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Response of lentil (*Lens culinaris*) to graded phosphorus application under varying soil phosphorus availability

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Abstract

Why do phosphorus recommendations for lentil still rely on generalized legume guidelines when lentil has one of the smallest and least efficient root systems among pulse crops? This research quantified lentil grain yield, P uptake, and economic return across five P₂O₅ rates (0, 20, 40, 60, 80 kg/ha) on soils classified as low, medium, and high in available P at the University of Bonn, Germany, during 2021 and 2022. On low-P soils, yield increased from 0.74 to 1.78 t/ha with 80 kg P₂O₅/ha, but the economic optimum was 60 kg P₂O₅/ha. On high-P soils, no significant yield response occurred beyond 20 kg P₂O₅/ha. Phosphorus harvest index averaged 67.3 percent, indicating strong grain P loading. Site-specific P management based on soil test values could save 20 to 60 kg P₂O₅/ha compared to blanket recommendations.

Keywords: Lentil, phosphorus response, soil phosphorus, P use efficiency, P harvest index, site-specific management, yield optimization, economic return, pulse crops, *Lens culinaris*

Introduction

Phosphorus is the most yield-limiting nutrient for lentil after nitrogen, yet P management recommendations for this crop are often borrowed from soybean or common bean, ignoring lentil's comparatively shallow and fibrous root system that explores less soil volume ^[1, 2]. In European cropping systems, lentil is experiencing a revival as a rotational crop, but P response data under temperate European conditions are surprisingly thin ^[3].

Lentil's responsiveness to P depends heavily on background soil P availability. On low-P soils, large yield gains are expected, while on well-fertilized soils, additional P may offer no economic return and could contribute to environmental P loading ^[4, 5]. This research established site-specific P response curves for lentil across three soil P categories to develop more precise fertilizer recommendations for European production.

Research area description

The trials were established at the University of Bonn's Klein-Altendorf Research Station (50.62°N, 6.99°E, elevation 160 m) on three adjacent fields with contrasting P histories. Low-P field: Olsen P 6.8 mg/kg; medium-P field: 14.7 mg/kg; high-P field: 27.3 mg/kg. All fields shared a silt loam Luvisol with pH 6.4–6.8 and organic carbon 1.2–1.5 percent. Mean annual rainfall is 625 mm with a growing season from March to August.

Experimental design

A split-plot design was used with soil P category as the main plot and P₂O₅ rate (0, 20, 40, 60, 80 kg/ha as triple superphosphate) as the subplot, with four replications per field. Subplot size was 6 × 2 m. Lentil cv. Castelluccio was sown at 300 seeds/m² in late March each year. Basal fertilization included 20 kg K₂O/ha and Rhizobium inoculation at sowing. No nitrogen fertilizer was applied.

Material and Methods

Material

Soil samples (0–20 cm) were collected before sowing for Olsen P, pH, and organic carbon. Plant

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tissue was sampled at flowering (50% bloom) and maturity for P concentration by nitric-perchloric acid digestion and colorimetric determination. Grain, straw, pod wall, and root fractions were separated at maturity for P partitioning analysis.

Methods

Grain yield was determined from a 4 m² harvest area per subplot, adjusted to 14 percent moisture. P uptake was calculated as tissue P concentration × dry matter. P use

efficiency (PUE) was defined as kg grain per kg P₂O₅ applied. P harvest index = grain P ÷ total plant P × 100. Economic optimum P rate was determined by marginal analysis using local fertilizer price (€1.20/kg P₂O₅) and lentil grain price (€0.85/kg). Data were analyzed by split-plot ANOVA in R 4.3.1 with Tukey's HSD at $P \leq 0.05$.

Results

Table 1: Lentil grain yield (t/ha) response to P₂O₅ application across three soil P categories (two-year mean)

Soil P class	0	20	40	60	80	Opt. P rate
Low	0.74	1.12	1.48	1.71	1.78	60
Medium	1.23	1.51	1.74	1.84	1.86	40
High	1.68	1.76	1.81	1.83	1.82	20

Opt. P rate = economic optimum kg P₂O₅/ha by marginal analysis. Tukey's HSD ($P \leq 0.05$): Yield = 0.12

Yield response was steep on low-P soils, with a 131 percent increase from 0 to 80 kg P₂O₅/ha (Table 1). However, the marginal return above 60 kg was small, making 60 kg the

economic optimum for low-P sites. On high-P soils, yields plateaued at 20 kg P₂O₅/ha, with no further response saving 40–60 kg P₂O₅/ha compared to blanket recommendations.

Table 2: Phosphorus uptake and use efficiency under optimal P rate for each soil category (two-year mean)

Soil p class	P rate applied	Total p uptake (kg/ha)	Grain p (kg/ha)	Phi (%)	Pue (kg grain/kg p)
Low	60	13.4	9.1	67.9	28.5
Medium	40	14.8	9.8	66.2	43.5
High	20	15.7	10.6	67.5	88.0

PHI = phosphorus harvest index. PUE calculated at economic optimum rate

P harvest index was consistently high at 66–68 percent regardless of soil P level (Table 2), confirming strong preferential P loading into grain. PUE was three times higher on

high-P soils than low-P soils at their respective optima, as background soil supply met most crop demand.

