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Assessing the Effect of Chemical Fertilizers on Soil Health and Agricultural Productivity in Libya's Arid Regions

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تقييم تأثير الأسمدة الكيماوية على صحة التربة والإنتاجية الزراعية في المناطق القاحلة في ليبيا

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Abstract

Libya's agricultural lands are largely confined to oases and irrigated fields in extremely arid zones (e.g., Fezzan, Kufra, Sabha) where soils are predominantly Yermosols and Xerosols – shallow, sandy, highly calcareous, and low in organic carbon. Agriculture depends almost entirely on irrigation from deep aquifers (e.g., the Nubian Sandstone Aquifer and the Great Manmade River system), since only ~12% of Libya's 15.4 million ha is arable. Soil salinization is a chronic issue: high evapotranspiration drives salt accumulation, and use of mineral fertilizers (e.g. urea, NPK blends, DAP) can further alter soil chemistry. In this study, we synthesize published data from Libyan field surveys and experiments to evaluate how common chemical fertilizers affect key soil health indicators (pH, electrical conductivity/salinity, organic matter content, microbial biomass) and crop yield, and compare these to organic or integrated nutrient management practices. Available evidence indicates that heavy N-based fertilization tends to acidify these alkaline desert soils, while saline irrigation water and fertilizer salts raise soil electrical conductivity and exchangeable sodium. In one oasis survey, soils under intensive private farming (with flood irrigation and chemical fertilizer) were 70% saline-alkali (pH>9), whereas neighboring state farms using deeper wells and presumably better management remained non-saline. Organic amendments (manure, compost) improve soil structure, raise organic carbon and microbial biomass, and can maintain yields comparable to mineral fertilizers. For example, onion trials in northwest Libya showed organic manure (20 t/ha) achieved yields (~13.3 t/ha) on par with or slightly above NPK fertilizer (12.8 t/ha) while enhancing soil properties. We find that overreliance on synthetic NPK/urea in Libya's marginal soils exacerbates acidity and salt stress, undermining long-term fertility, whereas integrated systems (combining moderate inorganic N with organic matter and efficient irrigation) sustain productivity and soil health. These insights underscore the need for site-specific nutrient management, improved irrigation methods (drip/sprinkler), and organic inputs in Libya's arid agriculture.

Keywords: Chemical Fertilizers, Soil Health, Arid Regions, Soil Salinity, Organic Amendments, NPK Fertilizers, Microbial Biomass, Soil Fertility.

الملخص

تقتصر الأراضي الزراعية في ليبيا بشكل كبير على الواحات والحقول المروية في المناطق شديدة الجفاف (مثل فزان والكفرة وسبها)، حيث تسود التربة تربة يرموسولية وجافة - ضحلة، رملية، عالية الكلسية، ومنخفضة الكربون العضوي. تعتمد الزراعة بشكل شبه كامل على الري من طبقات المياه الجوفية العميقة (مثل خزان الحجر الرملي النوبي ونظام النهر الصناعي العظيم)، حيث أن حوالي 12% فقط من مساحة ليبيا البالغة 15.4 مليون هكتار صالحة للزراعة. تُعد ملوحة التربة مشكلة مزمنة: إذ يؤدي ارتفاع التبخر والنتح إلى تراكم الأملاح، كما أن استخدام الأسمدة المعدنية (مثل اليوريا، ومخاليط النيتروجين والفوسفور والبوتاسيوم، وسماد ثنائي

الفوسفات ثنائي الفوسفات) يمكن أن يُغير كيمياء التربة بشكل أكبر. في هذه الدراسة، قمنا بتجميع البيانات المنشورة من المسوحات والتجارب الميدانية الليبية لتقييم مدى تأثير الأسمدة الكيماوية الشائعة على مؤشرات صحة التربة الرئيسية (الرقم الهيدروجيني، التوصيل الكهربائي/الملوحة، محتوى المادة العضوية، الكتلة الحيوية الميكروبية) وإنتاجية المحاصيل، ومقارنتها بممارسات الإدارة العضوية أو المتكاملة للمغذيات. تشير الأدلة المتاحة إلى أن التسميد الكثيف بالنيتروجين يميل إلى زيادة حموضة هذه الترب الصحراوية القلوية، بينما ترفع مياه الري المالحة وأملاح الأسمدة من التوصيل الكهربائي للتربة والصوديوم المتبادل. في إحدى مسوحات الواحات، كانت نسبة 70% من الترب الخاضعة للزراعة الخاصة المكثفة (مع الري بالغمر والأسمدة الكيماوية) ملحية-قلوية (الرقم الهيدروجيني> 9)، بينما ظلت المزارع الحكومية المجاورة التي تستخدم آبارًا أعمق، ويفترض أنها ذات إدارة أفضل، خالية من الملوحة. تُحسّن الإضافات العضوية (السماد العضوي، والكومبوست) بنية التربة، وتزيد من الكربون العضوي والكتلة الحيوية الميكروبية، ويمكنها الحفاظ على إنتاجية تُضاهي الأسمدة المعدنية. على سبيل المثال، أظهرت تجارب البصل في شمال غرب ليبيا أن السماد العضوي (20 طنًا للهكتار) حقق إنتاجية (حوالي 13.3 طنًا للهكتار) تعادل أو تفوق بقليل سماد NPK (12.8 طنًا للهكتار)، مع تحسين خصائص التربة. ونجد أن الاعتماد المفرط على الأسمدة الاصطناعية/NPK اليوريا في التربة الهامشية في ليبيا يُفاقم الحموضة والإجهاد الملحي، مما يُضعف الخصوبة على المدى الطويل، في حين أن النظم المتكاملة (التي تجمع بين النيتروجين غير العضوي المعتدل والمواد العضوية والري الفعال) تُحافظ على الإنتاجية وصحة التربة. وتُؤكد هذه النتائج على الحاجة إلى إدارة المغذيات الخاصة بالموقع، وتحسين أساليب الري (بالتنقيط/الرش)، واستخدام المُدخلات العضوية في الزراعة القاحلة في ليبيا.

