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Effect of nanomaterials on Soil Quality and Yield of Canola (*Brassica napus* L.) Grown in Heavy Clayey Soils

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NANOTECHNOLOGY in agriculture is an exciting strategy to enhance soil fertility and increase crop yields in heavy clay soils. Thus, the purpose of this research was to evaluate the effect of nanomaterials such as nano-biochar (nB) and nano-water treatment residues (nWTR) at 50, 100, 250 mg kg^{-1} rates in pots, on improving soil biological activity, soil aggregate stability, soil consistency and yield of canola (*Brassica napus*) cultivated in a heavy clay soil. The treatments used were conducted in a completely randomized experimental design with 5 replicates. The results indicated that the addition of the studied nanomaterials significantly improved soil consistency including organic matter (OM), cation exchange capacity (CEC) microbial biomass carbon (MBC), and soil fertility which played a major role in increasing biological activity and aggregate stability, thus increasing canola yield. The study observed an increase in aggregate stability in soil treated with nB and nWTR synchronized with their greater content of OM, CEC, nutrients and clay. The addition of nB_{100} gave the highest grain yield by 160 % compared to the control. The results of the pot experiment indicated that nWTR and nB could be used as a promising strategy to enhance the yield of canola and increase recycled efficiency WTR and rice straw on soil structure, biological activity and soil fertility in heavy clay soils.

Keywords: Aggregate stability; Nano-biochar; biological activity; Canola yield.

Introduction

In Egypt, there are heavy clay soils in the north of the Nile Valley that are densely populated as a result of the fertility of its soil and its high water-holding capacity (WHC), but due to the high level of groundwater, its high salinity and compaction, it reduced productivity (Antar et al., 2008). The DRI (2001) estimated that there are one million hectares in the Nile Delta Egypt. Heavy clay soils are characterized by extreme plasticity and glossy surfaces with a clay content of more than 50 % of the clay in the topsoil and the *vertic* horizon in the subsurface horizon (FAO, 2006). El-Sanat et al. (2017) found that adding gypsum improved soil structure and fertility. The application of nanotechnology in the agricultural sector is a promising strategy to increase agricultural production and solve environmental problems in heavy clay soils (Liu and Lal, 2012). Ghazi et al. (2022) concluded that adding manure, gypsum, sugar lime mud) in nano form has a beneficial effect in improving sandy soil fertility, performance and productivity of wheat plants.

Nanobiochar is a biochar with particle size <100 nm with better chemical, physical and surface properties. Also, it is characterized by higher surface areas, porosity, mineral adsorption, and the amount of surface functional groups than bulk biochar (Pratap et al., 2022). It has many advantages such as mitigating climate change, enhancing plant growth, soil health and fertility, managing plant diseases, bioremediation of pollutants and pesticides, and wastewater treatment (Chausali et al., 2021). Nanobiochar has

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been used as a material to conserve native plants and environments by decreasing the stress of invasive plants. In addition, nB showed promise in increasing rice yield, enhancing root length and chlorophyll concentrations (Shen et al., 2020). The addition of nano-biochar reduced nutrient loss under various vegetation cover resulting from rainfall-induced erosion on the plateau (Zhou et al., 2018). The application of nano-biochar significantly improved the yield of soybeans, by 10% to 20%, and reduced the amount of fertilizer by 30% to 50% (Wang et al., 2016). Some studies on the use of nB for strong adsorption of different pollutants (Mahmoud et al., 2020b; El-Ramady et al., 2022; Rajput et al., 2022; Pratap et al., 2022). However, there have been few studies to date on the role of nB in aggregate stability, biological activity and canola production in heavy clay soils. Hafeez et al. (2022) found that adding modified biochar to soil increased CEC, OM, soil porosity, hydraulic conductivity, infiltration rate, soil types, and microbial enzymes. Nanomaterials and Nano- fertilizers, because of their unique properties, are now a promising approach to enhance soil, fertility, enhance plant growth, and improve soil C sequestration (El-Ramady et al., 2021). Ibrahim and Hegab (2022) found that the use of nano-fertilizers reduces the negative effects of salinity stress on the barley crop grown under saline conditions. Elkhatib et al. (2015) and Mahmoud et al. (2020a) found that nWTR absorbs and reduces the bioavailability of minerals in the soil. The drinking water treatment residues (WTR), a by-product was obtained from drinking water plants and has been added as soil amendments due to its high content of OM and clay (Mahdy et al., 2009; Mahmoud and Ibrahim, 2012). Addition of nWTR resulted in immobilization of P and reduced release of P in salt-affected soils. WTR can be safely used as a low-cost and efficient sorbent in removing phosphorous from waterways, representing a significant reduction in the environmental impact of eutrophication (Mahmoud et al., 2020a). Therefore, the present study aims to evaluate the effect of nB and nWTR at different rates in pots, on improving soil biological activity, soil aggregate stability, soil consistency and yield of canola (*Brassica napus*) grown in a heavy clay soil (clay content =59.18%)

