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Fertilizer price escalation and soybean profitability in Brazil: statistical evidence, geopolitical exposure, and 2035 scenarios

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Introdution

Brazilian soybean production has expanded strongly during the last 25 years, supported by area growth, yield gains, and increasingly intensive nutrient management (Conab, 2026). However, the same period also shows a clear deterioration in the input–output relationship between fertilizer prices and soybean value. This is particularly relevant for phosphorus (P) and potassium (K) fertilizers because Brazil is structurally exposed to imported raw materials, international freight, currency movements, and geopolitical disruptions (Quitzow et al., 2025). In practical terms, when fertilizer prices rise faster than soybean prices or productivity, the system experiences margin compression even when gross production continues to grow.

The current global context reinforces this vulnerability. The Russia–Ukraine war demonstrated how sanctions, energy prices, trade restrictions, and logistical bottlenecks can rapidly transmit into fertilizer markets (Russo; Figueira, 2023). More recently, tensions involving the United States and Iran, disruptions around the Strait of Hormuz, and elevated oil prices have again shown how energy and fertilizer supply chains remain tightly connected. At the same time, China remains a central force in commodity demand, sulfur (S) and phosphate supply chains, and global fertilizer trade policy. Therefore, the Brazilian soybean sector is not only exposed to agronomic and climatic risks, but also to macroeconomic and geopolitical shocks outside the control of farmers.

Materials e Methods

The dataset covers the period from 2000 to 2025 and includes annual soybean area, yield, production, soybean price, K_2O and P_2O_5 annual

application rates, triple superphosphate (TS) price, and potassium chloride (KCl) prices (Conab, 2026; FAO, 2025; Estados Unidos, 2025; World Bank, 2024). The analysis generated descriptive indicators, *Pearson* correlations, multiple regressions, and projections to 2035. Fertilizer cost was estimated as an agronomic proxy for P and K expenditure per hectare. TS was assumed to contain 46% P_2O_5 and KCl was assumed to contain 60% K_2O. Therefore, estimated P+K fertilizer cost per hectare was calculated from nutrient rate, nutrient concentration, and product price. Soybean gross revenue per hectare was calculated as grain yield in Mg ha^{-1} multiplied by soybean price in R$ Mg^{-1}. A margin proxy was then calculated as soybean gross revenue minus estimated P+K fertilizer cost.

Multiple regressions were fitted using standardized variables, allowing direct comparison of coefficient magnitude. Because the dataset is annual (covering annual applications in Brazilian agricultural systems, primarily involving soybean) and relatively short, the regressions should be interpreted as explanatory statistical diagnostics rather than causal econometric identification. Heteroskedasticity and autocorrelation-consistent standard errors were used to reduce sensitivity to serial dependence. The 2035 projections were built as scenario exercises, not forecasts in the strict sense. The more resilient scenario assumes moderate fertilizer inflation, continued yield growth, and partial recovery of the soybean-to-fertilizer terms of trade. The high-pressure scenario assumes persistent geopolitical and energy-market pressure, faster increases in P and K fertilizer prices, and slower productivity gains.

Results and Discussion

Between 2000 and 2025, soybean area increased from 13,508 to 47,346 thousand ha, while yield increased from 2,395 to 3,622 kg ha^{-1}. Production increased from 32,345 to 171,480 thousand Mg. Figure 1 confirms that the sector expanded substantially. However, the input side became more volatile and more expensive. Indexed price trajectories show that triple superphosphate and KCl experienced sharper peaks than soybean prices (Figure 1), especially around 2021–2022, when global fertilizer markets reacted strongly to the energy shock and the Russia–Ukraine conflict.

