Nano-Soil Conditioners to Alleviate Water Stress and Boosting Crop Production

Turkey M.M., El-Sayed M.M., Abdel-Mawgoud A.S.A

Soils and water Sci. Dept., Fac. of Agric., Al-Azhar Univ., Assiut, Egypt

Abstract

Nanotechnology comprises nano-particles (NP) attracted great impulse to alleviate the limitations in plant growth resulted from abiotic stresses. The field trial was conducted in two successive growing seasons of 2021/22 and 2022/23 at experimental farm located at 31° 41ʹ 11ʺ E longitude and 26° 22ʹ 45ʺ N latitude of El-Sheikh Allam, Al-Monshaah, Sohag Governorate. The study aims to follow the effect of applying different nano-synthesized soil amendments (zeolite, rock phosphate and rice husk) dressing or foliar at different soil moisture schedule (60, 75 and 90% of available water) in order to mitigate drought effects on wheat crop production and soil conditions. The results revealed that all nano-particle application and compost enhanced hydro-physical soil properties, wheat-water behavior and grain wheat yield. It was noticed that adding nano-zeolite converted from rock phosphate (AM1) was superior the other nano-particles soil conditioners even the compost type. This nano-particle (AM1) realized the highest values of porosity, field capacity, available water, infiltration rate, hydraulic conductivity, irrigation water productivity, grain yield and crop water productivity. However, future investigation is still required to resolve the safety and health risks issues associated with nano-technology.

Keywords: Nano-particles, Soil conditioners, Water stress, Wheat crop, water productivity.

1. Introduction

Nano-particles (NP) attracted significant impulse to mitigate the negative effect of abiotic stresses in restricting plant growth. The exclusive properties of small sized nano-particles, in addition to surface area increment and high reactive potentiality, opens new scope in agriculture sector. Nano-particles emerged as magic bullets for agriculturists, farmers, and scientists to improve plant performance under stress conditions. Adding inorganic and/or organic nano-particles confer tolerance in plants against stresses. These particles cross talk with various plant hormones to make plants thrive under stress [1]. Water is crucial for life continuity and its deficiency leads to drought and severe growth conditions for plants. Drought restricts almost 45% of global agriculture area as the major environmental stress. Water scarcity not only manipulate water potential in cells but also affect the gaseous exchange and closure of stomata, in addition to ionic exchange, photosynthetic activity and transpiration rate [2-4] reported that the application of 0.02% TiO_2-NP as foliar spray improved the vigor of wheat plants by enhancing yield traits such as plant weight and height, ear number, harvest index, 1000-kernal weight, seeds plant^{-1}, in addition to the content of gluten and starch in plants grown under water shortage.

Yasmeen *et al.* [5] found that the abundance of the Rubisco protein in wheat plants exposed to Fe-NPs was 3 fold that in untreated plants. [6] Stated that at different doses of ZnO and CuO-NPs (act as fertilizers), the Zn-NPs affected on roots and enhanced lateral root growth whereas Cu-NPs improved proliferated and root hair elongation in wheat seedlings subjected to drought. [7] Stated that chitosan and Si application increased the growth and plant water status, along with the physiological trials and yield attributes in the wheat plants under drought stress. [8] Stated that nano-particles (NP) application can boost crop production in the current hostile environment, mainly subjected to drought and salinity stresses. The study aims to follow the effect of applying different soil amendments (zeolite, rock phosphate and rice husk) in nano-synthesized forms, dressing or foliar at different soil moisture schedule (60, 75 and 90% of available water) in order to mitigate drought effects on wheat crop production and soil conditions.

2. Materials and Methods

The field trial was conducted in two successive growing seasons of 2021/22 and 2022/23 at experimental farm located at 31° 41ʹ 11ʺ E longitude and 26° 22ʹ 45ʺ N latitude of El-Sheikh Allam, Al-Monshaah, Sohag Governorate (Fig.1). The area enjoys surface irrigation system and the main source of irrigation water is river Nile. The research was initiated to assess the effect of different synthesized nano-zeolites application as a smart soil conditioner either dressing or foliar on wheat crop grown on sandy soil under soil moisture stress. Nano-soil conditioner

(Nano-zeolite, clinoptilolite) named AM was synthesized by hydrothermal treatment at various crystallization temperature according to [9]. Also, nano-zeolite converted from rock phosphate named AM1 was synthesized according to [10] and nano-zeolite converted from rice husk named AM2 was synthesized according to [11]. The experiment was laid out in randomized complete design with three replicates. The treatments were three levels of soil moisture stress and three nano-soil conditioners plus plots treated with compost in addition to control plots received the traditional recommend fertilizer doses (15 total treatments). The plot width is 5 m and its length is 10 m with an area about 50 square meter (1/80 feddan). The plots were restricted with 2m width boundary as buffer zone in order to avert the horizontal leakage and to express soil moisture stress (60, 75 and 90% of available water). The treatments of each soil moisture schedule in each season were as follows:

1) Traditional recommend fertilizer doses as control
2) Compost named COM
3) Synthesized nano-zeolite named AM
4) Nano-zeolite from rock phosphate ore named AM1
5) Nano-zeolite converted from rice husk named AM2

