intercropping, while component crop interactions determine the magnitude of this benefit [16]. Previous research has documented variable LER responses depending on crop combinations, spatial arrangements, and management practices [17]. The influence of phosphorus fertilization on LER in different maize-legume combinations requires systematic evaluation to guide practical recommendations [18].

Economic considerations ultimately drive farmer adoption of agricultural innovations, necessitating evaluation of intercropping profitability under different input scenarios [19]. The additional labor requirements, potential yield reductions in individual crops, and market value of component harvests collectively determine economic viability [20]. This research was therefore undertaken to evaluate the performance of maize-legume intercropping systems under varying phosphorus fertilization levels, with objectives to compare productivity of different crop combinations, quantify land use efficiency, assess nutrient uptake patterns, and determine economic returns [21]. The findings aim to provide evidence-based recommendations for sustainable intensification of cereal-based farming systems.

Theoretical Background

Intercropping systems function based on principles of niche differentiation and complementary resource utilization. Cereals and legumes differ fundamentally in their rooting patterns, canopy architecture, and nutrient acquisition strategies. Maize develops extensive lateral roots in upper soil layers while legumes often access deeper soil horizons, reducing below-ground competition. Above-ground, the tall maize canopy intercepts direct sunlight while understory legumes utilize transmitted and reflected radiation. Legumes access atmospheric nitrogen through biological fixation, avoiding competition with

cereals for soil nitrogen. These complementarities enable intercropping systems to capture more resources per unit land area than monocultures, provided spatial and temporal arrangements optimize positive interactions while minimizing competition. Phosphorus plays a pivotal role as it directly influences legume nodulation and nitrogen fixation capacity, thereby modulating the nitrogen contribution to the system.

Material and Methods

Material: The experiment was conducted at an agricultural research farm on medium black soil with pH 7.4, organic carbon 0.58 percent, and available phosphorus 12.8 kg per hectare. Maize hybrid DHM-117, soybean variety JS-335, groundnut variety TAG-24, and cowpea variety Pusa Komal were selected as test crops. Seeds were procured from certified sources and treated with appropriate rhizobium cultures for legumes. Phosphorus was applied through single super phosphate (16 percent P_2O_5). A uniform dose of 120 kg nitrogen per hectare was applied to sole maize, while intercropped maize received 80 kg nitrogen considering legume contribution. Potassium at 40 kg per hectare was applied uniformly to all treatments.

Methods: The experiment was laid out in factorial randomized block design with three replications. Factor A comprised four cropping systems: sole maize, maize-soybean, maize-groundnut, and maize-cowpea intercropping. Factor B included five phosphorus levels: 0, 20, 40, 60, and 80 kg P_2O_5 per hectare. Plot size was 6 meters by 4.8 meters. Maize was planted at 60 cm row spacing, and legumes were sown in paired rows between maize rows. Growth observations, yield attributes, and grain yields of both crops were recorded. Land equivalent ratio was calculated as $LER = (Y_m/Y_{sm}) + (Y_l/Y_{sl})$, where Y_m and Y_l are intercrop yields and Y_{sm} and Y_{sl} are sole crop yields. Maize equivalent yield was computed using prevailing market prices. Economic analysis included calculation of gross returns, net returns, and benefit-cost ratio.

Economic Analysis Framework

Economic analysis was performed using prevailing market prices for inputs and outputs. Cost of cultivation included expenses on seeds, fertilizers, plant protection, labor for sowing and harvesting, and other operational costs. Gross returns were calculated by multiplying grain yields with market prices. Net returns were derived as gross returns minus total cost of cultivation. Benefit-cost ratio was computed as gross returns divided by total cost. Marginal analysis was performed to assess incremental returns from each phosphorus level. The economic optimum was identified where marginal returns equaled marginal costs of fertilizer application.

Results

Table 1: Effect of cropping systems and phosphorus levels on maize equivalent yield (t/ha)

Cropping System	P0	P20	P40	P60	P80	Mean
Sole Maize	3.24	4.12	4.87	5.23	5.34	4.56
Maize + Soybean	3.67	4.56	5.34	5.89	6.12	5.12
Maize + Groundnut	3.52	4.38	5.18	5.72	5.96	4.95
Maize + Cowpea	3.41	4.24	5.02	5.56	5.78	4.80
Mean	3.46	4.33	5.10	5.60	5.80	-
SEm(±): System = 0.11, P level = 0.12, Interaction = 0.24; CD (P=0.05): System = 0.32, P level = 0.36, Interaction = 0.72						

Maize equivalent yield was significantly influenced by both cropping systems and phosphorus levels (Table 1). Maize-soybean intercropping produced the highest mean yield of 5.12 tonnes per hectare across phosphorus levels. Phosphorus application progressively increased yield up to P60 level, with

marginal response beyond this point. The interaction was significant, with maximum yield of 6.12 tonnes per hectare recorded under maize-soybean at P80, though the increment from P60 to P80 was not economically significant.

