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YIELD RESPONSE AND SOIL PHOSPHORUS DYNAMICS UNDER INTEGRATED QUAIL MANURE-SP-36 FERTILIZATION

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ABSTRACT

Efficient phosphorus (P) management for black soybean requires rapid nutrient supply without neglecting the soil-improving functions of organic amendments. This study evaluated whether quail manure and SP-36 fertilizer interact to improve black soybean performance and post-harvest soil available P. A 3 x 3 factorial randomized complete block design with three replications was conducted in Medan Deli, Indonesia, from February to May 2026. Quail manure was applied at 0, 20, and 30 t ha-1, while SP-36 was applied at 0, 225, and 250 kg ha-1. Pod number, pod weight, seed weight, root length, root weight, 100-seed weight, and post-harvest available P were analyzed by ANOVA followed by Duncan's Multiple Range Test at 5%. Both inputs significantly improved all measured variables. Their interaction was highly significant for all yield and root traits, but not for soil available P. The 30 t ha-1 manure + 250 kg ha-1 SP-36 combination produced 268.00 pods plant-1, 89.32 g pod weight plant-1, 71.48 g seed weight plant-1, 64.34 cm root length, 20.02 g root weight, and 11.60 g 100-seed weight. Although this combination also had the highest numerical available P (15.61 ppm), the non-significant interaction indicates that the crop-response synergy was not mirrored by residual soil P. Integrated organic-mineral P management therefore improved black soybean productivity, while residual available P responded primarily to the independent effects of each fertilizer source.

Keywords: black soybean; integrated nutrient management; phosphorus; quail manure; SP-36.

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INTRODUCTION

Soybean is a strategically important legume because it provides protein and oil while contributing biologically fixed nitrogen to cropping systems. Black-seeded soybean is particularly valuable in Indonesia for food products such as soy sauce and other specialty uses. Yield formation in soybean depends on a coordinated supply of nutrients during root development, flowering, pod set, and seed filling; phosphorus is central to these processes because it is involved in energy transfer, nucleic-acid metabolism, membrane function, and reproductive development (Marschner, 2012; Salvagiotti et al., 2008).

Phosphorus management is difficult because the element is relatively immobile in soil and can become strongly sorbed or precipitated, especially in highly weathered tropical soils. Consequently, the amount of fertilizer P applied is not equivalent to the amount available to roots. Root architecture, rhizosphere chemistry, soil pH, organic ligands, and microbial activity jointly regulate acquisition (Shen et al., 2011; Vance et al., 2003). Improving P-use efficiency is therefore a major agronomic objective because phosphate rock is finite and inefficient P use creates both economic and environmental costs (Blackwell et al., 2019; Cordell & White, 2014; Veneklaas et al., 2012).

Mineral P fertilizers provide a concentrated and relatively rapid source of plant-available P. In soybean, P fertilization can improve root development, yield components, and seed yield when soil P is limiting, although the magnitude of response depends on genotype, soil characteristics, and the existing P status (Antonangelo et al., 2019; He et al., 2017; Moreira et al., 2017). SP-36, a commonly used Indonesian phosphate fertilizer, is therefore agronomically relevant for supporting pod and seed development. However, relying only on mineral P does not address constraints related to soil physical quality, organic matter, or biological nutrient cycling.

Organic amendments offer a complementary pathway. Manure can supply nutrients, add carbon, improve aggregation and water retention, and alter the chemical environment controlling P retention and release (Brady & Weil, 2017; Diacono & Montemurro, 2010). Integrated soil fertility management combines organic resources with mineral fertilizers so that immediate nutrient demand and longer-term soil functions are addressed simultaneously (Vanlauwe et al., 2010). Meta-analytic evidence shows that combined organic and mineral nutrient sources can produce responses that differ from either source alone, although interaction strength depends on soil and management conditions (Chivenge et al., 2011).

Quail manure is a locally available livestock residue with potential as an organic fertilizer. Studies have demonstrated that quail manure can support plant biomass production and improve crop performance, while its nutrient contribution depends on dose and processing (Latif et al., 2023; Parna et al., 2025). For soybean on Alfisols, quail manure combined with mineral amendments or rock phosphate has improved yield-related variables and soil chemical properties (Masruroh et al., 2019; Minardi et al., 2020). A recent experiment on millet likewise reported significant responses to quail manure combined with mineral phosphate fertilizer, reinforcing the relevance of organic-mineral P integration under Indonesian conditions (Santoso et al., 2026).