Material and methods

Soil samples

Soil samples were collected from 0-20 cm depth in Gemmayzeh area (30°43°N latitude, 31°47°E) Gharbia Governorate, Egypt. The soil used in the experiment is classified as *Vertic Torrifluvents* (Order Entisols) which originate from river deposits. The soil moisture regime of the studied area could be defined as *torric*, and the soil temperature regime as *thermic*.

Synthesis of Nano-B (nB)

Rice straw was prepared as biochar in a furnace at a temperature of about 400 °C with limited oxygen for two hour as residence time. A mill (DING CANG DC-500A) was utilized to prepare nanobiochar (nB) from rice straw (diameter >0.5 mm).

Table 1. Properties of soil, nB and nWTR.

Characteristics	units	soil	nB	nWTR
Sand	%	12.56	-	-
Silt	%	28.26	-	-
Clay	%	59.18	-	68.6
Soil texture		clay	-	-
pH		7.84	8.24	7.49
EC	dSm^{-1}	3.78	2.45	1.12
Ca^{++}	$meqL^{-1}$	7.9	55.11	5.56
Mg^{++}	$meqL^{-1}$	4.5	24.30	5.50
K^{+}	$meqL^{-1}$	0.57	-	-
Na^{+}	$meqL^{-1}$	25.7	-	-
Cl^{-}	$meqL^{-1}$	18	-	-
HCO_3^{--}	$meqL^{-1}$	2.5	-	-
SO_4^{--}	$meqL^{-1}$	18.3	-	-
SAR		10.29	-	-
OM	%	1.51	49.8	4.82
CEC	cmol(+) kg^{-1}		31.3	38.85
Total N	%	-	1.42	0.98
Total P	%	-	0.96	0.06
Total K	%	-	1.42	0.65
Total Al	%	-	-	0.25
Available P	mg kg^{-1}	-	856.2	14.46

Synthesis of Nano-WTR (nWTR)

WTR mass is collected from Al-Murasha drinking water plant in Tanta, Gharbia Governorate, Egypt. nWTR was obtained by crushed WTR (diameter > 0.5 mm) into powder utilizing a grinder (DING CANG DC-500A). WTR and B were crushed to nano size at the Nano Institute for Science and Technology, Kafr El-Sheikh University.

Transmission electron microscope (TEM) image for nB and nWTR to know that it is nano-sized Fig (1), and it was measured with an Electron Microscope Unit, Mansoura University. Some characterises of the studied soil, nB and nWTR are presented in Table (1).

