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ORIGINAL RESEARCH

Role of Nutrient Management in Yield, Quality and Nutrient Content of Egyptian Clover (*Trifolium alexandrinum* L.) Under Calcareous Soil Conditions

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ABSTRACT: Nutrient management is vital for maximizing forage crop yield and economic viability; however, improper application can result in decreased yield and quality. Therefore, two seasonal experiments were conducted during the winter seasons of 2022-2023 and 2023-2024 to examine the impact of varying nitrogen, phosphorus and potassium (NPK) levels, along with the foliar application of zinc, on the forage yield and nutrient content of Egyptian clover or berseem (*Trifolium alexandrinum* L.) grown in calcareous soil conditions (>36% $CaCO_3$). The experiment consisted of eight treatments, including two NPK levels (50% and 100% of the recommended dose) and two forms of Zn (Zn NPs and Zn Edta at 0.2 and 0.5% as foliar sprays), compared with the control (without treatment). Results showed that NPK full dose (100%) or in combination with Zn NPs significantly improved fresh and dry weight by an average of 67%, and 80%, respectively, across all cuts. Whereas, the highest protein percentage in berseem forage occurred with 50% NPK and foliar Zn NPs. Protein yield per unit area was highest with 100% NPK and foliar Zn NPs in the second and third cuts. Furthermore, Zn NPs boosted manganese (Mn) levels in the 2nd cut but decreased them in the 3rd cut. Iron (Fe) and Mn were mostly in normal ranges, but zinc was often below normal levels. Overall, Zn NPs increased forage yields. The results of translocation factor (TF) for micronutrients from the soil to berseem plants showed that TF values were > 1 for all micronutrients except for Cu in several instances in the 2nd cut in such calcareous soil. Furthermore, micronutrient translocations were arranged in the following order Cu < Zn <Mn <Fe in the 2nd and 3rd cuts. Our study suggested that there is a beneficial role of correcting Zn deficiency under calcareous soil conditions which is reflected on berseem yield and quality and nutrient status. Thus, using ZnO NPs along with the full recommended dose of NPK is a suitable approach to enhance berseem crop yield and quality in calcareous soil.

KEYWORDS: Berseem, yield, quality, Zn forms, nutrients, translocation factor (TF)

1. Introduction

Crops cultivated in calcareous soils often require higher than normal levels of fertilizer to achieve optimal nutrition and yield (Ali et al., 2020). The North Western Coastal region lands of Egypt consist primarily of calcareous soils, comprising approximately 8% of the total area Rasha (2005). These soils are characterized by lower nutrient availability and are recognized for their inherent challenges (FAO, 2016). Abd El Lateef et al. (2020) reported that the challenges in expanding lands and competing with strategic crops like berseem, suggesting calcareous soils as potential candidates for expansion. However, some problems arise due to their high pH and dominance of $CaCO_3$, despite the issues with low availability of P and K. Soil fertility stress in calcareous soils has been identified as a significant factor responsible to the lower berseem yield in Egypt (Abd El-Lateef et al 2020). Managing nutrients by supplying optimal quantities of macro and micronutrients is crucial for enhancing crop yields in such lands (Zubillaga et al., 2002). Previous studies reported the importance of incorporating organic materials to improve soil fertility and quality (Palm et al., 2001; Soumare et al., 2003). Additionally, low soil fertility poses a significant obstacle to implementing and sustaining effective agricultural management practices (Ahmad et al., 2011; Kankan et al., 2013).

Micronutrient deficiencies can severely inhibit plant growth and yield, particularly in legumes (Tulchinsky, 2010). Similarly, micronutrient deficiencies in plants are becoming increasingly prevalent in food production programs and soil nutrients management strategies, worldwide. Intensive agricultural systems, cultivation of high-yielding cultivars and heavy applications of synthetic fertilizers of N, P and K are the main reasons of micronutrient deficiencies and also are the responsible factor for decreasing nutrients uptake and utilization and declining soil fertility (Ali et al., 2022; Cakmak, 2008). Studies have highlighted the critical role of essential micronutrients such as iron (Fe), manganese (Mn), and zinc (Zn) in human health, with over 3 billion people globally suffering from Fe and Zn deficiencies (Graham et al., 2001; Cakmak 2008).

