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RESEARCH ARTICLE

MACRONUTRIENTS USE EFFICIENCY IN SANDY SOIL CULTIVATED BY MAGNETICALLY TREATED SEEDS PRE-SOWING AND SPRAYED BY N-FERTILIZER DISSOLVED IN MAGNETIZED WATER

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ARTICLE DETAILS

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ABSTRACT

Purpose: is to enhance the nutrients use efficiency (NUE) along with the crop yield and quality by magnetic treatment (MT) of the groundnut (*Arachis hypogaea* L.) seeds pre-sowing as well as the MT of water used to dissolve the nitrogen (N) fertilizer under sandy soil field conditions. Methods: Treatments were distributed in a split-plots design in triplicates. The control CL has received the recommended dose RD of the N-fertilizer while other treatments received a 50% of the RD applied to the surface soil 30 days after planting. The main factor (F1) was the N-application rates 1000, 2000, and 3000 mg kg^{-1} of urea dissolved in the magnetically treated water (MTW) then sprayed on the soil in the liquid form five times after planting. The sub-factor (F2) was the time of MT (15, 30, and 45 min) of the groundnut seeds exposed to a magnetic field MF 1.4 T intensity before planting. Results: The soil available N, P, K, Fe, Mn, and Zn (mg kg^{-1}) were increased significantly by 34.8%, 23.0%, 3.49%, 9.4%, 22.2%, and 23.2% respectively, at $P \leq 0.05$ by the 45 min MT and 3000 mg kg^{-1} N relative to its corresponding control (CL). The MT has increased the seeds yield (kg ha^{-1}) significantly in the order 45 min >30 min >15 min for the N-rates 1000, 2000, and 3000 mg kg^{-1}. At the 45-min time, it was increased by 17.5, 15.3, and 14.8% for the N-rates, respectively. Conclusions: The 2000 mg kg^{-1} rate with MT of seeds for 15 min can be recommended for an acceptable nutrients use efficiency (NUE).

KEYWORDS

Groundnut; Magnetic treatment; Magnetism; Nutrients use efficiency (NUE); Pre-sowing seed treatment

1. INTRODUCTION

Agronomists and climatologists try to improve the crops' yield and quality for sustainable agriculture using the eco-friendly and safe strategies especially under the conditions of the reclaimed sandy soils.

Modern methods to improve the crop production include the treatment by growth regulators, stimulation by the laser, UV, electric and magnetic fields (MF) of different intensities. Application of a MF to the plant seeds, fertilizers, or water used for irrigation and/or preparation of solutions of nutrients and fertilizers has improved the seeds germination, plant growth, yield, and yield parameters of many crops such as wheat and tomatoes under saline conditions (Hussain et al., 2020; Samarah et al., 2021).

Magnetic treatment of seeds pre-sowing by the exposure to a MF may be preferred compared to the biological and chemical stimulators because it may be free of toxic residues. It is an effective and secure method can improve the post-germination of plant especially for the temperature sensitive seeds, stress tolerance, and crop production. The beneficial stimulation effect of the MF was usually seen when seeds germinated under stress condition (Rochalska and Orzeszko-Rywka, 2005). It may work in the energy spectrum of plants. Some theories were suggested based on biological and biochemical changes (alternation of enzymes activities) occur due to exposure of seeds to the MF but do not occur in the untreated seeds. Any change in the concentration of ions within the cell or across the membrane can alter the speed of plant processes and activities such as photosynthesis, growth, mineral nutrition, water, and ion transport. Enhanced root and shoot system improve the nutrients and water uptake for plants, and provide good support to plants (Hussain et al., 2020). Exposure to a MF may induce enzyme changes and regulates the expression of different enzymes and the stimulation of proteins, which accelerate the germination of seeds (De Souza et al., 2014; Radhakrishnan, 2019; Vashisth and Nagaraja, 2010).

On another hand, many studies have been introduced to minimize or replace the inorganic chemical fertilizers, but their necessity still exists for the crops production. Magnetized fertilizers were prepared and studied for the sustainable agricultural purposes. For example, magnetized fly ash was a compound fertilizer prepared by mixing the fly ash with a certain amount of N, P, K, then treated with a MF. The magnetism in fertilizers may improve soil porosity, prevent soil hardening, and increase the use efficiency of N and K taking into account the environmental consideration (Wang et al., 2017). Some other magnetic fertilizers were synthesized and studied (Li et al., 2021; Li. et al., 2016). The magnetic susceptibility (χ_m, m^3 mol^{-1}) of chemical formulations possibly will play a role in their response to the MF and their influence upon use. Positive and negative values of susceptibility (χ_m) are likely energetic property because of which a substance may behave differently if exposed to a MF. Some values are available for chemicals used as fertilizers 1 such as aqueous ammonia NH_3 (χ_m = –18.3 m^3 mol^{-1}), Ammonium nitrate NH_4NO_3 (χ_m = – 33 m^3 mol^{-1}), ammonium sulfate $(NH_4)_2SO_4$ (χ_m = – 67 m^3 mol^{-1}), white phosphorus P (χ_m

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= –26.66 m³ mol⁻¹, Potassium nitrate KNO_3 (χ_m = – 33.7 m³ mol⁻¹), Potassium sulfate K_2SO_4 (χ_m = – 67 m³ mol⁻¹).