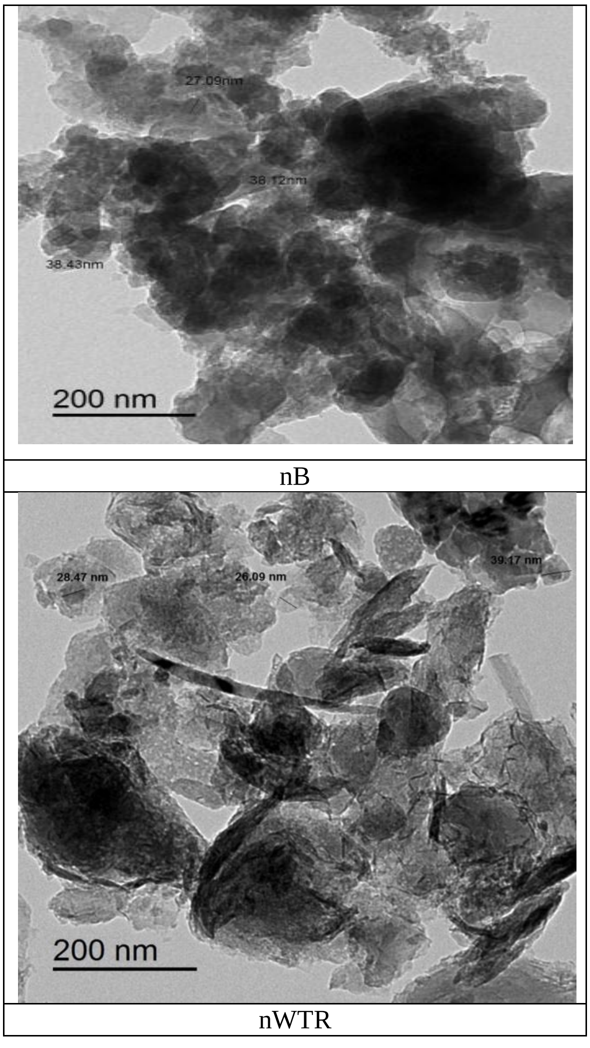

Fig. 1. Transmission electron microscope (TEM) image for nB and nWTR.

Experimental set up

Pot experiment was performed during the winter (12 August to 5 October) at the Egyptian Agricultural Research Center's Sakha Agricultural Research Station, Kafr El-Sheikh Governorate. Greenhouse experiment, canola seeds (*Brassica napus*) was cultivated in the pots (30 cm diameter (D) and 25 cm height (H)), each pot filling ten kg of soil. Soil samples were air-dried, ground and sieved utilizing a 4 mm sieve to reflect normal soil conditions.To investigate the responses of canola yield on soil biological activity, soil aggregate stability, and soil consistency by nB and nWTR amendments, a pot experiment in a heavy soil was performed. About 8 treatments were conducted in a completely randomized experimental design with 5 replicates as follows: Control (C) soil without nWTR and nB. Rice straw biochar level of 4.2 g kg^{-1} (B), Nanobiochar level of 50 mg kg^{-1} (nB_{50}), Nanobiochar level of 100 mg kg^{-1} (nB_{100}), Nanobiochar level of 250 mg kg^{-1} (nB_{250}), WTR level of 4.2 g kg^{-1} (WTR), NanoWTR level of 50 mg kg^{-1} ($nWTR_{50}$), NanoWTR level of 100 mg kg^{-1} ($nWTR_{100}$), and NanoWTR level of 250 mg kg^{-1} ($nWTR_{250}$). The nB and nWTR amendments were mixed after a period of irrigation about 2 h. After a period of irrigation, the nB and nWTR amendments were mixed and 8 seeds of canola plants were sown. After 3 weeks, the plants were thinned to 3 plants per pot. Equal amounts of irrigation were added according to the plant's need for irrigation without the use of chemical fertilizers. The temperature ranged from 17 and 20 °C. Harvest was achieved 153 days after planting, and measurements of canola yield, such as dry weight, root weight, and seed weight, were registered.

Soil, nB and nWTR analysis

The electrical conductivity (EC) and pH of 1:10 (weight/volume) of soil, nanobiochar and nano-water treatment residues were measured using a conductance meter and pH meter, respectively. The Walkley and Black method was used to measure organic matter (OM) in nWTR, nB and soil, as explained by Nelson and Sommers (1982). CEC was measured by utilizing $NH_4CH_3CO_2$ solution at pH 7.0 according to Graber et al. (2017)

Aggregate stability

The wet sieving method was used to measure the aggregate stability in n accordance with Savinov (1936). Weigh approximately 50g of air-dried soil through an 8 mm sieve, on a series of 2.00, 1.00, 0.5 and 0.25 mm sieve and then agitated under water for 5 minutes. After completion of the sieving process, the remaining fractions were weighed in each sieve after drying in the oven at 105°C for 24 hour. The stability of the aggregate was determined as a percentage of the residual on each sieve of the complete sifting sample. The equation for mean weight diameter (MWD) was estimated using the equation:

Where: Xi is the average diameter of each size fraction (mm), Wi is the amount of the whole weight of the sample in the corresponding size fraction, and n is the sample numbers.

Structure coefficient (SC) used as indictor of soil structure was evaluated by Shein et al. (2[24] and coefficient is calculated as:

SC = A ÷ B

Where A is the percentage of aggregation of particles > 0.25 mm (TWSA) and B is the percentage of aggregation of particles < 0. 25 mm (100 - TWSA). Aggregates index (AI) = MWD/2. Soil bulk density (BD) was measured by using a steel cylinder of 100 cm^3 on the undisturbed soil samples as explained by Grossman and Reinsch (2002).

