

Effect of organic fertilizers on soil nitrate content, grain protein percentage and yield of maize (**Zea mays** L.)

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Abstract

The combined use of organic and potassium fertilizers leads to a significant increase in the levels of available ammonium (NH_4^+) and nitrate (NO_3^-) in the soil. This experiment was conducted in a field at the Faculty of Agriculture, University of Gezira—the Gezira region being a major producer of yellow maize (**Zea mays** L., variety 113) in Sudan. The study aimed to evaluate the impact of organic and potassium fertilization on available soil ammonium and nitrate content, as well as on grain protein percentage and yield. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replicates, utilizing a split-plot arrangement. It involved two factors: potassium fertilizer (potassium sulfate at rates of 0, 100, and 200 kg K/ha) and organic fertilizer (sheep and cattle manure at rates of 0, 20, and 25 tons/ha). The results showed that the addition of sheep manure significantly increased the available ammonium content during the flowering and harvest stages, reaching 8.55 and 8.72 mg kg⁻¹ soil, respectively. This compared to 7.08 and 7.36 mg kg⁻¹ soil for the cattle manure treatment, and 6.22 and 6.56 mg kg⁻¹ soil for the control. However, the treatment did not significantly affect soil nitrate content at either stage or grain protein content. The third level of potassium fertilizer had a significant effect on available ammonium during the flowering and harvest stages, resulting in levels of 8.25 and 8.06 mg kg⁻¹ soil, respectively, compared to 6.16 and 6.94 mg kg⁻¹ soil for the first potassium level. Meanwhile, the interaction between organic manure and potassium fertilizer showed no significant effect on available ammonium, soil nitrate content at either stage, or grain protein content. The combination of organic amendments and potassium fertilizers creates an optimal soil environment that enhances microbial activity and nutrient retention capacity, leading to maximum levels of available inorganic nitrogen (NH_4^+ and NO_3^-). Effect on protein content in yellow maize grains.

Keywords: Ammonium, nitrate, organic manure, protein

Introduction

Organic matter is the fundamental basis for sustainable soil fertility and a crucial factor in boosting agricultural productivity. It influences soil properties through three primary roles: improving physical properties (such as soil structure, where organic matter acts as a binding agent that aggregates fine soil particles—sand, silt, and clay—into stable clumps, creating an ideal, sponge-like structure); facilitating aeration and drainage (as this sponge-like structure allows air and water to move freely through the soil, preventing compaction and enabling roots to breathe and grow); and increasing water-holding capacity (organic matter possesses a remarkable ability to absorb and retain water—much like a sponge—thereby protecting plants from drought for extended periods). It also enhances resistance to erosion, reducing soil loss caused by wind or rainwater runoff by improving particle cohesion. Chemically, organic matter is composed of carbon, oxygen, and hydrogen, along with trace amounts of sulfur, phosphorus, potassium, calcium, and magnesium; it plays a vital role in recycling nutrients back into the soil [1]. Organic matter is a mixture of complex compounds in various stages of decomposition or stabilization, consisting of microbial cell residues as well as plant and animal remains. Potassium fertilizers are indispensable in modern agriculture, playing a vital role in crop growth and soil improvement. Macronutrients are

crucial for plant nutrition and productivity; therefore, the soil content of these elements in forms available for plant uptake is a key factor determining crop yield [2]. Combining organic and mineral fertilizers enhances soil fertility. Furthermore, utilizing various sources of organic waste reduces the high cost of mineral fertilizers, making it a sound agricultural practice [3]. The combined use of organic and potassium fertilizers leads to a significant increase in soil-available ammonium (NH_4^+) and nitrate (NO_3^-) levels and raises the crude protein content in yellow maize grains. Impact on soil ammonium and nitrate—organic fertilizers: During the decomposition of organic matter (such as animal manure or compost), microorganisms break down nitrogen compounds and convert them into mineral forms accessible to plants [4]. This mineralization process steadily increases the levels of both ammonium and nitrate available in the root zone. Additionally, organic acids released during decomposition help lower high soil pH, thereby improving overall nutrient availability. Potassium (K^+) Fertilization: Potassium ions help release and increase the amount of ammonium available in the soil by competing with ammonium ions (NH_4^+) for soil exchange sites, thereby displacing bound ammonium and moving it into the soil solution [5]. Interaction: Combining organic amendments with potassium fertilizers creates an optimal soil environment that enhances microbial activity and nutrient