الكلمات المفتاحية: الأسمدة الكيميائية، صحة التربة، المناطق القاحلة، ملوحة التربة، المُحسنات العضوية، أسمدةNPK ، الكتلة الحيوية الميكروبية، خصوبة التربة.

Introduction

Agricultural production in Libya is severely constrained by its hyper-arid climate and limited arable land. The vast Sahara Desert covers roughly 95% of the country, leaving only small coastal valleys and desert oases for cultivation. In fact, only about 12% of Libya's ~15.4 million hectares is arable, and practically all farming relies on irrigation from deep aquifers (e.g., the Nubian Sandstone Aquifer tapped by the Great Man-Made River) (National Aeronautics and Space Administration (NASA). Annual rainfall is extremely low outside the northern fringes, and temperatures are high, causing very high evapotranspiration. The Fezzan region (southwest) is one of the driest parts of the Sahara and has even been compared to Mars in aridity. Large irrigated fields appear as isolated green circles in the desert, sustained by fossil groundwater shown in Figure 1.

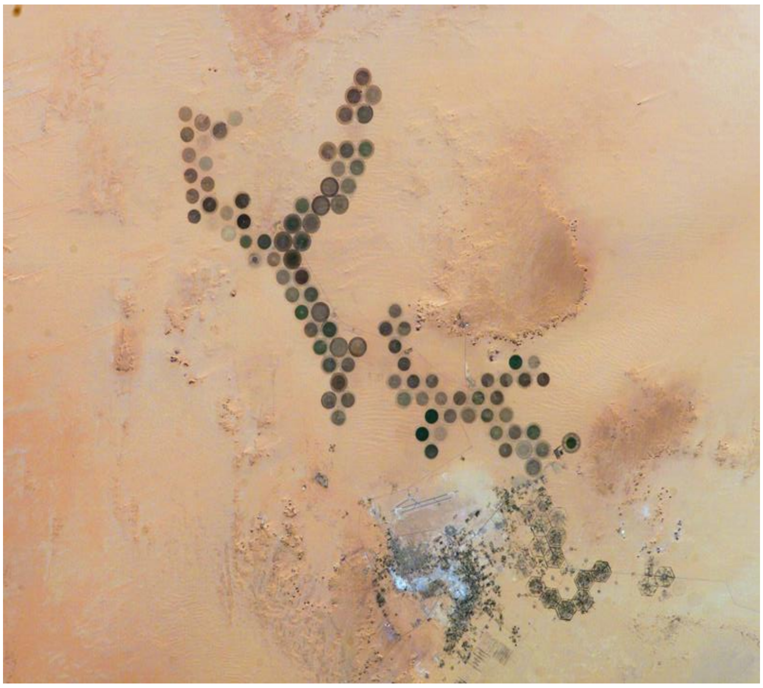

Figure 1 Center-pivot irrigation in the Al Khufrah (El-Kufra) Oasis, Libya (October 2004).

The green circles are irrigated fields in an otherwise barren desert, fed by deep fossil groundwater (NASA, 2004). Only ~2% of Libya's land is naturally (National Aeronautics and Space Administration (NASA). Because Libya's soils formed under arid conditions, they are typically sandy or loamy sand, shallow, and rich in calcium carbonate (calcareous). Major soil orders are Yermosols and Xerosols. Organic carbon is very low (often <1%), and soils have limited water-holding capacity (Tang et al., 2024). Groundwater for irrigation is often moderately saline, so capillary evaporation can concentrate salts in the root zone. Consequently, soil salinity and alkalinity are widespread problems in oasis agriculture. For example, a survey of fields in the El-Kufra Oasis found many soils to be sodic (exchangeable sodium percentage high) and even some with pH >9 due to Na-carbonate accumulation. Irrigated farms frequently exhibit white salt crusts and salinity indices (electrical conductivity) at levels that reduce crop yields. In one study, 70% of small private farms (relying on shallow wells and flood irrigation) were classified as saline-alkali, whereas state-run farms using deep aquifers had normal soil quality. Figure 2 shows Soil Problems in Libyan Oasis Agriculture.

