Research Article

Comparative Impact of Some Organic Soil Conditioners on Chemical Properties of Soil under Wheat Cultivation

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Abstract | Fortification of soil physicochemical and biological profiles is one of the key elements of sustained agricultural productions. This pot experiment evaluated the effect of four organic soil conditioners (*i.e.*, vermicompost, citric acid, humic acid, and sulfur) applied in up to four sequential batches at different growth stages. The trial was conducted following randomised complete block design (RCBD) having type of soil conditioners and their batch-wise application number as two major factors. Results of the experiment showed that the addition of sulfur was superior in increasing soil pH (up to 7.92), and the citric acid addition caused a significant reduction in the soil electrical conductivity (EC) (up to 2.31 $dS.m^{-1}$) in the fourth batch. Vermicompost exhibited an enhancement of soil cation exchange capacity (CEC) (22.93 $cmolc.kg^{-1}$ soil). Moreover, sulfur addition after fourth batch increased significantly the amount of Ca^{2+} and K^{+} ions, while it reduced Mg^{2+} and Na^{+} ions in the soil of all experimental pots. Overall, the study results have demonstrated that the organic soil conditioners, particularly vermicompost and sulfur, have considerable potential in improving the physicochemical properties of agricultural soils.

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Introduction

A Healthy, well-conditioned soil profile is one of the prime requisites of sustainable agricultural production. Supplementation of poor and salinity-affected soils with organic conditioners help to improve the soil physicochemical properties and to compensate for the lack of essential nutrients, ultimately leading to an enhanced crop productivity (Mishra *et al*., 2023; Xiao *et al*., 2025). There are various organic soil amendments which have the potential implication in soil reclamation and improvement processes such as humic acid, citric acid, sulfur and vermicompost. These materials are usually cost-effective, biodegradable and biorational with minimum ecological consequences, and are also culturally acceptable among farmers (Bharti *et al*., 2023). Such soil amendments are usually recommended for improving the saline-sodic soil amendments (Mousa, 2017; Xiao *et al*., 2025).

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For instance, the supplementation of humic acid to the soil directly enhances the absorption of nutrients, as it acts as a medium for the nutrients' transfer from soil to the plant, especially if the plant is exposed to the water or drought stress (Ampong *et al*., 2022; Zohaib *et al*., 2024). Similarly, addition of sulfur in the soil profile catalyzes the biological oxidation of sulfur by *Thiobacillus* spp. oxidize elemental sulfur to sulfuric acid, thereby lowering pH and enhancing nutrient solubility, which ultimately enhances the bioavailability of essential nutrients to the plant roots (Belal *et al*., 2019; Ranadev *et al*., 2023). Maruf and Rasul (2019) demonstrated that the release of humic acid and sulfur into soil profiles simultaneously increases the readiness of nutrients present around plant root system or rhizosphere.

Moreover, citric acid is also considered as an important soil conditioner which can enhance the soil physicochemical properties and exert a positive impact on plant physiology, growth and performance (Ali and Ahmed, 2016; Khoshgoftarmanesh and Raisi, 2022). Gerke *et al.* (2000) showed that citric acid increases the soil's ability to process phosphorus and the liberated phosphorus increases in an exponential relationship with the expansion in the concentration of acids adsorbed from the soil. To repair the soils affected by salinity depends on adding some materials including sulfur and citric acid, which can contribute to improve certain physical and chemical properties of saline-sodic soils, as it turned out that these substances are effective in overcoming the impact of salinity on vegetative and reproductive performance of various horticultural and agricultural crops (Kassem, 2012; Mehfooz *et al*., 2023).

Similarly, vermicompost is a bio-organic fertilizer naturally prepared by the digestive action of different earthworm species (Oyege and Bhaskar, 2023). This bio-compost constitutes of many beneficial microbes, nutrients and different plant growth stimulants. When added in the soil as fertilizer, it has shown a significant improvement in seed germination, growth, yield enhancement and suppression of plant diseases (Khattiyaphutthimet *et al*., 2019; Oyege and Bhaskar, 2023; Talaat and Abdel-Salam, 2024).