retention capacity, leading to maximum levels of available inorganic nitrogen (NH_4^+ and NO_3^-). Impact on Yellow Corn Grain Protein Content: Enhanced nitrogen uptake—high availability of soil ammonium and nitrate ensures the corn plant absorbs greater quantities of nitrogen, the fundamental building block for amino acids and plant proteins. Role of Organic Matter: Organic amendments provide essential micronutrients and support the metabolic pathways required for organic acid synthesis, which forms the basis for protein accumulation in the grain. Role of Potassium: Potassium improves enzyme activity and photosynthesis, as well as the translocation of sugars and nitrogenous compounds from vegetative parts to the developing corn kernels. Combined Outcome: Integrating organic and potassium fertilization results in a substantial and statistically significant increase in the total protein content of yellow corn grain compared to unfertilized control soil. Given the plant's critical need for nutrients—and the fact that organic fertilizers alone may not suffice—farmers often resort to applying various types of mineral fertilizers. Potassium is a vital macronutrient, playing a crucial role throughout all stages of plant growth and the life cycle. It is not incorporated into the structure of organic compounds; rather, it exists within plant tissues as free potassium ions (K^+). Requirements for potassium depend on factors such as the plant species, the growth stage, and the quality of the resulting grain or fruit [7]. Potassium enhances resistance to diseases and pests by promoting the formation of thicker cell walls; it also plays a vital role in the activity of photosynthetic enzymes and in the synthesis of proteins and carbohydrates [8]. Research by Brar *et al.* [9] has shown that potassium application improves nitrogen uptake, thereby increasing nitrogen use efficiency. Potassium also aids in transporting nitrates from the roots to the leaves in the form of potassium nitrate (KNO_3) [28]. Maize (*Zea mays* L.) is a vital grain crop cultivated extensively worldwide; it is a field crop that responds significantly to the application of nitrogen, phosphorus, and potassium fertilizers [10]. Yellow maize ranks first in terms of grain production volume for human and animal consumption and second in cultivated area—surpassed only by wheat—while also playing a crucial role in various industrial sectors, making it a strategic crop [11]. Yellow maize (locally known at times as *Shamiyah* maize or *Aish Reef*) is considered a key strategic crop in Sudan. It is primarily used in the production of animal and poultry feed, in addition to human consumption. The crop has a growth cycle of 100 to 120 days from planting to harvest and is cultivated in irrigated agricultural schemes and plains. It is grown in irrigated projects across central Sudan—such as the Gezira and Managil schemes—as well as in the River Nile and Northern states, and in sectors relying on supplementary or center-pivot irrigation.

This study aims to investigate the effects of organic and potassium fertilization on available ammonium and nitrate levels in the soil, as well as on the protein content of yellow maize grains.