The novelty of the present study lies in simultaneously evaluating black soybean productivity, root responses, and post-harvest available soil P under a factorial combination of quail manure and SP-36. This distinction is important because a statistically significant crop response to combined fertilizers does not necessarily imply a corresponding interaction in residual soil P. Such separation can help clarify whether the benefit of integration is expressed mainly through crop uptake and rhizosphere processes or through accumulation of measurable available P. The study therefore tested three hypotheses: (1) quail manure affects black soybean growth, yield, and post-harvest available P; (2) SP-36 affects the same responses; and (3) quail manure and SP-36 interact to influence crop performance and soil available P.

RESEARCH METHODS

The experiment was conducted from February to May 2026 in Medan Deli District, Mabar, Medan, Indonesia, at approximately 26 m above sea level. Black soybean was grown in 35 x 35 cm polybags. The planting medium consisted of topsoil and burned rice husk, and quail manure was incorporated into the medium according to treatment before planting.

A factorial randomized complete block design was used with two factors and three replications. Factor P was quail manure at P0 = 0 t ha-1, P1 = 20 t ha-1 (equivalent to 320 g polybag-1), and P2 = 30 t ha-1 (480 g polybag-1). Factor S was SP-36 at S0 = 0 kg ha-1, S1 = 225 kg ha-1 (3.6 g polybag-1), and S2 = 250 kg ha-1 (4.0 g polybag-1). The factorial arrangement generated nine treatment combinations and 27 experimental plots. Each plot contained five plants, three of which were

sampled, giving 135 plants in total. These treatment rates follow the experimental-method section and the data tables of the thesis, which are internally consistent with the subsequent results and conclusions.

SP-36 was dissolved in water and applied at the designated treatment rate one week before planting and again one week before flowering. Seedlings were transplanted at 10 days after sowing, one plant per polybag. Weeds were removed manually, and plants were watered in the morning and afternoon. No treatment effect was inferred for management inputs that were listed as materials but not described as experimental factors.

At harvest, pod number per plant was counted manually. Total pod weight and seed weight per plant were determined using a digital balance; seeds were air-dried for 48 h before weighing. Primary root length was measured from the stem base to the longest root tip, and root weight was determined after roots had been separated and cleaned. One hundred air-dried seeds were counted and weighed for 100-seed weight. Post-harvest soil samples were collected from each plot, composited within the corresponding experimental unit, and analyzed for available P using the Bray-II spectrophotometric method; values are reported as ppm.

Data were analyzed by factorial analysis of variance for a randomized complete block design. The model included block, quail manure, SP-36, and the quail manure x SP-36 interaction. When the F-test was significant, means were separated using Duncan's Multiple Range Test (DMRT) at the 5% level. Interpretation of interaction effects was based on the factorial ANOVA; therefore, numerical differences were not described as interactive effects when the interaction term was non-significant.

RESULTS AND DISCUSSION

Table 1. Main effects of quail manure and SP-36 on black soybean and post-harvest soil P

Factor level	Pods (no. plant-1)	Pod wt. (g plant-1)	Seed wt. (g plant-1)	Root length (cm)	Root wt. (g)	100-seed wt. (g)	Avail. P (ppm)
Quail manure							
0 t ha-1	107.07 c	36.92 c	28.80 c	40.16 c	10.37 c	9.04 c	11.81 c
20 t ha-1	163.52 b	54.16 b	43.32 b	43.80 b	11.36 b	9.91 b	12.35 b
30 t ha-1	227.07 a	75.68 a	60.85 a	57.05 a	16.85 a	10.78 a	13.13 a
SP-36							
0 kg ha-1	110.67 c	36.55 c	29.24 c	37.60 c	9.27 c	9.01 c	8.93 c
225 kg ha-1	162.78 b	54.26 b	43.70 b	46.98 b	12.70 b	9.87 b	13.46 b
250 kg ha-1	224.22 a	75.95 a	60.03 a	56.42 a	16.61 a	10.84 a	14.91 a

Note. Within each factor and column, means followed by different letters differ according to DMRT at 5%. Interaction means are presented in Table 2.

Both fertilizer sources produced clear dose-related main effects (Table 1). Increasing quail manure from 0 to 30 t ha-1 raised mean pod number from 107.07 to 227.07 pods plant-1 and seed weight from 28.80 to 60.85 g plant-1. The highest manure rate also increased root length, root mass, 100-seed weight, and available P. A comparable pattern occurred for SP-36: the 250 kg ha-1 rate produced 224.22 pods plant-1 and 60.03 g seed plant-1, while available P increased from 8.93 ppm without SP-36 to 14.91 ppm. These results are consistent with the central physiological role of P in ATP-dependent metabolism, root growth, reproductive development, and assimilate transfer (Havlin et al., 2014; Marschner, 2012). They also align with soybean research showing that P supply can improve root architecture and yield components when P availability constrains crop performance (Antonangelo et al., 2019; He et al., 2017; Moreira et al., 2017).

