Regional Programme
Energy Security and Climate Change
Middle East and North Africa

KONRAD ADENAUER STIFTUNG

The Potential of Biofertiliser for North Africa: Navigating Challenges for Sustainable Food Security, Climate Change Adaption & Economic Development

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KAS-REMENA Policy Paper Series No. 5 / 2024

kas.de/remena

Abstract

This paper explores the challenges of sustainable food security in North Africa amidst population growth, geopolitical turbulences, soil degradation and increased requirements for regulatory compliance. Emphasizing the potential of biofertilisers, it highlights their benefits compared to chemical fertilisers, including increased crop yields and environmental sustainability. The analysis reveals biofertilisers as a cost-effective alternative with the capacity to adapt to climate change consequences and soil degradation in North Africa, reduce dependence on international trade and enhance compliance with objectives to reduce greenhouse gas emissions. Drawing from these findings, we advocate firstly for the establishment of a database to monitor the demand and supply of biofertilisers in North Africa similar to existing ones on chemical fertiliser. Secondly, we recommend the formation of a transnational research collaboration on biofertilisers between North African and European entities, supported by the research funding programme Horizon Europe. The overall objective is to enable policymakers to navigate towards a resilient agricultural trajectory, ensuring sustainable food security and addressing socio-economic challenges in the region.

Introduction

Since human civilisation has shifted from a nomadic lifestyle to the establishment of permanent settlements, fertiliser has become indispensable for agricultural production due to its positive effects on crop yields. Consequently, the utilisation of fertilisers increased continuously along the development of the global population, supporting humanity to thrive. Accordingly, the role of fertilisers in promoting agricultural output and global food security was not questioned for a long time. In the early 1960s, however, chemical fertilisers became the target of criticism since studies revealed that their long-term application had adverse impacts on the environment and soil health (Sartori et al., 2021). In addition, climate change consequences, or more specifically increasing abiotic stress for crops, aggravate the negative impact of chemical fertiliser on agricultural production. This is especially true for North Africa, as the already poor soil and harsh climatic conditions pose a major hurdle for crop productivity (Drine, 2011; Raimi et al., 2021; Chaudhary et al., 2022).

Chemical fertiliser supply is further highly integrated into the world market. This product group includes nitrogenous, mixed mineral, potassic, phosphatic and animal or vegetable fertilisers, together representing 0.6% of global trade and a trade volume of 143 billion USD in 2022. Biggest export countries are Russia, Canada, the United States, China and Morocco, together accounting for 37.73% of global fertiliser exports (Observatory of Economic Complexity, 2022). Therefore, chemical fertiliser utilisation is not only subject to environmental and climatic challenges, but also to any major geopolitical turbulences and trade disruptions. This can be clearly demonstrated by the consequences of the outbreak of the Russian-Ukrainian war in 2022, which has led to a 50% fertiliser price increase from February to April of the same year, only returning to pre-war levels by March 2023. This was triggered, among other things, by the interruption of transport routes in the Black Sea, generally increasing energy prices, and imposed restrictions on fertiliser export by Russia (Kee et al., 2023).[1]

This nexus has led to a “fertiliser price shock” contributing to the FAO Food Price Index (FFPI) reaching its highest level in 2022 since its inception in 1990 (FAO and WTO, 2022). North African countries have not been spared by this trend and have experienced food price increases between 15.3% in Morocco and 67% in Egypt in 2023 (FAO, 2023). Accordingly, disruptions in global fertiliser supply chains and price volatility bear a stark risk to food security. In face of China’s (8.89%) and the United States’ (5.73%) share of fertiliser exports and ongoing geopolitical tensions, policymakers need to take this risk into account since any major geopolitical conflict has the potential to trigger another fertiliser price shock.

Even if fertiliser research is working on more sustainable solutions since the 1960s, these recent developments have raised awareness for the much-needed shift in fertiliser practice significantly. The general purpose of this endeavour is to find alternatives for chemical fertilisation that are continuously available and affordable, as well as capable of enhancing crop productivity and soil health under abiotic stress conditions. Looking for these desired characteristics, studies have revealed the potentials of so-called biofertilisers. However, only a few studies have been carried out to analyse the need for biofertilisers, their role in enhancing food security and improving soil health in North Africa (Benson et al., 2024; Freyer et al., 2024). The majority of relevant studies have been conducted in Asia and Latin America, which may be attributed to several factors, including the significant role of agriculture in these regions as a driver of the economy, and regulations that have been implemented to prioritise research on sustainable agricultural practices. (Espinoza et al., 2004; Joshi and Gauraha, 2022; Pandey and Chandra, 2016).

[1] The consequences of these export restrictions were so far-reaching, since Russia is the major global fertiliser actor considered by an export share of 13 percent in 2022 (Observatory of Economic Complexity, 2022).

Against this backdrop, the paper's aim is to highlight the benefits of biofertiliser with a particular focus on the North African region. Additionally, it seeks to analyse various challenges confronting the agricultural and fertiliser sectors, encompassing demographic, geopolitical, environmental, and climatic issues, as well as regulatory compliance. Subsequently, the paper introduces the current state of biofertiliser research, level of commercialisation, along with their cost and environmental advantages compared to chemical fertilisers. Furthermore, it advocates for a scaling-up strategy of research, production, distribution, and application of biofertilisers in North African countries, as well as for a stronger research cooperation between North Africa and the European Union. As the nexus of agricultural innovation converges with imperatives of net-zero carbon emission and zero hunger, as well as geopolitical considerations regarding the availability of mineral resources, the discourse surrounding fertilisers should gain more attention of policymakers. Accordingly, the overarching objective of this paper is to empower policymakers, stakeholders, and practitioners to steer towards a more resilient and sustainable agricultural trajectory, thereby ensuring food security in North Africa and beyond.

Contemporary Global Challenges for Food Security and the Role of Fertiliser

The agricultural sector in North Africa is facing a multitude of challenges that threaten future food security in the region. Rapid population growth necessitates a significant increase in food production, driving up the demand for fertiliser. Geopolitical tensions further complicate this landscape, since international trade of fertiliser commodities is susceptible to disruptions. It will be demonstrated that especially the Russian-Ukrainian war has destabilised global supply chains and led to price volatility of fertiliser products. This instability poses severe risks for the region, since some countries heavily rely on wheat and fertiliser imports. Environmental and climatic challenges, such as the increasing frequency and severity of extreme weather events, add another layer of complexity. The production and extensive utilisation of chemical fertilisers contribute significantly to greenhouse gas emissions and environmental degradation, thus negatively affecting agricultural productivity. Finally, regulatory compliance with international climate policies places additional pressure on the fertiliser sector. Initiatives like the EU Carbon Border Adjustment Mechanism (CBAM) aim to curb emissions and thus impose new costs and challenges for fertiliser producers and exporters. To better understand the consequences of these challenges for North Africa, each of them will be analysed in more detail in the following sections.