The added amount of compost was 4 kg/ m^2 and the added amount of nano-zeolite as fine granular whether it is AM, or AM1 or AM2 was 13.5 g/ m^2. The tested materials were mixed well with soil surface before cultivation. Also, the tested nano-zeolite (AM, AM1 and AM2) was foliar spraying on plants three times at 30, 45 and 60 day after sowing (DAS) by concentrated liquid of 25%. The pressure membrane apparatus and pressure cooker were used to determine permanent wilting point (PWP) and Field capacity (FC). An undisturbed and disturbed soil samples were saturated and equilibrated at 0.33 and 15 bar suction pressures, respectively, according to [12]. The estimation of available water capacity (AWC) was performed by the differences. The soil water content% was estimated gravimetrically before irrigation on soil dry weight basis. The plots were irrigated whenever the soil moisture reached the desired level (60, 75 and 90% from the AWC). The applied irrigation water was measured and delivered according to the technique of Water Requirements and Field Irrigation Research Dept., ARC, Egypt. The soil water content % was determined gravimetrically just before irrigation in order to estimate the actual Evapotranspiration (ETa), on soil dry weight basis, then one day after each irrigation, in addition to harvesting time. All samples were taken from 15 cm in the soil surface, then 60 cm deeper down. The actual evapo-traspiration (ETa) was estimated in two successive irrigations as water depth in root zone by cm following the method of [13]. The later mentioned equation is used:

$$ETa = \theta 2 - \theta 1/ 100 \times Bd \times D/100 \times 4200$$

Whereas:
ETa = water consumptive use (m^3).
θ_2 = water content% in soil subsequent irrigation.
θ_1 = water content% in soil prior to irrigation.
D = soil depth (cm).
Bd = bulk density (Mg/m^3).

Soil bulk density of different soil layers before and after each season was measured using the core sampling technique as described by [14]. The total soil porosity was calculated using bulk and particle density as proposed by the formula of [15] as follows:

$$Total\ porosity\ \% = (1 - Pb/Ps) * 100$$

Turkey et al., 2023

Where Pb is the bulk density (g/cm^3), Ps is the particle density which is taken as 2.65 g/ cm^3. The Infiltration rate was measured using the double ring infiltrometer as described by [16]. The estimation of hydraulic conductivity was carried out using the method of auger hole according to [17]. The Irrigation water productivity (IWP) and crop water productivity (CWP) were calculated according to [18] using the following equations:

$$IWP\ (kg/ m3) = 100\ (Y/ I)$$
$$CWP\ (kg/ m3) = 100\ (Y/ ET)$$

Where Y is the grain yield (kg/ fed.), I am the irrigation water applied (m^3/ fed.) and ET is the seasonal water requirement (m^3/ fed.).

Wheat (*Triticuma-estivum vulgar*) grains were sown in the winter seasons on November 27th and December 3rd, respectively of 2021/22 and 2022/23, in 800 cm long rows apart by15 cm space under flooding irrigation methods. Harvesting of wheat plants was on 1st and 2nd of May 2022 and 2023, respectively. The agricultural practices applied for growing wheat werethe commonly practices and followed the Ministry of Agriculture recommendations. Ammonium nitrate was applied in two equal doses at the rate of 120 kg fed^{-1} as nitrogen fertilizer (33.5% N). The first dose applied before planting irrigation, while the second fertilization dose applied before the second irrigation (tillering stage). Calcium super phosphate was added as phosphorus fertilizer (15.5% P_2O_5) as 100 kg/ fed. As single dose through the soil preparation. Potassium sulphate (48% K_2O) used for K fertilization as 50 kg/ fed. As double doses in conjunction with nitrogen fertilization.

At harvesting stage of wheat plants, soil samples were taken and collected for some soil analyses from plots representing each treatment from disturbed and undisturbed soils at 0-30 and 30-60 cm depths. After drying, disturbed soil samples were crushed then sieved through sieve (2 mm). The chemical and physical properties of soil and compost used were carried out following the methods of [16-19], respectively. The data are exhibited in tables (1&2). The data of grain and straw yield were recorded in each plot at harvest time, from 4 m2 (2m x 2m) in the centric area. These recorded data were used for the whole Fadden estimation. The Analysis of Variance (Two-way ANOVA) were performed. The comparison among treatments to distinct the significant differences were performed using Duncan multiple range tests at 5% level of probability using Costat software [20].

3. Results and discussion
3.1. Results

The use of nano clay and zeolite could improve fertilizer efficiency and crop production in coarse-textured soil. In corporating in organic amendments into sandy soils declined nitrogen losses and enhanced the N fertilizer yield of the agriculture systems.

3.1.1. Some physical soil properties and nano-particles application

The effect of nano-particles application on some physical soil properties with soil moisture stress are represented in table (3). Data of saturation percent (SP) decreased with soil depth with values ranged between 25.5 and 43.5 showing the common values of sand soil (Table 3). The SP values increased with nano-particles application especially in surface layers regardless the soil moisture stress.

The SP treatments were descendingly arranged as control < compost < AM < AM2 < AM1 regardless the soil moisture stress. Bulk density of the soil was improved by applying nano-particles. They varied from 1.32 mg/ m3 with AM2 application at 60% available water (AW) and 1.70 mg/ m3 for control treatment at 60% AW. Total soil porosity values were positively increased by nano-particles application. They changed from 35.97% at 30-60 soil depth of control treatment with 60% AW and 49.90 % at 0- 30 soil depth of AM2 treatment with 60% AW. It was noticed that total soil porosity values increased by adding AM and they almost remain stable with other nano-particles application (AM1 & AM2) despite soil moisture stress. Total soil porosity values were congruent with bulk density values since increasing total soil porosity always accomplish with decreasing of soil bulk density.