Magnetic treatment of water is to let water flow through a MF created by a magnet. Magnetization may affect the hydrogen bonds and Van der Waal's forces between the molecules, changes the size of water clusters that affect some properties of water due to its magnetic sensitivity (Absalan et al., 2021; Karkush et al., 2019). Magnetized water (MW) may break large moieties into smaller ones and facilitate passing through the roots of the pores of plants and soils. It increases minerals dissolution to provide sufficient nutrients for plants. Salts dissolved in water are not changed, but not detrimental. The plant roots absorb soluble nutrients necessary to grow, and the useless salt components are easily leached from the soil (Doklega, 2017). Interaction between bio and chemical fertilizers with MW have led to significant results for melon fruits including the yield (7.2 kg plant^{-1}), weight (3.4 kg^{-1}), and content of fructose sugar in fruits. Photosynthetic pigments (chlorophyll and carotenoids) kinetin, potassium, GA3, nucleic acids (RNA and DNA), photosynthetic activity were enhanced (Ali et al., 2019).

Direct magnetization of water containing fertilizers can increase the solubility and efficiency of fertilizers (Mohamed, 2020; Mostafa, 2020). The uptake of elements by hydroponically grown grapevines (with 0.1 and 0.2 T MF intensities) was evaluated. The solutions were magnetized in two ways: 1) solutions magnetized after preparing, and 2) salts were added to the pre-magnetized waters. The results revealed that magnetic treatments had effect on increasing of leaf elements uptake including N^+, P^+, K^+, Ca^{2+}, Fe^{2+}, and Zn^{2+}. Magnetic treatments also stimulated the chlorophyll content, leaf extension and weight, carbohydrates and biomass accumulation (Zareei et al., 2021).

Environmental and health problems have emerged due to the losses of nitrogen (N) fertilizers by leaching, nitrification-de-nitrification process or by ammonia NH_3 emission in addition to the decreased N-use efficiency. This depends on the climate, soil conditions, and management practices. A calculated annual NH_3 losses range is 10–19% has been reported, sometimes oxidized into nitrogen oxides (NO_x), while the N_2O emission may be resulted from the nitrification (Ding et al., 2017). Optimized fertilization can decrease the nitrate loss compared to the conventional fertilization to improve environmental quality (Wang et al., 2019).

This study aims to enhance the nutrients use efficiency (NUE) in sandy soil along with the crop yield and quality by the magnetic treatment (MT) of the groundnut (*Arachis hypogaea* L.) seeds pre-sowing as well as the MT of water used to dissolve the N-fertilizer applied as a sprayed solution.

2. MATERIALS AND METHODS

2.1 The Experimental Area Planning and Fertilizers Used

The field experiment has been carried out at the Agricultural Research Station, during the summer seasons of 2021 and 2022. The experiment area was sandy soil (*Typic Torripsamment; Entisol* [Arenosol AR] (FAO, 2014)). Its analysis before planting showed a sandy textured sample with the following properties: Coarse sand 70.12%, Fine sand 14.32%, Silt 6.22%, Clay 9.34%, $CaCO_3$ 0.38%, Organic matter (OM = 0.26%), pH 7.9 (1:2.5 soil: water suspension), Electrical conductivity (EC = 0.4 dS m⁻¹, in 1:5 soil: water extract), and available N, P, and K equals 25.5, 2.2, and 55.16 mg kg⁻¹, respectively.

Treatments were distributed in a split-plots design in triplicates with a plot area 10.5 m² (3.0 m × 3.5 m). The main factor (F1) of the study was the treatments of the N-fertilizer dissolved in the magnetically treated water (MTW). The sub-factor (F2) was the magnetically treated seeds sown in all plots in holes (20-cm apart) in lines (50-cm apart)

The applied mineral fertilizers were as follows: Before sowing, the phosphorous (P) fertilizer was applied as the super Calcium phosphate mixed with soil at application rate 476.19 kg ha⁻¹ recommended dose (RD). The nitrogen (N) in the form of urea 46% N was applied in three equal doses each of which is a twenty N unit 30, 45, and 60 days after sowing to obtain the total RD as sixty N units per fed (142.86 N unit per hectare) for the control (CL) plots. The potassium (K) fertilization was 119 kg ha⁻¹ of K_2SO_4 (48% K_2O) applied in two equal doses after planting as recommended.

2.2 Magnetic Treatment (MT) of Seeds and Water

A magnetic tube (70 cm length × 1.5-inch diameter) inside which a magnetic field MF 1.4 T intensity was used for the magnetic treatment (MT). Seeds of the groundnut (*Arachis hypogaea* L. cv. Giza 5) were exposed to the MF by placing inside the mentioned magnetic tube for 15, 30, and 45 min before planting. Magnetically treated water (MTW) was obtained by passage of water through the MF for 15 min then used to dissolve the N-fertilizer.