Demographic Challenges

Rising population numbers inevitably increase food demand. Consequently, the fertiliser demand increased from 46.31 million metric tonnes in 1965 to 201.84 million metric tonnes in 2020 (Statista, 2022) . This trend is expected to continue in face of a projected global population size of 9.7 billion in 2050 entailing an estimated increase in production of cereals and meat by respectively nearly 50% and 85% until 2030 if currently dominant diets are not changing (McMichael, 2013). Accordingly, fertilisers will inevitably play a vital role in meeting the demand for increasing agricultural output and supplying the ever-growing global population with sufficient food.

The intensity of this increased food demand, and therefore also fertilisers, will vary greatly from region to region. While the European demand will decrease, North African countries will experience a significant increase due to their expected population growth as shown in figure 1 (World Bank, 2021, 2022b). All countries of the region have at least grown 2.5 times from 1965 to 2020 and together exceeded the 200 million population mark in 2009. Egypt makes up the greatest share of this, as it inhabits about half of the overall North African population and accounts for about 80% of the region's fertiliser consumption. This increase in population – in face of the already existing levels of food import dependency of the region – will further challenge food security.

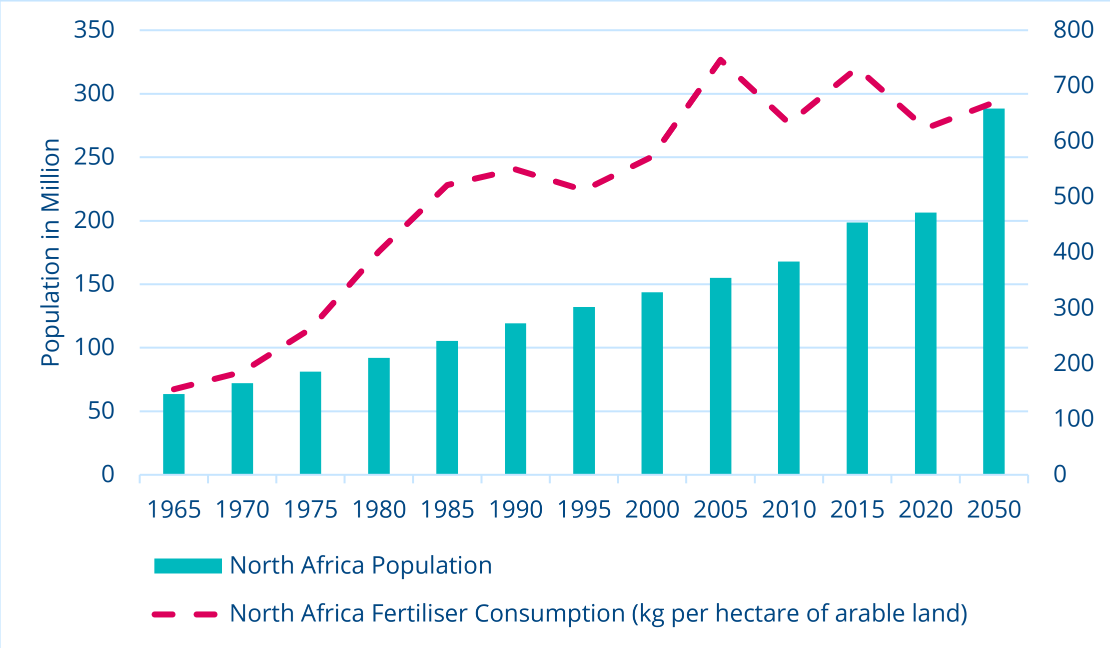

Figure 1: North African Population & Fertiliser Consumption
Source: World Bank, 2021, 2022a

Regarding the already existing shortage of sufficient arable land in the region, it is not possible to counter the above-mentioned demographic challenges by extending utilised agricultural area. Compared to the global average of 10.7% of arable land in percentage of respective land area, Algeria, Egypt and Libya have significant less potential for agriculture with respective 3.16%, 3.09% and 0.97% (Trading Economics, 2021a, 2021b, 2021c). To nevertheless increase food supply, these countries have two options: They could rely on chemical fertiliser to enhance domestic crop yields, or increase food imports. Both options, however, entail an exposure to the geopolitical risks of interrupted global supply chains, which will be elaborated in the following section.

Geopolitical Challenges

International trade underlies various geopolitical risks, which have the potential of triggering economic turmoil. The latest examples of political decisions with wide reaching geopolitical implications are the Covid-19 pandemic restrictions, the ongoing Russian war in Ukraine and the crisis in the Red Sea. The common denominator of these events is that they all pose risks for import-depending states by disrupting global supply chains.

This risk is particularly true for some North African countries, as their imports of staple food and chemical fertilisers were strongly affected by the outbreak of the war in Ukraine. As Egypt and Libya rely on imports from Russia or Ukraine for at least one-third, or more than half of their total wheat imports in 2021, they were forced to diversify their supply chains to ensure domestic food security. To a lesser extent Tunisia and Morocco did the same (for more information see Figure 2).

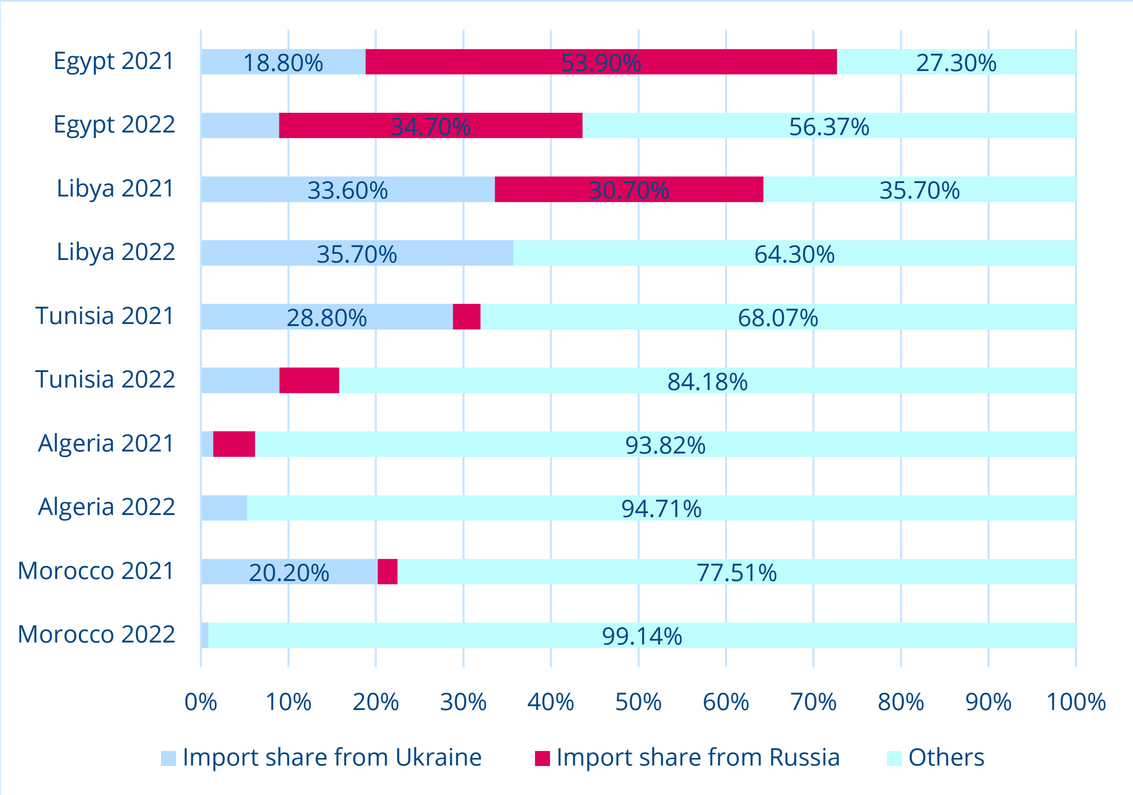

Figure 2: Wheat import share of North African countries from Ukraine and Russia before and after the outbreak of the war
Source: Observatory of Economic Complexity, 2021a, 2021b, 2021c, 2021d, 2021e, 2022a, 2022b, 2022c, 2022d, 2022e