Biological activity

DHA was measured according to Thalmann (1968). The samples about a 2 g with 2,3,5-triphenyltetrazolium chloride (TTC) was incubated for 24-hour at 37°C. Then, forming triphenylformazan (TPF) extracted from the soil by acetone. Colour formazan was determined at 485 nm by means of a spectrophotometer. DHA enzyme was estimated by a standard curve for TPF, as follows:

DHA enzyme µg TPF/g dry =OD /K ÷D .Wt.

Where: OD = Optical density

K= factor from standard curve.

Catalase activity

The catalase activity (CLA) was determined through titration of residual hydrogen peroxide (H_2O_2) with $KMnO_2$ (Johnson and Temple, 1964). 40 ml distilled water was added with 5 ml of 0.3% H_2O_2 solution to 2 g of soil samples. 5 ml H_2SO_4 is added to the mixture and vibrated for half hour. Afterthat, the mixture was calibrated by $KMnO_4$. The enzyme of CLA was estimated from the reacted quantity of 0.02 mol L^{-1} $KMnO_4$ per g soil (Minczewski and Marczenko, 1973).

Microbial biomass carbon

MBC was estimated by fumigating 25 g of sample with ethanol-free chloroform for 24 hour at 25°C (Wu et al. 1990). Soil organic carbon was extracted with K_2SO_4, then the extract was digested with H_2SO_4 and $K_2Cr_2O_7$ for half an hour at 170 °C and calibrated with $FeH_8N_2O_8S_2$ and ferroin was used as an indicator.

MBC was calculated from:

MBC = EC fumigated soil – EC un-fumigated soil/ Kc

Where:

EC = Extractable carbon

Kc = 0.379 (Kc is the K_2SO_4 extract efficiency factor

$$MWD = \sum_{i}^{n} XiWi$$ (Haynes, 1999)

2.8 Statistical analysis

All treatments have been replicated using five replicates. The obtained data were tested by a statistical method using the SAS software.

Results

Effect of soil amendments on soil biology

The application of B, WTR, nB, and nWTR amendments significantly increased MBC, dehydrogenase activity (DHA), and CLA (Table 2). The MBC, DHA, and CLA increased from 53.4 mg kg^{-1}, 0.24 mg TPF g^{-1} dry soil and 0.03 mL $KMnO_4$ g^{-1} in control to 221.7 mg kg^{-1} in WTR, 0.64 mg TPF g^{-1} dry soil in the WTR, and 0.3 mL $KMnO_4$ g^{-1} in the $nWTR_{250}$, respectively. MBC and CLA were significantly higher in nWTR than in nB when soils were treated at the same rate. The MBC, DHA, and CLA values increased as the addition rates of the soil amendments examined increased. MBC, DHA, and CLA values were non-significant between $nWTR_{50}$ and nB_{250}.

Table 2. Effect of soil amendments on soil biology.

Treatments	MBC mg kg^{-1}	DHA mg TPF/g dry soil	CLA mL $KMnO_4$ g^{-1})
C	53.4 d	0.24 f	0.03 d
B	111.1 c	0.45 cd	0.10 cd
nB50	55.6 d	0.35 e	0.15 bc
nB100	112.1 c	0.52 b	0.05 d
nB250	166.7 b	0.48 c	0.09 cd
WTR	221.7 a	0.64 a	0.20 b
nWTR 50	165.5 b	0.48 c	0.10 cd
nWTR 100	166.7 b	0.44 d	0.10 cd
nWTR 250	217.2 a	0.32 e	0.30 a
F-test	**	**	**
$LSD_{(0.05)}$	10.507	3.183	8.266
$LSD_{(0.01)}$	14.396	0.043	0.113

Effect of nanomaterials on soil chemical characteries

As presented in Table (3), EC values were significantly reduced in the amended pots with the application of nB and nWTR amendments. EC values reduced from 3.35 dSm^{-1} in the control to 2.27 dSm^{-1}.

Table 3. Impact of nB and nWTR amendments on some soil chemical properties.