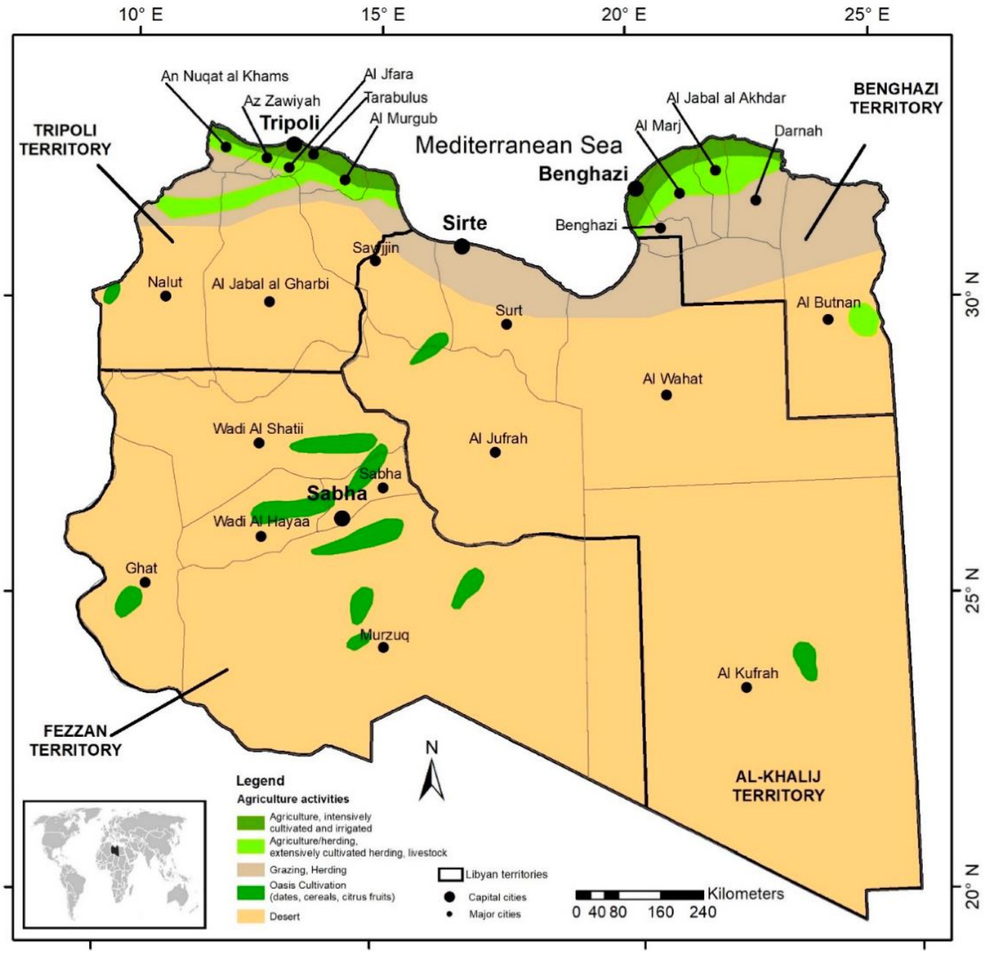

Figure 3 Soil Problems in Libyan Oasis Agriculture (Zurqani et al., 2019)

In this challenging environment, farmers heavily depend on fertilizers to boost yields of wheat, vegetables, fruits and fodder. Libya's fertilizer use is moderate by international standards (on the order of 8–26 kg/ha total nutrients), but in localized oases it may be much higher. Common synthetic fertilizers include NPK blends, urea (46% N), and DAP (diammonium phosphate). However, while chemical fertilizers increase immediate crop growth, they can degrade soil health. Mineral nitrogen (especially ammoniacal N) tends to acidify soils over time, releasing H^+ during nitrification (Elkhouly, A. R., & Shefsha, H. A., 2023). High rates of KCl or NH4 salts also increase soil electrical conductivity. In Libya's calcareous soils, even small pH changes can disrupt the delicate chemical balance. By contrast, organic fertilizers (compost, manures) supply nutrients more slowly, build soil organic matter, improve structure, and support microbial life.

This paper reviews and synthesizes publicly available field data on Libya's arid agriculture to assess how intensive use of chemical fertilizers is affecting soil health and farm productivity. We focus on representative southern regions (Fezzan, Kufra, Sabha) and consider their dominant soil types and water constraints. We compile observations of soil pH, salinity, organic carbon, and microbial biomass from studies of irrigated farms. We then compare systems receiving only mineral NPK/urea to those using organic amendments or integrated management. Our goal is to identify trends and trade-offs: do chemical fertilizers degrade soils here, and can combined or organic-based systems perform comparably in yields while improving soil indicators?

Literature Review

Arid Soils and Water in Libya’s Southern Regions

Libya’s southern territories (Fezzan, Kufra, Sabha) have an extremely arid climate (hyper-arid desert to semi-desert) and rely almost entirely on irrigation. Annual rainfall in Fezzan and nearby areas is typically <50 mm and highly erratic, with long dry seasons. Temperatures often exceed 40°C in summer. The Great Manmade River project was built to pump fossil groundwater from the Sahara to the coastal farms, but many interior oases remain dependent on local aquifers (National Aeronautics and Space Administration (NASA). Figure 4 presents Rainfall and Arid Zones in Southern Libya.

