AGREKON
2025, VOL. 64, NO. 2, 149–166
https://doi.org/10.1080/03031853.2025.2515868

Trends and drivers of fertiliser consumption in the South African agricultural industry

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ABSTRACT

The South African fertiliser industry plays a crucial role in supporting agriculture and ensuring food security. However, the country's dependence on fertiliser imports and inefficiencies in the supply chain pose significant economic and environmental challenges. Although South African farmers have managed to improve fertiliser use efficiency over time, broader application of precision agriculture technologies can enhance fertiliser use efficiency in the future. Sustainable practices and informed policies are necessary to balance agricultural productivity with environmental protection. This study provides an overview of fertiliser import trends, key driving factors, and future perspectives on fertiliser sources and emerging technologies. The study highlights the importance of fertilisers in addressing nutrient deficiencies in key grain-producing regions, such as the Free State, North West, and Western Cape provinces. South Africa's reliance on imports exposes the sector to price volatility and disruptions in the supply chain, influenced by global events like geopolitical tensions and the COVID-19 pandemic. While stable suppliers of imported products like Saudi Arabia and emerging markets like Qatar offer opportunities, challenges remain, including high costs and environmental risks. Precision agriculture technologies offer promising solutions to optimise fertiliser use and mitigate environmental impacts. The article discusses how targeted strategies and the adoption of precision agriculture technologies, such as variable rate applications, can enhance fertiliser efficiency. It also explores the implications of global environmental regulations and alternative fertiliser sources. Ultimately, the study emphasises the need for targeted policies to ensure a sustainable fertiliser supply while meeting the evolving demands of South Africa's agricultural sector.

ARTICLE HISTORY
Received 25 March 2025
Accepted 31 May 2025

KEYWORDS
Fertilizer industry; agriculture; food security; environmental impact; precision agriculture

1. Introduction

The fertiliser industry plays a crucial role in supporting agricultural sectors worldwide and safeguarding food security. Fertilisers are essential for enhancing soil fertility, boosting crop productivity, and increasing the quality of crops, thereby enabling farmers to meet sustainable economic goals (Singh

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et al. 2020; Stewart et al. 2005; Vanlauwe et al. 2023). Fertilisers are essential for enabling crop production on inherently unsuitable soils, where nutrient levels are inadequate or existing nutrients are inaccessible due to soil chemical, biological, or physical limitations (Liu, Li, and Waddington 2014; Wong, Wild, and Mokwunye 1991; Ngoze et al. 2008). Inefficient application of nitrogen (N) and phosphorus (P) fertilisers causes negative environmental effects. Unused N and P may end up in water bodies causing eutrophication, while N and potassium (K) losses to the environment by leaching and runoff spoils groundwater (Huang et al. 2017; Weitzman et al. 2022). Volatilisation losses contribute to air pollution by nitrous oxide emissions (Wu et al. 2021).

Over the past decade, global fertiliser prices have experienced significant fluctuations, primarily driven by geopolitical tensions, supply chain disruptions, and changing agricultural demands (Snapp et al. 2023). Following a period of relatively stable prices, the onset of the COVID-19 pandemic in 2020 led to global disruptions in the production and transportation of fertilisers, causing prices to rise sharply. In 2021 and 2022, prices reached record highs due to increased energy costs and sanctions on major fertiliser-producing countries, particularly considering the conflict between Ukraine and Russia (Hebebrand and Laborde 2022). While prices have shown signs of stabilisation since 2023, prices remain elevated compared to pre-pandemic levels, reflecting ongoing concerns about supply security and the need for sustainable agricultural practices (Penuelas, Coello, and Sardans 2023). Many countries, including South Africa, primarily rely on imports to address fertiliser requirements. Global market factors have increased production costs for farmers, impacting agronomic decisions, agricultural output efficiency, and agricultural sustainability. Additionally, fluctuations in the South African exchange rate have influenced the cost of imported agricultural inputs, driving changes in production costs and contributing to elevated fertiliser prices, particularly during periods of depreciation in recent years.

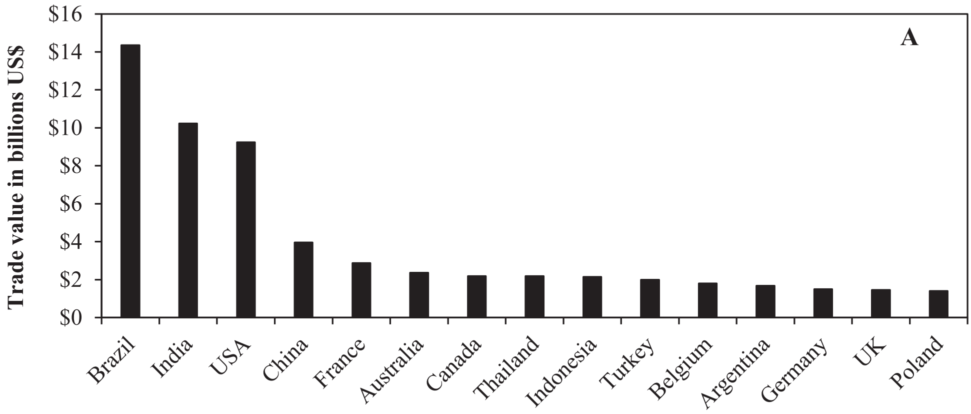
The demand for fertiliser minerals plays a crucial role in the growth of agriculture, a key sector that influences the economies of many nations, including South Africa. As a result, it indirectly contributes to the gross domestic product (Sihlobo and Kirsten 2021). Therefore, analyzing trends and drivers of fertiliser consumption in South Africa can help formulate strategies for sustained fertiliser availability in the agricultural industry. Assessing the effects of global fertiliser trade on South Africa, as well as the sources and types of fertilisers used promotes responsible and sustainable usage. This is crucial for maximising yields while minimising waste and environmental impact (Chien, Prochnow, and Cantarella 2009). Overuse or misuse of fertilisers leads to severe environmental issues, including soil degradation, water pollution, and loss of biodiversity, which may threaten sustainable agricultural production in South Africa. By understanding these trends, the fertiliser industry and farmers can make informed decisions about fertiliser investments, balancing costs against expected crop yields and market demands.

Studying the origins and availability of fertilisers can reveal information on sustainable access to fertilisers on the world market and help to identify factors that may threaten sustainable agricultural development. Data on fertiliser sources and consumption trends can inform agricultural policies aimed at promoting sustainable practices. This includes the development of guidelines for optimal fertiliser use, or a rationale for responsible fertiliser use on farms, and investments in research for alternative nutrient sources. The South African fertiliser industry, government, and policymakers can better address the challenges of fertiliser dependency and its environmental repercussions with a clear understanding of current practices. The study aims to provide an overview of fertiliser import trends in South Africa, identify the main factors driving these changes, and explore future perspectives on the development of fertiliser sources and emerging fertiliser technologies.