3.1.2. Soil moisture constants and water permeate with nano-particles application

Regarding soil moisture constants, the data revealed that the soil moisture constants decreased with soil depth but being slightly high when available water capacity increased (Table 4). At field capacity boundary soil water content varied from 14.75 up to 23.75%; the soil moisture at welting point differed between 6.88 and 11.38%. The available water capacity varied from 7.88 to 12.45%. The added AM1as a soil conditioner realized the highest soil moisture constants among the other treatments (table 4) regardless the water stress. The increment ranged from 20.0 up to 45.0% for field capacity (FC), 24.0 up to 56.0% for WP and 14.0 to 41.0% for AW as average values of both seasons. Infiltration and percolation phenomena as affected by nano-particles application with water stress are shown in Fig. (2). The data showed that the infiltration rate values increased with nano-particles application and by increasing available soil moisture; their values varied from 0.23 up to 0.795 cm h^{-1} as average value of two growing seasons. The highest infiltration rate was recorded at AM1 treatment despite water stress. The same trend was true for soil hydraulic conductivity and their values varied from 0.055 up to 0.195 mday^{-1}.

3.1.3. Wheat-water behavior

Irrigation water application (IWA) as affected by nano-particles application and water stress is presented in table (5). The amounts of IWA decreased either with nano-particles application or with increasing available water. The amounts of IWA ranged between 2530.11 and 3022.08 m^3/ fed. As average value of both seasons. The same trend was true for water consumptive use (ETa) since their values changed from 2123.00 to 1820.50 m^3/ fed. As average value of both seasons (Table 5). Wheat grain yield (ton/ fed.) increased by nano-particles application while it decreased by increasing the available water. Data of grain yield recorded diverged from 1.91 ton/ fed up to 3.99 as average value of both seasons (Table 5). IWP and CWP affected positively since their values increased either by nano-particles application or increasing water stress. The IWP values ranged from 0.58 to 1.40 and CWP values changed from 0.81 to 2.00 kg/ m^3 of water as average value of both seasons.

3.2. Discussion

Nanotechnology in agriculture has gained good momentum in the last decade with an abundance of public funding, but the stage of development is good, even though

many methods became under the umbrella of agriculture. Bulk density of the soil is connected with soil other properties such as moisture content and porosity (table 3). [21] Mentioned that there was negative fit between soil bulk density and nano-composite amendments at different levels, since it declined after applied treatments in comparison with control. Such reduction due to nano-composite soil amendments could be attributed to pore spaces increment which improved soil aeration in addition to soil moisture. Also, they observed a contradictory link between sandy soil total porosity and nano-organic or bulk organic soil amendments. Total porosity as average value of both seasons were increased either with organic and nano-organic soil conditioners compared to control treatment. This enhancement could be attributed to the increment in the pore space separate coarse sand particles, which rearranged around the puffy hydrogel particles.

Hence, the soil volume increases and the ratio of soil dry mass to its volume declined due to the displacement and reorientation of soil particles around the hydrogel puffy particles that may create new pores [22]. According to [23] they reported that the sandy soil amended with 0.4% nano-composite reduced bulk density value from 1.51 down to 1.21 g/ cm^3. The previously mentioned reduction could be attributed to water absorption by hydrogel particles in the soil matrix which become larger in size. Bayat et al. [24] reported the effect of applying engineered nano-particles<100 nmMgO and Fe3O4 (ENPs) as soil amendment and subjected to different abiotic stresses. It was reported that magnesium oxide (MgO) ENPs resulted in the soil bulk density reduction as compared to Fe3O4 ENPs effect. Decline observed in density could improve root growth and penetration accompanied with better soil aeration. It was also found that MgO NPs improved soil structure, increased porosity, and reduced bulk density, whereas Fe3O4 ENPs only increased the tensile strength of the aggregates by strengthening bonds between Fe and soil particles [24]. [25] Stated that silver nano-particles can stimulate wheat growth and yield. Soil applied 25 ppm SNPs had highly favorable growth promoting effects on wheat growth and yield.