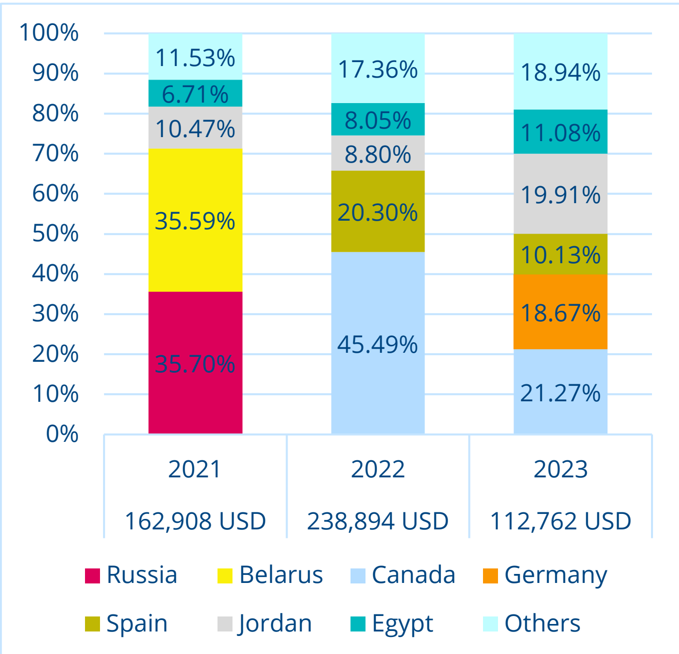

Figure 3: Origin of Moroccan potassic fertiliser imports (total value in 1.000 USD)
Source: International Trade Centre, 2024a, 2024b, 2024c, 2024d, 2024e, 2024f, 2024g.

Similar developments have also been observed with regard to the import of chemical fertilisers. Morocco for example felt compelled to diversify its imports of potassic fertiliser. This was due to the sanction regimes imposed by the European Union on Russia in relation to its war in Ukraine and restrictions by Russia itself on its fertiliser products in 2022. This affected supply to Morocco significantly since it sourced around 71% of its imports from Russia and Belarus in 2021. These were replaced by imports from Canada and Spain in 2022 and further diversified by supply from Germany in 2023 (for more information see Figure 3). Egypt faced a similar need in regard of its import of nitrogenous fertiliser, as global supply got shortened by export restrictions and bans from two of the largest exporters. The first instance was the Chinese strengthening of regulations on fertiliser exports from September 2021 until December 2022 (Laborde and Mamum, 2022). The second the Russian capping of nitrogenous fertiliser exports from December 2021 until May 2022 “to prevent a shortage on our domestic market and the resulting increase in food prices” due to increasing gas prices (Reuters, 2021). The result: While Egypt sourced around 32% of its nitrogenous fertiliser imports from China in 2021, this share was almost completely replaced by Norwegian supply in 2022 and only supplemented by imports from Russia in 2023 (for more information see Figure 4).

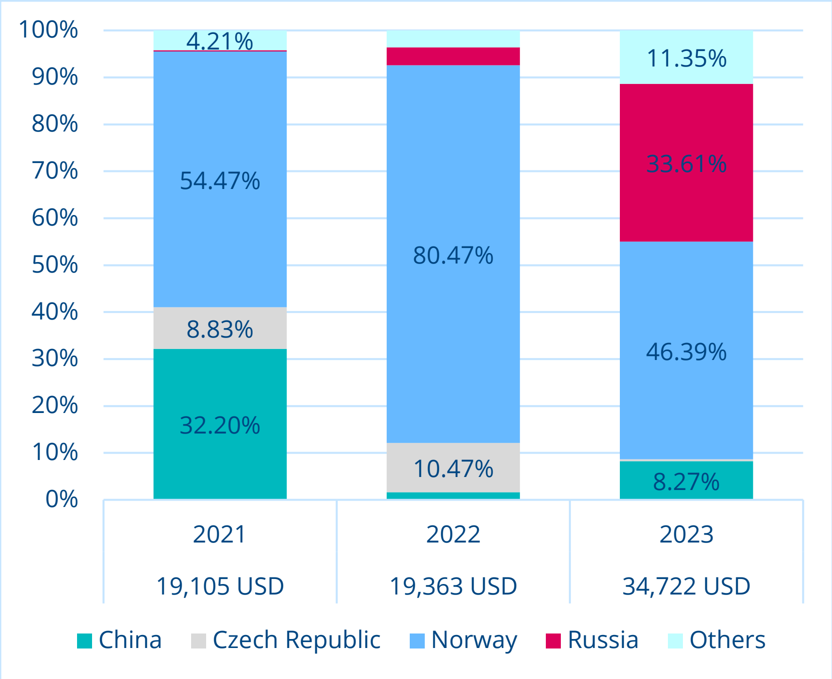

Figure 2: Origin of Egyptian nitrogenous fertiliser imports (total value in 1.000 USD)
Source: International Trade Centre, 2024a, 2024h, 2024i, 2024j.

Further challenges arise from the non-renewable character of the mineral resources required for chemical fertiliser production. This is illustrated in the following by the means of the geopolitical development concerning phosphate rock. According to estimates by the U.S. Geological Survey, some of the world largest phosphate deposits will be exhausted in the near future at current mining rates, including Chinese, Russian and US deposits with respectively 22, 43 and 45 years to remain (Hammarstrom et al., 2023). This certain future bottleneck already entails implications for today’s trade of the mineral, since the US and China have implemented exports bans or taxes on phosphate rock. The United States completely stopped exports already in 2003. China implemented an export tax in 2007, as well as a 100% increase of the same tax in 2008 (Jakobsen, 2021) and a complete ban of its export from September 2021 until December 2022. Russia has, in response to the sanctions imposed following its invasion of Ukraine in 2022 on it, temporarily suspended its fertiliser export completely from February until May of the same year (Laborde and Mamum, 2022). These trade restrictions have cut the global supply of phosphate rock and chemical fertiliser and accumulated in an over 100% increase of phosphate rock and phosphorus fertiliser prices from 2021 to 2022 (Statista, 2023b, European Commission, 2024a). However, this development also enabled other producers, such as Morocco and to a lesser extent Egypt and Tunisia, to significantly increase their share of fertiliser exports and generate revenues of 4.310 million USD, 874 million USD and 180 million USD respectively in 2022 (Trading Economics, 2022a, 2022b, 2022c).