2. Overview of fertiliser sources

2.1 Global fertiliser sources and traders

Brazil, India, and the United States are the largest importers of fertilisers, collectively accounting for approximately US$34 billion in imported fertiliser value over a five-year period from 2019 to 2023



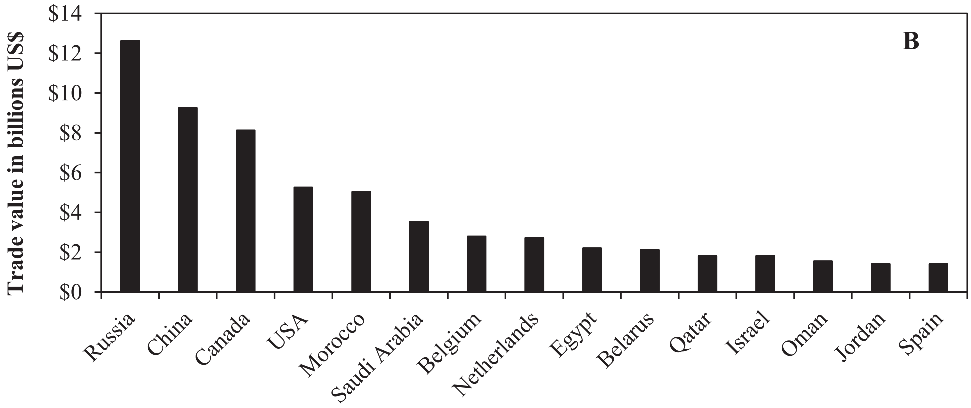


Figure 1. A global overview indicating key importers (A) and exporters (B) of fertiliser products using a five-year average of trade volume (2019–2023). Data obtained from TradeMap (2024).

(Figure 1). Over the past decade (2014–2023), fertiliser import values have shown consistent growth globally, but recent trends over the past five years (2019–2023) reveal an acceleration in several key markets. Brazil, which recorded an 11% annual increase over the past 10 years, has seen its growth surge to 21% in the last five years, reflecting a significant recent uptick in import activity. Similarly, India's 10-year annual growth of 10% has intensified to 16% over the five-year period. It is important to note that the significant increase in the value of fertiliser imports over the past five years may be partially attributed to rising fertiliser prices. The United States recorded a steady 5-year growth of 15%, although its 10-year growth rate was just 4%. China and France also demonstrated notable 5-year increases of 15% and 16%, respectively. Argentina's 13% annual growth in fertiliser imports over the past decade reflects its expanding agricultural sector, dominated by soybeans (*Glycine max* (L.) Merr.), wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), and sunflower (*Helianthus annuus* L.), which cover 90% of its crop area. Increased cultivation, improved yields, and recent tax cuts on imported fertilisers have boosted demand, solidifying Argentina's position as a fast-growing fertiliser importer. However, recent shifts highlight Brazil's emergence as a dominant player in fertiliser imports, surpassing even Argentina's decade-long annual growth rate of 13%. Brazil's strategic sourcing from major suppliers, including Russia (23% of imports), and responses to global supply chain disruptions have further strengthened Brazil's position as a leading importer, ensuring agricultural productivity amid rising demand. The changes reflect a significant shift in global trade, largely due to rising agricultural demands and recent market changes. Global fertiliser availability for trade is influenced by various factors, including climatic conditions, geological characteristics, and exploration capacity. These factors result in significant variations in availability between countries. South Africa is ranked 29th among global importers, accounting for 0.9% of the global fertiliser imports by value (2019–2023 average), indicating a relatively modest role in the international market.

Russia was the leading global exporter of fertiliser products during 2019–2023, exporting approximately 36% more than China, the second-largest exporter. Despite its significant export capacity (US $9 billion), China also imported about US$4 billion worth of fertiliser during this period, highlighting its complex role in the global fertiliser market. Fertiliser exports from the Middle East and North Africa have experienced remarkable growth over the past decade, with Saudi Arabia, Oman, and Egypt increasing their exports by 20%, 16%, and 19% over the past decade, respectively.

Over the past decades, total global fertiliser import values have increased at a higher rate than volumes reflecting significant fertiliser price surges (Figure 2). For example, the import value of N fertilisers rose from US$6.46 billion in 2001 to US$38.45 billion in 2023. The volume of N fertiliser imports peaked in 2021. However, the value peaked in 2022, and increased by approximately 65% from 2021, while the volume shrunk by 5% from 2021 to 2022. This disparity underscores the impact of global demand during periods of supply chain disruptions such as the Russia-Ukraine conflict (Alessandria et al. 2023), rising energy costs impacting fertiliser production (Min

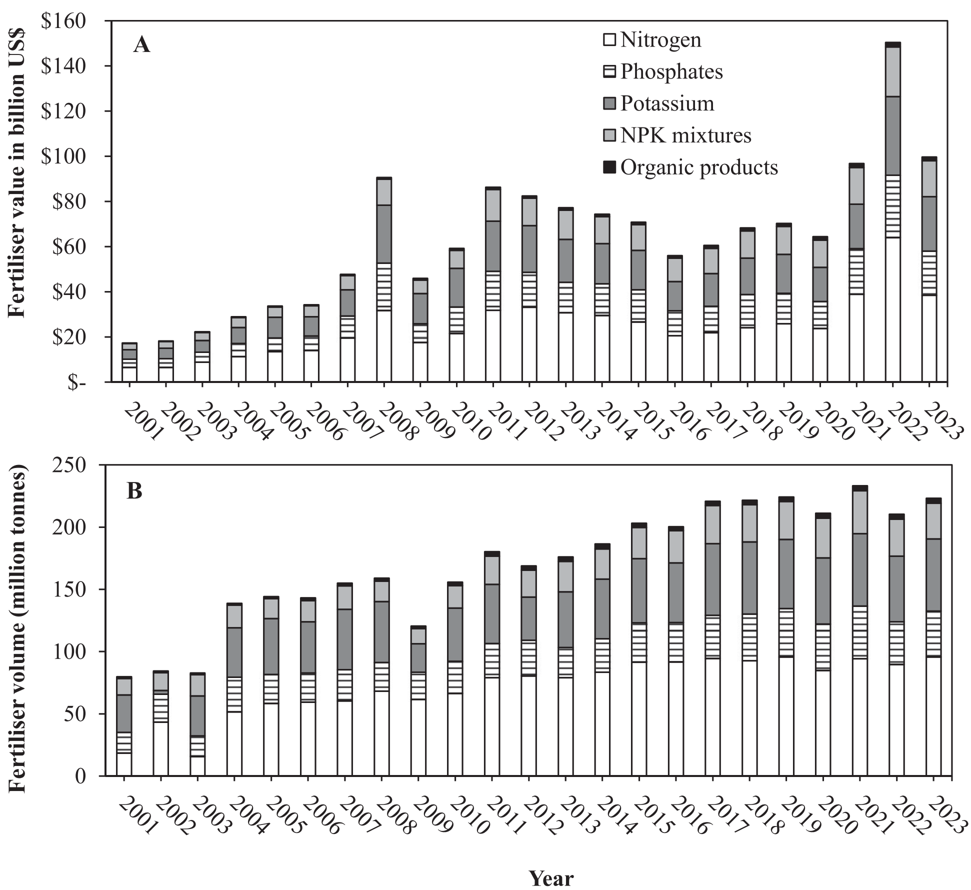


Figure 2. (A) Intrinsic fertiliser value of globally imported products containing nitrogen (N), phosphorus (P), potassium (K), NPK mixtures, and organics from 2001 to 2023 (distinct from nutrient equivalence). (B) Global import volume of products containing N, P, K, NPK mixtures, and organic products from 2001 to 2023. Data obtained from TradeMap (2024).