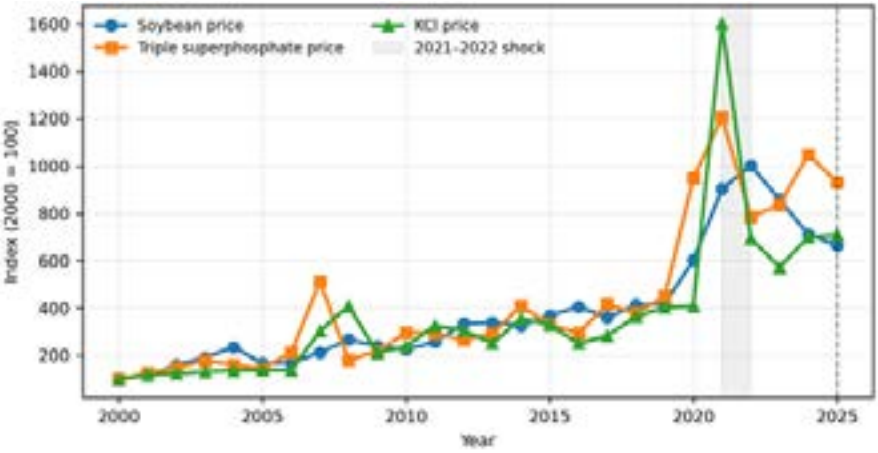

Figure 1. Indexed evolution of soybean, triple superphosphate, and potassium chloride prices in Brazil, using 2000 = 100.

The estimated P+K fertilizer cost share rose from 5.1% of soybean gross revenue in 2000 to 10.8% in 2025 (Figure 2). It is important to note that the cost share presented is an estimate, as it accounts for the annual applications of K and P in soybean production systems, not always in single crops. However, the most important message is not only the absolute increase, but the instability of the relationship. Years of geopolitical stress can rapidly increase fertilizer prices and raise the cost share even when soybean prices are also high. This behavior is agronomically relevant because P and K fertilization cannot be reduced indefinitely without affecting nutrient balances, soil fertility, and future yields.

The *Pearson* correlation matrix reinforces the central argument (Figure 3). Production is strongly associated with area and yield, whereas fertilizer cost pressure is more closely related to fertilizer prices and nutrient application rates. The strongest concern is the positive association between fertilizer prices and the estimated cost burden, combined with the weaker ability of soybean price and yield gains to fully offset high-cost episodes.

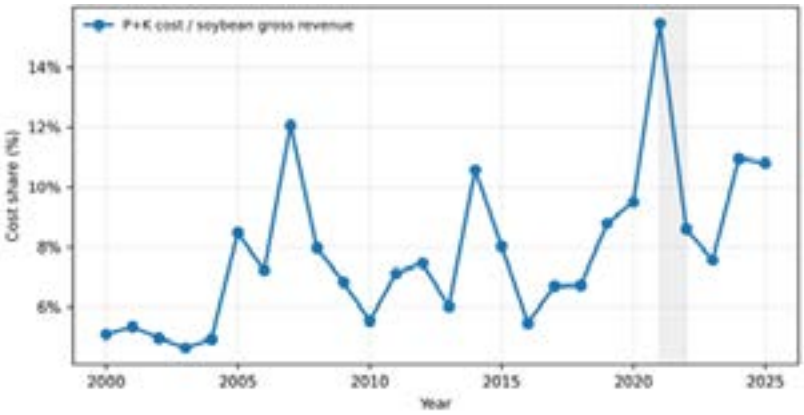

Figure 2. Estimated P+K fertilizer cost as a percentage of soybean gross revenue per hectare.