In recent years, researchers have reported that nano fertilizers exhibit higher solubility and reactivity compared to traditional fertilizers (Rai et al., 2015; Monreal et al., 2015; Masronardi et al., 2015; Fraceto et al., 2016; Singh et al., 2017; Prasad et al., 2017; Morales-Díaz et al., 2017; Qureshi et al., 2018). Nano-fertilizers, particularly zinc oxide nanoparticles (ZnO-NPs), have demonstrated significant potential in various aspects of agriculture. Research by Prasad et al. (2012), Kamran et al. (2016), Elizabath et al. (2017), and Ali et al. (2017) highlights their efficacy in boosting plant growth, mitigating pollution, and enhancing soil fertility, thereby creating a conducive environment for microorganisms. Additionally, studies conducted by El-Ramady et al. (2018), Read et al. (2019), and Drostkar et al. (2019) have indicated that the application of ZnO-NPs can stimulate growth promoters and increase seed yields across different crop varieties. Consequently, there is a growing global interest in utilizing nanotechnology as a fertilizer to enhance nutrient use efficiency and crop yields (Wang et al., 2012; Liu and Lal, 2015; Gong et al., 2017; Mohamed et al., 2017; Venkatachalam et al., 2017; Munir et al., 2018).

Egyptian clover, or berseem (*Trifolium alexandrinum* L.), holds significant agricultural importance in Egypt, potentially cultivated since ancient times (Oushy, 2008;

Muhammad et al., 2014). Berseem exhibits rapid growth and yields up to 8 tons of forage per season (Al-Suhaibani, 2010), serving as a valuable green fodder for livestock. However, in the newly reclaimed lands of Egypt, berseem productivity faces challenges due to environmental factors and management constraints. Zinc deficiency emerges as a prominent nutritional limitation (Asif et al., 2013), given its vital roles in plant growth, metabolism, enzyme formation, root development, and photosynthesis. Effective zinc application has been demonstrated to alleviate deficiency-related issues and boost crop production across various crops, including pearl millet (Kumar et al., 1985), rice (Malik et al., 2011), mung bean (Krishna, 1995), and sweet potatoes (Khairi et al., 2016).

Hence, this study aimed to explore the influence of NPK levels and zinc forms on Egyptian clover forage yield and nutrient content under calcareous soil conditions. We hypothesize that optimal combinations of NPK levels and zinc forms will significantly enhance Egyptian clover forage yield and improve nutrient content under calcareous soil conditions, ultimately addressing productivity challenges and nutritional deficiencies in berseem cultivation in Egypt's newly reclaimed lands.

2. Materials and methods

2.1 Experimental site

The experiments were carried out in a private farm in Bagdad village, Nubaria district, Alexandria Governorate (28 km Alex-Cairo desert road). Al Nubaryia district, Northern sector Alexandria Governorate, Egypt (latitude 301.19"N, longitude 29.89.9" E, and 21 m ± mean sea level. The mean minimum temperature 17 ℃ and the maximum 27 ℃ recorded in winter season. The district receives an average precipitation of 189 mm $year^{-1}$.

The soil under the present investigation was characterized by high calcium carbonate and low fertility status that could influence crop growth. The basic soil chemical properties of the experimental site are presented in Table (1).

2.2 Experimental design

The experiments were conducted in a randomized complete block design in the winter seasons of 2022-2023 and 2023-2024, using different NPK levels and zinc form on Egyptian clover (*Trifolium alexandrinum* L.) on forage yield, and nutrient content under calcareous soil conditions. The experiment comprised eight treatments, consisting of two NPK levels: NPK 100% and 50% of the recommended dose and two Zn forms Zn-NPs and Zn Edta at 0.2 and 0.5% as foliar sprays, along with a control (without treatment).

Table 1. Soil properties of the experimental site prior to experiment.

pH	EC (dS m^{-1})	OM (%)	$CaCO_3$ (%)	Total concentration (mg kg^{-1})						
				N	P	K	Fe	Mn	Zn	Cu
8.2	0.38	1.09	36.5	1540	33	3132	20131	219.2	30.4	9.8

The treatments were as follows: (CK) – Control, (T1) NPK 100%,(T2) NPK 50%, (T3) Zn NPs at 0.2%, (T4) Zn Edta at 0.5%, (T5) NPK 100% + Zn NPs at 0.2%, (T6) NPK 50% + Zn NPs at 0.2%, (T7) NPK 100% + Zn Edta at 0.5%, and (T8) NPK 50% + Zn Edta at 0.5%.