2023), and inflationary pressures globally (Kliesen and Werner 2022). The recent global price hikes for N fertiliser are further evident when comparing annual growth rates over time. Over the past 15, 10, and 5 years, the annual growth rate in the value of N fertilisers was 4%, 7%, and 18%, respectively, while the annual growth rates in volume increased by only 2%, 1%, and 1% over the same periods. Nitrogen fertilisers remain the largest component by value (40% average between 2019 and 2023) and volume (42%) of global fertiliser trade (data not shown), highlighting its critical role in modern agriculture (Rodríguez-Espinosa et al. 2023). Based on trade value and volume, K and P were the second and third-largest fertilisers traded globally between 2019 and 2023, accounting for 23 and 19% by value and 25 and 17% by volume, respectively (Figure 2). The import values for P and K imports increased from US$3.68 billion in 2001 to US$19.55 billion in 2023, and from US$4.21 billion in 2001 to US$24.07 billion in 2023, respectively. Like N, significant price increases were also evident for P and K. Despite low five-year annual volume growth rates of −2% and 1% for P and K, the value growth rates were 16 and 15% over the same period, respectively. The demand for NPK mixtures followed a steady trend, with 13.33 million tons in 2001–28.64 million tons in 2023, reflecting annual growth rates of 3% and −2% over 10- and five-year periods, respectively. Between 2019 and 2023, the five-year average contribution towards the total fertiliser trade value and volumes by NPK mixtures between 2019 and 2023 were 16 and 14%, respectively.

Although organic imports have risen steadily since 2001, they represented only a small share of crop production requirements, accounting for just 2% of imported value and volume between 2019 and 2023. Organic import value increased from US$230.9 million in 2001 to US$1.72 billion in 2023 with annual volume growth rates of 1% and 2% over both five- and 10-year periods, reflecting a 7% annual growth rate in value over both periods.

2.2 South African fertiliser industry stakeholders

The fertiliser trade in South Africa is primarily influenced by global market trends and domestic demand for crop production. The value of imports was US$824 million in 2023, following a peak in 2022 that exceeded US$1.5 billion (Figure 3). Between 2019 and 2023, N-related products dominated imports by value (56%) and volume (64%), followed by K (21% by value and 20% by volume) and P (18% by value and 13% by volume). Additionally, the total value of imports grew by an average of 18% per annum between 2019 and 2023, while the annual growth rate in total volumes remained stable at 2%. Both N- and P-related fertilisers experienced significant global price increases during the 2019–2023 period. Despite modest annual growth rates in volume of 5% for N and 1% for P, the corresponding annual growth rates in value increased by 20% and 16%, respectively.

Over the past decade, urea has consistently been the most imported fertiliser in South Africa, representing approximately 40–42% of all fertilisers imported over both five- and ten-year periods in terms of value and volume (Table 1). This demand for N fertiliser is further highlighted by the five-year (2019–2023) average annual imports, which account for 56% by value and 64% by volume, with an annual growth rate in volume of 5% during the same period. A modest 3% increase in urea import volumes, coupled with a 20% rise in import value over the past five years, highlights the impact of global price surges. This contrasts with the 10-year average import value increase of 9%, reflecting more recent price volatility. These price increases have been driven partly by global supply chain disruptions and geopolitical tensions, such as the Russia-Ukraine war, which have significantly impacted N fertiliser availability (Hebebrand and Laborde 2022; Vos et al. 2025).

Potassium chloride (KCl) and monoammonium phosphate (MAP) represented 18% and 11% of fertiliser volume imported over ten years, respectively, reflecting the need for P and K in South Africa's crop production systems. Overall, the average P and K imports by value were 18% and 21% respectively during the 2019–2023 period. Potassium chloride showed a slight declining trend in imported volume during the 2019–2023 period, however, a 4% increase per annum was observed from 2009 to 2023. Potassium chloride's relatively stable trade volumes highlight its critical

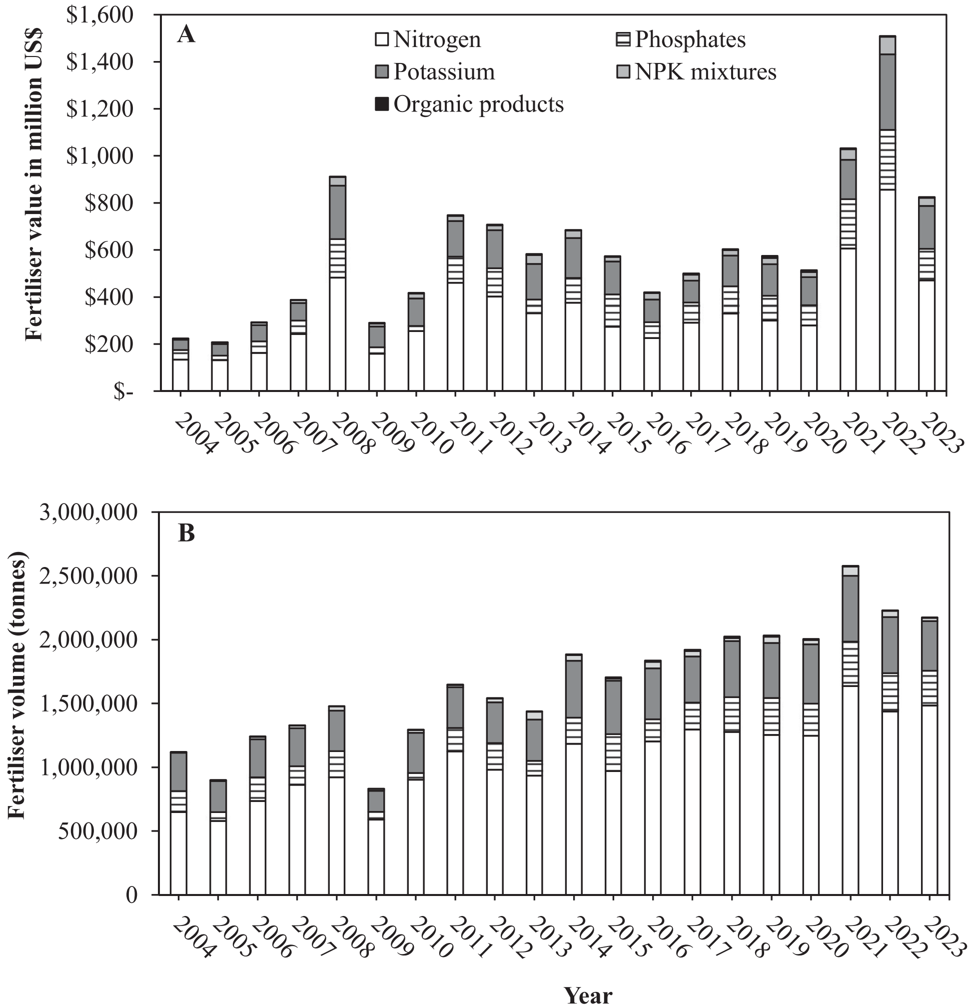


Figure 3. (A) South Africa physical fertiliser import value of products containing nitrogen (N), phosphorus (P), potassium (K), NPK mixtures, and organic products from 2004 to 2023 (distinct from nutrient equivalence). (B) South Africa imported volume of fertiliser products containing N, P, K, NPK mixtures, and organic products from 2001 to 2023. Data obtained from TradeMap (2024).

role in K replenishment in agricultural soils, particularly in irrigated perennial and annual cropping systems where high volumes of elemental K are removed at harvest.