Keeping in view the potential advantages of above-mentioned soil amendments, the main aim of this research work was to determine the effect of these organic soil amendments on some soil chemical properties which can ultimately enhance the crop growth and performance.

Materials and Methods

This pot experiment was performed during wheat growing season of Fall 2022/2023 in the experimental facility of the Al-Mussaib Technical College, Al-Furat Al-Awsat Technical University, Iraq, situated within the Al-Mussaib Project Area of Iraq. For studying the impact of various organic soil conditioners or amendments on certain soil physicochemical properties and on the readiness of some nutrients, soil was collected from an agricultural field located in the Al-Azzawiya region of district Al Musayyab, about 40 km North of the center of Babylon Province. This soil was then well mixed and homogenized. Then, sampled soil was sifted by an iron made sifter with mess size 2.0 mm and were air-dried in the laboratory. An aliquot of soil sample was taken for the determination of physical and chemical laboratory analyses before wheat plants cultivation. Samples of the field soil taken before and after the cultivation period for analysis. The determinations included pH, EC, CEC, Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}.

Table 1: *Some physico-chemical properties of the pot soil before wheat planting and the method of dividing Soil conditioners into four batches.*

Soil properties	Value	Unit
Soil reaction (pH)	7.9	-
Electrical conductivity (EC) $_{1:1}$	5.1	ds m^{-1}
Cation exchange capacity (CEC)	19.6	Cmolc kg^{-1}
Organic matter	7.78	G kg^{-1} soil
Calcium (Ca)	8.65	mmol L^{-1}
Magnesium (Mg)	6.9	mmol L^{-1}
Sodium (Na)	19.89	mmol L^{-1}
Potassium (K)	1.06	mmol L^{-1}
Sand	430	g kg^{-1} soil
Silt	319	g kg^{-1} soil
Clay	251	g kg^{-1} soil
Soil texture	Loam	-
Bulk density	1.34	Mg m^{-3} (Megagrams per cubic meter)
Particle density	2.66	Mg m^{-3}
Porosity	46.7	%

The experiment basically involved two factors: the first was the soil conditioner type (*i.e.* citric acid, sulfur, humic acid and vermicompost) three replicates for each treatment. The second one was the number of application batches (*i.e.* application in one, two, three and four batches) at certain plant growth stages. Soil conditioner applications were added to the soil before planting in different concentrations in four batches (one, two, three, and four batches) as detailed in Table 2, including citric acid added @ 1000 mg L^{-1}, sulfur at @ mg S h^{-1} and humic acid @ 18 ml L^{-1}. Addition of vermicompost and sulfur was done according to potting mix and their dose levels, and then citric and humic acids were applied in the soil along with the irrigation water. With a 30 kg pot size, the addition of vermicompost and sulfur was done according to potting mix and their dose levels, and then citric and humic acids were applied in the soil along with the irrigation water.

Table 2: *Batch-wise application of different concentrations of soil conditioners.*

Soil conditioners	One batch	Two batches	Three batches	Four batches	Unit
Vermicompost	6	3	2	1.5	t ha^{-1}
Citric acid	1000	500	333.3	250	mg L^{-1}
Humic acid	18	9	6	4.5	ml L^{-1}
Sulphur	15	7.5	5	3.7	mg S ha^{-1}

According to fertilizer recommendations, urea and DAP fertilizers were incorporated with the soil @ 200 kg ha^{-1} (Ali *et al*., 2014).

DAP was mixed with the soil at a level before planting, and urea was added in two batches at certain plant growth stages. After two weeks of growth, we applied the first batch, and before flowering, we applied the second batch.

Seeds of wheat cultivar (Ebaa 99) were sown (@ 20 seeds per pot, 30 kg) on 15th November, 2022. One-week post-germination, plant numbers were lessened up to 10 plants per pot. Then the irrigation of pots was done initially up to the field capacity, and then later on, all pots were brought to 60–70% of field capacity. Gravimetric methods (weighing soil samples before and after drying) are used to measure field capacity in situ. During the entire plant growth, pots were irrigated as per water requirement according to the plant's needs. Data were collected and were analyzed statistically.