The positive manure response is agronomically plausible because organic amendments act through more than direct nutrient addition. Organic carbon can improve aggregation and water relations, while decomposition products and microbial activity may modify P sorption and mineralization in the rhizosphere (Brady & Weil, 2017; Diacono & Montemurro, 2010; Shen et al., 2011). Quail manure has also been shown to support plant growth in other systems, and soybean studies on Alfisols have reported improved yield or soil properties when quail manure is combined with mineral or mineral-derived amendments (Latif et al., 2023; Masruroh et al., 2019; Minardi et al., 2020). Thus, the present response is consistent with integrated soil fertility management, in which organic resources improve the soil environment while mineral fertilizer supplies readily available nutrients (Vanlauwe et al., 2010).

Table 2. Interaction means for quail manure x SP-36 on black soybean yield and root traits

Treatment	Pods (no. plant-1)	Pod wt. (g plant-1)	Seed wt. (g plant-1)	Root length (cm)	Root wt. (g)	100-seed wt. (g)
P0S0	42.00 i	13.98 h	11.18 f	31.57 h	7.13 h	7.83 g
P0S1	91.78 h	30.59 g	24.48 e	38.06 f	9.48 f	9.06 f
P0S2	187.44 e	66.19 d	50.73 cd	50.84 c	14.51 c	10.23 c
P1S0	102.00 g	33.04 fg	26.43 e	34.48 g	7.64 g	9.33 ef
P1S1	171.33 f	57.09 e	45.67 d	42.84 e	11.13 e	9.69 de
P1S2	217.22 c	72.34 c	57.87 bc	54.07 b	15.29 b	10.70 b
P2S0	188.00 d	62.62 d	50.11 cd	46.77 d	13.03 d	9.87 d
P2S1	225.22 b	75.09 b	60.96 b	60.04 a	17.49 a	10.88 b
P2S2	268.00 a	89.32 a	71.48 a	64.34 a	20.02 a	11.60 a

Note. P0, P1, and P2 = 0, 20, and 30 t ha-1 quail manure; S0, S1, and S2 = 0, 225, and 250 kg ha-1 SP-36. Different letters within a column indicate significant differences by DMRT at 5%.

The factorial interaction was highly significant for all six plant traits. The P2S2 combination (30 t ha-1 manure + 250 kg ha-1 SP-36) was the best overall treatment, producing 268.00 pods plant-1, 89.32 g pod weight plant-1, 71.48 g seed weight plant-1, 64.34 cm root length, 20.02 g root weight, and 11.60 g 100-seed weight (Table 2). Relative to P0S0, P2S2 increased pod number by approximately 538%, seed weight by 539%, root length by 104%, and root weight by 181%. Because the interaction term was significant, these treatment-combination differences cannot be interpreted only as independent additive responses. Rather, the effect of one input depended on the level of the other for the measured crop traits.

This interaction is consistent with the conceptual basis of integrated nutrient management. Mineral P can satisfy immediate plant demand, whereas manure can improve rooting conditions and nutrient-retention processes that influence access to applied P. Chivenge et al. (2011) found that combined organic and mineral nutrient sources can generate productivity gains that are context-dependent rather than strictly additive. The present result is also supported by Masruroh et al. (2019), who reported improved soybean yield components from combinations involving quail manure and phosphate-related amendments, and by Santoso et al. (2026), who observed significant interactions between organic fertilizers including quail manure and mineral phosphate in millet. Recent Indonesian agronomic studies published in Algebra likewise demonstrate the usefulness of factorial designs for detecting treatment interactions that would be obscured by considering main effects alone (Azhari et al., 2025; Hasibuan et al., 2024).