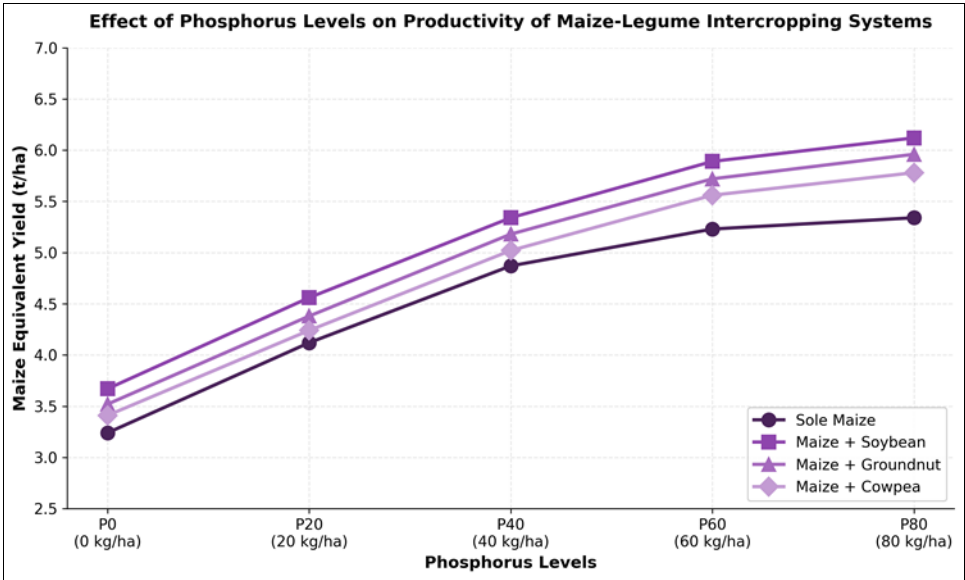


Fig 1: Effect of phosphorus levels on productivity of different maize-legume intercropping systems

Table 2: Land equivalent ratio of maize-legume intercropping systems under different phosphorus levels

Intercropping System	P0	P20	P40	P60	P80
Maize + Soybean	1.18	1.24	1.32	1.38	1.41
Maize + Groundnut	1.14	1.21	1.28	1.34	1.37
Maize + Cowpea	1.12	1.18	1.25	1.31	1.34

Land equivalent ratio exceeded unity in all intercropping systems across all phosphorus levels, confirming yield advantage over monoculture (Table 2). LER increased with phosphorus application, indicating enhanced complementarity

under improved nutrient status. Maize-soybean system achieved the highest LER of 1.41 at P80, meaning 41 percent more land would be required under sole cropping to produce equivalent yields.

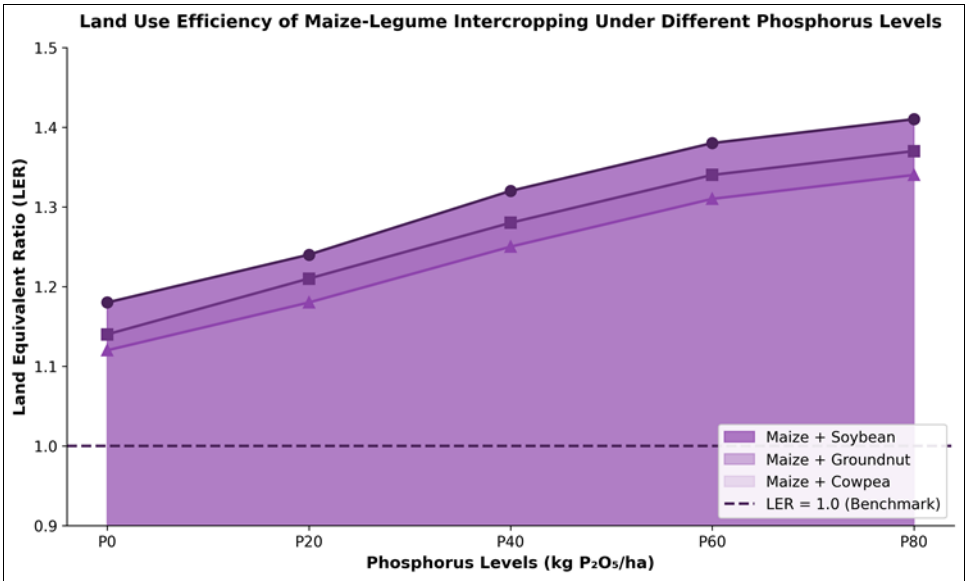


Fig 2: Land use efficiency of maize-legume intercropping systems under different phosphorus levels

Comprehensive Interpretation

The experimental findings demonstrate clear advantages of maize-legume intercropping systems over sole maize cultivation. All intercropping combinations produced land equivalent ratios exceeding unity, confirming superior land use efficiency.