2.3 Sowing and Harvesting

Magnetically treated seeds were sown for all plots in holes (20-cm apart) in lines (50-cm apart) on the 15th of May 2020 and May 2021. A 50% N RD was applied to the surface soil for all treatments except for the CL after 30 days from planting. The liquid form of the N-fertilizer was then sprayed on soil at three-application rates 1000, 2000, and 3000 mg kg⁻¹ N applied five times 45, 60, 75, 90, 105 days after planting. Plots under study have received the desired fertilization as mentioned. Other agronomic practices were followed according to the recommendations of Ministry of Agriculture. The groundnut crop was harvested in October 2020 and/or 2021.

2.4 Soil and Plant Sampling and Analysis

Representative soil and plant samples from all treatments' plots were randomly selected after harvesting the crop and air-dried to estimate some parameters according to the mentioned methods (Black, 1982). Yield (kg ha⁻¹) and some yield components such as seeds yield (kg ha⁻¹), and 100-seeds weight (g) and the mean of the two seasons was recorded.

The soil available N, P, and K were extracted by 1% K_2SO_4, 0.5 N $NaHCO_3$, and 1 N NH_4OAc (pH 7.0), respectively (Jackson, 1973). Groundnut seeds and straw were dried at 70 ºC for 48 h and ground. A half gram of the ground seeds and/or straw was wet digested using the acid mixture (1:1 $H_2SO_4/HClO_4$) (Chapman and Pratt, 1961). Total concentrations of the N, P and K in plant and soil extracts were estimated by distillation using Kjeldahl apparatus, colorimetrically by the UV-Vis. Spectrophotometer and by flame photometer, respectively.

Nutrient Use Efficiency Indices: they were calculated for different treatments according to (Echeverria and Videla, 1998; Roozbeh et al., 2011) as follows:

$$\text{Nutrient Use Efficiency (UE)} = \frac{(Pn_f - Pn_0)}{Fertilizer\ rate\ (N\ or\ P\ or\ K,\ \ kg\ ha^{-1})} \times 100$$

P_{nf} = seeds N and/or P and/or K in fertilized plots as (g kg⁻¹)

P_{n0} = seeds N and/or P and/or K in non-fertilized plots as (g kg⁻¹)

2.5 Statistical Analysis

Calculations of the least significant difference (LSD) between the treatments effect were done by the two-way analysis of variance (ANOVA) at a significance level $P \leq 0.05$ (Gomez and Gomez, 1984) using the Co-State software Package (Ver. 6.311), a product of Cohort software Inc., Berkley, California.

3. RESULTS

3.1 Effect of the Studied Treatments on Some Properties of The Experiment Soil

Magnetic treatment (MT) of groundnut seeds pre-sowing and/or of water used for preparation of the urea ($CO(NH_2)_2$) fertilization solution has resulted in significant variations in some of the estimated soil and plant parameters. As presented in Tables 1 and 2, variation in the soil pH, EC (dS m⁻¹), and available K (mg kg⁻¹) was non-significant neither due to different N application rates (F1) nor due to MT of seeds before cultivation (F2) depending on the LSD values. The 3000 mg kg⁻¹ of N-fertilization at 45 min MT resulted in a significant relative increase at $P \leq 0.05$ for the soil available N, P, Fe, Mn, and Zn (mg kg⁻¹) by 34.8%, 23.0%, 9.4%, 22.2%, and 23.2%, respectively, compared to its corresponding control (CL). The effects of F1 or F2 were independent of each other since the interaction of F1 × F2 was non-significant for the estimated soil properties in Tables 1 and 2.

3.2 Effect of the MT of Seeds Before Cultivation and The Studied N-Fertilization Rates on The Groundnut Yield (Kg Ha⁻¹) and Some Yield Parameters

Table 3 shows that pre-sowing MT of seeds for 45 min along with the 3000 mg kg⁻¹ N-fertilization resulted in the most significant relative increase in the plant height (cm), no. of pods/Plant, wt. pods/plant (g), and wt. seeds/plant (g) by 53.7, 75.3, 45.0, and 60.2%, respectively, compared to its corresponding CL. The effects of F1 or F2 may be complementary to each other in case of the wt. seeds/plant (g) as indicated by their significant interaction.

However, the effect of the studied factors F1 and F2 on the increase of the yield (kg ha^{-1}) of groundnut pods and seeds was non-significant at *$P \le 0.05$* as indicated by Table 4. The interaction of the F1 × F2 was significant only for the 100 seeds weight. The 100 seeds weight (g) has increased by 17.9 and 19.2% at the 3000 mg kg^{-1} N-fertilization upon MT of seeds for 30 and 45 min, respectively, compared to the CL. The relative increase in the yield (kg ha^{-1}) of the pods and seeds due to the MT followed the order 45 min > 30 min > 15 min for the three N-rates 1000, 2000, and 3000 mg kg^{-1}. At the 45 min time, the pods yield (kg ha^{-1}) has increased relatively by 21.1, 17.8, and 20.6%, while the seeds yield has increased by 17.5, 15.3, and 14.8% for the N-rates, respectively, compared to the corresponding CL (El-Basioni et al., 2015).