Treatments	EC dSm^{-1}	pH	SAR	Anions			Cations			
				Cl^-	HCO_3^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	K^+
				meq L^{-1}						
C	3.35a	7.86	9.69a	15.9a	4.0a	14.5a	7.0a	4.0a	22.8a	0.62a
B	2.87b	7.74	8.81b	13.7ab	2.5bc	13.2ab	6.0b	3.4b	19.5b	0.41b
nB50	2.27e	7.7	7.98d	10.8c	2.5bc	10.0e	4.8f	2.7d	15.4e	0.37b
nB100	2.37de	7.6	8.15cd	11.3bc	3.0abc	10.2de	5.0ef	2.8d	16.1cde	0.45b
nB250	2.69bc	7.77	8.68b	12.8bc	3.5ab	10.5de	5.6c	3.2bc	18.3bc	0.57a
WTR	2.63bcd	7.73	8.59b	12.5bc	2.0c	12.4bc	5.5cd	3.2bc	17.9bcd	0.42b
nWTR 50	2.34de	7.72	8.10d	11.1bc	2.0c	10.9de	4.9ef	2.8d	15.9de	0.41b
nWTR 100	2.49cde	7.70	8.35c	11.9bc	3.0abc	10.8de	5.2de	3.0cd	16.9cde	0.45b
nWTR 250	2.64bcd	7.71	8.60b	12.6bc	3.0abc	11.6cd	5.5cd	3.2bc	18.0bcd	0.45b
F-test	**		**	*	*	**	**	**	**	**
$LSD_{(0.05)}$	0.307		0.225	2.809	1.305	1.478	0.323	0.324	2.260	0.102
$LSD_{(0.01)}$	0.420		0.309	3.849	1.788	2.025	0.443	0.442	3.097	0.141

Table 4. Impact of soil amendments on soil fertility.

Treatments	OM %	Available nutrients		
		N	P	K
		mg kg^{-1}		
C	1.46c	49.83g	39.7i	327.6g
B	1.93a	51f	48.5a	374.4f
nB_{50}	1.64b	52.56e	45.7c	405.6d
nB_{100}	1.61b	54.25d	43.9f	389.6e
nB_{250}	1.59b	59.41a	41.5h	452.4a
WTR	1.94a	57.41b	41.6g	436.8b
$nWTR_{50}$	1.86a	50.46fg	45.7d	421.2c
$nWTR_{100}$	1.56bc	54.33d	47.9b	374.4f
$nWTR_{250}$	1.63b	56.40c	44.7e	400.4de
F-test	**	**	**	**
$LSD_{(0.05)}$	0.128	0.867	0.165	13.881
$LSD_{(0.01)}$	0.175	1.188	0.226	18.923

in the nB_{50}. EC values decreased with decreasing rates of nB and nWTR application. EC decreased by 14.32 % and 21.99 % with the application of B and WTR to the soil, respectively, relative to the C treatment. The variation in EC values between nB_{50}, nB_{100}, $nWTR_{50}$ and nWTR $_{100}$ is statistically insignificant. pH values are lower when nB and nWTR are added at 100 mg kg^{-1} soil relative to 50 and 250 mg kg^{-1} soil. The addition of nB $_{100}$ resulted in the in the largest increase in the pH relative to other treatments. The difference in pH values between the studied soil amendments is not statistically significant. Cations and anion concentrations decreased significantly ($p < 0.05$) with the addition of the nB and nWTR amendments at different levels. The concentrations of Cl^-, HCO_3^-, SO_4^{--} and Na^+ decreased from 15.9, 4.0, 14.5 and 22.8 meq L^{-1} in the control to 10.8 in the nB_{50}, 2.0 in the nWTR $_{50}$, 10.0 in the nB_{50}, and 15.4 meq L^{-1} in the nB_{50}, respectively. The difference in anions value between the studied soil amendments is not statistically significant. SAR in soil ranged from 9.69 in the control to 7.98 in the nB_{50} and a significant difference observed between the treatments and control (Table 3). In our study, the SAR was not significant between nB_{50}, nB_{100} and nWTR $_{50}$.

Impact of nWTR and nB amendments on soil fertility

Soil organic matter (SOM) in the studied soil ranged from 1.46% in the control treatment to 1.94% in B treatment. Addition of amendments at different rates showed a significant increase (Table 4). SOM with addition of nB_{50}, nB_{100} and nB_{250} increased by 8.91%, 10.27% and 12.32%, respectively, relative to the control. In our study, SOM was not significant between nB and nWTR except for $nWTR_{250}$. The concentrations of nitrogen (N), phosphorous (P), and potassium (K) and K were significantly increased in the pots amended with the application of the studied nanomaterials, except for the concentration of N at $nWTR_{50}$. The nitrogen concentration increased with increasing rates of application of nB and nWTR and no effect of increasing their rates was observed in the concentration of P and K.