Similarly, [26] concluded enhancing effect of applying MgO (ENPs) could be attributed to improvement of soil mechanical and physical properties resulted from their outstanding reaction capacity, adhesiveness, activity and specific surface. Regarding wheat-water behavior, [27] revealed that iron ENPs, with particle size smaller as compared to clay soil pores size, could easily leach down through soil. However, after period of time these pores mayformat aggregations and become blocked, as a result this could decline the hydraulic conductivity of the soil. [28] Found that nano-silica significantly increased the water storage capacity of soils up to 180% by the addition of 3 wt % nano-silica only. [29] Reported an increment of soluble silicate Si^{4+} after applying Si-NP that caused a rise in soil water properties behavior such as WP, FC, AW and soil water content (θs), which in turn resulted in increment of WUE and yield by about 178% when compared to silicon nano-particles (Si-NPs). The highest mean values out of all treatments were recorded in plants subjected to (400 nm) Si-NP. [30] Reported that amending soil with metal or metallic oxide nano-particles could improve hydraulic conductivity and porosity of the soil in addition to close the distance between the particles of the treated soil.
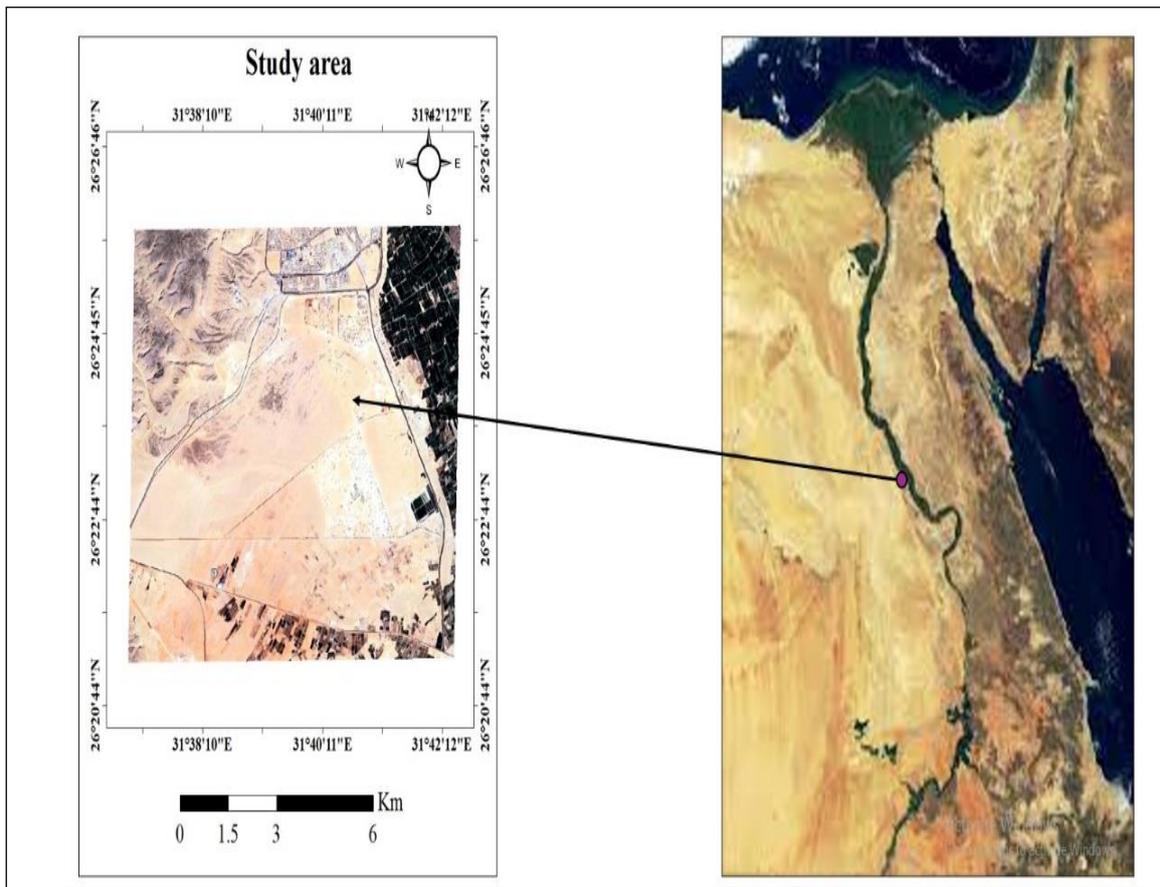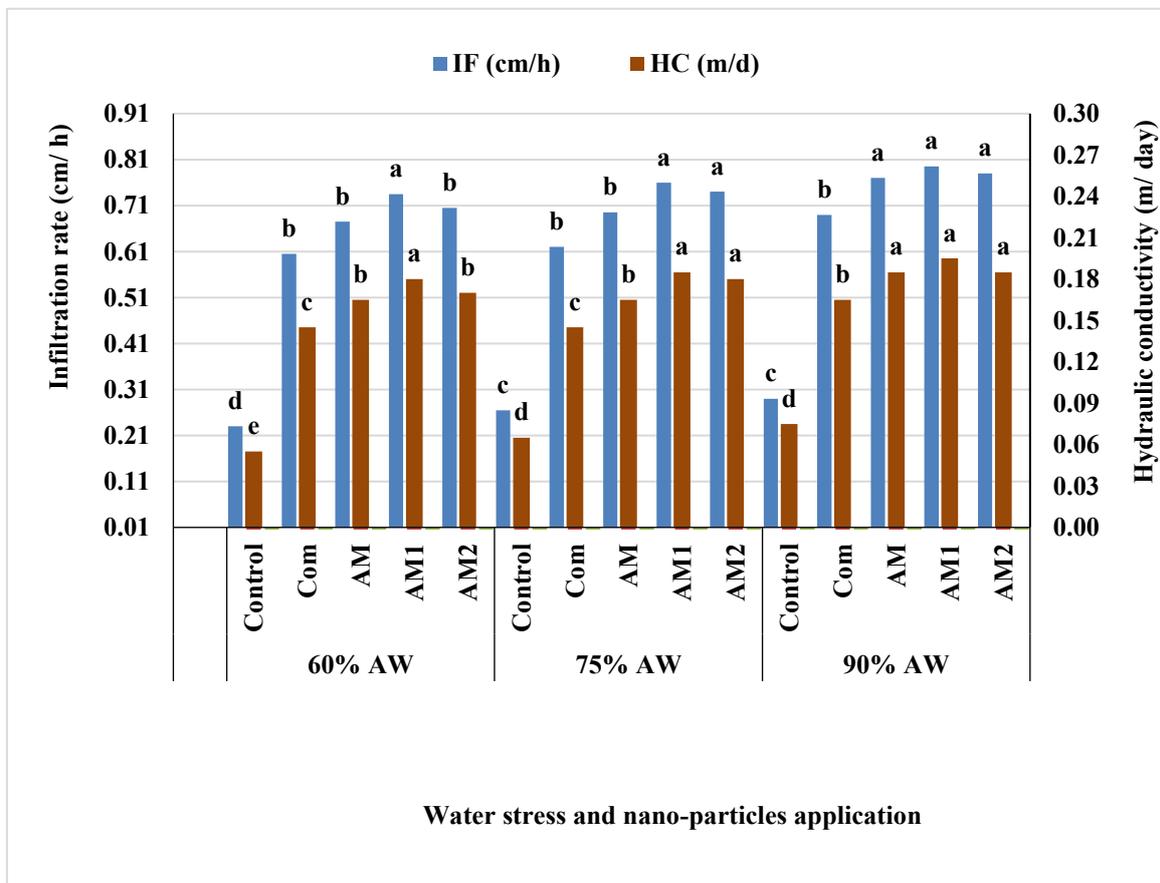
Fig.1: Location of study