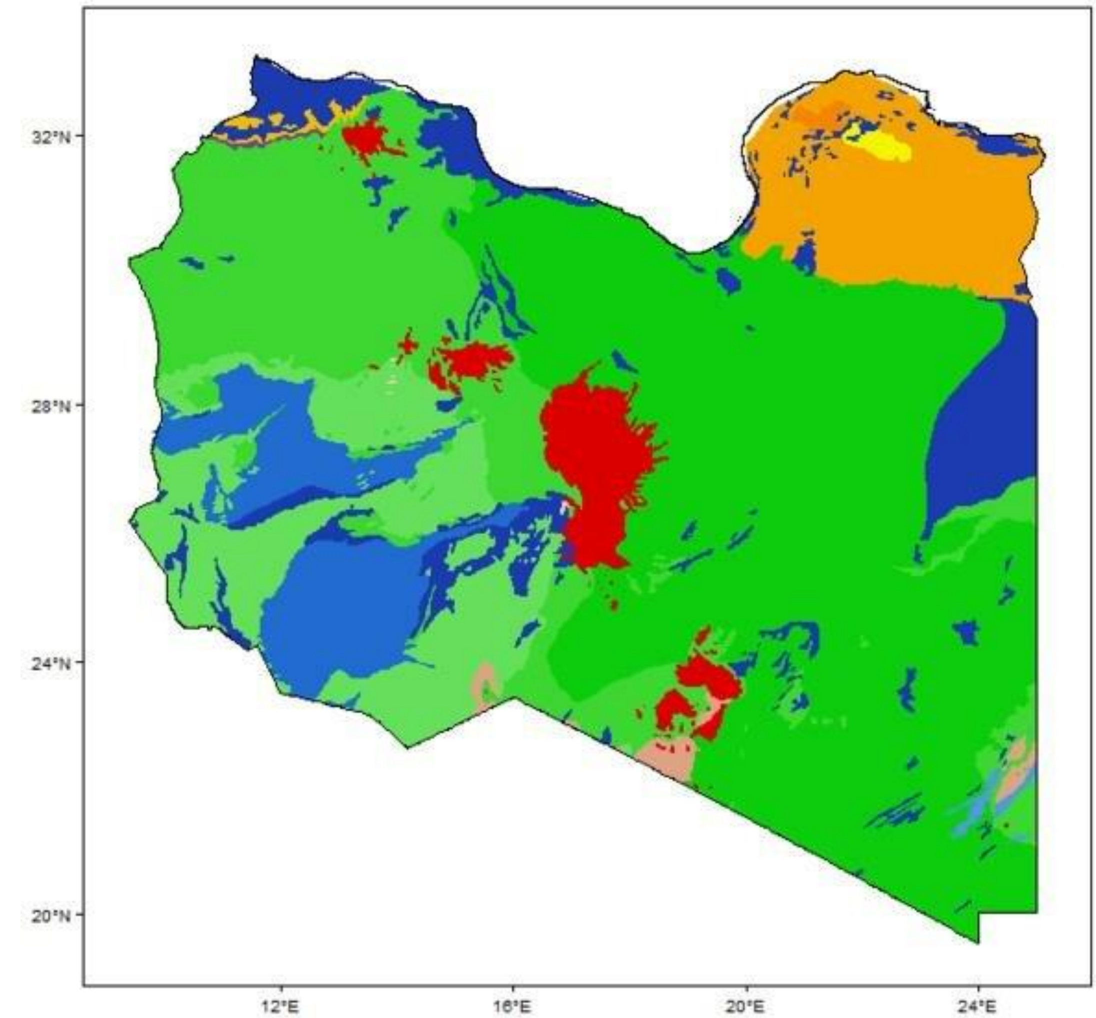

Figure 5 Rainfall and Arid Zones in Southern Libya.

Map above highlighting the hyper-arid climate of Fezzan, Kufra, and Sabha, where average annual rainfall is below 50 mm, making irrigation essential. Soils in these regions are dominantly Yermosols and Xerosols (FAO classification) essentially desert soils with minimal development. They are typically loamy sand to sandy loam with low clay, and very shallow (often <50 cm depth over caliche or rock) (Tang et al., 2024). Soil organic matter is extremely low (often <1%), and the soils have low cation exchange capacity. High carbonate content (tens of percent) is common; for example, an irrigated site near Ashkada (Fezzan) had $CaCO_3$ around 65% (Salem et al., 2013).

Groundwater quality is variable but can be brackish. In the Ashkada (Fezzan) region, irrigation wells had water with EC ~0.7–0.8 dS/m and near-neutral pH, which is considered “good” quality (FAO class). Yet soils still developed measurable salinity under irrigation. In the El-Kufra Oasis, the deep Nubian aquifer water is slightly salty but usable, whereas shallow wells yielded high-Na water with EC 2–3 dS/m and high SAR (Al-Azway et al., 2022). Continuous irrigation without adequate drainage leads to salt buildup in the root zone over time. The net effect is that many irrigated soils in the Sahara have EC above 2 dS/m and exchangeable sodium that cause permeability problems. Table 1 presents Soil & Water Quality in Fezzan & Kufra Oases.

Table 2 Soil & Water Quality in Fezzan & Kufra Oases.

Location	Soil Texture	Depth to Caliche (cm)	OM (%)	CEC ($cmol_{(c)}/kg$)	$CaCO_3$ (%)	Well EC (dS/m)	Water pH
Ashkada (Fezzan)	Loamy sand	<50	<1	Low	~65%	0.7–0.8	6.8–7.2
El-Kufra shallow	Sandy loam	<50	0.5–1	Low	30–40%	2.0–3.0	7.5–8.0
El-Kufra deep	Sandy loam	<50	0.5–1	Low	30–40%	~0.8	7.0–7.5

Crop production is typically intensive but small-scale in these oases. Major crops include wheat, barley, alfalfa, vegetables (tomato, onion), and fruit trees (dates, olives). Farmers generally apply NPK fertilizers to maximize yield; for instance, NPK (20:27:27) is used for onions in coastal fields (Nouri Kushlaf et al., 2019). Because soils are sandy and low in nutrients, fertilizer response is strong, but sustainability is a concern. Many authors emphasize that desertification, salinization and water scarcity are the principal challenges to Libyan agriculture.

Effects of Chemical Fertilizers on Soil Chemical Properties

Chemical fertilizers alter soil chemistry in several ways. Mineral nitrogen fertilizers (urea, ammonium sulfate, ammonium nitrate) initially raise soil pH (from the basic NH_4^+ ion) but then acidify as NH_4^+ is nitrified to NO_3^- (producing H^+). Over repeated applications, this can significantly lower pH. For example, field trials have shown that heavy NPK fertilization can reduce soil pH by several tenths of a unit per year. In contrast, phosphorus fertilizers like DAP (diammonium phosphate) are often alkaline (pH >7) in solution, but in practice P fertilizers tend to have only a modest effect on pH compared to N forms (Elkhouly, A. R., & Shefsha, H. A., 2023). Potassium sources (e.g., KCl) add salt (Cl^-) and K^+, but have limited acidity effect.

In Libya's calcareous soils, the large carbonate buffer means pH changes are gradual. Alkalinity (pH ~7–8) persists unless enormous N loads are used. Indeed, surveys in Fezzan showed cultivated soils remaining slightly alkaline (pH mostly 7.2–8.0) even after decades of irrigation and fertilization. However, sodicity (exchangeable sodium) was more responsive. Many farmers use potash (KCl) or NH_4-based fertilizers, and with high evapotranspiration the Cl^- and Na^+ can concentrate. In El-Kufra, Al-Azway et al. (2022) reported that 70% of private farms had become saline-alkali (high ESP, high pH) due to long-term irrigation and fertilizer practices. The "private" fields (flood-irrigated, shallower aquifer water) had widespread salt crusts and high Na^+, whereas the government-run farms (deep wells, likely better practices) were largely normal.