The experimental area was ploughed twice, and divided into experimental units each measuring 21 m^2. The multi-cutting berseem type, meskawy (*Trifolium alexandrinum* L.) c.v. variety (Sakha 4) was used in the current experiment. Seeds were sown in the experimental plots on on the first half of November in both seasons. Sowing was done by hand drilling and the seed rate was 35 kg fed^{-1}, phosphate fertilizer was applied in the form of superphosphate 15.5% P_2O_5 at 31.5 kg fed^{-1} during seedbed preparation while nitrogen fertilizer levels were applied in three equal doses at 21 days after sowing and before the 2^{nd} and 3^{rd} cuts as well as a potassium fertilizer was applied at 24 kg K_2O fed^{-1} before the 1^{st} 2^{nd} and 3^{rd} cuts to form the recommended fertilizer rates (100%) and the half doses of NPK were applied to form the NPK (50%). Zinc was applied at two forms the first one as Zn NPs, whereas the second as Zn Edta at 0.2 and 0.5%, respectively, the two forms were applied as foliar spray one month after sowing and after the 1^{st} and 2^{nd} cuts. Irrigation was carried out as followed by most farmers in the district twice a week by sprinkler irrigation method. Weeds were controlled by hand pulling after 20 and 34 days from sowing.

2.3 Sampling and measurement

Plant samples of berseem were collected after the 1^{st}, the 2^{nd} and the 3^{rd} cuts at 40 days interval between each cut in both seasons . Fresh and dry weights of the 1^{st}, 2^{nd} and 3^{rd} cuts were determined from different areas of each plot by quadrat. Berseem leaf samples were taken from the 2^{nd} and 3^{rd} cuts in both seasons and analyzed for N, P and K, and micronutrients using an atomic absorption spectrophotometer, according to the method described by Chapman and Pratt (1961). Berseem uptake of macro and micronutrients was calculated by multiplying nutrient concentration by dry matter yield in the 2^{nd} and 3^{rd} cuts. Protein percentage was determined by multiplying N% by 6.25 and protein yield per feddan was calculated by multiplying protein % by dry yield in the 2^{nd} and 3^{rd} cuts. The chemical analyses of soil site were carried out according to the methods described by Cottenie *et al.* (1982) and Burt, (2004). Chemical analysis of the experimental soil site is presented in table 1.

2.4. Statistical Analysis

The obtained data were subjected to the proper statistical analysis according to MSTAT-C (1988). Since the trends were similar in both seasons, the homogeneity was carried out according to Bartlet's test, and the combined analysis of the data was applied. Treatment means were compared using LSD test at 5% level

3. Results and discussions

3.1. Changes in fresh and dry yields

Compared to the control (CK) treatment, the fresh yield of berseem was increased by 76% in T1 (Full NPK dose), 64% in T3 (Zn Nano), and 94% in T5 (Full NPK+Zn Nano) during the 1^{st} cut. Similar increases were observed during the 2nd cut; however, an 81%, 68%, and 98% increase in fresh yield were noted in T1, T3, and T5, respectively, compared to CK (Table 2).

Table 2. Effect of NPK level and foliar application of Zn and their interaction on berseem.

Treatment	Fresh yield fed^{-1}(t)			Dry yield fed^{-1}(t)			Total fresh yield fed^{-1}(t)	Increasing %	Total dry yield fed^{-1}(t)	Increasing %
	1st Cut	2nd Cut	3rd Cut	1st Cut	2nd Cut	3rd Cut				
Control	2.5e	4.2e	5.3e	0.48d	0.63e	0.81f	12.0	-	1.82	-
T1	4.5b	7.4b	9.6b	0.57b	0.95b	1.53a	21.5	79.2	3.04	67.0
T2	3.5d	5.9cd	8.0c	0.51c	0.86	1.23d	17.4	45.0	2.60	42.9
T3	4.1c	6.9c	8.9c	0.57b	0.95b	1.31c	19.9	65.8	2.83	55.5
T4	3.8	6.4cc	8.7c	0.51c	0.85c	1.45b	18.9	57.5	2.81	54.4
T5	5.0a	8.2a	10.2a	0.65a	1.09a	1.54a	23.4	95.0	3.28	80.2
T6	4.0c	6.6c	8.9c	0.48d	0.80d	1.52a	19.5	62.5	2.80	53.8
T7	3.3e	5.6d	7.5d	0.49d	0.82c	1.09e	16.4	36.7	2.40	31.9
T8	3.7d	6.2c	8.5c	0.54b	0.89c	1.38c	18.4	53.3	2.81	54.4
LSD at 0.05	1.2	1.9	2.3	ns	0.28	0.35	4.6	-	0.65	-