Fig. 2: Effect of nano-particles application on infiltration rate and soil hydraulic conductivity with water stress as average value of both seasons

Table 1: Some soil properties of the experimental site

Property	2021/22		2022/23	
	Soil depth (cm)		Soil depth (cm)	
	0-30	30-60	0-30	30-60
pH (1: 2.5)	7.89	7.91	7.88	7.94
EC$_e$ (dS/m)	5.83	5.68	5.76	5.74
CaCO3 %	47.75	51. 53	45.70	52.25
OM %	0.25	0.15	0.35	0.18
Sand %	85.30	83.90	85.10	84.80
Silt %	13.10	14.10	13.00	13.20
Clay %	1.60	2.00	1.90	2.00
Texture class	sandy	sandy	sandy	sandy
SP %	27.00	25.00	29.00	26.00
FC %	15.50	14.50	16.50	15.00
WP %	7.00	6.75	7.25	7.00
AW %	8.50	7.75	9.25	8.00
Bd (Mg/m^3)	1.65	1.70	1.63	1.70
Porosity %	37.26	35.85	38.26	36.09
IF (cm/h)	0.22	----	0.24	---
HC (m/d)	0.05		0.06	
Available N (mg/ kg)	17.00	14.00	18.00	13.00
Available P (mg/ kg)	8.61	7.78	8.67	7.91
Available K (mg/ kg)	199.00	206.00	210.00	215.00

pH= soil reaction, EC$_e$= electrical conductivity,　　　OM= organic matter, SP= saturation percent,　FC= field capacity,　WP= wilting point, AW= available water,　Bd= bulk density,　　　　IF= infiltration rate, HC= hydraulic conductivity,　N= nitrogen, P= phosphorus, K= potassium,

Table 2: Some chemical analyses of the added compost

Property	EC (1:2.5)	pH (1:2.5)	OM %	N %	P %	K %
Compost	2.70	8.60	65.50	1.850	0.520	1.350

Table 3: The effect of nano-particles application on some physical soil properties with soil moisture stress during both growing seasons

Treatments		Soil depth (cm)	Saturation percent			Bulk density (Mg /m³)			Porosity %		
			2021/22	2022/23	mean	2021/22	2022/23	mean	2021/22	2022/23	mean
60% AW	Control	0-30	27.00q	29.00o	28.00	1.65a	1.63ab	1.64	37.26n	38.26m	37.76
		30-60	25.00s	26.00r	25.50	1.70a	1.70a	1.70	35.85o	36.09o	35.97
	Com	0-30	35.00j	34.00k	34.50	1.45e	1.43f	1.44	43.14h	44.36g	43.75
		30-60	32.00m	32.00m	32.00	1.49e	1.48e	1.49	42.91h	43.30h	43.10
	AM	0-30	40.00e	43.00b	41.50	1.32e	1.36e	1.34	49.43b	48.09c	48.76
		30-60	38.00g	39.00f	38.50	1.38g	1.40f	1.39	47.92c	47.37d	47.65
	AM1	0-30	41.00d	44.00a	42.50	1.34h	1.36g	1.35	48.85b	48.09c	48.47
		30-60	38.00g	39.00f	38.50	1.40f	1.43f	1.42	46.97d	46.04e	46.50
	AM2	0-30	40.00e	42.00c	41.00	1.32h	1.32h	1.32	50.00a	49.81a	49.90
		30-60	37.00h	38.00g	37.50	1.41f	1.41f	1.41	46.99d	46.79d	46.89
75% AW	Control	0-30	28.00p	30.00n	29.00	1.61b	1.62b	1.62	39.47d	39.33d	39.40
		30-60	26.00r	27.00q	26.50	1.66a	1.69a	1.68	38.29m	37.17n	37.73
	Com	0-30	36.00h	38.00g	37.00	1.38g	1.39g	1.39	46.09e	45.91e	46.00
		30-60	33.00l	34.00k	33.50	1.51d	1.49e	1.50	42.59h	42.91h	42.75
	AM	0-30	42.00c	43.00b	42.50	1.35g	1.37g	1.36	48.67b	47.51c	48.09
		30-60	38.00g	38.00g	38.00	1.48e	1.48g	1.48	44.15g	43.51g	43.83
	AM1	0-30	43.00b	44.00a	43.50	1.33h	1.35g	1.34	48.65b	48.47c	48.56
		30-60	37.00h	38.00g	37.50	1.47e	1.48e	1.48	43.89g	44.15g	44.02
	AM2	0-30	41.00d	43.00b	42.00	1.34h	1.34h	1.34	48.66b	48.66b	48.66
		30-60	38.00g	39.00f	38.50	1.45e	1.48e	1.47	45.28l	43.94l	44.61
90% AW	Control	0-30	30.00n	29.00o	29.50	1.64ab	1.61b	1.63	37.88m	39.47l	38.68
		30-60	28.00p	26.00r	27.00	1.70a	1.65a	1.68	36.09o	38.43m	37.26
	Com	0-30	40.00e	41.00d	40.50	1.38g	1.35g	1.37	46.09f	47.67e	46.88
		30-60	36.00i	38.00g	37.00	1.51d	1.49e	1.50	41.92i	43.13h	42.53
	AM	0-30	41.00d	42.00c	41.50	1.33h	1.37g	1.35	48.65b	47.10d	47.88
		30-60	38.00g	38.00g	38.00	1.47e	1.49e	1.48	43.68g	43.13h	43.40
	AM1	0-30	44.00a	43.00b	43.50	1.36g	1.34h	1.35	47.89c	49.05b	48.47
		30-60	39.00f	40.00e	39.50	1.44f	1.46e	1.45	45.66e	45.11f	45.39
	AM2	0-30	42.00c	41.00d	41.50	1.34h	1.32h	1.33	48.26c	48.84b	48.55
		30-60	38.00g	38.00g	38.00	1.47e	1.47e	1.47	44.53f	44.74f	44.63