Table 1: Effect of the Studied N-Fertilization Rates and Magnetic Treatment of Seeds Before Cultivation on Some Properties of the Experiment Soil

Treatments	pH (1:2.5)				EC (dS m^{-1})				Available concentration (mg kg^{-1})											
									N				P				K			
Application rate of N fertilizer	CL	Time of MT (min)			CL	Time of MT (min)			CL	Time of MT (min)			CL	Time of MT (min)			CL	Time of MT (min)		
		15	30	45		15	30	45		15	30	45		15	30	45		15	30	45
1000	8.00	7.96	7.95	7.93	1.07	1.04	0.97	0.94	36.2	39.4	42.3	45.6	3.89	4.15	4.55	4.93	166.3	169.0	173.2	176.0
2000	7.98	7.95	7.91	7.88	1.05	0.96	0.92	0.91	37.0	42.8	45.7	48.3	4.12	4.65	4.90	5.04	168.0	172.9	176.4	178.5
3000	7.96	7.92	7.87	7.85	1.03	1.00	0.96	0.93	39.4	45.3	49.0	53.1	4.18	4.79	4.95	5.14	172.0	174.0	176.5	178.0
F1	**LSD**	0.01			LSD	0.11			LSD	5.89			LSD	0.03			LSD	6.54		
	SL	***			SL	ns			SL	ns			SL	***			SL	ns		
F2	**LSD**	0.50			LSD	0.10			LSD	2.43			LSD	0.02			LSD	5.72		
	SL	ns			SL	ns			SL	***			SL	***			SL	*		
F1*F2		ns			F1*F2	ns			F1*F2	ns			F1*F2	***			F1*F2	ns		

F1: main factor (application rates of the N-fertilizer), F2: sub-factor (time of magnetic treatment), LSD: least significant difference at p ≤ 0.05, SL: Significance of Level, ns: non-significant.

Table 2: Effect of the Studied N-Fertilization Rates and Magnetic Treatment of Seeds Before Cultivation on the Available Micronutrients (Mg Kg^{-1}) of the Experiment Soil

Treatments	Available concentration (mg kg^{-1})											
	Fe				Mn				Zn			
Application rate of N fertilizer	CL	Time of MT (min)			CL	Time of MT (min)			CL	Time of MT (min)		
		15	30	45		15	30	45		15	30	45
1000	1.98	2.06	2.13	2.19	1.09	1.12	1.18	1.20	0.64	0.66	0.69	0.74
2000	2.05	2.14	2.19	2.25	1.15	1.25	1.30	1.33	0.67	0.73	0.77	0.82
3000	2.13	2.18	2.28	2.33	1.17	1.29	1.35	1.43	0.69	0.75	0.79	0.85
F1	**LSD**	0.12			LSD	0.13			LSD	0.20		
	SL	ns			SL	ns			SL	ns		
F2	**LSD**	0.17			LSD	0.11			LSD	0.06		
	SL	ns			SL	**			SL	***		
F1*F2		ns			F1*F2	ns			F1*F2	ns		

F1: main factor (application rates of the N-fertilizer), F2: sub-factor (time of magnetic treatment), LSD: least significant difference at p ≤ 0.05, SL: Significance of Level, ns: non-significant.

Table 3: Effect of the Studied N-Fertilization Rates and Magnetic Treatment of Seeds Before Cultivation on Some Groundnut Yield Parameters

Treatments	Plant height (cm)				Plant wt. (g)				No. of Pods/Plant				Wt. Pods/Plant (g)				Wt. Seeds/Plant (g)			
Application rate of N fertilizer	CL	Time of MT (min)			CL	Time of MT (min)			CL	Time of MT (min)			CL	Time of MT (min)			CL	Time of MT (min)		
		15	30	45		15	30	45		15	30	45		15	30	45		15	30	45
1000	39.7	46.5	53.9	56.4	146.3	130.2	110.9	98.4	15.4	22.3	28.5	33.2	34.6	41.9	48.9	55.9	18.9	21.6	26.8	27.9
2000	41.3	47.6	56.6	61.2	129.8	132.0	134.7	121.8	19.6	25.5	31.3	35.8	37.9	46.3	55.1	57.8	21.8	25.3	27.2	31.6
3000	43.2	52.9	62.4	66.4	119.2	121.1	141.4	103.2	23.1	28.6	37.6	40.5	43.1	47.5	59.1	62.5	23.1	25.9	32.8	37.0
F1	LSD	3.26			LSD	0.03			LSD	1.80			LSD	1.89			LSD	0.20		
	SL	**			SL	***			SL	***			SL	***			SL	***		
F2	LSD	5.48			LSD	-			LSD	1.77			LSD	2.46			LSD	0.17		
	SL	***			SL	-			SL	***			SL	***			SL	***		
F1*F2		ns			F1*F2	-			F1*F2	ns			F1*F2	ns			F1*F2	***		

F1: main factor (application rates of the N-fertilizer), F2: sub-factor (time of magnetic treatment), LSD: least significant difference at p ≤ 0.05, SL: Significance of Level, ns: non-significant.