Altogether, the necessities of impeccable running supply chains and low-price volatility mirror the disadvantages of a globalised economy and food production. As shown in this section, they have the potential to trigger a supply shortage of chemical fertiliser and therefore contribute to amplifying existing food security grievances in North Africa. This feature of international commodity trade thus poses a severe threat to sustainable food security and is exacerbated by the environmental drawbacks of chemical fertiliser utilisation and the consequences of climate change, which are elaborated in the next section.

Environmental & Climatic Challenges

Despite their positive effect on enhancing crop yields, chemical fertilisers have their downsides in terms of climatic and environmental effects. This encompasses various stages, spanning from production to application. Indeed, the production of one tone of nitrogen or phosphorus fertiliser causes 1.9 – 7.8 CO_2e and 2.3 – 4.5 tonnes of CO_2e respectively (Havukainen et al., 2018). Responsible for this is the utilisation of ammonia within their production process, consuming about 70% of global ammonia supply. The International Energy Agency points out that “ammonia production accounts for around 2% of total final energy consumption and 1.3% of CO2 emissions from the energy system” (IEA, 2021). Therefore, a growing global population with current fertiliser practices would entail a growth in ammonia production, thus contradicting the efforts to bring emissions towards net zero. Applying too much fertiliser further contributes to the emission of greenhouse gases (GHG) of the agriculture sector (Jote, 2023). These are mainly caused by anthropogenic nitrogen oxides, for which agriculture accounts for 60%, and ultimately contributing to increase atmospheric N2O from 0.2 to 0.3% annually. This is important to note, since the global warming potential of N2O is 310 times more potent than that of carbon dioxide (Jote, 2023).

From an environmental perspective, sown over a long period of time, chemical fertiliser evokes a leaching out of the soil’s nutrients which in turn negatively affects crop yields. This process can further lead to nutrient concentration in water and soil, potentially resulting in eutrophication[2], long-term soil degradation, as well as acidification and salinisation of soil and surface water. Such processes are accelerated by nitrogen and phosphorus fertiliser leaching into waterbodies leading to a concentration of fertiliser components. The long-term application of chemical fertiliser is further responsible for the deterioration of soil fertility, as reported by the United Nations Environment Program (2021). According to the report, chemical fertilisers unbalance the elements within the soil, leading to an accumulation of toxic substances inside the crop. This can even affect livestock and human health due to their uptake of these substances by food consumption. Among these substances are, according to the UNEP, trace elements like mercury, cadmium, arsenic and lead. Overuse of chemical fertiliser can further lead to soil acidification and soil crust building, which entails degradation of overall soil quality. Results can be the reduction of organic matter and humus content, as well as other beneficial organisms, stunting plant growth, shifting of soil pH and increasing likelihood of pests (Jote, 2023). Even when applied correctly, 2 to 10% of fertiliser components interfere with surface and ground water and thus generate environmental harm (Jote, 2023).

These negative environmental impacts of the production and application of chemical fertiliser get amplified by the consequences of climate change. This has severe effects for the region of North Africa, which is characterised by its arid and hot climate, bordered by the Atlantic and Mediterranean to the north and the vast expanse of the Sahara Desert to the south. In addition to already being one of the

[2] Eutrophication describes the process of waterbodies becoming “increasingly rich in aquatic plant life such as algae and aquatic macrophytes”, ultimately leading to the formation of dead zones through oxygen reduction inside the water (Lee and Jones-Lee, 2005).

hottest regions globally, the region faces challenges like rising temperatures, water scarcity and degrading soil health. Together, these issues present a great challenge to North African food security.

The above-average rise in temperature is especially noteworthy in the region. Studies on climate change have revealed that the average annual temperatures in North Africa are rising faster than the global average (Cramer et al., 2018). However, not only the temperature is rising, but also the frequency and severity of extreme weather events like heat waves and droughts. This is illustrated by Largeron et al., 2020 who found that the heat wave hitting North Africa in April 2010 had maximum temperatures exceeding 40° for more than five consecutive days. Events like this are just a taste for a potential increase of mean temperature of 1.7° to 2.6° between 2020 and 2070 and an increase of the likelihood of droughts by 150% (FAO, 2022). These developments will have severe consequences not only for human but also for soil health, as well as water availability. The latter, however, is already becoming scarce as North Africa, which is characterised as "largely comprised of water-scarce nations, with an average of less than 1.000 cubic meters of renewable fresh water per person per year (Chibani, 2023)." This fact is illustrated by Table 2, highlighting the water stress North Africa is facing as indicated by the high levels of freshwater withdrawals (Ritchie and Roser, 2023). This is likely to negatively affect crop yields and endanger future food security.

Table 1: Freshwater withdrawals in North African countries as a share of internal resources [3]
Source: Ritchie and Roser, 2023

	2000	2005	2010	2015	2020
Morocco	60.48%	63.47%	50.75%	50.75%	50.75%
Algeria	66.02%	72.85%	79.12%	92.02%	98.11%
Tunisia	79.26%	92.49%	104.92%	110.93%	137.92%
Libya	103.88%	119.15%	134.43%	125.99%	141.17%
Egypt	615.43%	698.07%	783.12%	817.14%	817.14%

In an already wate scarce region, climate change consequences like seasonal changes in rainfall will therefore have a far-reaching impact on water availability affecting agriculture processes, especially rainfed agriculture. This can further affect soil degradation and salinization through overutilisation of groundwater, allowing salty sea water to penetrate into the soil (Drine, 2011). Such a process is described by Hamed et al. (2018) analysing the continuous exploitation of saline groundwater in the Grand Erg basin, spreading over Algeria and Tunisia, which has led to severe soil degradation in the region. Overall, the FAO states that in Morocco 750.000 ha, in Algeria 1.000.000 ha and in Tunisia 1.5000.000 ha of arable land is affected by soil salinisation. In Egypt a 25% reduction in crop yield in by salinisation-affected areas was measured (FAO, 2019). This problem can be potentially intensified by the consequences of chemical fertiliser application like the eutrophication of water bodies, which will further decrease the availability of water in the region.

Challenges of Regulatory Compliance

Another challenge emerging in relation to chemical fertilisers is regulatory compliance, especially to curb CO2 emissions, as several international and national frameworks have recently been created to incentivise more sustainable products and the reduction of carbon emission. Worth mentioning are

[3] Withdrawals can exceed 100% of total renewable resources where extraction from non-renewable aquifers or desalination plants is considerable.

the United Nations Framework Convention on Climate Change, the US Inflation Reduction Act and the European Green Deal which have the objective to reduce carbon emission. To this end, also fertiliser technology must be included into these objectives and reduce its carbon footprint.