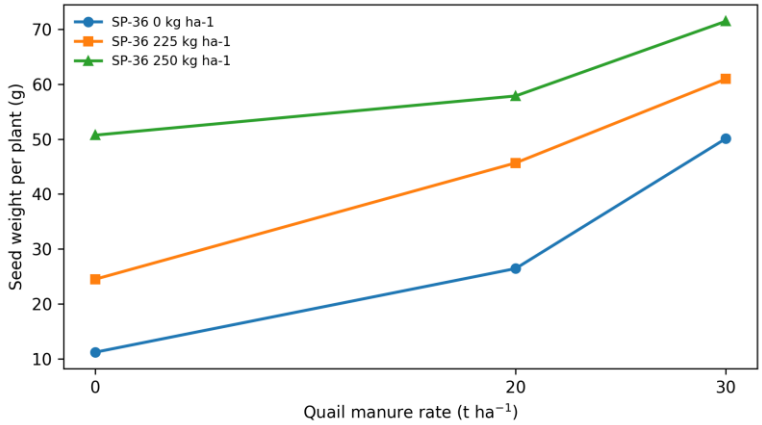


Figure 1. Seed weight response to combined quail manure and SP-36 rates

Figure 1 illustrates the interaction for seed weight. The response to increasing manure was strongest when SP-36 was absent or supplied at 225 kg ha-1, while the 250 kg ha-1 SP-36 treatment produced a high seed weight even without manure and reached the overall maximum at P2S2. This pattern suggests that neither fertilizer source alone fully describes the yield response. It is consistent with the principle that P acquisition depends on both nutrient supply and the rooting/rhizosphere environment (Shen et al., 2011; Vance et al., 2003). Nevertheless, the experiment did not directly measure P uptake, root exudation, microbial activity, or P-use efficiency; those mechanisms should therefore be treated as plausible explanations rather than demonstrated causal pathways.

Table 3. Factorial ANOVA F-statistics for plant traits and post-harvest available P

Response	Quail manure (P)	SP-36 (S)	P x S
Pod number	263.53 **	236.24 **	9.00 **
Pod weight	637.97 **	658.93 **	32.18 **
Seed weight	551.97 **	508.35 **	20.99 **
Root length	2597.43 **	2907.01 **	61.80 **
Root weight	7008.91 **	7758.95 **	90.65 **
100-seed weight	151.32 **	168.04 **	5.90 **
Available P	490.31 **	22.04 **	0.47 ns

Note. ** = highly significant at 1%; ns = not significant at 5%.

A key finding is the contrast between plant performance and residual soil P (Table 3). Quail manure and SP-36 each significantly affected post-harvest available P, but their interaction did not (F = 0.47, ns). Numerically, P2S2 had the highest available P value (15.61 ppm), but this value must not be interpreted as evidence of a synergistic soil-P interaction. Instead, the factorial result indicates that the detectable post-harvest P response was explained primarily by the independent main effects of manure and SP-36. This is scientifically important because a strong interactive yield response can occur even when a standard residual-P test does not show interaction. Crop uptake, temporal P availability, root proliferation, and rhizosphere transformations may influence performance without leaving a proportionate signal in post-harvest available P (Shen et al., 2011; Veneklaas et al., 2012).

From a resource-management perspective, the result supports combining organic and mineral inputs but also argues against using residual soil P alone as a proxy for agronomic efficiency. Global P stewardship emphasizes increasing crop output per unit of applied P while avoiding unnecessary accumulation in soil (Blackwell et al., 2019; Cordell & White, 2014). In the present experiment, the high crop response at P2S2 is promising, yet a formal claim of improved P-use efficiency cannot be made because P uptake and P recovery were not measured. Future work should quantify plant P concentration, total P uptake, apparent P recovery, soil pH, organic carbon, microbial activity, and sequential P fractions. Such measurements would test whether the observed plant interaction is mediated by greater acquisition efficiency, improved root exploration, altered P sorption, or a combination of these processes.

The findings should also be interpreted within the experimental boundary. The study used polybags at one lowland site and one growing season; therefore, the 30 t ha-1 manure + 250 kg ha-1 SP-36 combination is best described as the optimum among the tested treatments, not as a universally optimal field recommendation. Soil type, initial P status, manure composition, moisture regime, and soybean genotype can modify P responses (Antonangelo et al., 2019; He et al., 2017). Field-scale validation across contrasting soils and seasons is required before a generalized fertilizer recommendation is made.

CONCLUSIONS

Quail manure and SP-36 independently increased black soybean yield components, root development, 100-seed weight, and post-harvest available P. Their interaction was highly significant for pod number, pod weight, seed weight, root length, root weight, and 100-seed weight. The best tested combination was 30 t ha-1 quail manure + 250 kg ha-1 SP-36, which produced 268.00 pods plant-1 and 71.48 g seed plant-1 together with the highest root and seed-size responses. In contrast, the interaction was not significant for post-harvest available P, even though the same combination produced the highest numerical value of 15.61 ppm. The study therefore demonstrates a distinctive result: organic-mineral P integration generated an interactive agronomic response without a corresponding interaction in residual available soil P. The treatment combination is promising for black soybean under the tested conditions, but field validation and direct measurements of P uptake and P-use efficiency are required before broader recommendations are made.

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