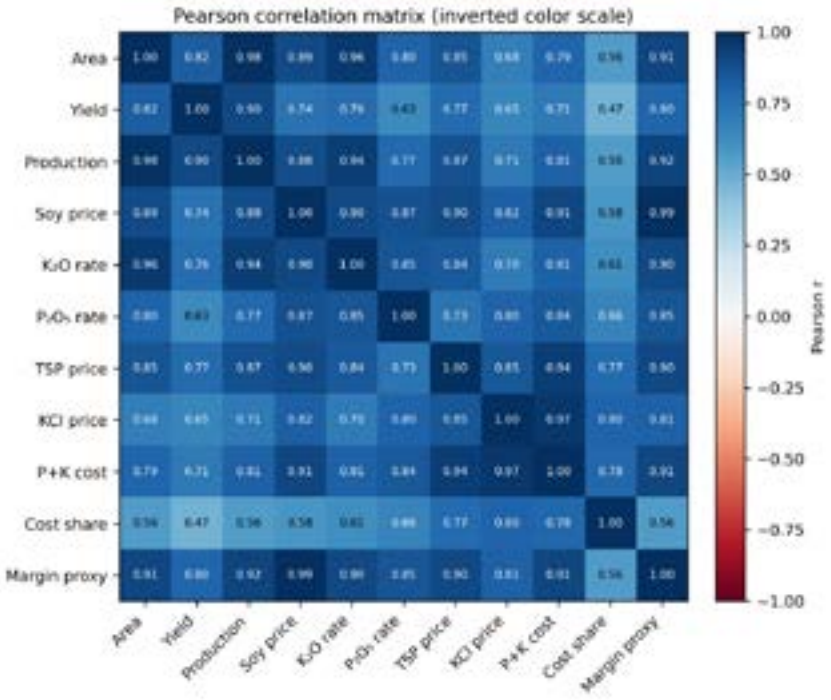

Figura 3. *Pearson* correlation matrix among production, price, nutrient-use, cost, and margin indicators.

The regression results indicate three complementary patterns. First, the margin proxy is primarily explained by soybean price and yield, but the negative coefficient for the time trend suggests that, after controlling for the other variables, the economic environment has become less favorable over time. Second, the fertilizer cost share is strongly increased by triple superphosphate and KCl prices and strongly reduced by soybean price and yield. This means that agronomic efficiency and favorable grain prices can buffer part of the shock, but they do not remove the systemic exposure to fertilizer markets. Third, production remains overwhelmingly driven by area expansion, with yield also contributing positively (Table 1). This separation is important: Brazil can continue increasing production while producer margins become more exposed to input-price shocks.

Table 1. Standardized multiple regression coefficients.

Model	Predictor	Standardized β	p-value	R^2	Adj. R^2
Margin proxy (R$ ha^{-1})	Yield	0.179	<0.001	0.996	0.995
Margin proxy (R$ ha^{-1})	Soybean price	0.970	<0.001	0.996	0.995
Margin proxy (R$ ha^{-1})	TS price	-0.002	0.942	0.996	0.995
Margin proxy (R$ ha^{-1})	KCl price	-0.041	0.285	0.996	0.995
Margin proxy (R$ ha^{-1})	P_2O_5 rate	-0.034	0.294	0.996	0.995
Margin proxy (R$ ha^{-1})	K_2O rate	0.060	0.052	0.996	0.995
Margin proxy (R$ ha^{-1})	Time trend	-0.112	0.005	0.996	0.995
P+K cost share (%)	Soybean price	-1.511	<0.001	0.910	0.874
P+K cost share (%)	Yield	-0.283	<0.001	0.910	0.874
P+K cost share (%)	TS price	1.321	<0.001	0.910	0.874
P+K cost share (%)	KCl price	0.396	0.032	0.910	0.874
P+K cost share (%)	P_2O_5 rate	0.702	<0.001	0.910	0.874
P+K cost share (%)	K_2O rate	0.186	0.196	0.910	0.874
P+K cost share (%)	Time trend	0.013	0.937	0.910	0.874
Production (1000 Mg)	Area	0.988	<0.001	0.997	0.996
Production (1000 Mg)	Yield	0.330	<0.001	0.997	0.996
Production (1000 Mg)	Time trend	-0.279	<0.001	0.997	0.996

The dataset supports a broader economic interpretation that fertilizer prices are not governed only by agricultural demand. They are also linked to energy

prices, shipping routes, sanctions, export restrictions, and the strategic behavior of large suppliers. Nitrogen (N) fertilizers are directly tied to natural gas and ammonia markets, while phosphate fertilizers depend on sulfur, ammonia, and global mining and processing chains. Potassium markets are especially sensitive to supply from a small group of exporters. This concentration makes Brazilian agriculture vulnerable to external shocks.