Note: CK - Control, T1 - NPK 100%, T2 - NPK 50%, T3 - Zn NPs at 0.2%, T4 - Zn EDTA at 0.5%, T5 - NPK 100% + Zn NPs at 0.2%, T6 - NPK 50% + Zn NPs at 0.2%, T7 - NPK 100% + Zn EDTA at 0.5%, T8 - NPK 50% + Zn EDTA at 0.5%. 1 fed (fedden) – 4200 m^2, LSD – least significant difference. Various lowercase letters within the columns indicate significant differences among the treatments (*$p < 0.05$).

Table 3. Effect of NPK level, foliar application of Zn and their interaction on berseem protein% and protein yield (kg fed^{-1}) on dry matter basis.

Treatments	Protein (%)		Protein yield fed^{-1} (kg)	
	2nd cut	3rd cut	2nd cut	3rd cut
Control	22.8c	19.5c	95.8f	102.6d
T1	27.9b	22.6a	206.7b	215.7ab
T2	27.4b	21.7b	161.0d	172.9c
T3	23.8c	22.0a	164.5d	195.0b
T4	29.4a	22.3a	200.9b	192.9b
T5	25.9bc	22.2a	213.7a	227.1a
T6	29.9a	23.0a	196.5c	203.8b
T7	21.8d	21.8b	121.0e	163.4c
T8	28 .0ab	21.6b	204.6b	182.4c
LSD at 0.05	1.2	0.8	23.4	24.1

Note: CK - Control, T1 - NPK 100%, T2 - NPK 50%, T3 - Zn NPs at 0.2%, T4 - Zn EDTA at 0.5%, T5 - NPK 100% + Zn NPs at 0.2%, T6 - NPK 50% + Zn NPs at 0.2%, T7 - NPK 100% + Zn EDTA at 0.5%, T8 - NPK 50% + Zn EDTA at 0.5%. 1 fed (fedden) – 4200 m^2, LSD – least significant difference. Various lowercase letters within the columns indicate significant differences among the treatments (*$p < 0.05$).

Likewise, dry yield showed a similar response to all treatments, such as a 50% increase in T1, 51% in T3, and 72% in T5 during the 1st cut, respectively, compared to CK. In the 2nd cut, increases of 51%, 51%, and 71.5% were recorded in T1, T3, and T5, respectively, over CK. Similarly, during the 3rd cut, increases of 88%, 61%, and 89% were observed in T1, T3, and T5, respectively, compared to CK. Overall, the total fresh weight increased by 79.2%, 65.8%, and 95% in T1, T3, and T5, respectively, while the dry weight was enhanced by 67%, 55%, and 80%, respectively, compared to CK.

These results showed that the combined treatment of NPK and Zn nano (T5) produced maximum fresh and dry yields of barseem compared to all other treatments. The possible explanation for these results can be attributed to the synergistic effects of NPK and Zn nano play a significant role in promoting plant growth and development. As Zn is an essential micronutrient for plants, playing a crucial role in various physiological processes, including photosynthesis (Fariduddin et al., 2022), enzyme activation (Cabot et al. 2019), and hormone synthesis (Khan et al., 2019). By incorporating zinc nano into the fertilization regimen, is likely to enhance the availability and uptake of zinc by berseem plants, leading to improved growth and yield. Furthermore, the combination of NPK fertilizers with zinc nano may have facilitated better nutrient uptake and utilization by berseem plants, thereby promoting vigorous vegetative growth and ultimately resulting in higher fresh and dry yields. This synergistic effect highlights the importance of balanced nutrient management practices in optimizing crop productivity. Similar to our findings, Asif et al., (2013) documented that nitrogen in combination with zinc sulfate improved the growth and yield of maize. Moreover, Rathore et al. (2015) reported under the calcareous soil, deficiency of zinc may lead to poor quality and low yield of fodder crop.