At end of the experiment, soil was sampled from all treatment pots, and their analyses were conducted for certain chemical and physical characteristics. The volume distribution of soil particles was estimated using the pipette method according to the method described by Day (1965) and presented in Black (1965). Bulk density was estimated using a core sampler according to Black (1965). Porosity: The porosity was calculated according to the equation:

$$pb/ps \times 100\text{-}P=1$$

Field capacity: The field capacity was estimated at tensile strength according to the procedure given by Black (1965). Cation exchange capacity (CEC) was assessed using 1 M $NH_4CH_3CO_2$ (ammonium acetate) at pH 7, and according to the procedure given by Black (1965). The dissolved positively charged cations, *i.e.* Ca^{++}, Mg^{++}, K^{+} and Na^{+}, were estimated in an extract (1:1), as Ca^{++} and Mg^{++} were estimated by the leaching method using Na_2EDTA according to the method given in (Zuzana *et al*., 2021) and the dissolved Na^{+} and K^{+} were estimated by flame-photometry according to procedure given by (Allison and Richards, 1954).

Results

Impact of soil amendments on soil pH

Results in Table 3 showed a significant (p= 006) impact of the soil conditioner types on pH of the soil pH. The treatment of agricultural sulfur significantly reduced the soil pH interaction. It exhibited the lowest value of (7.92) compared to adding humic acid (7.93), and then citric acid and vermicompost (7.94). On average, vermicompost gave the highest average soil pH value of 8.05. Regarding batch numbers of soil conditioners, the 4th batch surpassed showing the lowest average soil pH value (7.93). Regarding the interaction among soil conditioners and their batch-wise application numbers, sulfur treated soil in the fourth batch showed a significantly lowest soil pH value (7.92), compared with the vermicompost treatment having 8.22 pH.

Effect of soil conditioners on soil EC

Results regarding soil EC showed that a significant effect of the soil conditioner types on soil salinity (Table 3). Citric acid supplementation significantly decreased the soil salinity and had the average lowest value 4.33 ds m^{-1} of electrical conductivity, followed by vermicompost and sulfur i.e. 4.36 and 4.45 ds

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m^{-1}, respectively. Moreover, humic acid exhibited the highest soil electrical conductivity value (5.03 ds m^{-1}). For application batch number of soil conditioners, it was observed that 4th batch exhibited the lowest value of electrical conductivity (3.94 ds m^{-1}) as compared to the first batch (4.87 ds m^{-1}) (Table 3).

Table 3: *The effect of soil conditioner type and application batch number on soil pH, electrical conductivity (EC) and cation exchange capacity (CEC) assessed after harvesting of wheat.*

	Type of added conditioners	Number of batches				Average
		One batch	Two batch	Three batch	Four batch	
soil pH	Vermicompost	8.22	8.11	7.95	7.94	8.05
	Citric acid	7.99	7.99	8.15	7.94	8.02
	Humic acid	8.15	7.99	7.96	7.93	8.01
	Sulphur	7.95	7.98	7.96	7.92	7.96
	Average	8.08	8.02	8.00	7.93	
	LSD 0.05	Type 0.06	Added conditioners		Interaction 0.12	
EC	Vermicompost	4.44	4.07	0.06	4.42	4.36
	Citric acid	4.96	4.99	5.07	2.31	4.33
	Humic acid	5.07	5.00	5.03	5.03	5.03
	Sulphur	5.03	4.70	4.06	4.00	4.45
	Average	4.87	4.68	4.66	3.94	
	LSD 0.05	Type 0.73	Added conditioners 0.73		Interaction 1.47	
CEC	Vermicompost	19.42	21.68	20.58	22.93	21.15
	Citric acid	19.06	19.53	19.70	20.76	19.76
	Humic acid	19.70	20.03	21.80	21.19	20.68
	Sulphur	20.61	19.86	19.81	22.25	20.63
	Average	19.70	20.28	20.47	21.78	
	LSD 0.05	Type 0.77	Added conditioners 0.77		Interaction 1.53	