The value of MAP increased from US$116.3 million (10-year average) to US$140.5 million (5-year average), reflecting an annual increase of 14% between 2009 and 2023. In contrast, MAP volume imports remained relatively stable recently due to elevated global prices, indicating a drop of 1% per annum between 2019 and 2023. This trend may be linked to the greater adoption of precision agriculture fertilisation strategies (Amusan and Oyewole 2023) by farmers, which aim to improve the economic use efficiency of applied MAP in cropping systems.

Phosphorus is highly immobile in soils used for crop production across South Africa reducing its availability and efficiency for crop uptake and utilisation. Phosphorus fertilisation using MAP is particularly critical across large cropping regions dominated by P-deficient sandy soils to ensure economically sustainable production (Beukes et al. 2019; Smit, Strauss, and Swanepoel 2021). The stable import volumes and efficient use of MAP may also further reflect alignment with global trends in P efficiency aimed at reducing runoff and minimising environmental degradation (Cordell and White 2014), while the adoption of precision fertilisation is growing among South African grain and oilseed

Table 1. Five-year (2019–2023) and ten-year (2014–2023) average values and volumes of various fertiliser products imported by South Africa. Data obtained from TradeMap (2024).

	5-year average		10-year average	
Product composition*	Value (US$)	Volume (tons)	Value (US$)	Volume (tons)
Urea	372 729 000	874 618	299 322 700	856 745
Potassium chloride	144 290 000	368 588	120 499 900	363 400
Mono ammonium phosphate	140 455 200	262 321	116 276 800	231 458
Ammonium sulphate	63 644 800	286 119	45 642 800	226 037
Limestone ammonium nitrate	32 875 800	119 409	19 326 700	72 459
N + K[†]	27 825 200	27 320	21 381 900	20 761
Potassium sulphate	34 615 800	67 203	31 422 800	60 203
Ammonium nitrate and calcium carbonate	17 774 200	72 493	18 628 300	83 954
NPK mixture	9 657 200	15 476	9 374 400	18 103
Di-ammonium phosphate	9 076 400	10 623	6 542 400	8 174
Other	38 250 400	100 743	5 585 700	98 722

*Grouped per the Harmonized System (HS) codes (Supplementary Table S-1).
[†]Mineral or chemical fertilisers containing the two fertilising elements nitrogen (N) and potassium (K) or one principal fertilising substance only, including mixtures of animal or vegetable fertilisers with chemical or mineral fertilisers (excl. those in tablets or similar forms, or in packages with a gross weight of ≤10 kg).

farmers. Precision agriculture improves P management by using technologies like soil chemical analysis and variable rate application to align fertiliser use with soil and crop needs. This targeted approach optimises P inputs, balancing them with crop demand to reduce environmental impact. In maize and soybean regions, grid soil analyses can point out P deficiencies, which may lead to increasing demand for fertilisers like MAP. Precision agriculture can shift the focus from blanket fertiliser applications to nutrient optimisation based on soil profiles, improving economic returns and sustainability.

Ammonium sulphate imports experienced extensive growth between 2019 and 2023, reflecting an increase in the imported volume of approximately 10%. Due to its role as an N and sulfur fertiliser source has likely driven demand, especially in soils with low sulfur contents as found across the major cropping systems of South Africa, such as the maize-sunflower-soybean dominated cropping systems across the central region, and wheat-canola (*Brassica napus* L.) and barley (*Hordeum vulgare* L.) dominated cropping systems in the southern regions of South Africa (Haarhoff, Kotzé, and Swanepoel 2020; Haarhoff and Swanepoel 2021; Tshuma et al. 2021). Sulfur plays a crucial role in optimising yields in cereal and oilseed crop production systems, especially as its deficiency becomes increasingly problematic (Sharma et al. 2024). This deficiency is often addressed through the application of sulfur fertilisers, which are commonly used for topdressing grain and oilseed crops during the growing season (Van Der Laan et al. 2017). Research indicates that sulfur is essential for various physiological processes, including pod formation in oilseeds, where its deficiency can lead to reduced yield and quality.

Limestone ammonium nitrate import volumes reported high annual growth rates over a 10 – and 15-year period of 32 and 22%, respectively. Organic fertiliser product imports recorded substantial declines in both annual value (307%) and volume (18%) over the period of 2019–2023. Multiple N sources (e.g., urea- and ammonium-based fertilisers) can be used tactically for a steady supply of plant-available N after application. Ammonium-N is readily available, while urea-N is gradually converted to plant-available N forms as the growing season progresses (Crous, Labuschagne, and Swanepoel 2021).

Saudi Arabia is the largest contributor to South Africa's fertiliser imports, accounting for 19% of the total value (US$891 194) over the five-year average (2019–2023) (Figure 4). Annual growth rates of 15% (5-year average) and 12% (10-year average) suggest a consistent and expanding trade relationship between South Africa and Saudi Arabia. This dominance can be attributed to Saudi Arabia's significant production capacity, particularly in N-based fertilisers like urea and MAP, the two main products imported from Saudi Arabia.

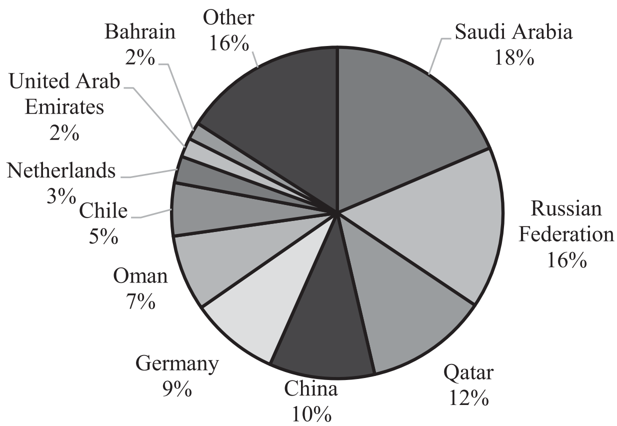


Figure 4. Key fertiliser import partners for South Africa by total average value from 2019 to 2023 (5-year average). Data obtained from TradeMap (2024).

Despite geopolitical challenges, Russia is South Africa's second largest fertiliser trade partner, primarily supplying MAP, urea, and KCl with strong annual growth rates of values of 32% (5-year average) and 19% (10-year average). Fertiliser imports from Saudi Arabia, Russia, Qatar (urea), and China (ammonium sulphate, MAP, and potassium sulphate) accounted for 57% of all fertiliser imports by value between 2019 and 2023, highlighting South Africa's strong reliance on these import partners for both N and P fertilisers.