Table 5. Impact of nanomaterials on soil aggregate stability.

Treatments	Distribution of water stable aggregates %				TWSA	OWSA	MWD	AI	SC	Bulk density
	> 2.0	2-1	1-0.5	0.5-0.25						
	mm				%					gcm^{-3}
C	0.58	3.01	26.6	10.45	40.63g	29.61f	0.31e	0.15c	0.68g	1.45a
B	1.07	2.38	29.75	15.85	49.05f	32.13e	0.37e	0.18bc	0.96f	1.43a
nB_{50}	0.7	0.79	33.93	18.58	54e	34.72d	0.37e	0.18bc	1.17e	1.38ab
nB_{100}	0.72	3.46	37.4	14.58	56.15d	40.86c	0.41de	0.21bc	1.28e	1.4a
nB_{250}	7.93	4.22	35.52	12.99	60.66c	39.74c	0.77ab	0.38a	1.54bc	1.29bc
WTR	2.57	9.75	35.43	9.74	57.49d	45.18ab	0.57cd	0.28abc	1.35de	1.25c
$nWTR_{50}$	4.24	5.61	38.32	11.69	59.866c	43.93b	0.62bc	0.31ab	1.48cd	1.35abc
$nWTR_{100}$	6.98	13.08	33.74	9.83	63.63b	46.68a	0.83a	0.42a	1.7b	1.25c
$nWTR_{250}$	8.28	1.64	37.49	19.1	66.51a	39.13c	0.79ab	0.39ab	1.98a	1.29bc
F-test					**	**	**	*	**	**
$LSD_{(0.05)}$					1.8981	2.2895	0.1811	0.1521	0.1899	2.607
$LSD_{(0.01)}$					2.6006	3.1369	0.2481	0.2084	0.2603	3.579

SC: structure coefficient; AI: aggregates index; MWD: Mean weight diameter; OWSA: Optimum size aggregates; TWSA: Total water stable aggregates.

Effect of soil amendments on soil aggregate stability

As can be seen from the Table (5) showed that the distribution of WSA fraction increased with the application of nanomaterials various levels. The highest values were observed in WSA fraction in the size between 0.5-0.25 mm and 1-0.5 mm with the addition of $nWTR_{250}$ and $nWTR_{50}$ which increased by 82.78 % and 44.10 % compared to the control treatment, respectively. Results regarding total water stable aggregates (TWSA) are presented in Table (5). It was showed that the impact of nB and nWTR amendments at different levels on TWSA was significant. The highest values were observed in TWSA with the application of nWTR at a level of 250 mg kg^{-1} soil, which increased their value by 63.7 % compared to the C treatment, respectively. TWSA increased with increasing rates of nB and nWTR addition.

The nWTR application gave a better effect than nB on the total TWSA. Mean weight diameter (MWD) values improvedsignificantly ($p < 0.05$) with the addition of nB and nWTR amendments at different rates, except for B, nB_{50} and nB $_{100}$ (Table 5). The highest MWD was observed in the pots amended with nWTR $_{100}$ while the lowest was observed under the C. MWD increased with increasing rates of nB and nWTR application. The results indicated that the rate of increase in the MWD between B or WTR and their nanoparticles was not significant. The difference in MWD between $nWTR_{100}$, nWTR $_{250}$ and nB_{250} is not statistically significant. Adding the studied soil amendments at different levels resulted in a significant increase in the aggregate index (AI), optimum size aggregates
(OWSA), and structure coefficient (SC) (Table 5). The AI increased by 106%, 180% and 160% for $nWTR_{50}$, $nWTR_{100}$ and $nWTR_{250}$, respectively, relative to the C treatment. Soils treated with nB_{250} and $nWTR_{100}$ showed the largest significant increase in AI and SC relative to other treatments. AI and SC increased with the increase in nB and nWTR addition rates. Soil treated with nWTR gave higher AI, OWSA and SC values than soil treated with nB. The difference in AI between the nB as well as nWTR treatments is not significant. OWSA values are higher when nB and nWTR are added at 100 mg kg^{-1} soil than at levels 50 and 250 mg kg^{-1} soil. The results demonstrated that the BD values reduced significantly at $p < 0.05$, relative to the C, when nB and nWTR were added.