Influence of soil amendments on cation exchange capacity (CEC)

Both factors *i.e.* soil conditioners and their batch-wise application had a significant effect on the parameter of cation exchange capacity of the treated soils (Table 3). The treatment of adding vermicompost significantly increased the CEC producing highest value (21.15 cmol c kg^{-1}), followed by humic acid, sulfur and citric acid exhibiting CEC of 20.68, 20.63 and 19.76 cmol c kg^{-1} soil, respectively. Regarding application batch numbers, CEC of soil treated with fourth batch application was significantly higher (21.78 cmol c kg^{-1}) as compared to first batch (19.70 cmol c kg^{-1}). However, the interaction of soil conditioner and batch number of application, vermicompost supplementation appeared significantly superior in the fourth batch exhibiting highest value of CEC in the soil measuring 22.93 cmol c kg^{-1} soil as compared to citric acid treatment in first batch (19.06 cmol c kg^{-1}).

Influence of soil organic conditioners and their batch-wise application on soil nutrients

According to data presented in Table 4, soil conditioners type and their batch-wise applications had significant effects on the concentrations of all dissolved nutrient/mineral ions in the soil. Sulfur addition exhibited highest value of 10.05 mmol L^{-1}, followed by humic acid, citric acid and vermicompost measuring 9.94, 9.47 and 8.77 mmol L^{-1}, respectively. Similarly, the fourth and first batch applications excelled and produced the highest and lowest value of dissolved calcium ions (*i.e.* 10.83 and 8.99 mmol L^{-1}). Similarly, agricultural sulfur addition also exhibited significant and lowest magnesium concentration (4.18 mmol L^{-1}) followed by humic acid (4.73 mmol L^{-1}), citric acid (mmol L^{-1}) and vermicompost (5.52 mmol L^{-1}) (Table 4). Fourth batch application showed least concentration of magnesium (4.73 mmol L^{-1}) as compared to first batch application (5.36 mmol L^{-1})

Similar trend of effect of soil conditioners and their application batches were recorded for sodium and potassium ions. Agricultural sulfur had a significantly lower value of sodium ion concentration (16.70 mmol L^{-1}) as compared to other additions, followed by humic acid, citric acid and vermicompost giving sodium ion concentrations of 17.06, 18.08, and 19.03 mmol L^{-1}, respectively (Table 4). Fourth batch application significantly decreased the sodium ions up to 16.01 mmol L^{-1} as compared to the first batch (19.08 mmol L^{-1}). in the soil. However, The Batches of soil conditioner applications varied from batch to batch. Regarding the interaction among soil conditioner types and their application batch numbers, sulfur and vermicompost application in the fourth batch exhibited respectively lowest and highest sodium concentrations *i.e.* 12.17 and 19.53 mmol L^{-1}. Similarly, supplementation with sulfur gave significantly highest value (2.29 mmol L^{-1}) of potassium ions, followed by humic acid (1.67 mmol L^{-1}), vermicompost (1.50 mmol L^{-1}), and citric acid, (1.48 mmol L^{-1}). Similar effect trend was recorded regarding batch wise application of soil conditioners on potassium ion concentrations (Table 4).

Table 4: *The effect of soil conditioner type and application batch number on soil calcium, magnesium, sodium and potassium ions (mmol L⁻¹).*