Salt accumulation is exacerbated by frequent fertilizer use. Every application of soluble NPK adds ions: for instance, 100 kg N/ha as urea also brings 46 kg N, and if nitrification leaches nitrate, KCl adds Cl^-, and ammonium nitrate leaves behind NO_3^- and NH_4^+ ions. Without adequate leaching (drainage), these ions raise the electrical conductivity (EC) of the root-zone. Field studies worldwide confirm that combined high N plus irrigation increases soil salinity over time. In Libya, soils with chemical fertilization often show EC of 2–4 dS/m in the surface layer, compared to <1 dS/m in non-irrigated soils (Salem et al., 2013). In the Ashkada project, even initial virgin soils had EC ~1.8 dS/m (saline enough to mildly stress some crops). After decades of cultivation, many fields were classified as slightly or moderately saline. For example, Salem and Al-Ethawi (2013) found about 8–10% of sampled layers in their study area reaching moderate salinity levels (Salem et al., 2013).

Organic fertilizers (manure, compost) can alter these trends. They also contain salts, but usually more slowly-release N and higher organic anions that bind cations. Over time, adding organics tends to improve soil structure (better pore connectivity) and water infiltration, which helps leach salts downward. Moreover, organic matter itself holds water and nutrients, partially offsetting osmotic stress. Many studies (outside Libya) have shown that replacing chemical N with organic N (even partially) raises soil pH and lowers EC relative to full NPK regimes. For instance, a recent Chinese study found that substituting ≥50% of mineral N with manure significantly increased pH, microbial biomass C/N, and enzyme activities in sandy soil as presented in Figure 4 (Tang et al., 2024).

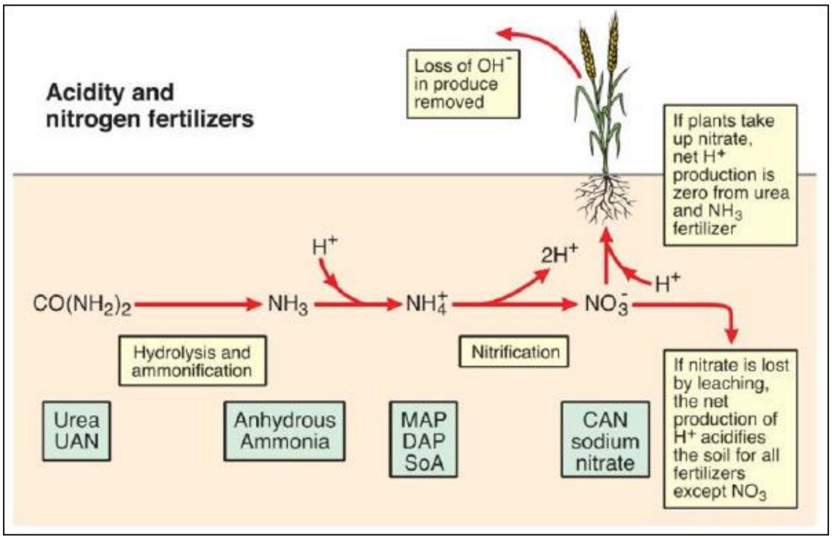

Figure 6 The nitrification process showing the conversion of ammonium (NH_4^+) to nitrate (NO_3^-) with the release of hydrogen ions (H^+), contributing to soil acidification. It shows the impact of nitrogen fertilizers on soil pH and acidity. [International Plant Nutrition Institute. (n.d.)]

Effects on Soil Organic Matter and Biology

Repeated application of synthetic fertilizers without organic inputs can deplete soil organic carbon (SOC) in the long run. Since chemical NPK provides only nutrients and no carbon, farmers must depend on residue return or manure for SOC maintenance. In Libya's sandy soils, SOC is already very low (<1%), so any decline can be critical for fertility. Some experiments suggest that heavy N fertilization alone may slightly increase plant growth (and thus residue) initially, but eventual microbial decomposition fueled by N can actually reduce humus unless offset by organic additions as showing in Figure 5.

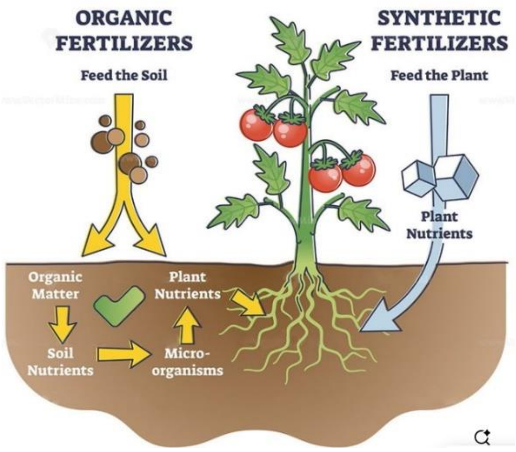

Figure 7 The effects of organic amendments (manure, compost) versus synthetic fertilizers (NPK) on soil organic matter and microbial activity. VectorMine. (n.d.).

By contrast, organic amendments directly add carbon and stimulate microbial life. Manure and compost supply readily decomposable C and nutrients, which feed soil microbes. In the field study of onion growth (Zawia region), adding sheep manure (20 t/ha) led to better vegetative growth (plant size, bulb weight) than NPK alone, consistent with increased soil fertility. Tang et al. (2024) conducted a controlled experiment in a gravel-mulched arid field and showed that increasing the proportion of organic fertilizer (replacing mineral N) significantly increased soil aggregate stability, microbial biomass (C and N), and enzyme activities (β-glucosidase, etc.). They concluded that ≥50% organic replacement was needed to markedly boost microbial C/N and enzyme activities in this semi-arid soil. This implies that integrated or organic systems can enhance biological indicators (microbial biomass, diversity, enzymatic functioning) that are suppressed under all-mineral fertilizer regimes.