Table 6. Effect of soil amendments on canola yield.

Treatments	Plant height cm	1000-seeds weight g	Pod number per plant	Seeds weight g per plant
C	92f	3.52b	93g	12.23g
B	117b	3.95ab	107d	25.49cd
nB_{50}	107d	4.02ab	102e	24.01de
nB_{100}	110c	4.16a	115b	31.79a
nB_{250}	112c	4.06ab	106d	25.22cde
WTR	120a	4.14a	112c	27.02bc
$nWTR_{50}$	106d	4.05ab	105d	23.28e
$nWTR_{100}$	122a	4.12a	118a	28.64b
$nWTR_{250}$	95e	3.98ab	96f	16.15f
F-test	**		**	**
$LSD_{(0.05)}$	2.801	0.592	2.915	1.980
$LSD_{(0.01)}$	3.837	0.811	3.994	2.713

Effect of soil amendments on canola yield

The impact of nano-B on canola yield is shown in Table (6). In this study, nB generally increased plant height (10.3 to 21.732.26%), weight of 1000 seeds (14.2 to 118.18%), pod number per plant (9.6 to 23.6 %), seeds weight per plant (96.2 to 158.8 %), and dry weight (28.48 to 37.55%). While nWTR increased plant height (3.26 to 21.74 %), weight of 1000 seeds (13.07 to 17.04 %), pod number per plant (3.23 to 26.88 %), seeds weight per plant (32.05 to 134.18 %), and dry weight (17.72 to 26.62 %). Canola yield was higher when nB and nWTR are added at 100 mg kg^{-1} soil than at levels 50 and 250 mg kg^{-1} soil. Soil treated with nB gave higher yield values of canola compared to soil treated with nWTR. Seed weight of the canola plant enchanced from 12.23 to 25.49 for B and to 27.02 g per plant for WTR, respectively.

Discussion

Impact of nanomaterials on soil biology

Soil DHA is a perfect indicator of soil quality and soil biology and is generally positively linked with soil nutrients, OM and clay content (Pinna et al., 2012; Mahmoud et al., 2021). In this study, the high soil MBC, CLA and DHA observed in WTR-amended soil coincided with the CEC, nutrients and clay content. The residues of WTR utilized in this experiment included clay, OM, nutrients, and CEC, which may been involved in higher MBC, CLA and DHA activities (Table 1). Mahmoud et al. (2021) found that adding WTR to soil significantly improved both DHA and MBC. And also, Quilchano and Marañón, (2002) found that soil DHA is positively related with soil pH, calcium, magnesium, potassium, and clay content. Beyer et al. (1992) showed a positive relation between clay content and soil DHA. Ladd et al. (1996) found a favourable correlation between clay content and MBC. Soil DHA and MBC in nB-amended soils are attributed to the improvement of their physical and chemical properties. Leirós et al. (2000) showed a positive relation between soil DHA and OM. Brendecke et al. (1993) showed that the number of soil microbes or organisms increased with the addition of organic materials such as biochar that increases enzymatic activity and microbial biomass in it, indicating soil fertility and sustainable productivity.

Impact of nanomaterials on soil physicals properties

It is known that OM is low in BD and thus can decrease BD and compaction level because compaction as an indicator of the process, which increased the aggregate stability of soil, thus improving porosity and reducing BD of soil (Mahmoud et al., 2017). The observed reduce in soil BD with the application nB and nWTR is attributed to their high content of OM. These results are consistent with those of Busscher et al. (2010) and Lusiba et al. (2016) who showed that BD reduced under the influence of biochar addition. The reduction in the BD values corresponds to the increase in the organic matter in all treatments (Table 5). In this study, SOM increased significantly by 12.32% with addition of nanobiochar ($nB_{250} \approx 595.23$ kg ha^{-1}).