Table 4: The effect of nano-particles application on soil moisture constants with soil moisture stress during both growing seasons

Treatments		Soil depth (cm)	FC %			WP %			AWC%		
			2021/22	2022/23	mean	2021/22	2022/23	mean	2021/22	2022/23	mean
60% AW	Control	0-30	15.50i	16.50h	16.00	7.00e	7.25e	7.13	8.50d	9.25d	8.88
		30-60	14.50i	15.00i	14.75	6.75f	7.00e	6.88	7.75e	8.00e	7.88
	Com	0-30	19.50e	19.00e	19.25	9.25c	9.00c	9.13	10.25c	10.00c	10.13
		30-60	18.00f	18.00f	18.00	8.50d	8.50d	8.50	9.50d	9.50d	9.50
	AM	0-30	22.00b	23.50a	22.75	10.50b	11.00a	10.75	11.50b	12.50a	12.00
		30-60	21.00c	21.50c	21.25	10.00b	10.25b	10.13	11.00b	11.25b	11.13
	AM1	0-30	22.50c	24.00a	23.25	10.75b	11.50a	11.13	11.75b	12.50a	12.13
		30-60	21.00c	21.50c	21.25	10.00b	10.25b	10.13	11.00b	11.25b	11.13
	AM2	0-30	22.00b	23.00a	22.50	10.50b	11.00a	10.75	11.50b	12.00a	11.75
		30-60	20.50d	21.00c	20.75	9.75c	10.00b	9.88	10.75c	11.00b	10.88
75% AW	Control	0-30	16.00h	17.00g	16.50	7.50e	8.00d	7.75	8.50e	9.00d	8.75
		30-60	15.00i	15.50i	15.25	7.00e	7.25e	7.13	8.00e	8.25e	8.13
	Com	0-30	20.00d	21.00c	20.50	9.50c	10.00b	9.75	10.50c	11.00b	10.75
		30-60	18.50f	19.00e	18.75	8.75d	9.00c	8.88	9.75d	10.00c	9.88
	AM	0-30	23.00a	23.50a	23.25	11.00a	11.12a	11.06	12.00a	12.38a	12.19
		30-60	21.00c	21.00c	21.00	10.00b	10.00b	10.00	11.00b	11.00b	11.00
	AM1	0-30	23.50a	24.00a	23.75	11.25a	11.50a	11.38	12.25a	12.50a	12.38
		30-60	20.50d	21.00c	20.75	9.75c	10.00b	9.88	10.75c	11.00b	10.88
	AM2	0-30	22.50b	23.50a	23.00	10.75b	11.25a	11.00	11.75b	12.25a	12.00
		30-60	21.00c	21.50c	21.25	10.00b	10.25b	10.13	11.00b	11.25b	11.13
90% AW	Control	0-30	17.00g	16.50h	16.75	8.00d	7.75e	7.88	9.00d	8.75e	8.88
		30-60	16.00h	15.00i	15.50	7.50e	7.00e	7.25	8.50e	8.00e	8.25
	Com	0-30	22.00b	22.50b	22.25	10.50b	10.75b	10.63	11.50b	11.75b	11.63
		30-60	20.00d	21.00c	20.50	9.50c	10.00b	9.75	10.50c	11.00b	10.75
	AM	0-30	22.50b	23.00a	22.75	10.65b	11.00a	10.83	11.85b	12.00a	11.93
		30-60	21.00c	21.00c	21.00	10.00b	10.00b	10.00	11.00b	11.00b	11.00
	AM1	0-30	24.00a	23.50a	23.75	11.40a	11.20a	11.30	12.60a	12.30a	12.45
		30-60	21.50c	22.00b	21.75	10.25b	10.50b	10.38	11.25b	11.50b	11.38
	AM2	0-30	23.00a	22.50b	22.75	11.00a	10.70b	10.85	12.00a	11.80b	11.90
		30-60	21.00c	21.00c	21.00	10.00b	10.00b	10.00	11.00b	11.00b	11.00