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Table 4: Effect of the Studied N-Fertilization Rates and Magnetic Treatment of Seeds Before Cultivation on The Groundnut Pods and Seeds Yield (Kg Ha^{-1})

Treatments	**100 grain wt. (g)**				**Pods Yield (kg ha^{-1})**				**Seeds Yield (kg ha^{-1})**			
Application rate of N fertilizer	**CL**	**Time of MT (min)**			**CL**	**Time of MT (min)**			**CL**	**Time of MT (min)**		
		15 min	**30 min**	**45 min**		**15 min**	**30 min**	**45 min**		**15 min**	**30 min**	**45 min**
1000	74.30	73.16	72.79	68.67	2928.6	3214.3	3500.0	3547.6	1904.8	2023.8	2142.9	2238.1
2000	81.96	77.87	78.42	71.49	3071.4	3333.3	3523.8	3619.0	2023.8	2119.0	2214.3	2333.3
3000	65.34	57.22	77.02	77.88	3119.0	3523.8	3642.9	3761.9	2095.2	2190.5	2309.5	2404.8
F1	**LSD**	6.54			LSD	130.88			LSD	130.88		
	SL	ns			SL	*			SL	ns		
F2	**LSD**	4.95			LSD	66.03			LSD	66.03		
	SL	ns			SL	***			SL	***		
F1*F2		**			F1*F2	ns			F1*F2	ns		

F1: main factor (application rates of the N-fertilizer), F2: sub-factor (time of magnetic treatment), LSD: least significant difference at $p \leq 0.05$, SL: Significance of Level, ns: non-significant.

Table 5: Effect of the Studied N-Fertilization Rates and Magnetic Treatment of Seeds Before Cultivation on the Total Concentration (G Kg^{-1}) Of N, P, And K in the Seeds and Straw

	Total concentration (g kg^{-1})								
Treatments	**Seeds**					**Straw**			
	N					**N**			
Application rate of N fertilizer	**CL**	**Time of MT (min)**				**CL**	**Time of MT (min)**		
		15 min	**30 min**	**45 min**			**15 min**	**30 min**	**45 min**
1000	29.51	39.50	32.38	45.14		10.92	17.36	18.48	11.20
2000	32.61	38.19	33.31	43.19		15.50	19.60	20.16	19.04
3000	27.60	35.91	31.92	40.90		20.09	11.20	18.48	11.76
F1	**LSD**	2.27				LSD	1.31		
	SL	ns				SL	**		
F2	**LSD**	1.75				LSD	1.14		
	SL	***				SL	***		
F1*F2		*				F1*F2	***		
	P					**P**			
1000	4.18	4.40	4.73	4.90		1.05	1.65	1.35	1.30
2000	3.73	4.84	4.54	4.39		1.25	1.60	1.65	1.40
3000	4.45	4.16	4.08	4.25		1.51	1.30	1.45	1.25
F1	**LSD**	0.65				LSD	0.01		
	SL	ns				SL	***		
F2	**LSD**	0.81				LSD	-		
	SL	ns				SL	-		
F1*F2		ns				F1*F2	-		
	K					**K**			
1000	5.86	5.51	5.69	4.92		5.86	5.65	6.28	8.03
2000	5.06	5.38	5.17	4.82		6.24	8.10	5.79	6.84
3000	4.61	5.27	5.10	5.52		6.61	7.05	8.38	6.56
F1	**LSD**	0.65				LSD		0.65	
	SL	ns				SL		ns	
F2	**LSD**	0.57				LSD		0.81	
	SL	ns				SL		ns	
F1*F2		ns				F1*F2		**	

F1: main factor (application rates of the N-fertilizer), F2: sub-factor (time of magnetic treatment), LSD: least significant difference at $p \leq 0.05$, SL: Significance of Level, ns: non-significant.

3.3 Effect on the Nutrients' Total Concentrations (G Kg^{-1}) of The N, P, K, Na, and Na/K Ratio in The Seeds and Straw

Table 5 shows that the range of the significant relative increase in the total concentration of N (g kg^{-1}) was from 2.1% (30 min, 2000 mg kg^{-1}) to 53.0% (45 min, 1000 mg kg^{-1}) in the seeds and from 2.6% to 69.2% at 1000 mg kg^{-1} for 45 and 30 min, respectively in the straw. For P (g kg^{-1}) in the straw, the relative increase ranged from 12.0% (45 min, 2000 mg kg^{-1}) to 57.1% (15 min, 1000 mg kg^{-1}). Variation in the total concentration of the P (g kg^{-1}) in the seeds and the K in the seeds and straw was non-significant at $P \leq 0.05$.

Table 6 refers to that the Na concentration (g kg^{-1}) in the seeds was almost decreased significantly due to the

N-fertilization rates compared to the corresponding CL at *$P \leq 0.05$*. Its minimum decrease was by 10.3% at 3000 mg kg^{-1} N with 15 and 45 min of MT, while its sole maximum increase was by 24.1% at 1000 mg kg^{-1} N and 15 min of MT. The Na/K ratio was also mainly decreased but non-significantly and only increased by 18.2% at 1000 mg kg^{-1} N and 15 min of MT. Variation of the Na concentration (g kg^{-1}) in the straw was non-significant, but the Na/K ratio was varied significantly that may be dependent on the significant variation of K concentration (g kg^{-1}) in the straw.