From a perspective of practical impact on chemical fertiliser trade, North Africa is most impacted by the framework of the EU Carbon Border Adjustment Mechanism (CBAM). The mechanism entered into application in a transitional phase in October 2023 and will be fully applied by 2026. It is based on the European Emission Trading System (ETS), which has established the first major carbon market to cap and trade produced emissions within the European Union. The novum of the CBAM is, however, that the carbon pricing is now extended towards products which are exported to the EU. It covers high-emitting industries including cement, iron, steel, as well as aluminium, fertilisers, hydrogen and electricity with exceptions for individual products.[4] Consequently, it will have a great impact on the trade of fertiliser, but also food products, since it taxes a great share of CO_2e emissions flowing into a product. Within the fertiliser sector this includes 1) released CO_2 from the combustion of fossil fuels and the conversion of methane to hydrogen and N_2O from the conversion of ammonia to nitric acid, 2) the emissions caused by electricity used in the production process, and 3) emissions of the production of precursors used for the production of fertiliser like ammonia, nitric acid, urea and the embedded indirect emissions of their production (Atagher, 2023).

An example calculation is provided below to illustrate the effects: Emissions of fertiliser production, falling under the CBAM, amount for about 1.6t CO_2 for one ton of ammonia and 2.25 kg N_2O (0.59 t CO_2e) per one ton of nitric acid (Skowrońska and Filipek, 2014). Calculated from this, the overall emission for one ton of nitrogenous fertiliser would amount between 1.9 – 7.8 ton of CO_2e and 2.3 – 4.5 ton of CO_2e for one ton of phosphorus fertiliser. This ultimately causes additional costs due to the CBAM of respectively about 436 Euro and 306 Euro per ton of respective fertiliser (Havukainen et al., 2018). This will have significant impact, particularly on fertiliser-exporting countries like Morocco which stands as the fifth-largest exporter of fertilisers and holds the world's largest deposits of phosphate rock. Such implications will undeniably burden these countries. For instance, considering fertiliser exports values of 350 million USD the additional costs due to CBAM lie at about 12.5 million USD when applying a price of 60$ per metric ton of CO_2e (Berahab and Dadush, 2021). Regarding the volatility and the relatively high price (69.81 Euro at May 13, 2024) for one ton of CO_2e compared to the initially 25 Euro these additional costs are likely to rise in the future and make alternative production processes and technologies even more attractive (Ember, 2024).

The attractiveness of an alternative to chemical fertilisers is further increased by the limited availability of the underlying mineral resources used for their production. The EU has also recognised this and characterised phosphate rock and phosphorus as critical raw materials since 2014 and 2017 respectively. Both commodities were integrated into the EU's Critical Raw Materials Act in 2023 due to the EU's respective import dependencies of 84% and 100% (EU Commission, 2020).

These policy measures and strategic objectives are encouraging to produce fertilisers with lower GHG emission. There are already several instances where these requirements got picked up, as for example by Morocco which "has already taken decisive steps to reduce the footprint of its highly energy- and water-intensive phosphate industry" (World Bank, 2022b). One of the most promising alternatives that already gained great interest by researchers, however, is not the innovation of current fertiliser production processes but a new category of fertilisers – referred to as biofertiliser – which not only support plant growth and crop yield, but also long-term soil quality. Against this backdrop, the next section will delve into the current status of biofertiliser research and commercialisation and present its beneficial aspects compared to its chemical counterpart.

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[4] The affected products are listed in Annex I of the CBAM Regulation 2023/956.

Biofertiliser: The Sustainable Solution for the Challenges of the 21st Century

Given the demographic, geopolitical, environmental and climate, as well as regulatory compliance related challenges North Africa is facing, biofertiliser emerges as an attractive alternative to chemical fertiliser (for an overview see Table 3) (Ullah et al., 2023). It is a promising cost-effective technology for eco-friendly and sustainable agriculture. It offers avenues for urgent increases in crop yields and reductions in dependence on international trade while mitigating environmental risks associated with current fertiliser practices and adapting climate change consequences.

Table 2: Overview of Advantages and Limitations of Biofertiliser
Source: Ullah et al., 2023

Advantages of Biofertiliser	**Limitations of Biofertiliser**
Reduces the need for chemical fertilisers and therefore soil degradation	Can only complement chemical fertiliser and not replace them
Increases plant growth and root proliferation	Slower processing than chemical fertilisers
Increases availability and uptake of nutrients	Difficult to store as sensitivity towards changes in temperature and humidity is high
Increases organic matter of the soil and overall soil health	Currently limited availability
Assists in the elimination of plant illnesses	Need for customised solutions for individual crops
Reduces overall fertilisation costs for farmers	High initial costs due to the need for extensive research and development

Biofertilisers are substances containing living microorganisms that are applied to seeds, plant surfaces, soil colonizers or the rhizosphere – the nutrient-rich region of the soil surrounding the plant root – which promotes plant growth by increasing the supply or availability of primary nutrients to the host plant. Most important for food security, however, is the scientific evidence that biofertilisers have an enhancing impact on crop yields, increasing agricultural output by 10 - 40% (Daniel et al., 2022). For example, a grain yield increase from 4.45 to 8.60 tons/ha (Rakshit et al., 2021). Considering those yield improvements, biofertilisers seem similarly suitable as chemical fertiliser to support the necessary increase in crop yields to feed the growing global population.

The Current State of Biofertiliser Research and Commercialisation

Biofertiliser technology is attracting more and more interest globally. This is not only the case for scientific research, but also for commercialisation. The extent however is differing starkly between regions. A meta-study published in 2024 revealed that the number of publications in 2022 was 20 times higher compared to 2000. It is remarkable that the countries most involved in biofertiliser research are all confronted with demographic and/or environmental and climatic challenges. Thus, India and China lead the list in terms of the number of publications with 2.797 and 2.013 articles followed by Brazil, the United States. Other main contributors are Pakistan, Iran, Spain, Canada, Egypt and Mexico (Zhao et al., 2024). The scholars further found a common research focus and identified nitrogen-fixation, yield and plant-growth promotion as well as salinisation and heavy metals as new research areas that need to be developed (Zhao et al., 2024). Biofertiliser research in North Africa so far remains limited, with the exception of emerging research initiatives at certain research centers and universities. One notable example is Mohammed VI Polytechnic University (UM6P), where laboratories are actively developing biofertilisers tailored to the climatic conditions of Morocco and Africa as a whole. For example, a recent study by Raklami *et al.* (2024) successfully developed a laboratory-scale biofertiliser capable of facilitating nutrient assimilation under harsh conditions.

From a commercialisation perspective biofertilisers are still in their infancy with a global market of estimated 3.27 billion USD in 2024 and expected to grow to 5.23 billion USD in 2029 (Mordor Intelligence, 2024). Field application is mostly concentrated on row crops including rice, wheat, soybeans among others with about 74.6% (Mordor Intelligence, 2024). In contrast to the numbers of published articles, the market has it greatest share in North-America (33%) and Europe (30%), followed by Asia-Pacific (19%), South-America (16%) and Africa (3%) (Basu et al., 2021). The biofertiliser market report by Grand View Research (2023) further identified China as the greatest consumer with 30% followed by the USA with consumption market share of 26%. This is a high level of concentration compared to the production market where the five biggest producing companies only account for 12% of the global market (Grand View Research, 2023). However, none of these corporations are based in Africa despite the fact that biofertilisation is an appropriate solution for African countries tackling the prevailing challenges agriculture is facing (Raimi, *et al*., 2021). Even with some projects supporting the utilisation of biofertilisers in Africa, like N2Africa, initiated by the UNESCO and the Nitrogen Fixation in Tropical Agriculture (NifTAL) in the 1980s, biofertiliser technology has not yet been able to thrive in Africa and is only sparsely monitored (Raimi, *et al*., 2021).