Table 5: The effect of nano-particles application on wheat-water behavior with soil moisture stress during both growing seasons

Treatments		IWA (m³/ fed)		ETa (m3/ fed)		Grain yield (ton/fed)		IWP (kg/ m³)		CWP (kg/m³)	
		2021/22	2022/23	2021/22	2022/23	2021/22	2022/23	2021/22	2022/23	2021/22	2022/23
60% AW	Control	3025.71	3018.44	2118.00	2128.00	1.95 e	1.87 e	0.64 d	0.62 d	0.92 d	0.88 d
	Com	2947.14	2936.17	2063.00	2070.00	2.32 d	2.55 d	0.79 c	0.87 c	1.12 c	1.23 c
	AM	2881.43	2866.67	2017.00	2021.00	3.75 a	3.82 a	1.30 a	1.33 a	1.86 a	1.89 a
	AM1	2841.43	2838.30	1989.00	2001.00	3.97 a	4.00a	1.40 a	1.41 a	2.00a	2.00a
	AM2	2892.86	2912.06	2025.00	2053.00	3.42 b	3.53 b	1.18 b	1.21 b	1.69 b	1.72 b
75% AW	Control	2795.77	2797.22	1985.00	2014.00	1.82 e	1.75 e	0.65 d	0.63 d	0.92 d	0.88 d
	Com	2721.13	2813.89	1932.00	2026.00	2.25 d	2.37 d	0.83 c	0.84 c	1.16 c	1.17 c
	AM	2670.42	2686.11	1896.00	1934.00	3.55 b	3.67 a	1.33 a	1.37 a	1.87 a	1.9 a
	AM1	2660.56	2648.61	1889.00	1907.00	3.80 a	3.65 a	1.43 a	1.38 a	2.01 a	1.91 a
	AM2	2683.10	2691.67	1905.00	1938.00	3.22 b	3.25 b	1.20 b	1.21 b	1.69 b	1.68 b
90% AW	Control	2600.98	2605.39	1861.00	1885.00	1.55 f	1.48 f	0.60 d	0.57 d	0.83 d	0.79 d
	Com	2563.24	2599.86	1834.00	1881.00	2.18 d	3.22 b	0.85 c	1.24 b	1.19 c	1.71b
	AM	2525.51	2583.28	1807.00	1869.00	3.19 bc	3.25 b	1.26 a	1.26 ab	1.77 a	1.74 ab
	AM1	2508.74	2551.49	1795.00	1846.00	3.55 b	3.35 b	1.42 a	1.31 a	1.98 a	1.81 a
	AM2	2517.12	2576.36	1801.00	1864.00	3.10 c	3.12 c	1.23 ab	1.21 b	1.72 ab	1.67 b

4. Conclusions

Nano-fertilizers are essential sources of fertilizers, which can improve the crop production, compared to traditional chemical fertilizers. Hence, the use of nano-materials constitutes an effective and environmentally friendly method to enhance plant tolerance to abiotic stress. It was noticed that adding nano-zeolite converted from rock phosphate (AM1) superior the other nano-particles soil conditioners even the compost type. This nano-particle (AM1) realized the highest values of porosity, field capacity, available water, infiltration rate, hydraulic conductivity, irrigation water productivity, grain yield and crop water productivity. However, future studies are still required to resolve the health risks and safety issues associated with the nano-technology.

References

[1] S. Fahad, A.A. Bajwa, U. Nazir, S.A. Anjum, A. Farooq, A. Zohaib, S. Sadia, W. Nasim, S. Adkins, S. Saud. (2017). Crop production under drought and heat stress: plant responses and management options. Frontiers in Plant Science. 8: 1147.

[2] E.-D. Schulze, E. Beck, N. Buchmann, S. Clemens, K. Müller-Hohenstein, M. Scherer-Lorenzen, Water deficiency (drought). (2018). In Plant ecology. Springer. 165-202.

[3] A. Jaberzadeh, P. Moaveni, H.R.T. MOGHADAM, H. Zahedi. (2013). Influence of bulk and nanoparticles titanium foliar application on some agronomic traits, seed gluten and starch contents of wheat subjected to water deficit stress. Notulae botanicae horti agrobotanici cluj-napoca. 41(1): 201-207.

[4] A.M. Ali, S.M. Ibrahim, A.M. Omer. (2023). Foliar spraying of nano-silicate and nano-zinc on wheat (Triticum aestivum L.) under salt stress conditions enhances productivity and reduces the optimal nitrogen fertilizer rate. Communications in soil science and plant analysis. 54(19): 2731-2744.

[5] F. Yasmeen, N.I. Raja, A. Razzaq, S. Komatsu. (2016). Gel-free/label-free proteomic analysis of wheat shoot in stress tolerant varieties under iron nanoparticles exposure. Biochimica et Biophysica Acta (BBA)-Proteins and Proteomics. 1864(11): 1586-1598.

[6] K.-Y. Yang, S. Doxey, J.E. McLean, D. Britt, A. Watson, D. Al Qassy, A. Jacobson, A.J. Anderson. (2018). Remodeling of root morphology by CuO and ZnO nanoparticles: effects on drought tolerance

for plants colonized by a beneficial pseudomonad. Botany. 96(3): 175-186.