Soil aggregate stability is important for a good and sustainable soil structure. Good stability allows motion of H_2O and air in and out of the soil, and facilitates penetration of roots, thus encouraging downward movement of H_2O and the exit of salts from the root zone as a main step for soil improvement. Adding organic matter increases soil soil aggregates, thus improving soil salt leaching. It also leads to improving the physical properties and supplying them with nutrients under the saline condition (Emam et al., 2020). In our study, the application of the nB amendment led to improve in the aggregate stability of the soil due to OM (Table1). Similar results by Liu et al. (2015) showed that the application of nB in sandy clay soils enhanced the formation and stability of large aggregates in this soil. Nano-biochar binds to minerals and organic substances in the soil that help in the formation of microaggregates through organo-mineral interactions (Archanjo et al., 2017; Weng et al., 2017).

Nanobiochar gave better results in the aggregate stability compared to bulk biochar due to the speed and ease of movement in the root zone, contact with the roots, entry between the pores, bonding with clay minerals and the formation of microaggregates. The results signalized that increasing the rate of addition of nB and nWTR resulted in increased MWD values. Mahmoud et al. (2017) found that MWD increased linearly with biochar addition. MWD and AI are indicators of improved physical properties, which may be beneficial in chemical reactions and microorganisms required for plant growth. The addition of the nWTR amendment led to an enhance in the aggregate stability of the soil due to the increase in its content of clay and OM (Table 1), which are binding agents between mineral particles (Ibrahimet al., 2015). Impact of nanomaterials on soil microbial and biomass enzyme activity.

Impact of nanomaterials on soil fertility and yield attributes of canola plant

Soil fertility is important to soil sustainability because it reflects the maximization of the productive capacity of the soil to maintain the growth of plants (Wasli et al., 2011). The enhanced in the soil fertility with the addition of nB synchronized with their higher content of nutrients, OM and CEC (Table 1).

The nB and nWTR used in our study included OM, CEC, nutrients and clay, which may have participated to the increase in soil fertility (Table 1). In our study, available nitrogen increased in the nB- and nWTR-treated pots due to decreased N loss as NH_3 volatilization. Thus, more nitrogen derived from the nB and nWTR was retained in the soil system, reflecting the increased nitrogen available in the soil.

Application of nWTR or nB significantly increases the canola growth in soil, which is confirmed by the increase in 1000-grain weight, number of pods per plant, and seed weight, especially when added at 50 mg kg^{-1} soil (Table 6). Nevertheless, the addition of nWTR greater than 100 mg kg^{-1} soil led to a reduce in the yield and this is due to the increase in the toxicity of aluminum (Al) and the reduction of available P. Identical results were found by Zhao et al. (2021). The variation in response to canola growth between nWTR and nB is attributed to their various characterises such as OM, pH, clay content, CEC, and nutrient contents. The increase in the grain yield using nB and nWTR is due to the improvement of the physical characterises of the soil as well as their content of OM and nutrients and their effect on the biology properties and MBC of the soil (Table 2 and Table 5), which promotes the increase of canola plant growth. Ali (2018) found that the strong favourable relation between dry weight of canola with MBC (R^2 = 0.80), CEC (R^2 = 0.72), and OM (R^2 = 0.83). Bassouny and Abbas (2019) found that organic carbon is an important factor in improving the physical properties and maize yield of clay soils. The addition of nano-BC improves soil quality, provides a suitable environment for microbes and increases soil WHC as well as soil fertility, thus soil suitability improvement for plant yield and development (Farid et al., 2014; Liu et al., 2020). Elkhatib et al. (2018) found that n WTRs application from 0 to 0.3% resulted in a significant increase in dry weight of canola grains from 24.8 to 39.2 g pot^{-1}.

Conclusions

The results showed that the MWD, TWSA, OWSA, AI, SC, OM, MBC, DHA, and CLA, availability of NPK and canola yield enhaced significantly (P>0.05) with the addition of nanomaterials at different levels. Aggregate index values are higher when nB and nWTR are added at 250 mg kg^{-1} soil relative to levels 50 and 100 mg kg^{-1} soil. Canola yield was higher when nB and nWTR are added at 100 mg kg^{-1} soil than at levels 50 and 250 mg kg^{-1} soil. The application of the studied soil amendments improved soil consistency including OM, MBC, CEC and soil fertility which played a major role in increasing biological activity and building rate, thus increasing canola yield. The high level of nWTR redues yield of canola plant and soil biology and these results may avail as an important clue in regulation the addition of nanomaterials in the fields. The results of this study suggest adding nWTR and nB as a new sustainable strategy to improve heavy clay soils.

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