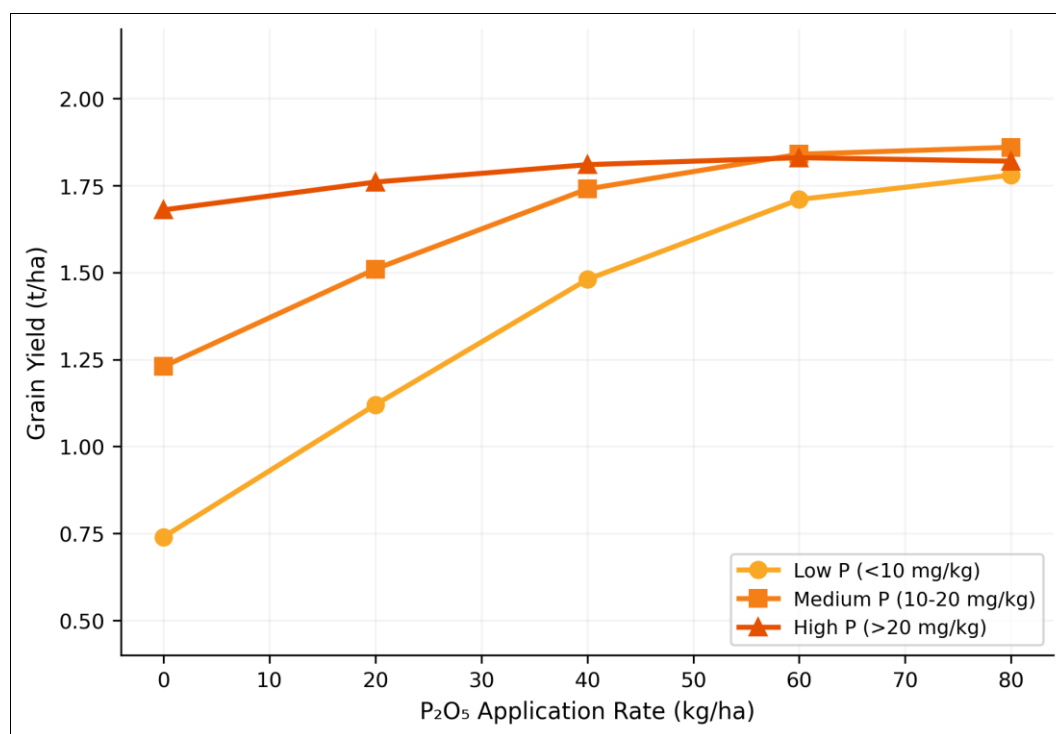


Fig 1: Lentil grain yield response curves to graded P₂O₅ application under three soil phosphorus availability categories

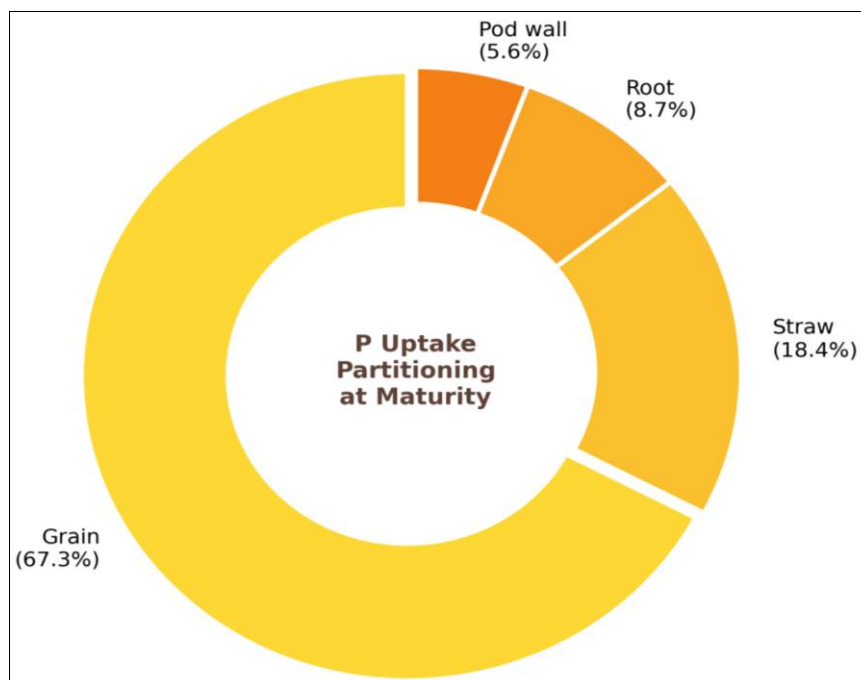


Fig 2: Partitioning of phosphorus uptake among grain, straw, root, and pod wall fractions at maturity (mean across all P rates and soil categories)

Limitations

The research covered only two growing seasons at one location, limiting extrapolation to other European lentil-growing areas with different soils and climates. Only one cultivar was tested, and genotypic variation in P efficiency exists among lentil germplasm. The economic analysis used fixed prices, which fluctuate. Mycorrhizal colonization, an important contributor to lentil P uptake, was not assessed.

Discussion

The steep yield response on low-P soils confirms lentil's high P requirement relative to soil supply, consistent with its shallow rooting habit that limits exploration of subsoil P reserves [6, 7]. The 67.3 percent P harvest index higher than most cereal crops means that lentil grain removes a disproportionate share of system P, accelerating depletion if not replaced [8].

The absence of yield response above 20 kg P₂O₅/ha on high-P soils is economically and environmentally important. Blanket recommendations of 60 kg P₂O₅/ha would waste 40 kg/ha on these soils, contributing to P runoff risk without yield benefit [9, 10]. Site-specific management based on Olsen P soil tests could reduce P fertilizer use across European lentil production by an estimated 30 percent [11].

Conclusion

Lentil yield response to phosphorus was strongly dependent on soil P status. Economic optimum rates ranged from 20 kg P₂O₅/ha on high-P soils to 60 kg on low-P soils. The high P harvest index (67%) underscores the importance of P replacement fertilization to sustain soil fertility.

Site-specific P management using soil test categories would improve both economic returns and environmental outcomes for European lentil production. Routine Olsen P testing before sowing should become standard practice for this crop.

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