In recent years, there has been a greater emphasis on urea supply from Qatar, with a significant increase (11%) in the annual growth rate of total value imported between 2019 and 2023. Despite being one of the largest producers of N and P fertilisers globally, the annual growth in total imports from China was only 13% (5-year average) and 6% (10-year average). Chinese export restrictions during periods of local shortages in recent years have resulted in reduced import fertiliser volumes (Vos et al. 2025).

Both Germany (supplying KCl and potassium sulphate) and Chile (KCl and NP) are important suppliers of K-based fertilisers for South Africa, collectively accounting for US$123 508 (14%) of total fertiliser value imports (averaged 2019–2023). Fertiliser imports from Chile increased by 16% per annum between 2019 and 2023 although its longer-term decline (−3%) in annual growth (2014–2023) suggests market shifts or supply chain challenges. Fertiliser imports from the Netherlands (−4%) and the UAE (−17%) indicated a significant decline in annual growth, suggesting a shift in South Africa's sourcing of urea.

The total South African fertiliser export values indicate significant fluctuation between 2001 and 2023 (Figure 5). Notably, South African fertiliser exports in value reached a maximum in 2022 at US $662 million, although the highest fertiliser exports in volume were found in 2015. Although it appears as if fertiliser export has a cyclical pattern, the key driver for exports are commodity prices. For example, commodity prices spiked in 2008 mainly due to the introduction of biofuel mandates and Chinese growth, in 2013 due to the drought in the USA and in 2022 due to the Russia-Ukraine war. These were also the years where the demand for fertiliser exports in neighbouring countries spiked. Over the five-year period of 2019–2023, N fertilisers represented 71% of all fertilisers exported by South Africa in terms of volume, followed by NPK mixtures (15%), K (8%), P (4%), and organic products (2%). The highest annual growth in exporting value (24%) and volume (11%) from 2019 to 2023 was P. Both N and NPK mixtures indicated annual value and volume growth rates of 22 and 9%, respectively, while K export volume declined by 15%, but increased in terms of value (3%) over the period of 2019–2023.

Southern African countries are key partners in fertiliser exports for South Africa, with Zambia, Zimbabwe, Namibia, Botswana, and Eswatini making up 78% of all fertiliser exports in terms of values

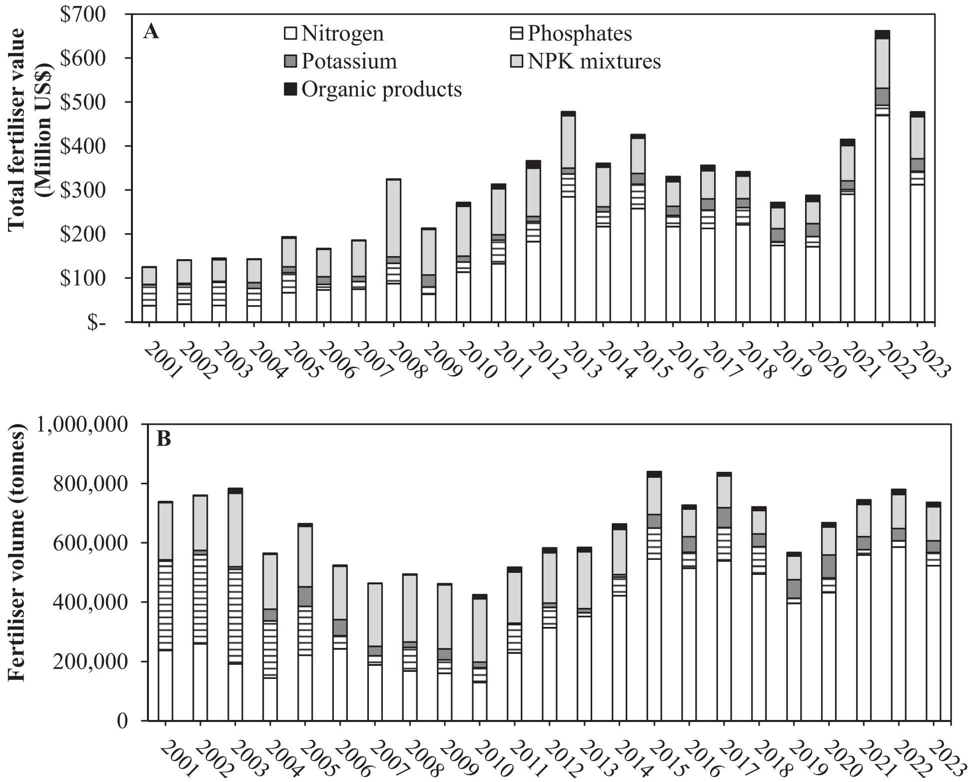


Figure 5. South Africa's fertiliser export value (a) and volume (b) of products containing nitrogen (N), phosphorus (P), potassium (K), NPK mixtures, and organic products from 2001 to 2023 (distinct from nutrient equivalence). Data obtained from TradeMap (2024).

(Figure 6). The demand for fertilisers has significantly increased, particularly in Zambia, which experienced a remarkable annual growth rate of 21% from 2019 to 2023. This surge highlights the pressing need for nutrient supplementation in the cultivation of high-demand crops such as maize, which is the cornerstone of Zambian agriculture (FAO 2023). Furthermore, Zambia's consistent growth in

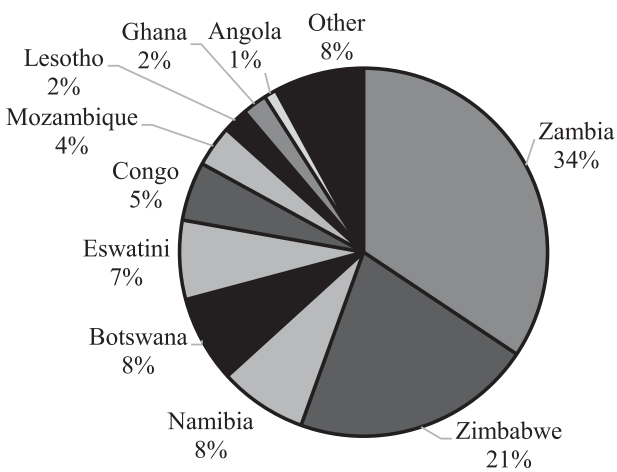


Figure 6. Key fertiliser export partners for South Africa by total value from 2019 to 2023 (5-year averages). Data obtained from TradeMap (2024).

fertiliser imports is indicated by a 6% annual increase between 2014 and 2023, demonstrating stable trade relations with South Africa.

South Africa has also sustained steady fertiliser export relations with other neighbouring countries. The annual growth rates for fertiliser exports from South Africa to Zimbabwe, Namibia, and Botswana were 17%, 18%, and 22%, respectively, between 2019 and 2023. However, a closer examination of the longer-term trends reveals stagnant growth rates of 2%, 2%, and 0% for Zimbabwe, Namibia, and Botswana, respectively, from 2014 to 2023. This stagnation suggests a static demand for fertilisers from South Africa as a supplier, coupled with limited agricultural expansion in these regions. Contributing factors include supply chain disruptions, inadequate infrastructure, and ongoing economic challenges (Nel 2024).