Materials and Methods

A field experiment was conducted during the autumn season at the experimental site of the Faculty of Agriculture, University of Gezira (Al-Nashishiba campus). The soil at the site is classified at the sub-great group level as *Typic Torrifluvent*. Soil samples were randomly collected from the surface layer (0–30 cm) prior to planting; after drying and removing root residues, the samples were ground and sieved through a 2 mm mesh. Physical and chemical analyses were performed as detailed in Table (1). Two types of organic manure—cattle and sheep—were prepared by composting in separate pits for 50 days; the manures were then removed and spread in thin layers to air-dry. Table (2) lists the specifications of the organic manures used. Soil preparation operations—including plowing, pulverizing, and leveling—were carried out. The field was divided into plots measuring $3 \times 2 \text{ m}^2$ using a split-plot design arranged in a Randomized Complete Block Design (RCBD) with three replicates. The main treatments consisted of organic manure applications at a rate of $25 \text{ tons} \cdot \text{ha}^{-1}$ —comprising cattle manure, sheep manure, and a control treatment—which were mixed into the soil prior to planting. The secondary treatments involved potassium fertilization, comprising three levels of potassium sulfate (42% K; K_2SO_4): 0, 100, and 200 kg K ha^{-1} . The potassium fertilizer was applied in two split doses: the first during the branching stage and the second during the flowering stage. Nitrogen fertilizer was applied at a rate of 240 kg N ha^{-1} using urea (46% N); half the amount was applied before planting, and the remaining half during the branching stage. Phosphate fertilizer was applied at a rate of 100 kg P ha^{-1} as triple superphosphate, mixed into the soil prior to planting. Soil samples were collected from the 0–30 cm layer during the flowering and harvesting stages to form composite samples, which were then dried for the determination of ammonium and nitrate levels. Physical and chemical analyses were conducted, including: mechanical analysis to determine soil texture (percentage) using the hydrometer method; soil bulk density (g/cm^3) using the density cylinder method; porosity; electrical conductivity (ECe) in dS/m using a conductivity meter; soil pH using a pH meter; organic matter using the wet oxidation method; and mineral nitrogen (including available ammonium and nitrate), non-exchangeable potassium, total potassium, soluble potassium, exchangeable potassium, and mineral potassium using the Kjeldahl method. Additionally, available phosphorus was determined using the Olsen method, and available potassium was measured using a flame photometer.

Table 1: Some chemical and physical properties of the field soil before planting.

Property	Value	Unit
pH2.5:1	8.11	-
EC2.5:1	4.02	dS m^{-1}
OM	18	g kg^{-1}
	Potassium Forms	cmol K kg^{-1}
Soluble	0.141	

Exchangeable	0.452	
Non-exchangeable	2.00	
Mineral	11.004	
Total	13.722	
Available Ammonium	8.2	mg kg ⁻¹
Nitrate	18	
Available Phosphorus	19.8	
Soil Separates		g kg ⁻¹
Sand	122	
Silt	487.3	
Clay	390.1	
Texture	Silty Clay Loam	

Table 2: Some characteristics of the two organic fertilizers used in the study

Property	Sheep	Cattle
Reaction (pH) (1:5)	7.36	7.08
Electrical Conductivity (1:5)	19.5dS·m ⁻¹	8.4dS·m ⁻¹
Electrical Conductivity (1:5)	%67.1	1.43%
Total Phosphorus	%0.6	%0.4
Total Potassium	%1	%0.6
Total Organic Carbon	%31.87	34.30%
Organic Matter	%54.96	%59.15
C/N Ratio	19.08%	23.99%

Results and Discussion

1. Available Ammonium

Table (3) illustrates the effect of organic and potassium fertilizers on available soil ammonium during the flowering stage of maize. Statistical analysis revealed significant differences among treatments resulting from the application of organic fertilizers (sheep manure); sheep manure resulted in the highest available soil ammonium level (8.91 mg kg⁻¹ soil) at the flowering stage, surpassing cattle manure (7.36 mg kg⁻¹ soil) and the control treatment (6.62 mg kg⁻¹ soil). However, there was no statistically significant difference

between cattle manure and the control treatment regarding available soil ammonium levels at the flowering stage. Statistical analysis also showed significant differences in available soil ammonium levels due to potassium fertilizer application; the K2 treatment (8.50 mg kg⁻¹ soil) outperformed the K0 treatment (6.56 mg kg⁻¹ soil), and the K1 treatment (7.86 mg kg⁻¹ soil) also outperformed the K0 treatment (6.56 mg kg⁻¹ soil). Regarding the interaction between the two organic fertilizers (cattle and sheep manure) and potassium fertilizer, no statistically significant effect was observed.