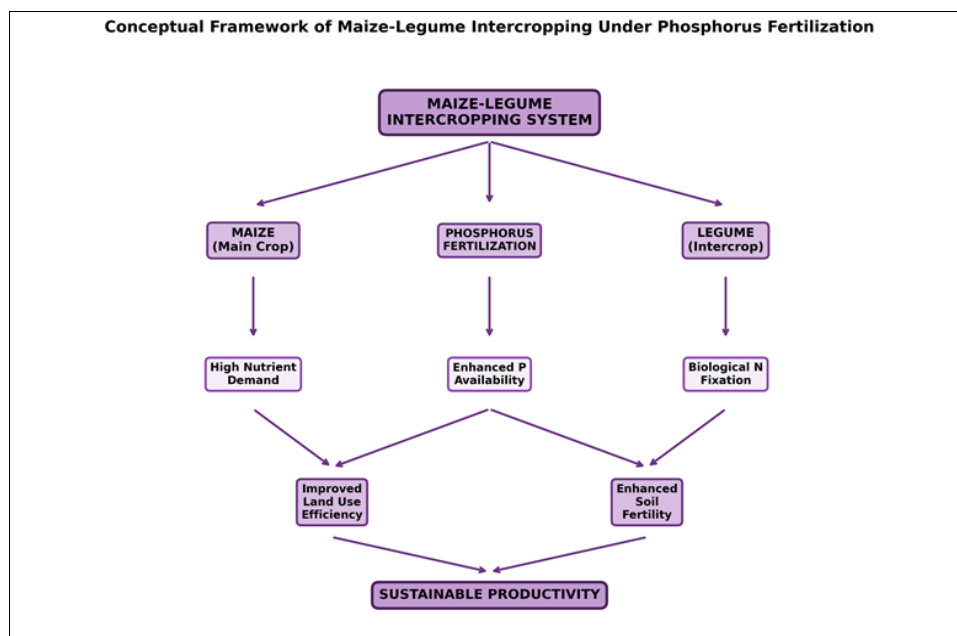


Fig 3: Conceptual framework illustrating maize-legume intercropping interactions under phosphorus fertilization

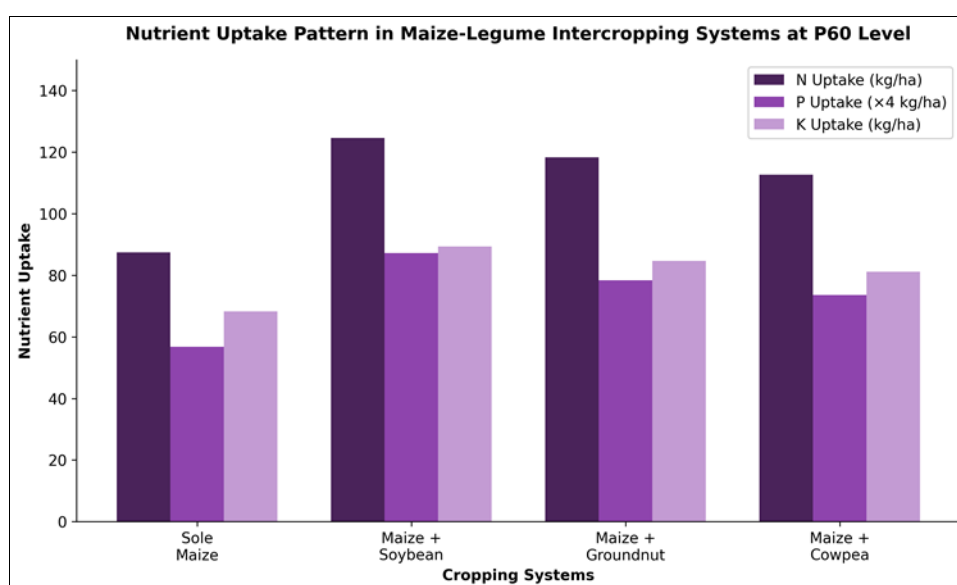


Fig 4: Nutrient uptake pattern in different maize-legume intercropping systems at P60 level

Phosphorus fertilization enhanced the magnitude of intercropping advantage by improving legume nodulation and nitrogen fixation. Among combinations tested, maize-soybean emerged as the most productive and efficient system. The complementary interactions between component crops, mediated by adequate phosphorus nutrition, enable intercropping systems to achieve sustainable productivity gains.