3. South African fertiliser consumption trends

3.1 General consumption trends and key factors

An analysis of NPK fertiliser consumption trends in South African agriculture revealed distinct patterns (Figure 7). Due to crops' inherent fertiliser nutrient requirements, the NPK fertiliser consumption (as discussed above) is coupled with the area change. To estimate NPK consumption in South Africa, the nutrient application rate (kg ha^{-1}) was multiplied by the area. Due to N's inherent yield advantage, it was assumed that the N rate remained constant over time. However, P and K applications for field crops and pastures are highly dependent on farm location, production practices, and farm profitability. Therefore, it could not be assumed that their application rates (kg ha^{-1}) remained constant. Thus, the locally available supply of P and K was calculated by adding local production and imports and subtracting exports. The local P and K supply was then allocated proportionally to the included field crops (horticulture P and K application rates remained the same). No fertiliser stocks were assumed, hence the local demand for phosphorous and potassium was adjusted downwards in years with lower supply and upwards in years with higher supply. NPK consumption was projected by multiplying the BFAP-projected crop area with the average NPK application rates from the past five years (2019–2023).

The consumption trends for N, P and K exhibit significant variation. Nitrogen consumption showed slight fluctuations, peaking at 648 000 tons in 2003, dropping by 28% to 466 750 tons in

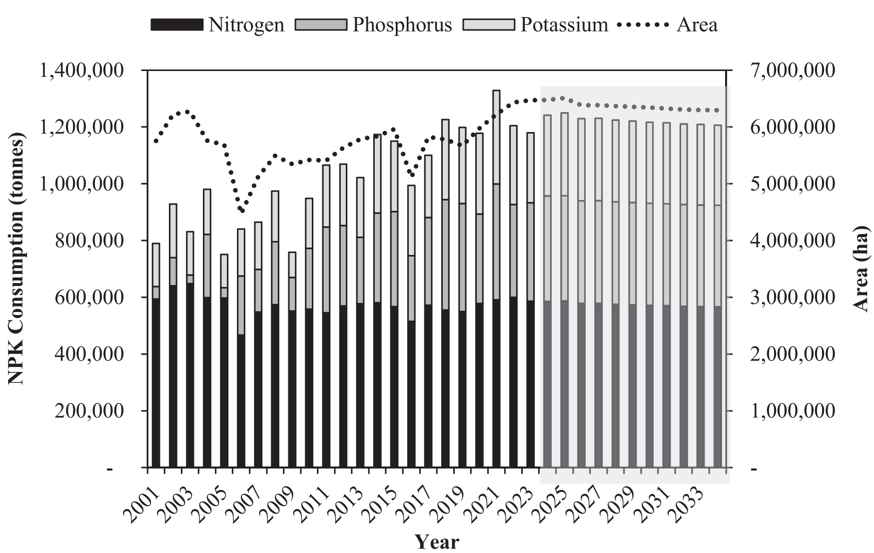


Figure 7. Historic and projected nitrogen (N), phosphorus (P), and potassium (K) fertiliser consumption from 2001 to 2034 for South Africa based on area (ha) planted annually for crop production. Data obtained from BFAP and sources listed in Table S-3.

2006 due to area reduction, before stabilising around 560 000 tons annually from 2007 onward (only realising a 0.3% per annum increase until 2024). (BFAP 2024). Phosphorus and K exhibited significant growth (with variation) over the past two decades. Agricultural P consumption increased by 6.3% per annum from the 2004 to 2024, while K increased by 4.4% per annum over the same period. In other words, while N consumption has remained relatively stable over the past two decades, the consumption of P and K has increased significantly. This shift can be attributed to changes in cropping patterns. The area under crop production, including field crops, horticulture, and pastures, as indicated in Supplementary Table S-2, expanded from 5.76 million hectares in 2001 to 6.48 million hectares by 2024, reflecting continuous growth over the past few decades. However, within this overall increase in production area over the past twenty years, distinct trends have emerged that have influenced fertiliser usage. South Africa's area under major cereals (maize, wheat, barley, etc.) declined by approximately 900 thousand hectares, from 4 million to 3.1 million hectares. Simultaneously, the area under oilseeds (primarily soybeans and canola) increased by 1.1 million hectares. Oilseeds, especially soybeans, have a higher requirement for P and K, while also producing N as a leguminous plant, which enhances nitrogen levels in the soil for the subsequent year's crops. The influence of N on the following cropping season is significant and reduces the need for inorganic N fertiliser, but the need for both P and K will increase due to the high P and K requirements of soybean (Salvagiotti et al. 2021).

The area under horticultural production has also expanded rapidly over the past two decades, resulting in increased consumption levels of P and K. Additionally, growing awareness of soil correction and nutrient management has significantly improved fertiliser efficiency. For example, from 2001 to 2003, South Africa produced an average of 20 kilograms of maize for every kilogram of fertiliser applied. By 2021–2023, this figure had doubled, with South Africa now producing 40 kilograms of maize per kilogram of fertiliser applied. This increase in nutrient use efficiency can be partially attributed to the development and adoption of improved maize cultivars with enhanced nutrient uptake and utilisation traits (Ordóñez et al. 2025). A more detailed analysis of productivity rate shifts for various crops is provided in Otterman et al. (2025).

The majority of the NPK fertilisers are applied to maize, sugarcane, and intensive pastures for dairy cows (Figure 8(A)) and overall consumption showed a modest increase from 2013–2015 to 2021–2023. Nitrogen fertiliser remains the most important nutrient to produce field, horticultural, and pasture crops in all periods in South Africa (Figure 8(B)). Total N fertiliser use increased by 3.1% from 2013–2015 to 2021–2023, field crop N fertiliser usage increased by 1%, horticulture increased by 20%, while N fertiliser demand for pasture production remained low but consistent compared to the other sectors. There was an increasing demand (23%) for total P fertiliser from 2013–2015 to 2021–2023, indicating intensification in fertilisation strategies by farmers. Due to the high K fertiliser requirements of horticultural crops the total K demand increased by approximately 16.1% from 2013–2015 to 2021–2023.

The three intervals were selected to exclude extreme drought years, such as 2016 and 2024, which were significantly affected by El Niño events. Aiming to identify periods with relatively normal weather to allow for a more accurate and consistent comparison across current, past, and future scenarios. This is especially important for the 2032–2034 period, as the BFAP baseline assumes normal weather conditions in its outlook (BFAP 2024).