Table 6: Effect of the Studied N-Fertilization Rates and Magnetic Treatment of Seeds Before Cultivation on the Total Concentration (G Kg^{-1}) of Na And Na/K Ratio in The Seeds and Straw

	Seeds								**Straw**							
Treatments	**Total Na^+ concentration (g kg^{-1})**				**Na^+ / K^+**				**Total Na^+ concentration (g kg^{-1})**				**Na^+ / K^+**			
Application rate of N fertilizer	**CL**	**Time of MT (min)**			**CL**	**Time of MT (min)**			**CL**	**Time of MT (min)**			**CL**	**Time of MT (min)**		
		15 min	**30 min**	**45 min**		**15 min**	**30 min**	**45 min**		**15 min**	**30 min**	**45 min**		**15 min**	**30 min**	**45 min**
1000	0.68	0.36	0.36	0.54	0.12	0.07	0.06	0.11	0.14	0.14	0.14	0.14	0.02	0.03	0.02	0.02
2000	0.58	0.72	0.50	0.47	0.11	0.13	0.10	0.10	0.21	0.29	0.22	0.22	0.03	0.04	0.04	0.03
3000	0.68	0.61	0.54	0.61	0.15	0.12	0.11	0.11	0.30	0.14	0.22	0.22	0.05	0.02	0.03	0.03
F1	**LSD**	0.07			LSD	0.07			LSD	0.07			LSD	0.01		
	SL	*			SL	ns			SL	*			SL	*		
F2	**LSD**	0.10			LSD	0.03			LSD	0.06			LSD	0.01		
	SL	*			SL	ns			SL	ns			SL	ns		
F1*F2		*			F1*F2	ns			F1*F2	ns			F1*F2	ns		

F1: main factor (application rates of the N-fertilizer), F2: sub-factor (time of magnetic treatment), LSD: least significant difference at $p \leq 0.05$, SL: Significance of Level, ns: non-significant.

3.4 The Effect of the Studied Treatments on the Chlorophyll Content (Mg G^{-1} F.W) In the Groundnut Leaves

Both of the N-fertilization rates and the MT of seeds pre-sowing as well as their interactive effect have significantly affected the chlorophyll a, b, and a/b ratio although the total chlorophyll (mg g^{-1} f.w) showed non-significant variations (Table 7). Increasing the N rates from 1000 to 3000 mg kg^{-1} with 15 and 30 min of pre-sowing MT of seeds have decreased the chlorophyll a, b, total chlorophyll (a + b) but increased the chlorophyll a/b ratio. At 45 min of MT, the chlorophyll a, b, total chlorophyll (a + b) were decreased at 1000 and 3000 mg kg^{-1} N while increased the 2000 mg kg^{-1} N-fertilization rate that was opposite to the trend of the chlorophyll a/b ratio. Pre-sowing MT of seeds for 30 min showed the maximum significant increase of the chlorophyll a (by 35.3%), b (by 70%), total chlorophyll (a + b) (by 48.9%), and the minimum significant decrease of the chlorophyll a/b ratio (by – 20.1%) at 1000 mg kg^{-1} N. The same time of MT at 3000 mg kg^{-1} N showed the minimum significant decrease the chlorophyll a (by – 38.5%), b (by –60.7%), total chlorophyll (a + b) (by – 47.5%), and the maximum significant increase of the chlorophyll a/b ratio (by 56.8%).

Table 7: Effect of the Studied N-Fertilization Rates and Magnetic Treatment of Seeds Before Cultivation on the Chlorophyll Content (Mg G^{-1} F.W) in the Groundnut Leaves

Treatments	**Chl a (mg g^{-1} f.w)**				**Chl b (mg g^{-1} f.w)**				**Total Chl (mg g^{-1} f.w)**					**Chl a/b**		
Application rate of N fertilizer	**CL**	**Time of MT (min)**			**CL**	**Time of MT (min)**			**CL**	**Time of MT (min)**			**CL**	**Time of MT (min)**		
		15 min	**30 min**	**45 min**		**15 min**	**30 min**	**45 min**		**15 min**	**30 min**	**45 min**		**15 min**	**30 min**	**45 min**
1000	1.39	1.76	1.88	1.48	0.90	1.33	1.53	0.87	2.29	3.09	3.41	2.35	1.54	1.32	1.23	1.70
2000	1.48	1.22	1.61	1.58	0.99	0.80	1.11	1.12	2.46	2.02	2.72	2.70	1.50	1.53	1.45	1.41
3000	1.56	1.35	0.96	1.24	1.07	0.87	0.42	0.74	2.63	2.22	1.38	1.98	1.46	1.55	2.29	1.68
F1	**LSD**	**0.13**				**0.06**				**0.65**				**0.13**		
	SL	**				***				**ns**				**		
F2	**LSD**	**0.16**				**0.20**				**0.63**				**0.16**		
	SL	**ns**				**ns**				**ns**				**ns**		
F1*F2		***				***				**ns**				***		

F1: main factor (application rates of the N-fertilizer), F2: sub-factor (time of magnetic treatment), LSD: least significant difference at $p \leq 0.05$, SL: Significance of Level, ns: non-significant.