Figure 5 illustrates the research and development process for biofertilisers using the plant growth-promoting type as an example. The process will vary depending on the desired product or effect (Bharti and Suryavanshi, 2021). What becomes clear, however, is that the development of biofertilisers involves a great share of investment before tackling industrial manufacturing. Significantly in this regard is the formulation procedure and according in which form the biofertiliser is applied, differentiating between liquid and dry forms. Before, however, they are applied to suitable carriers like minerals or humus. This also enhances the shelf life of biofertilisers while reducing complexity of handling (Chaudhary et al., 2022).

In contrast to this, the formulation and the carriers also possess the greatest market constraint for a wider distribution and commercialisation of biofertilisers. This is due to their non-tolerance to UV rays and temperatures above 30°C, which is especially a problem in hotter regions such as North Africa. As it is based on biological material its general shelf life of two to three months is comparably short. It can, however, be extended by supplementing the carrier with additives and nutrients. Another limitation is the need for crop-specific biofertiliser, which can only be used for one crop compared to the all-in-one solution of most chemical fertiliser. Other limitations to overcome are lack of awareness and investments, as well as inexperienced staff and native microbial populations varying from country to country (Kumar et al., 2022). However, the main benefits of biofertilisers are inherent to their production processes and related costs, as well as their sustainable soil quality enhancing ability.

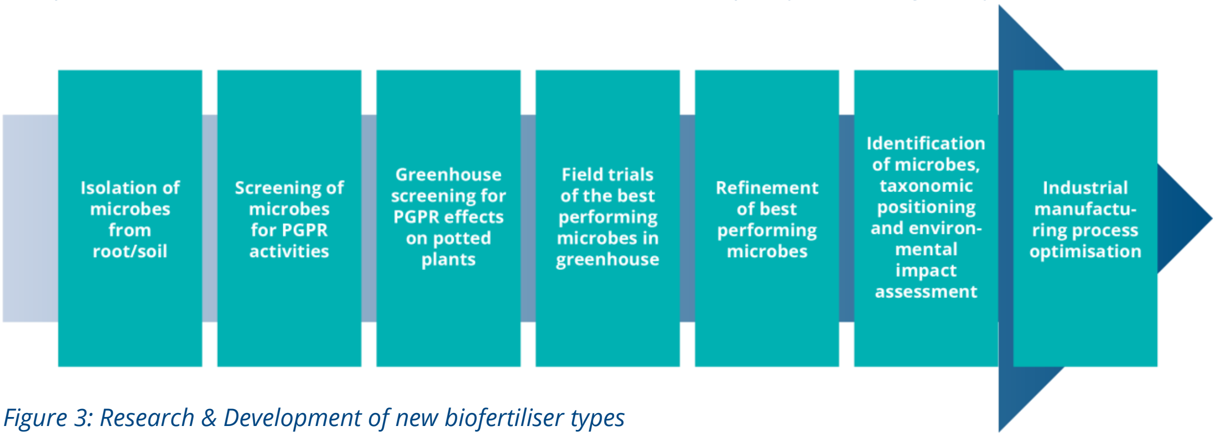

Figure 3: Research & Development of new biofertiliser types
Source: Bharti and Suryavanshi, 2021

Cost Benefits of Biofertiliser

Bio- and chemical fertiliser differ significantly regarding their general production processes and related energy consumption. Chemical fertilisers are dependent on natural gas, phosphate and potash rock. As these commodities can be affected by geopolitical tensions and economic turmoil, they are potentially exposed to strong price fluctuations and also harbour a risk of depletion due to their non-renewable nature. The composition of biofertilisers is therefore more attractive, as well as sustainable from a cost perspective. A great share of chemical fertiliser production further relies on the Haber-Bosch process, which is, however, only attractive to industrialised countries, since developing countries often struggle to bear the costs associated with this energy-intensive process. In addition, the process of ammonia production from natural gas consumes about 5% of global supply (Ahamed et *al.,* 2021). All this is not the case for the production of biofertilisers. This results in a significantly lower energy consumption of biofertiliser, compared to the approximately 16.620, 4.016 and 2.216 kWh per ton of nitrogen, phosphorus and potassium fertiliser production, respectively (Mariani, 2015). It is, however, difficult to give a concrete estimate about the energy consumption of biofertiliser production, since the process varies strongly depending on the utilised microorganism and the inoculum production, including formulation technology. By promoting the biofertiliser market, however, it should be possible to make them cost-effective and therefore competitive to their chemical counterpart. This is not only of general interest to meet climate objectives, but also significant for lowering costs regarding the application of the CBAM. Lowering the CO_2 emissions of the production of fertiliser should therefore be a core interest of countries of the European Union and major suppliers to the EU.

On top of that, the use of biofertilisers themselves reduces the costs of agricultural production in the long term. This is due to the fact that biofertilisers only need to be applied continuously for a maximum of four years to achieve the desired effect (Daniel et al., 2022). This is due to their sustainable and environmentally friendly mechanism of action, which results in a slow but long-lasting improvement of soil fertility (Kumar et al., 2022). Subsequent application is not necessary if the soil quality remains the same, whereby farmers have less expenditures. This is also complementary to the fact that about 60% to 90% of applied chemical fertiliser is not utilised by plants due to soil-leaching (Lesueur et al., 2016). The application of biofertiliser therefore has a great potential of lowering the overall application of fertiliser by a more efficient management (Lesueur et al., 2016).

Environmental Benefits of Biofertiliser and Enhancing Soil Resilience in Changing Climates

Agricultural land is not only deteriorating due to the extensive crop growth and the described harmful consequences of chemical fertiliser utilisation, but also threats arising from climate change consequences. Many regions of the world are confronted with increasing challenges, such as water scarcity, rising temperatures, soil salinisation and contamination. Against this backdrop, researchers anticipate a future decline of crop yields up to 70% (Ahamed et al., 2021). Given this context, it has been demonstrated that biofertilisers possess several characteristics that could aid in countering this trend.

The environmental benefits of biofertiliser begin, as outlined in the section above, with the lower input of energy and non-renewable resources, which is not only reducing the production costs but also lowers emissions and negative environmental impacts of related raw material extraction like phosphate rock. On top of that, biofertilisers offer multifaceted benefits in enhancing crop resilience to various stresses, including those induced by climate change. The beneficial microbes in biofertilisers not only bolster crop tolerance to biotic and abiotic stresses but also stimulate crop growth and yield under harsh conditions. One of the advantages of biofertilisers is their ability to prevent water eutrophication, primarily through their phosphorus solubilisation effect. This mechanism allows plants to absorb phosphorus from the soil more efficiently, thereby reducing the risk of phosphorus leaching into waterways. Consequently, biofertilisers not only offer a potential alternative to chemical phosphorus fertiliser but also mitigate the potential negative impacts associated with their chemical counterpart (Mulbry et al., 2005).