The field crop sector has consistently dominated fertiliser consumption in South Africa, accounting for approximately 73% of total NPK fertiliser use over the past decade (Figure 8(B)). Among all field crops, the most rapid growth in NPK fertiliser consumption has been observed in soybeans and canola, where the area under production has increased sharply over the past ten years. The expansion in soybean production area was primarily driven by substantial investments in soybean crushing plants, aimed at replacing imported soya meal and soya oil with locally produced products. This growth was further supported by significant investments from seed companies in climate-adapted and herbicide-resistant cultivars, technology providers, and farmers' adoption of improved farming practices. Over the past decade, the horticultural sector accounted for approximately 15% of

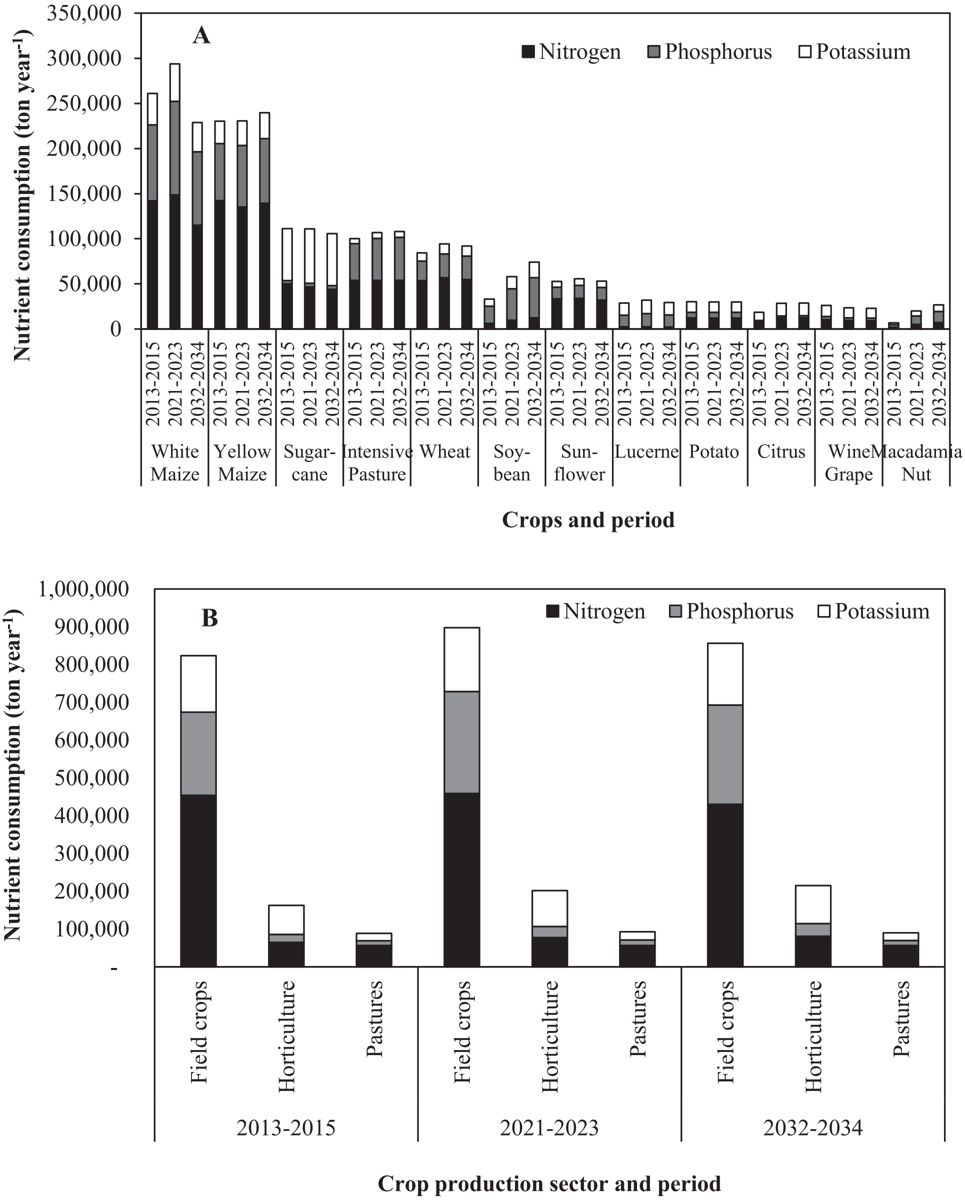


Figure 8. (A) Historic, current, and projected nitrogen (N), phosphorus (P), and potassium (K) fertiliser consumption across the major crop types in South Africa. (B) Corresponding nutrient use across various crop production sectors (field crops, horticulture, and pastures). A list of crops considered in these nutrient use figures is included in Supplementary Table S-2. Data for both panels were obtained from BFAP and sources listed in Table S-3.

NPK fertiliser consumption annually. It exhibited steady growth, with a 24% increase from 2013–2015 to 2021–2023, reflecting an increasing focus on high-value crop production. Some horticultural products exhibited even faster growth. For example, the NPK fertiliser consumption for macadamia nut production increased by 195% from 2013–2015 to 2021–2023, with an additional 35% projected growth between 2021–2023 to 2032–2034 (Figure 8). This can be attributed to the rapidly expanding macadamia nut industry in South Africa (SAMAC 2022) thereby further establishing South Africa as the largest producer of macadamia nuts globally.

The remaining 12% of NPK fertilisers are used annually for pasture production, primarily to support high biomass yields and enhance the profitability of pasture-based dairy systems in the Western, Eastern, and KwaZulu-Natal provinces (Galloway, Swanepoel, and Haarhoff 2024). In contrast to the trends observed in field crops and horticulture, the use of NPK fertilisers in pastures has remained relatively unchanged over the past decade. This suggests limited expansion or reduced investment in pasture fertilisation for future production systems.

When considering the future consumption of fertiliser, various scenarios could unfold. For instance, under BFAP's Baseline projections, despite some further substitution of maize with soybeans, the rapid expansion in soybean hectares is anticipated to decelerate. Overall, maize hectares are expected to contract slightly as some of the more marginal production regions face challenges in competing in the global market, where prices are projected to come under increasing pressure due to slow economic growth. However, if the South African and global economic growth rates begin to improve, this scenario could change, and fertiliser use might start to increase again, as observed over the past two decades. It is also worth noting that fertiliser use in the horticultural sector is expected to rise as horticultural trees come into production, thereby increasing their fertiliser usage.

3.2 Emerging technologies and future perspectives

This continued demand for NPK fertilisers for field crop production highlights the need for tailored nutrient management strategies to enhance profitability and quality (Haarhoff, Kotzé, and Swanepoel 2020). Nitrogen, P, and K follow different historical, current, and future trends based on various external influences. Nitrogen availability during the growing season is one of the main factors influencing crop productivity. In field crop systems, N fertiliser application is determined by yield potential, which is influenced by factors such as crop type and needs, cultivar, water system (rainfed or irrigated), and soil type. Despite greater fertiliser prices in some years, farmers continued applying similar rates of N compared to years when prices were lower thereby limiting possible yield penalties due to N deficiencies. Recently, grain farmers are increasingly implementing precision agriculture practices with or without conservation agriculture principles to lower agronomic inputs and improve the efficiency of inputs such as seed, fertiliser, and agrochemicals. Precision agriculture includes using various technologies to capture on-farm data related to the soil and crops, thereby improving the decision-making process when managing external inputs such as fertilisers (Thompson et al. 2019). For example, N rates based on pre-determined management zones (e.g., based on soil textural and depth differences) or in-season N applications based on satellite imagery (Normalised Difference Vegetation Index) can influence overall N consumption and efficiency (Kizilgeci et al. 2021). Adoption is, however, slower than expected due to high initial investment costs and a lack of technical knowledge managing all the complex soft- and hardware systems. Nitrogen fertiliser application rates of horticultural crops are more stable over time but differ based on the age of the orchard, crop vigour, cultivar, soil type, and yield potential. High rates (300-600 kg N ha^{-1}) of N are applied in pasture-based systems where intensive grazing is performed with dairy cattle, as commonly found in the Eastern Cape and KwaZulu-Natal Provinces (Swanepoel et al. 2015). Lucerne (*Medicago sativa* L.), which was excluded from the other pastures grouping in Figure 8, is less reliant on fertiliser N due to its N fixing capability but is heavily dependent on regular P and K fertiliser inputs as large amounts of nutrients are removed when cutting hay for off-field livestock feeding. Conservation agriculture consists of three main principles: (i) minimum soil disturbance; (ii) a permanent organic soil cover, and (iii) a diversified crop rotation system with three or more crop types. Minimum soil disturbance and crop rotations could lead to small shifts in overall N quantities over the long term depending on soil organic matter levels, nutrient cycling, and crop types. Crop rotation systems that include leguminous crops such as soybean and medics (*Medicago* spp.) could contribute to reduced N rates in field crop systems, however, high variability in soil N levels following the legume crop cause uncertainty among farmers and agriculturists (Haarhoff and Swanepoel 2018). Adoption rates of conservation agriculture practices are relevantly greater in the winter grain-oilseed crop systems, but conventional farming practices are still utilised in the summer field crop systems allowing the noticeable change in N consumption to remain low.