[7] S. Farouk, I. El-Metwally. (2019). Synergistic responses of drip-irrigated wheat crop to chitosan and/or silicon under different irrigation regimes. Agricultural water management. 226: 105807.

[8] M. Cooper, C.D. Messina. (2023). Breeding crops for drought-affected environments and improved climate resilience. The Plant Cell. 35(1): 162-186.

[9] A. Hassan, A. Mahmoud. (2015). Hydrothermal synthesis of nano crystals (AM) zeolite using variable temperature programs. Journal of Nanomaterials & Molecular Nanotechnology. 4(4): 7-8.

[10] A. Hassan, A.W.M. Mahmoud. (2016). Strategy for boosting rock phosphate efficiency and conversion into nano zeolite. American Journal of Nanomaterials. 4: 27-38.

[11] A. Hassan, A.W.M. Mahmoud, G. Turky. (2017). Rice husk derived nano zeolite (AM 2) as fertilizer, hydrophilic and novel organophillic material. American Journal of Nanomaterials. 5(1): 11-23.

[12] M. Shawky. (1967). Micro and macro pore-space distribution in profiles of typical Egyptian soils and factors affecting them. M. SC. Thesis, Fac. of Agric., Cairo Univ., ARE.

[13] O.W. Israelsen, V. Hansen. (1962). (1994). rrigation principles and practices. New York.

[14] D. Campbell, Determination and use of soil bulk density in relation to soil compaction. In Developments in agricultural engineering. Elsevier. 11: 113-139.

[15] N. Brady, R. Weil. (1996). Organisms and ecology of the soil. The nature and properties of soil. 11: 328-360.

[16] G.W. Gee, J. Bauder, A. Klute. (1986). Methods of soil analysis, part 1, physical and mineralogical methods. Soil Science Society of America, American Society of Agronomy. 5.

[17] W.F.J. van Beers. (1958). The auger-hole method: A field measurement of the hydraulic conductivity of soil below the water table. Rev. ed. ILRI Bull., Wageningen, The Netherlands. No1.

[18] Y.-D. Du, H.-X. Cao, S.-Q. Liu, X.-B. Gu, Y.-X. Cao. (2017). Response of yield, quality, water and nitrogen use efficiency of tomato to different levels of water and nitrogen under drip irrigation in Northwestern China. J. Integr. Agric. 16(5): 1153-1161.

[19] A. Page, R. Miller, D. Keeny. (1982). Part II: Chemical and Microbiological Methods. Methods of Soil Analysis, 2nd ed.; American Society of Agronomy: Madison, WI, USA. 225-246.

[20] R.G.D. Steel, J.H. Torrie. (1960). Principles and procedures of statistics. A biometrical approach, 3rd edn.; McGraw Hill Book Company Inc: New York, USA.

[21] H. El-Abdeen, K. Farroh. (2019). Preparation and characterization of nano organic soil conditioners and it's effected on sandy soil properties and wheat productivity. Nat. Sci. 17: 115-128.

[22] W. Bai, H. Zhang, B. Liu, Y. Wu, J. Song. (2010). Effects of super-absorbent polymers on the physical and chemical properties of soil following different wetting and drying cycles. Soil use and management. 26(3): 253-260.

[23] S. Soil. (2015). Characterization and Impact of Newly Synthesized Superabsorbent Hydrogel Nanocomposite on Water Retention Characteristics of. International Journal of Soil Science. 10(4): 153-165.

[24] H. Bayat, Z. Kolahchi, S. Valaey, M. Rastgou, S. Mahdavi. (2018). Novel impacts of nanoparticles on soil properties: tensile strength of aggregates and compression characteristics of soil. Archives of Agronomy and Soil Science. 64(6): 776-789.

[25] A.Y. Ghidan, T.M. Al-Antary, A.M. Awwad, O.Y. Ghidan, S.-E.A. Araj, M.A. Ateyyat. (2018). Comparison of different green synthesized nanomaterials on green peach aphid as aphicidal potential. Fresenius Environmental Bulletin. 27(10): 7009-7016.

[26] H. Bayat, Z. Kolahchi, S. Valaey, M. Rastgou, S. Mahdavi. (2019). Iron and magnesium nano-oxide effects on some physical and mechanical properties of a loamy Hypocalcic Cambisol. Geoderma. 335: 57-68.

[27] C. Reginatto, I. Cecchin, R.L. Carvalho, K. Heineck, A. Thomé, K.R. Reddy, Influence of Iron nanoparticle concentration on the hydraulic conductivity of a residual clayey soil and Modeling of the Filtration Parameter. Environmental Science and Pollution Research. 27: 9288-9296.

[28] J. Schaller, S. Frei, L. Rohn, B.S. Gilfedder. (2020). Amorphous silica controls water storage capacity and phosphorus mobility in soils. Frontiers in Environmental Science. 8: 94.

[29] A.H. AlSaeedi. (2022). Enhancement of soil water characteristics curve (SWCC) and water use efficiency of cucumber (Cucumis sativus L.) in sandy soils by using silica nanoparticles. Journal of King Saud University-Science. 34(4): 101926.

[30] J. Suazo-Hernández, N. Arancibia-Miranda, R. Mlih, L. Cáceres-Jensen, N. Bolan, M.d.l.L. Mora. (2023). Impact on some soil physical and chemical properties caused by metal and metallic oxide engineered nanoparticles: A review. Nanomaterials. 13(3): 572.