Moreover, biofertilisers demonstrate promise in enhancing soil fertility by remedying soils contaminated with heavy metals. Through specialised physiological and molecular mechanism evolved over time, these microbes facilitate the remediation of heavy metal-contaminated soils, thereby increasing crop resilience against them. Similarly, heavy metal-tolerant microbes offer a pragmatic approach to improving crop resilience to heavy metal stress. Through processes such as metal transportation, biosorption, and detoxification, these microbes aid in mitigating the harmful impacts of heavy metals on plant growth and development (Haroun et al., 2023).

Specifically, certain beneficial microbes exhibit dual functionality, augmenting crop tolerance to both biotic and abiotic stresses while fostering growth and yield in stress-prone environments. Notably, microbes with traits conducive to plant growth promotion (PGP) and drought tolerance are increasingly utilized to improve the performance of horticultural crops, particularly in regions facing water deficit conditions. Given their prevalence in diverse soil types, including arid and dry regions, leveraging these microbes as biofertilisers presents a promising strategy for mitigating drought stress in crops.

Furthermore, conventional methods for reclaiming saline soils have shown limited efficacy, underscoring the need for sustainable approaches. Salt-tolerant microbes present a viable solution for enhancing crop tolerance to salinity stress, as they employ various mechanisms to ameliorate the adverse effects of high salt concentrations on plants (Daniel et al., 2022).

In addition, microbial inoculants have been successfully deployed to enhance crop tolerance to cold and heat stress, thereby enabling plants to withstand extreme temperature fluctuations. Biofertilisers are able to enhance heat shock proteins within crops and the growth of root systems to allow for more efficient water absorption (Chaudhary et al., 2022). On top of that, and related to their mobilising and solubilising ability, they also increase soil water retention (Chen, 2006). Despite the potential of biofertilisers in improving temperature-tolerance, research in this area remains limited, highlighting opportunities for further exploration.

Chances and Limitations for Scale Up in North Africa

Amidst the quest for increased agricultural output amidst in face of the versatile challenges illustrated above, biofertilisers present an effective and sustainable contribution to ensuring future food security. This is not only due to their plant growth promoting capabilities, but their additional benefits for improving overall soil health under stress conditions. Especially latter holds strong potential benefits for agricultural production in North Africa. Moreover, biofertilisers are also a cost-effective alternative to chemical fertilisers, which can simultaneously contribute to a reduction in carbon emission. To this end, they can play a role in decarbonisation strategies, in particular with regards to the European Carbon Border Adjustment Mechanism (CBAM).

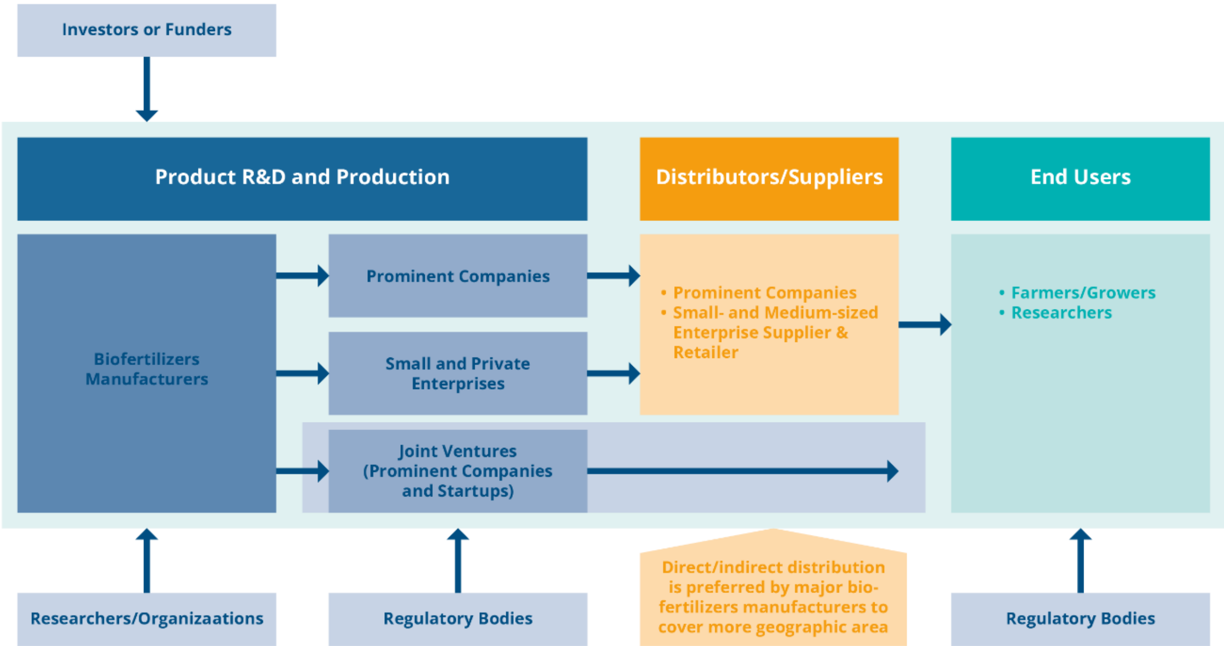

Figure 4: Biofertiliser Market Segmentation
Source: Markets and Markets, 2023

However, in order to increase biofertiliser utilisation in North Africa, efforts must be made to overcome the general limitations of the technology and the specific constraints in North Africa. The strategy to achieve this objective needs to be aligned with four different scopes including investments, research and production, distribution, as well as application, as illustrated in figure 6 (Markets and Markets, 2023). Investors are a crucial actor for the further development of the biofertiliser field, as they provide the required finance to push its development and production. For the production stage, both big corporations and smaller enterprises have a role to play, as in the distribution and supply of biofertiliser products. Looking at the end users, there is the need to instruct farmers on the use of biofertilisers, which entails financial investments too. Furthermore, all three scopes need to involve regulatory bodies, to assure regulatory compliance and consistent high quality.

If sufficient financial resources for the distribution of biofertilisers are generated, there are mainly four practical challenges to overcome in North Africa. This is the lack of biofertiliser research in regard to African crops, lack of adequate supply chain infrastructure, lack of awareness, and a shortage of skilled personnel. Regarding research and development, it is crucial to invent biofertilisers that are customised for crops domestic to the African continent. Currently, “African agromarkets are full of imported products which are mostly non-specific to local crops and ecological conditions” (Raimi *et al*., 2021). Therefore, existing biofertilisers remain below their potential in Africa. Considerable activities in this field that could serve as a guide exist in Morocco and Egypt. The Institut Agronomique et Vétérinaire Hassan II and the Mohammed VI Polytechnic University (UM6P) in Morocco, for example, are involved in the development of various biofertilisers that respond to the climatic conditions of different African countries. A project at Ain-Shams University in Cairo, which has been working on the development of biofertilisers since 1980, has made progress with regard to biofertilisers for rice cultivation (Raimi *et al.,* 2021).

Regarding the distribution of biofertiliser in North Africa it will be most important to implement comprehensive supply chains and sufficient storage facilities. Most crucial is the aspect of a consistent cooling chain, given the hot climate in North Africa and the vulnerability of biofertiliser towards UV-rays and temperatures above 30°. Given the prevalence of small-scale farmers in remote regions in the North African agriculture sector, establishing these infrastructures will require significant efforts and meticulous planning. In these contexts, leveraging solar energy generation can facilitate the adoption of decentralised solutions, thereby minimizing the required initial investments into supply and cooling chains.