Trends of P consumption are influenced by more external factors than N and K. The application of P fertilisers is more sensitive to soil chemical parameters and farming system cash flow. Farmers often increase P fertiliser rates in seasons following favourable growing conditions, driven by improved cash flow. Precision agriculture and the ability to apply P variably based on grid-based soil chemical analysis, play a large role in the changed P fertiliser application strategies over the last two decades. In soil-crop systems where grid-based soil samples are conducted and analyzed, P fertiliser is applied variably to increase the P soil levels to a predetermined quantity, leading to a fluctuating consumption rate by grain farmers. The introduction of alternative crop types in cropping systems over large areas, for example the rapid rise in soybean hectares that was previously mentioned, further leads to changes in fertiliser consumption, especially P and K.

In general, advancements in precision agriculture are continuously influencing fertiliser consumption patterns, with variable rate applications playing an important role in optimising fertiliser use. By integrating high-definition soil and crop maps with advanced application equipment, farmers can optimise fertiliser applications and minimise waste. Emerging technologies in fertiliser application, including variable rate spreaders, precision planters, IoT (internet of things)-enabled sensors, and drones, contribute to greater accuracy, reduced overlap, and optimised resource use. Data-driven decision-making is becoming increasingly critical in modern commercial crop production systems (Fleming et al. 2018), improving productivity, profitability, and sustainability (Truter et al. 2025). Predictive modelling and real-time field monitoring also support improved decision-making. In-season monitoring and decision-making will mainly influence N rates and application timing, and to a lesser extent K application rates. Market dynamics also drive these trends, as financial pressures force farmers to adopt technology such as variable rate applications to enhance profitability in the face of volatile fertiliser prices.

Furthermore, advanced fertiliser products, like controlled-release fertilisers and bio-fertilisers, are becoming increasingly popular due to their emphasis on nutrient efficiency (Bhardwaj et al. 2014; Moradi et al. 2024; Schütz et al. 2018). High costs of products, uncertain nutrient release rates, low nutrient concentrations compared to chemical fertilisers and crop penalties are practical limitations for broadcasting adoption (Govil et al. 2024; Singh et al. 2024). Stricter global environmental

Table 2. Summary of emerging fertiliser developments, their agronomic descriptions, implications for crop productivity and nutrient management, and associated limitations in the South African crop production context.

Development	Description	Agronomic implication	Limitations/trade-offs
Precision agriculture technologies	Integration of various technologies, digital tools, and sensors to apply fertilisers more precisely	Optimises nutrient applications, uptake efficiency and productivity	High initial costs; limited adoption; requires farmer training and data management resources
Nutrient recovery technologies and practices	Technologies focused on recycling nutrients from waste (e.g., sewage sludge, manure) Cover crops as catch crops	Reduce soil nutrient imbalances and promote nutrient cycling Changes in crop hectares	Minimal infrastructure and adoption
Alternative fertiliser sources	Slow-release products, organic-based biological products	Reduced nutrient input costs Reduced environmental losses	High costs Uncertain nutrient release rates Low nutrient concentrations Crop yield penalties
Increased fertiliser costs	Rising raw material costs (e.g., natural gas for ammonia production, phosphate rock)	Encourages efficient use; challenges affordability for farmers in marginal regions	May reduce overall fertiliser use and yields Nutrient mining of soils
Regulatory changes (local & global)	National policies and international agreements on fertiliser use, imports, and environmental regulations	Agronomic recommendations affected due to fertiliser availability and irregular prices Unpredictable nutrient uptake leading to crop yield penalties and environmental pollution	Can limit access to affordable fertilisers Discontinuation of products or de-registration of products

regulations on nutrient runoff and greenhouse gas emissions are furthermore beginning to influence practices, allowing organic amendments like manure products to play a more significant role (Thangarajan et al. 2013). Even though this is not a major driver in South Africa, the potential of global regulation implications influencing our local utilisation can be applicable soon. Other runoff mitigation strategies include practices like conservation or no-tillage, crop rotation, and usage of cover crops (Luna Juncal et al. 2023) (Table 2).

4. Conclusion

The South African fertiliser industry is heavily influenced by global trade dynamics, local agronomic needs, and environmental considerations. The South Africa agricultural industry is continually under pressure by especially erratic rainfall patterns which play a critical role in fertiliser consumption annually. Fertilisers remain indispensable for enhancing soil fertility and sustaining agricultural productivity, especially in nutrient-deficient soils as found across the major grain-producing regions such as the Free State, North West, and Western Cape provinces of South Africa. However, the reliance on imports exposes South Africa to price volatility and supply chain disruptions, as evidenced by recent global challenges such as geopolitical tensions and the COVID-19 pandemic. South Africa's fertiliser import landscape is shaped by a mix of dominant suppliers, emerging players, and declining contributors. The rapid growth from Qatar and Oman suggests opportunities for strengthening ties with emerging markets, while stable relationships with Saudi Arabia and Germany provide consistency. However, geopolitical challenges (conflict and sanctions) and price volatility necessitate strategies to ensure a sustainable and secure fertiliser supply for the agricultural sector, especially N-based fertilisers. Nitrogen, P, and K continue to dominate fertiliser imports and consumption, reflecting their critical roles in the production of field and horticultural crops. The growing adoption of precision agriculture technologies in the grain and oilseed cropping systems presents a promising opportunity for optimising fertiliser use, improving economic returns, and mitigating environmental impacts. Emerging trends, such as the rapid expansion of soybean and macadamia production, underscore the progressiveness of South Africa's agriculture industry and its developing nutrient demands. However, challenges like soil nutrient deficiencies, high production costs, and environmental concerns necessitate targeted strategies. These include improving fertiliser use efficiency, exploring alternative fertiliser sources, and developing resilience against uncertain global market trends.

Acknowledgements

We express our sincere gratitude to the Protein Research Foundation and the Oilseeds Advisory Committee/Oil and Protein Seeds Development Trust for funding this project. We also extend our thanks to the Fertilizer Association of South Africa (FERTASA) for providing valuable information and their critical contributions to the interpretation of the data. Furthermore, we acknowledge the contributions

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Oil and Protein Seeds Development Trust/ Oilseeds Advisory Committee; Protein Research Foundation.

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