The Russia–Ukraine war is the clearest recent example (Russo; Figueira, 2023). International analyses reported that fertilizer prices rose sharply during 2021 and early 2022, reflecting energy-price escalation and supply disruption. The current U.S. and Iran tension and Strait of Hormuz risk are also relevant because oil and gas disruptions transmit into fertilizer production costs and freight. Higher oil prices also affect diesel, logistics, and the macroeconomic environment. China adds another layer of complexity because its demand trajectory influences commodity markets, while its role in sulfur, phosphate, industrial inputs, and export policies can alter fertilizer availability and prices. For Brazil, this means that soybean profitability depends simultaneously on domestic agronomic performance and external geopolitical stability.

By 2035, the more resilient scenario projects a P+K fertilizer cost share of 8.6% of soybean gross revenue (Figure 4). In contrast, the high-pressure scenario projects a cost share of 15.8%. The gap between these trajectories illustrates how relatively small differences in annual price growth compound into a large economic divergence over a decade. The high-pressure scenario should be interpreted as a plausible stress pathway under persistent oil-price pressure, fertilizer-market disruption, freight constraints, and weaker yield growth.

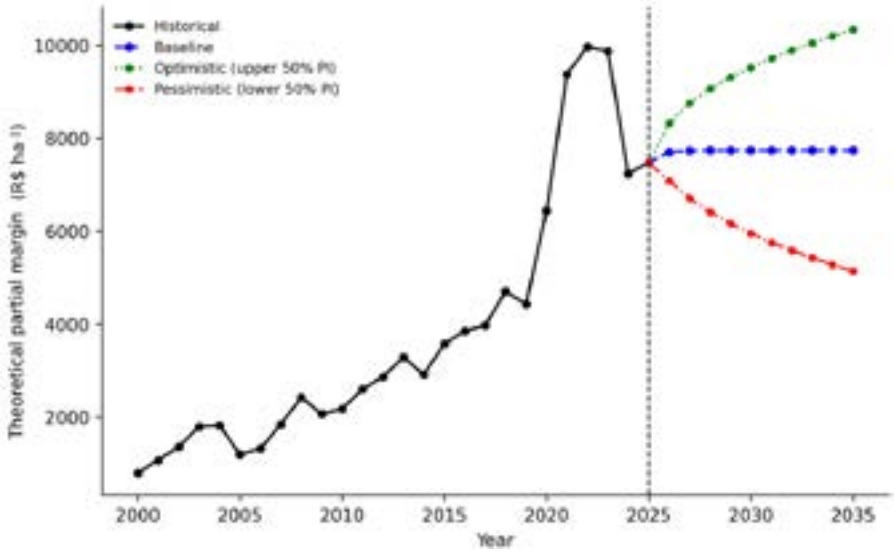

Figure 4. Scenario projections to 2035 for the estimated P+K fertilizer cost share. (Note: Theoretical partial margin = gross revenue - K_2O+P_2O_5 fertilzer cost; without considering all other production costs of the crop).

Conclusion

Over the last 25 years, Brazilian soybean systems have expanded in area, yield, and production, but fertilizer prices have become more volatile and often increased faster than soybean value, compressing margins. Regression results show that profitability depends on soybean prices and productivity gains but remains highly sensitive to fertilizer price shocks. This reflects increasing exposure to global factors such as energy markets, supply concentration, geopolitical tensions, and demand from economies like China. By 2035, profitability will depend on the stabilization of fertilizer prices relative to soybean value and the ability of productivity gains to offset rising input costs.

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