Table 3: Effect of organic and potassium fertilizers on available soil ammonium (mg kg⁻¹ soil) at the flowering stage of maize

Mean	OMS	OMC	OM0	Treatments
6.56 a	8.13	6.27	5.27	K0
7.86 b	9.17	7.60	6.80	K1
8.50 cb	9.43	8.27	7.80	K2
	8.91 b	7.38 a	6.62 a	
	K x OM	K	OM	L.S.D. 0.05
	n.s.	0.892	1.347	L.S.D. 0.05

K0 = 0 kg K ha⁻¹, K1 = 100 kg K ha⁻¹, K2 = 200 kg K ha⁻¹, OM0 = No organic fertilizer added, OMC = Cattle manure 25 t ha⁻¹, OMS = Sheep manure 25 t ha⁻¹

Table (4) illustrates the effect of organic and potassium fertilizers on available soil ammonium at the maize harvest stage. Significant differences were observed among treatments due to the application of organic fertilizer (sheep manure); the sheep manure treatment resulted in the highest available soil ammonium value (8.55 mg kg⁻¹), surpassing both cattle manure (7.76 mg kg⁻¹) and the control treatment (6.96 mg kg⁻¹). However, there were no statistically significant differences between the cattle manure and control treatments regarding available soil ammonium levels (7.76 and 6.96 mg kg⁻¹, respectively).

Overall, sheep manure outperformed cattle manure in terms of available soil ammonium levels at both the flowering and harvest stages; this is attributed to the fact that sheep manure has a higher total nitrogen content and a lower C/N ratio compared to cattle manure (Table 2). The effect of potassium

fertilizer on ammonium availability at this stage was also statistically significant; statistical analysis revealed significant differences in available soil ammonium levels resulting from the potassium application. Treatment K2 outperformed treatments K1 and K0, with values of 8.25, 7.73, and 7.24 mg kg⁻¹ soil, respectively; however, treatment K1 did not significantly outperform treatment K0 (7.73 vs. 7.24 mg kg⁻¹ soil). It is evident that potassium fertilization increases available soil ammonium (Tables 3 and 4). This may be attributed to the competition between the potassium ion (K⁺) and the ammonium ion (NH₄⁺) for exchange complex sites, due to the similarity of their ionic radii (K = 1.33 Å; NH₄ = 1.34 Å). Abu Nuqta and Al-Shatir (2011) noted that the release of ammonium adsorbed onto the internal surfaces of clay minerals depends on the presence of high concentrations of potassium ions in the soil. Regarding the interaction between the two organic fertilizers (cattle and sheep manure) and the potassium fertilizer, no statistically significant effect was observed.

Table 4: Effect of organic and potassium fertilizers on available soil ammonium (mg kg⁻¹ soil) at the harvest stage of yellow maize

Mean	OMS	OMC	OM0	Treatments
7.24 a	8.80	6.80	6.13	K0
7.73 ab	9.13	8.27	6.40	K1
8.25 b	8.53	8.20	8.33	K2
	8.82 b	7.76 a	6.96 a	
	K x OM	K	OM	L.S.D. 0.05
	n.s.	0.822	0.873	L.S.D. 0.05

K0 = 0 kg K/ha, K1 = 100 kg K/ha, K2 = 200 kg K/ha; OM0 = no organic fertilizer added, OMC = cattle manure (25 t/ha), OMS = sheep manure (25 t/ha).