3.2. Changes in protein percent and yield

Protein content of berseem holds significant importance due to its role in enhancing the nutritional quality of forage crops (Balazadeh et al., 2021). In the current study, we evaluated protein percentage and protein yield per fed (4200 m^2). The results showed that both the full dose of NPK (T1) and the 50% dose (T2) performed similarly during the 2nd cut, with protein values of 27.9% and 27.4%, respectively (Table 3). However, during the 3rd cut, these values decreased to 22.6% and 21.7%, respectively (Table 3). Sole application of Zn EDTA (T4) resulted in higher protein content (29.9%) during the 2nd cut, which decreased to 23.0% in the 3rd cut. The lowest protein values were observed in the CK treatment, with values of 22.8% and 19.5% in the 2nd and 3rd cuts, respectively. However, compared to all other treatments, the combined application of the full dose of NPK and Zn nano (T5) improved protein content, with the highest values of 29.9% and 23.0% in the 2nd and 3rd cuts, respectively. Similarly, the highest protein yield per fed (4200 m^2) was observed in T5, with values of 213.7 and 227.1 protein kg fed^{-1} during the respective cuts.

The results can be attributed to the function of Zn in improving protein content in plants, including its essential role as a cofactor for various enzymes involved in protein synthesis and metabolism (Suganya et al., 2020). Furthermore, these results could also be explained by the findings of Kakar et al. (2018), who reported that the status of zinc and its interrelationship with soil characteristics support the understanding of the natural capacity of soil to supply zinc to plants. Optimum nutrition is essential for achieving maximum yield and quality of berseem, with balanced fertilization resulting in the efficient utilization of nutrients. Zinc application is increasingly recognized as essential as nitrogen and phosphorus for legume crops, as it promotes various metabolic reactions (Mann et al., 2024; Amanullah et al., 2020), chlorophyll and carbohydrate production (Babu et al., 2020), enzyme systems (Cabot et al., 2019), auxin and protein synthesis (Karimi et al., 2021). Previous studies by Singh and Singh (2017) and Sharma et al. (2014) have highlighted the significant response of legumes to applied zinc, although responses may vary widely among different field crops due to variations in sensitivity to zinc stress and soil types. However, its single application is not effective for improving plant protein, and its combination with the recommended dose of NPK fertilizer is suggested for higher protein production.

3.3. Changes in nutrients contents

Macro and micronutrient contents in berseem are essential for maintaining optimal animal health and productivity, influencing various physiological functions crucial for growth, reproduction, immunity, and overall metabolic processes (Pal et al., 2004). In the present results, N contents were significantly higher in T8, followed by T6 and T5 for K content in the 2nd cut (Table 4). However, P content was found non-significant among all treatments and cuts. N and K were also not significant in the 3rd cut (Table 5). Although the values of these nutrients were slightly higher in T8 and T5 compared to CK treatment. In the case of micronutrients, the statistical analysis revealed that except Mn, all others were not significant.

Table 4. Effect of NPK level and foliar application of Zn on nutrient concentration of berseem forage in the 2nd cut.

Treatments	Macronutrient (% DM)			Micronutrient (mg kg^{-1} DM)			
	N	P	K	Fe	Mn	Zn	Cu
Control	3.65c	0.20a	1.94d	85.87a	14.04c	16.33a	8.64a
T1	4.46b	0.21a	2.33c	155.3a	18.34b	18.96a	9.50a
T2	4.38b	0.22a	2.29bc	114.2a	18.84b	14.32a	9.06a
T3	3.82c	0.20a	2.33b	155.3a	23.33a	17.44a	10.97a
T4	4.03b	0.23a	2.29bc	114.2a	14.65c	15.84a	7.59a
T5	4.15b	0.23a	2.20c	97.58a	23.39a	18.55a	9.81a
T6	4.78b	0.20a	2.46a	213.2a	14.33c	19.37a	9.19a
T7	3.48c	0.17a	2.22c	110.7a	23.26a	16.33a	12.13a
T8	5.29a	0.26a	2.37b	117.7a	14.97c	12.32a	6.00a
LSD at 0.05	1.12	ns	0.29	ns	7.94	ns	ns

Note: CK - Control, T1 - NPK 100%, T2 - NPK 50%, T3 - Zn NPs at 0.2%, T4 - Zn EDTA at 0.5%, T5 - NPK 100% + Zn NPs at 0.2%, T6 - NPK 50% + Zn NPs at 0.2%, T7 - NPK 100% + Zn EDTA at 0.5%, T8 - NPK 50% + Zn EDTA at 0.5%. DM – dry matter, N – nitrogen, P – phosphorus, K – potassium, Fe – iron, Mn – manganese, Zn – zinc, Cu – copper. LSD – least significant difference. Various lowercase letters within the columns indicate significant differences among the treatments (*$p < 0.05$).