4. DISCUSSION

In the present study, the urea fertilizer dissolved in magnetically treated water and sprayed on soil planted by magnetically treated groundnut seeds significantly affected the N availability in soil and uptake by groundnut seeds and straw. Additionally, it affected the equilibrium concentrations of P and K nutrients along with the Na/K ratio. The balanced content of chlorophyll a and b in the leaves was highly disturbed. It may be due to the structural difference between the two chemical forms being chlorophyll b containing an aldehyde moiety (– CHO) of higher susceptibility χ_m compared to the methyl moiety (– CH_3) Scheme 1.

Nutrient use efficiency (%) illustrated in Fig. 1 (a-c) indicates that the 1000 mg kg^{-1} and the 3000 mg kg^{-1} N-fertilization rates shall be eliminated for the studied times of MT (15, 30, and 45 min) because they are negatively affected the KUE (%) and the PUE (%), respectively. The 2000-mg kg^{-1} rate at 45 min MT negatively affected the KUE. Therefore, the 2000-mg kg^{-1} rate used with MT of seeds for 15 or 30 min before cultivation may be suitable to obtain acceptable N, P, and KUE with the 15 min is more recommended. At the 15-min time and 2000-mg kg^{-1} rate, the yield of pods and seeds (kg ha^{-1}) has increased relatively by 8.5% and 4.7% respectively, compared to the corresponding CL. It may avoid the abnormal changes of the MT.

Magnetism expressed as the magnetic susceptibility χ_m (10^{-6} cm^3 mol^{-1}) can be responsible for a matter behavior when it is induced by a MF. Many studies have revealed that MT of water used for irrigation and/or plant seeds before cultivation effectively enhanced the plant growth and yield parameters. Although

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measurable values of the susceptibility χ_m were provided in the literature for different elements and some of their polyatomic forms (Appendix I), it is extremely difficult to predict their magnetic response and behavior as nutrients within the soil or plant matrix. This is due to the complex chemical and biological reactions taking place in soil solution and inside the plant cells. Positive susceptibility χ_m of oxygen (Appendix I) is expected to affect that of water so that water can be considered as a mobile phase carries a magnetic force to magnetically induce matter in contact (Wang et al., 2018; Xiao-Feng and Bo, 2008a 2008b). They include soluble plant nutrients with different chemical forms and different constituents of soil. In addition, ions of potassium (K), iron (Fe), manganese (Mn), and perhaps the nitrate (NO_3^-) and phosphate (PO_4^{-3}) may possess positive susceptibility χ_m. In the soil-plant system, the magnetic susceptibility χ_m of different constituents, magnetic induction created by the magnetically treated water or seeds, and the resulted magnetic attraction/repulsion forces are factors expected to control the equilibria of chemical and biological reactions. It may works in the energy spectrum of plants and affects the balanced uptake of nutrients by plant. Some studies referred to that the magnetization of water increased some ions such as Mg, K, Na, Cl, and SiO_2 and decreases Ca and SO_3. The spectral lines of an atom are splitted in the presence of a MF, called the Zeeman Effect theory. Under a MF, the electrons in the orbitals of an atom become distorted and the gap between the different lines depends on the strength of the MF. Magnetic fertilizers were believed to manage and harmonize the molecular structure of the soil (Li et al., 2021; Rochalska and Orzeszko-Rywka, 2005; Vasilyeva et al., 2021).

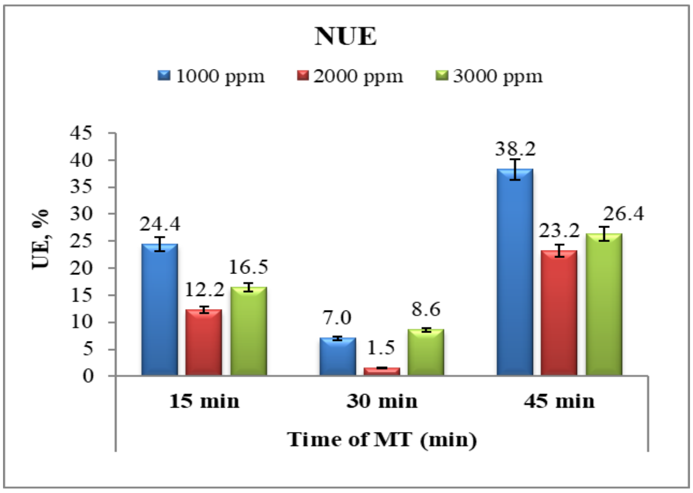


Figure 1a: Nitrogen use efficiency (NUE, %) under the effect of the studied treatments

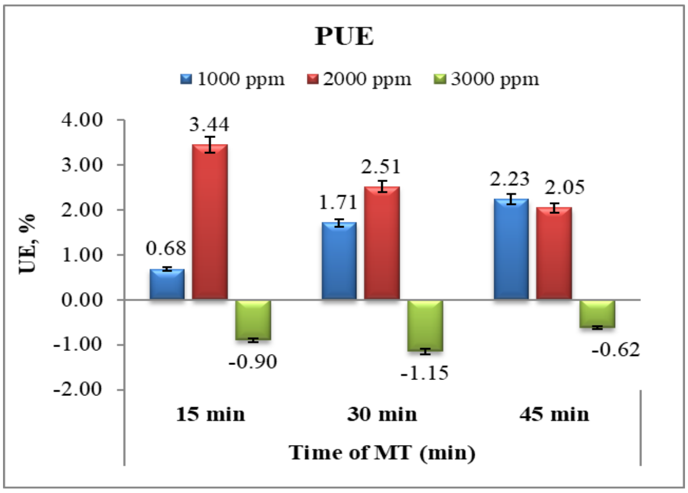


Figure 1b: Phosphorus use efficiency (PUE, %) under the effect of the studied treatments