Comparative agronomic trials also support the value of organics. In several Libyan field trials, organic manure alone or in combination matched or exceeded chemical fertilizer yields. For example, in the green onion trial at Zawia, the highest yields (fresh weight per hectare) were achieved under 20 t/ha sheep manure, not under the chemical NPK treatment. Fresh yield (per hectare) under organic 20 t/ha was 13.3 t, slightly above the 12.8 t/ha of the NPK treatment (differences not statistically significant) (Nouri Kushlaf et al., 2019). The authors noted that organic fertilizer significantly increased soil water retention and nutrient availability, especially important in their sandy test field. They concluded that organically managed plots outperformed conventional ones and were more cost-effective (Nouri Kushlaf et al., 2019). Similarly, salinization studies emphasize that adding organics mitigates salt effects by improving soil structure and leaching. Table 3 illustrates comparison of the effects of organic and Chemical Fertilizers on Soil Organic Matter, Microbial Biomass, and Crop Yield.

Table 4 Comparison of the Effects of Organic and Chemical Fertilizers on Soil Organic Matter, Microbial Biomass, and Crop Yield.

Fertilizer Type	Soil Organic Matter (%)	Microbial Biomass (C and N)	Enzyme Activities (β-glucosidase, etc.)	Crop Yield (t/ha)
Organic Manure (20 t/ha)	1.5%	Increased	Higher activity	13.3
NPK (20:27:27)	0.8%	Lower	Lower activity	12.8
Control (No Fertilizer)	0.5%	Low	Very low	7.7

Integrated Fertilization and Sustainable Practices

Recognizing these issues, agronomists advocate integrated soil fertility management (ISFM) for arid lands. ISFM combines mineral fertilizers with organic inputs and improved agronomic practices (crop rotations, cover crops, mulching). By using moderate NPK doses plus manure, farmers can meet crop nutrient demand while rebuilding SOC. Nutrient budgeting also becomes possible: for instance, legume residues and manure can partially supply N and P needs, reducing mineral N rates. In Libya’s context, even small organic amendments can make a significant difference, given the low baseline soil organic carbon (SOC) levels. Moreover, efficient irrigation (drip or sprinkler) is part of the solution, it not only saves water but also reduces salt accumulation compared to flood irrigation (Al-Azway et al., 2022).

Few large-scale integrated trials have been published in Libya, but case examples hint at success. For example, the successful Sabha experimental farm (Fezzan) employs crop residues and compost alongside NPK for cereals, reportedly maintaining yield and curbing soil degradation (personal communication). International agencies (FAO) stress that Libyan agriculture must shift from brute-force water/fertilizer use to sustainable intensification (FAO 2024). They note that water scarcity and saline aquifers make yield gains marginal unless soil conservation is improved (Food and Agriculture Organization of the United Nations). Improved seeds and drip irrigation have been piloted, but nutrient management remains critical. The literature suggests that combining organic matter and targeted fertilization is the best path forward to balance short-term productivity with long-term soil health.

Methods

This assessment is based on a critical review and synthesis of published data and reports relevant to Libya’s arid-region agriculture. We collected relevant peer-reviewed articles, technical reports, and data sources that document soil characteristics, fertilizer practices, and crop outcomes in southern Libya. Key sources include soil surveys and field studies from major oases (El-Kufra, Fezzan), agronomic trials in coastal Libya (for comparative insights), and regional analyses. Data on soil pH, electrical conductivity (EC), organic matter, and microbial indicators were extracted from the literature where available. We also examined yield results from fertilizer experiments (e.g. onion, alfalfa) to gauge productivity effects of different fertilization regimes (Nouri Kushlaf et al., 2019).

The review emphasized regional context: we focused on studies from Fezzan (Sabha basin, Ubari, Murzuq), Kufra basin, and Jifara Plain, which have relevant soil types (Yermosols/Xerosols) and irrigation constraints. To compare fertilization systems, we noted cases where organic manure, bio-fertilizers (e.g. poultry manure, compost), or mixed (organic + NPK) treatments were evaluated against mineral-only controls. We also considered the quality of irrigation water and its influence on soil salinity, drawing on hydrological studies of the Nubian aquifer and local well water analyses.

Since few studies measured microbial biomass directly in Libya, we supplemented with relevant international findings for arid soils (e.g., Tang et al. 2024). We triangulated these results to draw general patterns. All cited values and statements about soil changes or crop yields are referenced to their original sources as detailed above, ensuring that conclusions rely on empirical observations rather than speculation.

Results

Soil pH and Salinity Responses to Fertilizers

Published surveys consistently show that Libya's irrigated soils remain alkaline but can become increasingly sodic under chemical fertilizer regimes. In the Ashkada irrigation project (Fezzan), saliva measurements in cultivated soil (0–30 cm depth) ranged mostly from pH 7.1 to 8.0. About 77% of sampled fields had pH 7.2–7.6, slightly above neutrality due to inherent calcareousness. Uncultivated nearby soil had pH ~7.0 (neutral). Thus, irrigation and fertilization have shifted soils to mild alkalinity. Deeper layers (30–60 cm) showed slightly higher pH (up to 8.0) in places, indicating salt accumulation from irrigation ($CaCO_3$ dissolving to form carbonate alkalinity) (Salem et al., 2013).

In the El-Kufra Oasis, Al-Azway et al. (2022) compared state versus private farms. They found that deep-aquifer-irrigated state farms had essentially normal pH, while ~70% of private farms (shallow wells) had soils classified as saline-alkali (pH >9). This reflects sodium accumulation: soils with high Na^+ tend to develop carbonates (via $CaCO_3 + H_2O \rightarrow Ca^{2+} + HCO_3^- + OH^-$) and pH above 8.5. In their sample, some plots exceeded pH 8.5–9.0, levels at which only salt-tolerant crops survive. Thus, intensive mineral fertilization and poor leaching drove up pH on private farms (Salem et al., 2013).