In addition, such new infrastructure can create local job opportunities in the manufacturing and distribution sector. Most important, however, will be the recruitment of skilled personnel to provide advice to agricultural corporations and teach small-scale farmers about the application of biofertiliser. The latter is particularly important to also reach farmers in remote areas in order to transform fertiliser practices in large areas.

Beyond the region of North Africa and from a meta and geopolitical perspective there are several benefits of biofertilisers that finally should be highlighted. The CBAM provides significant incentives to reduce carbon emissions from fertiliser production, presenting wide-reaching potential to spur the expansion of biofertiliser manufacturing. Given its comparatively lower costs compared to carbon-intensive technologies such as carbon capture or ammonia production via green hydrogen, biofertilisers stand poised to benefit from these incentives, fostering opportunities for scalability. This would entail a reduction in the consumption of ammonia, which could – as a side effect – be favourable regarding developments in the Power-to-X field, where ammonia consumption will most likely increase in the future.

Concluding Recommendations

The overarching objective of this paper is to empower policymakers, stakeholders, and practitioners to steer towards a more resilient and sustainable agricultural trajectory to ensure sustainable food security in North Africa. Against this backdrop, we analysed the current state of the fertiliser sector and identified population growth, geopolitical turbulences, soil degradation, as well as regulatory compliance with the European Carbon Border Adjustment Mechanism (CBAM) as its main challenges. Their consequences are versatile: while population growth and soil degradation increase the demand for chemical fertiliser, geopolitical turbulences can negatively affect the supply side by disruption of transportation routes and export taxes or bans. Due to the general increase in demand, there is already an increase in the price of chemical fertilisers, which will be further intensified by financial incentives to reduce emissions and may skyrocket abruptly as a result of price shocks triggered by any major geopolitical conflict. Even if the implications of these developments vary from country to country, they have the potential to endanger food security specifically and socio-economic development in the region of North Africa more generally.

Against this background, we illustrated the benefits of biofertiliser compared to its chemical counterpart and concluded that this alternative has the greatest potential to overcome the described challenges and foster sustainable food security. Summarised, biofertilisers harness the symbiotic relationship between plants and beneficial microorganisms to optimise nutrient uptake and foster plant growth. Moreover, biofertilisers confer ancillary benefits such as enhanced soil structure, water retention, and nutrient cycling, aligning seamlessly with the imperatives of sustainable agriculture. Their production is further independent of non-renewable resources, consumes less energy, as well as produces less emissions and is therefore cheaper compared to chemical fertilisers. This unique set of benefits makes biofertilisers particularly amenable for North Africa, as it is severely affected by climate change, having a general low rate of cultivable land available, suffering from water scarcity and import dependence.

Based on this analysis, we conclude this paper by formulating two specific recommendations to pave the way for generating investments to ultimately realise the potential of biofertiliser for North Africa and beyond.

Establish a database of biofertilisers

It is imperative to create and monitor statistics related to biofertilisers in Africa. As this data is hardly available, we suggest implementing a central monitoring process covering research projects, production capacities and locate existing application areas of biofertilisers. This can serve as a foundational resource for evaluating the effectiveness of biofertiliser adoption and guiding future policy and investment decision.

This data could be gathered collectively by domestic actors like the Institut Agronomique et Vétérinaire Hassan II, the Mohammed VI Polytechnic University (UM6P) in Morocco and the Ain-Shams University in Egypt in co-operation with international institutions such as the Food and Agriculture Organisation (FAO) or other United Nations institutions, the World Bank or bodies of the African Union.

This monitoring and surveying could be modelled on existing metrics of chemical fertilisers like the *Promotion of Fertilizer Production, Cross-Border Trade and Consumption in Africa* by the African Union, the Africa Fertilizer Financing Mechanism (AFFM) and the United Nations Economic Commission for Africa (2019) or *Fertilizer Allocation for Africa* by the FAO (2022).

Promote an international research initiative on biofertiliser in cooperation with the European Union

Enabling the benefits of biofertilisers for North African will only be possible if sufficient investments are generated to further develop research, production, distribution and application. Since research is firstly the fundament for the subordinate steps, and secondly still in its infancy in Africa, we urge all North African states to initiate a large-scale research collaboration on the potentials of biofertilisers for the region.

Such research collaborations can build on existing regional and international initiatives, particularly including the European Union, since improving sustainable food security in North Africa is not only in the interest of the region itself, but also of strategic interest for the European Union. Existing cooperation formats and initiatives include the *EU-Africa cooperation in Research & Innovation* (European Commission, 2022) as part of the *African Union-European Union High Level Policy Dialogue (European Commission, 2023b)* and the European Commission's joint communication *Towards a comprehensive strategy with Africa* (European Parliament, 2024) which fit the scope of a research endeavour "building resilience for people through sustainable food systems, tackling climate and environmental crises and humanitarian action." This also accounts for direct research collaborations of universities such as between the Mohammed VI Polytechnic University (Morocco) and Université Côte d'Azur (France) (Université Côte d'Azur, 2024) or the Ain Shams University (Egypt) and the University of Stuttgart (Germany) (University of Stuttgart, 2023).

We further see a strong momentum for establishing new bilateral science and technology agreements on biofertiliser between North Africa and the European Union, based on latter's major funding program for research and innovation *Horizon Europe*. This program is backed with a budget of 95.5 billion Euro to tackle climate change, help to achieve the United Nations Sustainable Development Goals while simultaneously boosting the EU's competitiveness and growth (European Commission, 2021). Since the case of biofertiliser falls within this scope and all North African countries are eligible for funding (European Commission, 2024b), this framework provides an opportunity to develop and harness the potentials of biofertiliser in North Africa and beyond.

Establishing such a collaboration will allow for effective allocation and coordination of investments for research and production of biofertilisers in North Africa, as well as in Europe. This partnership can include common research projects for crop specific biofertiliser, technology transfer, establishment of production, distribution and storage facilities, as well as education networks to allow the technology to thrive in remote areas. Such a policy impulse should be capable of implementing a transnational network of political, private and civil-society actors to successfully navigate the challenges for sustainable food security, climate change adaption and economic development in North Africa.

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Ansgar is a junior professional in International Relations and a member of the German Council on Foreign Relations (DGAP). He recently obtained his master degree from the University of Groningen, from which he gained specific knowledge of energy security, the transition towards renewable energies and ethics in the global political economy. With a background in Sociology and Political Science and a commercial training with a transnational agromarket corporation, he utilised his master thesis to specialize in global food security issuing the depleting global phosphate rock deposits in light of a global theory of justice. The present paper is the result of his collaboration with the Regional Programme of the Konrad-Adenauer-Stiftung for Energy Security and Climate Change in the Middle East and North Africa, based in Rabat, Morocco, during an internship in 2024.

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Imprint

Konrad-Adenauer-Stiftung e. V.
Regional Programme
Energy Security and Climate Change
Middle East and North Africa

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Published by: Konrad-Adenauer-Stiftung e. V.