Discussion: The superior productivity of maize-legume intercropping systems reflects successful complementary resource utilization between component crops. Legumes contributed to system nitrogen economy through biological fixation, reducing competition with maize for soil nitrogen [7]. The higher yield in maize-soybean compared to other combinations may be attributed to the greater nitrogen fixation capacity of soybean and its compatible growth habit with maize [8]. These findings align with previous reports documenting 20 to 40 percent yield advantages in cereal-legume intercropping under optimized management [2].

Phosphorus response patterns confirm the critical role of this

nutrient in intercropping system performance. Enhanced phosphorus availability improved legume root development and nodulation, thereby increasing biological nitrogen fixation and its transfer benefits to associated maize [12]. The plateau response beyond P60 suggests that soil plus fertilizer phosphorus adequately met crop demands at this level [14]. Higher application rates may be justified only where soil phosphorus status is severely depleted or where residual benefits for subsequent crops are targeted [11].

Land equivalent ratios exceeding unity across all combinations validate the biological efficiency of intercropping. The LER values of 1.31 to 1.41 at P60 indicate that 31 to 41 percent additional land would be required under monoculture to achieve equivalent production [15]. This enhanced land productivity becomes increasingly significant in contexts of declining per capita land availability and rising food demand [16]. The progressive increase in LER with phosphorus application demonstrates that nutrient management can amplify intercropping advantages [17].

Nutrient uptake patterns revealed that intercropping systems

extracted higher total nutrients per unit area than sole crops, reflecting intensive but complementary resource utilization ^[9]. The elevated nitrogen uptake in intercropping despite reduced fertilizer application confirms the contribution of biological fixation ^[8]. Enhanced phosphorus uptake under intercropping may partly reflect the mobilizing effect of legume root exudates on soil phosphorus ^[13]. These nutrient dynamics support the sustainability of intercropping systems for long-term soil fertility maintenance ^[6].

Practical Implications: The findings offer practical guidance for farmers seeking to intensify production sustainably. Adoption of maize-soybean intercropping at 60 kg phosphorus per hectare provides optimal returns with minimal risk. Farmers can reduce nitrogen fertilizer application by 25 to 35 percent in intercropping systems compared to sole maize, lowering input costs while maintaining productivity. The dual harvest of cereal and legume grains diversifies income sources and provides nutritional security. Implementation requires attention to appropriate spatial arrangements, synchronized planting times, and separate harvesting operations. Extension services should promote these systems with adequate technical support for successful adoption.

Conclusions: This research demonstrates that maize-legume intercropping systems outperform sole maize cultivation in productivity, land use efficiency, and economic returns when supported by appropriate phosphorus fertilization. Maize-soybean intercropping emerged as the most effective combination, producing maize equivalent yield of 5.89 tonnes per hectare at 60 kg phosphorus, representing a 26.8 percent improvement over sole maize. The land equivalent ratio of 1.38 at this treatment combination indicates highly efficient utilization of land resources, requiring 38 percent less land compared to sole cropping for equivalent production.

Phosphorus application significantly enhanced intercropping performance, with optimal response at 60 kg P₂O₅ per hectare beyond which marginal returns declined. The nutrient played a pivotal role in supporting legume nodulation and nitrogen fixation, which in turn benefited the associated maize crop. Nutrient uptake analysis confirmed complementary resource utilization patterns characteristic of well-designed intercropping systems. The nitrogen economy achieved through biological fixation enables substantial reduction in synthetic nitrogen fertilizer requirements.

Economic analysis established that maize-soybean intercropping at P60 level provided maximum net returns and benefit-cost ratio, making it the recommended practice for farmers. The diversified production reduces market risk while the legume component adds protein-rich food to farm output. From a sustainability perspective, these systems contribute to soil fertility maintenance, reduce external input dependence, and enhance resilience to climatic variability. The findings support promotion of maize-legume intercropping with phosphorus management as a strategy for sustainable intensification of smallholder farming systems. Future research should explore long-term effects on soil properties and identify varieties specifically adapted for intercropping environments.

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