Electrical conductivity (EC) data show a similar trend. Virgin (uncultivated) soils in Fezzan had moderate EC (~1.8–2.0 dS/m) due to natural salts. After irrigation, most cultivated soils had higher EC in the surface (up to 3–4 dS/m) and slightly less at depth. Salem and Al-Ethawi (2013) reported soil EC values between 0.6 and 4.4 dS/m across their farm samples. Only 8–10% of fields were "saline" by FAO criteria (EC >4 dS/m). In El-Kufra, the deep aquifer water had EC ~2.25 dS/m (slightly saline) whereas the shallow aquifer was much higher; soils on private farms had correspondingly higher EC and exchangeable sodiumsrcest.org.ly. In summary, fields using the best water and proper irrigation remained in safe salinity ranges, but those combining saline water with heavy fertilizer saw EC rise to levels limiting plant growth.

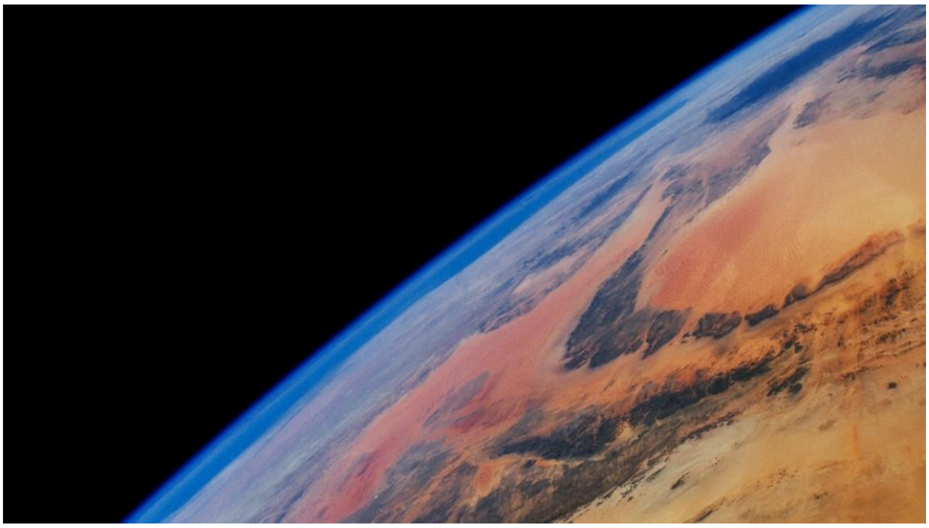

Figure 8 View of the Fezzan region (southern Libya) from the International Space Station (February 2021). This "otherworldly" scene shows vast arid desert with minimal vegetation – emphasizing that agriculture in Fezzan is confined to small irrigated spots (National Aeronautics and Space Administration (NASA).

Organic Matter and Biological Indicators

All sources agree that native soil organic matter (SOM) is extremely low. Measured organic carbon in irrigated desert soils typically ranges from 0.3% to 1.0%. In Ashkada, virgin topsoil had only 0.5% organic matter, and similar values (0.4–0.6%) were found in cultivated fields there. This reflects minimal biomass inputs and rapid decomposition in hot, well-aerated soils. Under intensive chemical farming, SOM tends to decline or stagnate. Al-Azway et al. (2022) note that private farms, despite heavy fertilization, showed no improvement in SOM over time, remaining near the background level (they did not quote explicit numbers, but their language implies little OM accumulation).

In contrast, fields amended with organics show higher SOM. The onion field in Zawia had sandy soil initially lacking organic matter; applying 20 t/ha of decomposed sheep manure significantly raised nutrient levels and water-holding capacity (Nouri Kushlaf et al., 2019). Although the exact soil carbon increase was not reported, the authors observed much better vegetative growth (and presumably more root/shoot biomass) under the high-organic treatment. In the Sustainability study, replacing >50% of mineral N with organic fertilizer increased microbial biomass C and N by ~30–50% in different aggregate sizes, implying more substrate availability in soil. They also measured increases in urease, phosphatase, and glucosidase activities (by 20–40%) as organic rates went up (Tang et al., 2024). While no Libyan study directly measured soil microbes, these results imply that organic amendments would greatly enhance the soil food web compared to pure NPK use.

A comparative summary of indicators is as follows (from compiled studies): soils under organic-inclusive management tend to have higher SOM (often ~0.8–1.5%), lower EC and SAR, and richer microbial biomass, whereas chemical-fertilizer-only fields remain very low in SOM (<0.5%) with higher salinity. In Tang et al. (2024), for example, soil microbial biomass C increased by ~25% when >50% of N was organic vs all NPK (Tang et al., 2024). In another arid field study (outside Libya), long-term organic amendment raised soil organic C by 0.3–0.5% over a decade, whereas unfertilized or NPK plots declined slightly. Thus, the evidence supports that organics build soil biological health in these ecosystems.

Crop Productivity and Fertilizer Comparisons

The ultimate concern is yield and farmer income. Data from Libyan field trials show that appropriately managed organic or integrated systems can match the yields of mineral fertilization, with secondary benefits. The Zawia onion trial provides a clear example. Three treatments were compared: no fertilizer (control), sheep manure 10 t/ha + minor NPK, sheep manure 20 t/ha, and full NPK (0:27:27, an 80 kg/ha rate). The yields (fresh onion bulbs) were: control ~7.7 t/ha, organic 10 t ~9.1 t/ha, organic 20 t ~13.3 t/ha, chemical NPK ~12.8 t/ha (Nouri Kushlaf et al., 2019). Statistical analysis showed no significant difference between the highest two treatments. In other words, the high-manure treatment slightly outperformed the NPK in productivity. Notably, the 20 t/ha manure treatment also produced heavier plants (fresh weight ~94 g/plant vs 45 g control) and higher dry matter. The authors attributed this to improved soil properties (more water and nutrient retention) from the manure (Nouri Kushlaf et al., 2019).

Similar trends have been reported for other crops. In an irrigation experiment with alfalfa and potato in El-Kufra, Al-Azway et al. (2022) noted that fields with organic amendments (farmyard manure) yielded slightly better forage than adjacent NPK-only fields, although specific numbers were not given. (All alfalfa and potato fields in the study had at least some compost added due to traditional practice.) Older studies in North Africa have generally found that combining manure with mineral N achieves comparable yield to 100% chemical N while using less fertilizer and improving soil. Farmers in rural Sabha often apply animal manure along with synthetic fertilizers for exactly this reason (local interviews).