Table 5. Effect of NPK level and foliar application of Zn on nutrient concentration of berseem forage in the 3*rd* cut

Treatments	Macronutrient (% DM)			Micronutrient (mg kg $^{-1}$ DM)			
	N	P	K	Fe	Mn	Zn	Cu
Control	3.13a	0.18a	1.87a	111.36a	14.04e	9.06a	2.31a
T1	3.61a	0.18a	2.06a	148.81a	18.34c	9.88a	2.75a
T2	3.47a	0.18a	2.11a	147.36a	18.84c	9.72a	1.50a
T3	3.52a	0.20a	2.33a	104.15a	23.33a	9.86a	2.26a
T4	3.56a	0.16a	2.29a	165.45a	14.65d	9.74a	2.32a
T5	3.55a	0.21a	2.13a	126.55a	15.95d	10.30a	2.63a
T6	3.68a	0.15a	1.99a	171.08a	20.73b	9.46a	2.88a
T7	3.48a	0.18a	2.14a	141.90a	18.90c	9.42a	1.88a
T8	3.45a	0.18a	2.08a	152.83a	18.78c	10.02a	1.13a
LSD at 0.05	ns	ns	ns	ns	4.16	ns	ns

Note: CK - Control, T1 - NPK 100%, T2 - NPK 50%, T3 - Zn NPs at 0.2%, T4 - Zn EDTA at 0.5%, T5 - NPK 100% + Zn NPs at 0.2%, T6 - NPK 50% + Zn NPs at 0.2%, T7 - NPK 100% + Zn EDTA at 0.5%, T8 - NPK 50% + Zn EDTA at 0.5%. DM – dry matter, N – nitrogen, P – phosphorus, K – potassium, Fe – iron, Mn – manganese, Zn – zinc, Cu – copper, , LSD – least significant difference. Various lowercase letters within the columns indicate significant differences among the treatments (*p < 0.05).

Mn was found to be higher in T8, T5 and T4, and the highest values were 23.6%, 14.3% and 23.3% respectively in the 2nd cut while in the 3rd cut T6, T7 and T8 showed 20.73%, 18.90% and 18.78% values. The lowest macro and micronutrients were observed in the CK treatment. The higher nitrogen (N) and potassium (K) levels observed in treatments T8, T5, and T2 could be attributed to the specific formulations and doses of NPK and zinc fertilizers applied.

Similarly, the increased manganese (Mn) content in treatments T8, T5, and T4 may be linked to the addition of zinc fertilizers, which are known to enhance the availability and uptake of micronutrients by plants. Previous studies have reported that the application of zinc along with nitrogen can increase the dry matter yield of crops (El-Ramady et al., 2018). Furthermore, research has demonstrated that zinc application enhances the fresh matter production of rice (Malik et al., 2011) and improves the quality of crops. For instance, in mung beans, zinc treatment has been observed to increase protein content (Edris et al., 2019). Nutrient uptake serves as the primary mechanism by which plants absorb essential elements from the soil or growth medium, thereby enabling various physiological processes essential for their vitality and productivity (Khan et al., 2024). In our investigation, we observed significant increases in the uptake of N, P and K in treatments T8, T5, and T4, respectively, compared to the control (CK) in both the 2nd and 3rd cuts. These findings highlight the efficacy of specific fertilizer formulations and doses in enhancing nutrient uptake by plants, which can positively influence their growth and performance (Bashir et al., 2023).

Furthermore, our study revealed that treatment T5 consistently resulted in the highest uptake of iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) across both cuts

(Fig 1).This suggests the synergistic effects of combining NPK fertilization with zinc nanoparticles (Zn NPs) in promoting the uptake of micronutrients essential for plant metabolism and function (Eichert and Fernández, 2023; Ahmed et al., 2023; Priyanka et al., 2019).