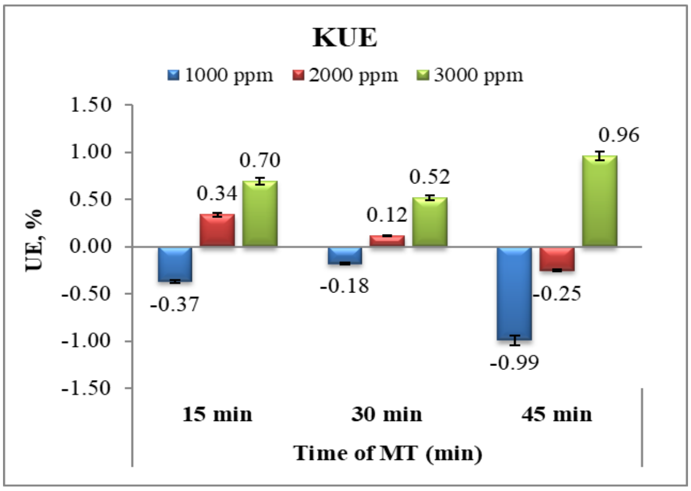
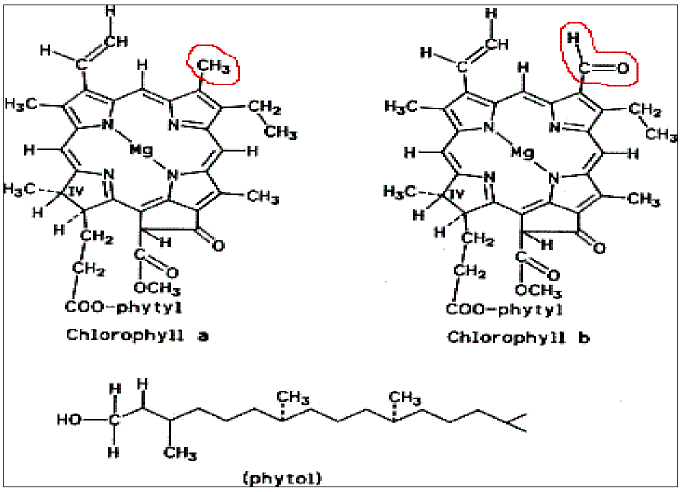


Figure 1c: Potassium use efficiency (KUE, %) under the effect of the studied treatments



Scheme 1: Structural formula of chlorophyll a and b

The physicochemical properties of solvents such as water change under an applied MF with novel properties. Water is diamagnetic, and when magnetized with a MF, the hydrogen bond in water breaks, the number of water monomers increases, a reactive oxygen is formed, which increases salt mobility. One of the most significant advantages of water magnetization is that water retains its new properties from several minutes to hours and even days. It has been believed that solvents lose some properties obtained by magnetization but not all properties referred to as "solvent's memory" (Absalan et al., 2021).

Multi-component magnetic fertilizer studied previously strengthens the magnetic and energetic field around plants for both grain and crops. The growth parameters were also enhanced significantly in plants from magnetically treated seeds. The chlorophyll contents (35.41%), fruit length (18.11%), fruit weight (14.93%), yield (29.16%) and mineral contents were also recorded to be higher in MF treated plants group versus control (Iqbal et al., 2016).

5. CONCLUSION

The present study aimed to improve the sandy soil productivity via improving the use efficiency (UE) of mineral fertilization. Magnetic treatment (MT) of groundnut seeds before cultivation and/or water used to prepare fertilization solutions can be recommended to enhance the N, P, and K nutrients use efficiency under the sandy soil conditions. This can be attributed to the induction effect of the magnetic force on the chemical and biological reactions that control the nutrients' availability and uptake in the soil-plant system. The 2000 mg kg^{-1} rate used with MT of seeds for 15 or 30 min before cultivation may be suitable to obtain acceptable N, P, and KUE with the 15 min is more recommended. At the 15 min time and 2000 mg kg^{-1} rate, the yield of pods and seeds (kg ha^{-1}) has increased relatively by 8.5% and 4.7% respectively, compared to the corresponding CL. It may avoid the abnormal changes and disturbed equilibria of the nutrients' availability or uptake by plant that may result from the induction effect of the MT leading to a negative NUE.

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HIGHLIGHTS

- Fertilizers dissolved in the magnetized water may increase the nutrients use efficiency.
- Magnetic treatment of the groundnut seeds pre-sowing can affect the balanced nutrient uptake.
- Magnetic treatment technology can be recommended for sandy soil conditions.
- The magnetic induction may affect the bio/chemical reactions in the soil-plant system.

SUPPLEMENTAL MATERIAL

Appendix I Magnetic Susceptibility χ_m (10^{-6} cm^3 mol^{-1}) of the plant nutrients in their elemental form and some of their inorganic Compounds

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