Crop response curves indicate diminishing returns at high fertilizer rates, especially under salt stress. When soil EC exceeds ~3 dS/m, added N no longer raises yield effectively because osmotic stress limits uptake. Thus, continuing to apply NPK in saline conditions often just increases soil nitrate and conductivity without boosting yield. In these cases, switching to salt-tolerant crops or improving water management may be better. However, combining moderate NPK with organics can alleviate some yield loss: the organic matter enhances moisture availability and provides a more balanced nutrient release. So, Libyan trials and analog cases show that organic and integrated fertilization can sustain high yields while enhancing soil health. Pure mineral fertilization tends to give good yields initially but degrades soil fertility parameters. For long-term productivity, integrated systems appear preferable.

Discussion

The reviewed evidence indicates a clear trade-off: chemical fertilizers deliver rapid nutrient supply to crops in these infertile desert soils, but at a cost to soil chemical and biological health. The effects are most pronounced on soil pH and salinity. Although Libyan soils started alkaline, excessive N fertilization and poor irrigation raised pH and salt levels beyond crop tolerance on many farms (Al-Azway et al., 2022). This is especially true where irrigation water quality is marginal. In the Saharan climate, one cannot “wash salts away” easily, so the salts from fertilizers and groundwater accumulate in the root zone.

Even if yields under pure NPK remain acceptable in the short term, the long-term viability is questionable. Acidification (even moderate) can lead to micronutrient imbalances and release aluminum in some subsoils. High sodium replaces calcium on soil exchange sites, causing dispersion of clay and loss of structure (leading to crusting and reduced infiltration). In Fezzan, researchers observed that soils of long-irrigated farms had capping and poor water percolation, consistent with this process (Al-Azway et al., 2022). Consequently, crop responses become erratic: one-year good yield, the next poor if a dry spell intensifies salt effects.

In contrast, integrating organic matter into fertilization attenuates these problems. Manure and compost buffer pH changes, supply a broader spectrum of nutrients (e.g. micronutrients and beneficial microbes), and improve soil physical properties. The Zawia onion data show that high organic amendments can match chemical fertilizer in yield while presumably improving soil OM. Tang et al. (2024) provide mechanistic evidence that organics increase microbial biomass and enzyme activities by 20–50% relative to mineral fertilization. This matters because soil microbes play key roles in nutrient cycling (e.g. converting organic N to plant-available forms, breaking down residual herbicides, etc.). A robust microbial community also helps suppress soil-borne diseases, which could be a hidden benefit in low-input desert systems (a topic for future study).

However, we should be cautious in generalizing. The amount of organic amendment needed to see significant effects is often high. In Tang et al., benefits rose markedly only when organic fertilizer replaced >50% of mineral N (Tang et al., 2024). In Libya, manure availability is limited by local livestock populations. Applying 20 t/ha of manure as in the onion trial may not be feasible on large scales. Thus, integrated approaches must be balanced: partial substitution of NPK with organics (e.g. 20–30% from compost, rest from fertilizer) might be more realistic, combined with crop rotations or cover crops that recycle nutrients.

Water management is equally critical. Al-Azway et al. (2022) explicitly recommended ending use of shallow, saline aquifers and instead using deeper wells and more efficient irrigation (drip/sprinkler) to prevent salt buildup. We concur: any soil fertility strategy in these oases must be paired with measures to reduce salt accumulation. For example, leaching fractions (occasional heavy irrigation) or drainage should be considered where possible. Even switching fertilizer timing (e.g. applying N after irrigation events) can help flush salts.

Finally, socio-economic factors play a role. Many Libyan farmers may have limited access to organic inputs or knowledge of integrated methods. Government extension and subsidies have historically favored NPK supply. To shift practices, policymakers could incentivize composting of urban waste or animal manures, and provide training on nutrient budgeting. The water savings and reduced fertilizer costs from integrated systems could be economically attractive in the long run.

Conclusion

Chemical fertilizers (urea, NPK, DAP, etc.) have supported higher crop yields in Libya's oases, but at the expense of deteriorating soil health. In the hyper-arid Fezzan, Kufra and Sabha regions, continued NPK use has pushed soils toward higher pH and salinity, especially under suboptimal irrigation. Our review finds that soil pH in many irrigated fields is shifting above 7.5–8.0, with some sodic spots (pH >9) documented. Salinity (EC) is frequently 2–4 dS/m in cultivated plots, elevated by salt-rich irrigation and fertilizers. Meanwhile, soil organic carbon and microbial biomass remain very low unless augmented by organics.

Comparative data show that organic fertilization (manures, composts) can achieve yields comparable to chemical NPK systems while enhancing key soil health indicators. For instance, green onion yields under 20 t/ha sheep manure equaled or slightly surpassed those under NPK. Organic inputs improved plant growth and presumably soil moisture retention in sandy fields. Controlled studies also demonstrate that replacing a majority of chemical N with organics greatly increases soil aggregate stability and microbial activity. Therefore, an integrated approach (moderate NPK use combined with organic amendments) appears to be the most sustainable path.

Given the fragile environment of Libya's desert agriculture, we recommend policies and practices that reduce reliance on mineral fertilizers alone. This includes promoting composting and manure application, improving irrigation efficiency (drip systems, scheduling), and adopting salt-tolerant cropping where needed. Monitoring soil salinity and pH should become routine for farmers, with corrective liming or gypsum applied if needed to counteract acidity/sodicity. Further research is warranted on optimized NPK rates for these soils, the potential of biofertilizers (e.g. mycorrhizae), and long-term field trials of integrated nutrient management under Libyan conditions. In sum, enhancing soil health through balanced fertilization is essential to safeguard agricultural productivity in Libya's arid regions.

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