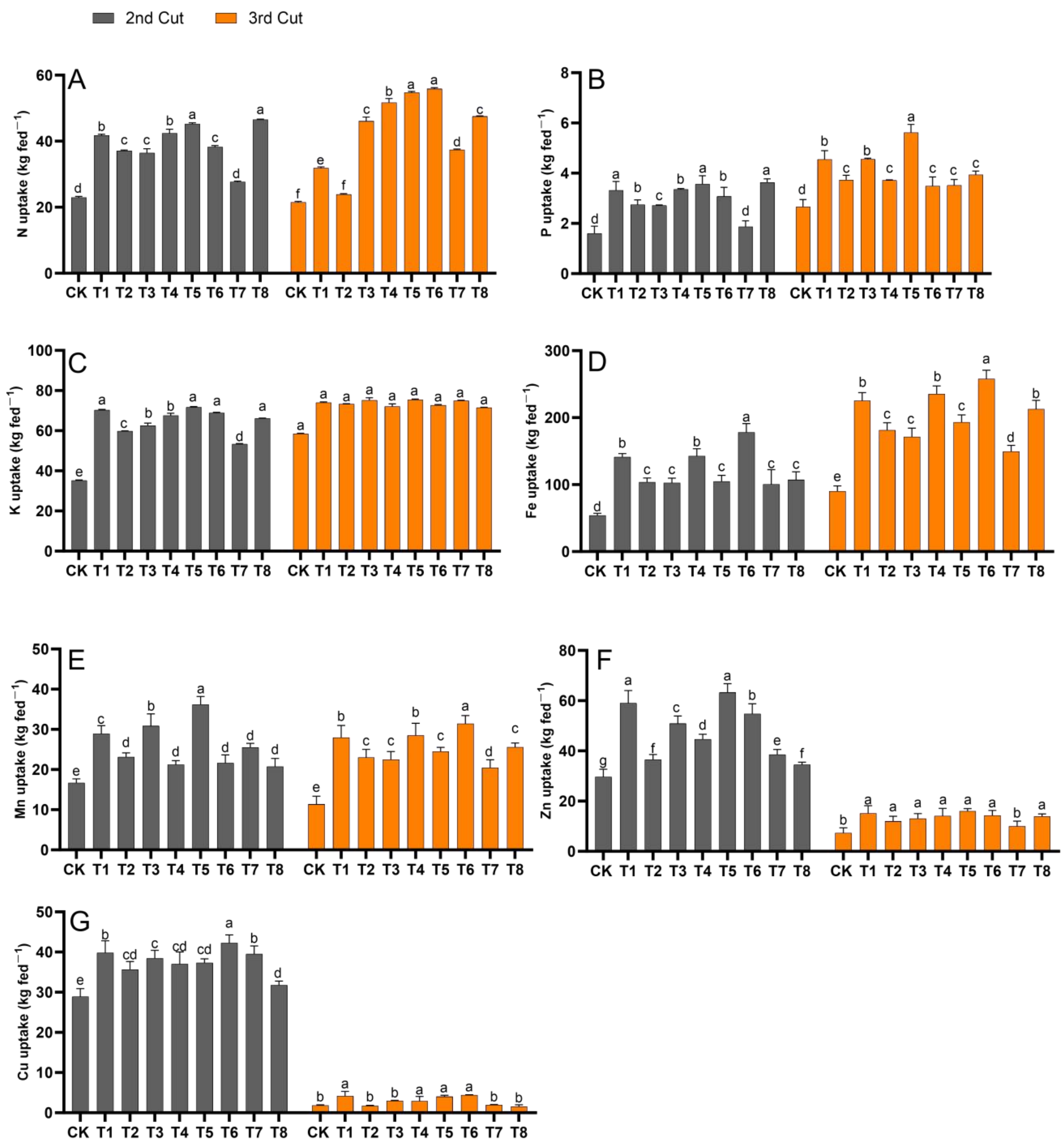

Figure 1. Impact of NPK fertilizer and Zn form on macro and micronutrietnts. Note: N – nitrogen, P – phosphorus, K – potassium, Fe – iron, Mn – manganese, Zn – zinc, Cu – copper, fed – 4200m. CK - Control, T1 - NPK 100%, T2 - NPK 50%, T3 - Zn NPs at 0.2%, T4 - Zn EDTA at 0.5%, T5 - NPK 100% + Zn NPs at 0.2%, T6 - NPK 50% + Zn NPs at 0.2%, T7 - NPK 100% + Zn EDTA at 0.5%, T8 - NPK 50% + Zn EDTA at 0.5%. Lowercase letters on the bars indicate significant differences among the treatments (*p < 0.05).