2. Nitrate Values

Table (5) illustrates the effect of organic and potassium fertilizers on soil nitrate content during the flowering stage of yellow maize. Statistical analysis revealed no significant differences resulting from the application of the two organic fertilizers and the potassium fertilizer, nor from the interaction between the organic fertilizers (cattle and sheep manure) and the potassium fertilizer regarding soil nitrate content. The highest value was recorded in the OMC K0 treatment (20.0 mg kg⁻¹ soil), while the lowest value was observed in the OMC K1 treatment (8.5 mg kg⁻¹ soil).

Table 5: Effect of organic and potassium fertilizers on soil nitrate content (mg kg⁻¹ soil) during the flowering stage of yellow maize.

Mean	OMS	OMC	OM0	Treatments
14.2	12.6	20.0	10.0	K0
9.9	10.1	11.0	8.5	K1
10.0	11.3	9.1	9.6	K2
	11.3	13.3	9.4	
	K x OM	K	OM	L.S.D. 0.05
	n.s.	n.s.	n.s.	L.S.D. 0.05

K0 = 0 kg K/ha, K1 = 100 kg K/ha, K2 = 200 kg K/ha; OM0 = no organic fertilizer added, OMC = cattle manure (25 t/ha), OMS = sheep manure (25 t/ha).

Table (6) illustrates the effect of organic and potassium fertilizers on soil nitrate content at the time of maize harvest. The results indicate no significant differences resulting from the application of the two types of organic fertilizer or the potassium fertilizer, nor from the interaction between the organic fertilizers (cattle and sheep) and the potassium fertilizer regarding soil nitrate content. The highest value was recorded in the OM0 K2 treatment (11.1 mg kg⁻¹ soil), while the lowest value was observed in the OMC K1 treatment (8.9 mg kg⁻¹).

Table 6: Effect of organic and potassium fertilizers on soil nitrate content (mg kg⁻¹ soil) at the harvest stage of yellow maize

Mean	OMS	OMC	OM0	Treatments
9.7	10.2	9.8	9.0	K0
9.6	10.6	8.9	9.1	K1
9.9	9.5	9.0	11.1	K2
	10.1	9.2	9.8	
	K x OM	K	OM	L.S.D. 0.05
	n.s.	n.s.	n.s.	L.S.D. 0.05

K0 = 0 kg K. ha-1, K1 = 100 kg K. ha-1, K2 = 200 kg K. ha-1, OM0 = not adding organic fertilizer, OMC = cow manure 25 tons. ha-1, OMS = sheep manure 25 tons.ha-1

3. Protein percentage in grains

Table (7) shows the effect of organic and potassium fertilizer on the protein percentage in yellow corn grains. We notice that there is no significant effect for both organic fertilizers (cows and sheep) and potassium fertilizer, as well

as the interaction between them on the protein percentage in yellow corn grains, as indicated by the results of the statistical analysis, as the highest value was in the OM0 K2 treatment, which amounted to 10.38%, while the lowest value was in the OM0 K0 treatment, which was 7.67%.

Table 7: Effect of organic and potassium fertilizers on the protein percentage in yellow maize grains

Mean	OMS	OMC	OM0	Treatments
8.96	9.39	9.83	7.67	K0
9.25	9.57	9.36	8.81	K1
9.86	9.42	9.77	10.38	K2
	9.46	9.65	8.95	
	K x OM	K	OM	L.S.D. 0.05
	n.s.	n.s.	n.s.	L.S.D. 0.05

K0 = 0 kg K/ha, K1 = 100 kg K/ha, K2 = 200 kg K/ha; OM0 = no organic fertilizer added, OMC = cattle manure (25 t/ha), OMS = sheep manure (25 t/ha).

We conclude that organic fertilization plays a significant role in increasing available ammonium in the soil—a role no less important than that of potassium fertilization in this regard. Potassium fertilization is also important for increasing available ammonium in the soil. It is essential to consider the balance between nitrogen and potassium fertilization; achieving this balance allows for a reduction in nitrogen fertilizer application—thereby mitigating pollution caused by nitrogen fertilization—and we recommend conducting further experiments in this area.

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