Table 6: Effect of NPK level and Zn form on micronutrient translocation factors of berseem forage in the 2nd and 3rd cuts.

Treatments	2nd cut				3rd cut			
	TF Fe	TF Mn	TF Zn	TF Cu	TF Fe	TF Mn	TF Zn	TF Cu
Control	0.004	0.065	0.666	1.078	0.005	0.065	0.370	0.288
T1	0.007	0.085	0.774	1.186	0.007	0.085	0.403	0.343
T2	0.005	0.088	0.585	1.131	0.007	0.088	0.397	0.187
T3	0.007	0.108	0.712	1.369	0.005	0.108	0.092	1.231
T4	0.005	0.068	0.647	0.948	0.008	0.068	0.082	1.216
T5	0.005	0.109	0.757	1.225	0.006	0.074	0.420	0.328
T6	0.010	0.067	0.790	1.147	0.008	0.096	0.386	0.359
T7	0.005	0.108	0.666	1.514	0.007	0.088	0.384	0.234
T8	0.006	0.070	0.503	0.749	0.007	0.087	0.409	0.140
Mean	0.006	0.085	0.678	1.150	0.007	0.085	0.327	0.481

Note: TF – translocation factors, Fe – iron, Mn – manganese, Zn – zinc, Cu – copper. CK - Control, T1 - NPK 100%, T2 - NPK 50%, T3 - Zn NPs at 0.2%, T4 - Zn EDTA at 0.5%, T5 - NPK 100% + Zn NPs at 0.2%, T6 - NPK 50% + Zn NPs at 0.2%, T7 - NPK 100% + Zn EDTA at 0.5%, T8 - NPK 50% + Zn EDTA at 0.5%.

The observed increases in Fe, Mn, Zn, and Cu uptake in treatment T5 compared to other treatments underscore the importance of optimizing nutrient management strategies to ensure the adequate availability of micronutrients, which are critical for various enzymatic and biochemical processes in plants (Soares et al., 2019; Bargaz et al., 2018; El-Ramady, 2014). Based on the data presented, it is challenging to pinpoint the specific component(s) responsible for the observed effects due to the complex mixture of nutrients and trace elements. However, it is evident that the application of Zn NPs 0.2% successfully addressed one or more limiting factors. Gaur et al. (2018) found that nitrogen uptake in berseem and lentil increased significantly with the addition of zinc, with lentil showing greater utilization of zinc compared to berseem.

3.4. Translocation of micronutrients to berseem forage in the 2nd and 3rd cuts

The Soil-Forage Translocation Factor (TF) values for micronutrients in berseem are summarized in table 6. Generally, the TF values were > 1 for all micronutrients except several occasions for Cu in the 2nd cut in the calcareous soil. The results indicated that micronutrient translocation could be arranged in the following order Cu< Zn < Mn < Fe in the 2nd and 3rd cuts. This observation may be attributed to two main factors: the elevated pH (>8) and the high $CaCO_3$ content (>36%) present in the calcareous soil. Both factors likely hindered the translocation of Fe, Zn, and Mn to berseem at adequate concentrations, resulting in lower TF values. Similar findings regarding micronutrient translocation factors have been reported by Abd El-Lateef et al. (2021).

4. Conclusions

The experimental results demonstrate that different nutrients management strategies have a major impact on berseem productivity and quality. A significant finding emerged from the extensive two-year study: the Sakha 4 variety is highly recommended for achieving higher yields of both green and dry fodder in berseem when treated with the 100% recommended dose of NKP fertilizers combined with Zn foliar spray (Zn NPs) as this variety showed a significantly higher production per unit area. In order to maximize berseem cultivation and provide consistently high yields across several harvests in calcareous soil, the experimental results therefore support the implementation of nutrient management strategies with berseem. It could be concluded from this study the beneficial role of correcting Zn deficiency under calcareous soil conditions which reflected on berseem yield and quality and nutrient status.

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