	Type of added conditioners	Number of batches				Average
		One batch	Two batch	Three batch	Four batch	
Soil calcium (Ca^{2+})	Vermicompost	8.77	8.90	9.00	8.40	8.77
	Citric acid	8.87	9.00	9.20	10.80	9.47
	Humic acid	9.20	9.07	9.90	11.60	9.94
	Sulphur	9.13	9.20	9.37	12.50	10.05
	Average	8.99	9.04	9.37	10.83	
LSD 0.05, Type 0.77, Added conditioners 0.77, Interaction 1.53						
Soil magnesium (Mg^{2+})	Vermicompost	6.67	6.53	4.33	4.53	5.52
	Citric acid	4.70	4.60	5.97	4.90	5.04
	Humic acid	5.97	4.17	4.73	4.03	4.73
	Sulphur	4.10	4.37	4.27	4.00	4.18
	Average	5.36	4.92	4.83	4.37	
LSD 0.05, Type 0.71, Added conditioners 0.71, Interaction 1.42						
Soil sodium (Na^{+})	Vermicompost	19.53	19.13	19.03	18.43	19.03
	Citric acid	18.77	17.80	18.83	16.90	18.08
	Humic acid	18.83	17.43	15.43	16.53	17.06
	Sulphur	19.17	17.90	17.57	12.17	16.70
	0Average	19.08	18.07	17.72	16.01	
LSD 0.05, Type 1.36, Added conditioners 1.36, Interaction 2.72						
Soil potassium (K^{+})	Vermicompost	1.21	1.31		2.38	1.50
	Citric acid	1.55	1.38		1.81	1.48
	Humic acid	1.38	1.55		2.38	1.67
	Sulphur	1.25	2.68		2.95	2.29
	Average	1.35	1.73		2.38	
LSD 0.05, Type 0.38, Added conditioners 0.38, Interaction 0.75						

Discussion

Supplementation of saline and sodic soils with different soil conditioners is one of the best strategies of soil reclamation all over the world (Leogrande and Vitti, 2019). This study evaluated the effect of four organic soil amendments in four different batches on the chemical and ionic properties of wheat cultivated soil using a pot-experiment approach. Results showed a significant effect of supplementation of soil with agricultural sulfur when applied in four batches.

The possible cause of reduction in soil pH by the addition of sulfur would be the role of sulfuric acid, which ionizes into the SO^{4-} and H^+ ions formed by the oxidation of added sulfur, which works to increase the hydrogen ion concentration in soil solutions and reduces reaction degree value of the soil. These results confirm the similarities found in earlier research (Jabbar and Al-Ziyadi, 2021; Lee *et al*., 2021; Alemu *et al*., 2023; Barrow and Hartemink, 2023) reporting a significant decrease in the degree of soil interaction when sulfur was added to the study soils. As well as the function of citric acid in the reduction of soil salinity might be due to citric acid's role in liberating certain nutrients in improving the porosity of the soil, which facilitates the leaching of salts. These findings are consistent with results of Tahjib-Ul-Arif *et al.* (2021) and Syed *et al*., (2021). Similarly, the reason for the significant superiority in the CEC by vermicompost supplementation is attributed to the reason that the ionization of hydrogen from the active aggregates included in the composition of the organic matter contributes to increasing the density of the negative charge on the surfaces of soil colloids. The charge source of the organic matter may range between 10–60% of the CEC. The totality depends on the characteristics of the soil and its components, and therefore it was noted that there is a direct effect of the organic matter on the availability of nutrients as it plays a role in improving the cationic exchange capacity, especially in sandy soils (Lisowska *et al*., 2022), as the organic matter leads to a high CEC (Paramisparam *et al*., 2021; Leeson and Hinchee, 2022).

Moreover, the increase in calcium ions by soil conditioners would be due to sulfuric acid, resulted by the sulfur oxidation of sulfur, in dissolving certain minerals and compounding bearing potassium and in dissolving calcium carbonate and the possible substitution of Ca^{++} with K^+ ions and thereby releasing potassium in the soil solution. Moreover, reduction in soil interaction would lead to an upsurge in hydrogen ions (H^+), which compete K^+ ion on the soil exchange surfaces liberating potassium to the soil solution, and an increase in the proportion of Ca^{++} ions and replacing them with Na^+ ions on the exchange complex. These results corroborate the reports of Elsharawy *et al.* (2008), Belal *et al.* (2019), Brownrigg *et al.* (2022), Magnucka *et al.* (2023) and Jing *et al.* (2024).

The reason for the reduction of sodium and magnesium ions in soil by sulfur addition would be the improvement of the soil properties and its reclamation because of its acidic effect in reducing the pH values of the soil by oxidizing it biologically and chemically by types of microorganisms. This is in agreement with Jarallah and Abbas (2019), Liao *et* al. (2019) and Al-Mayahi *et al.* (2024). Similarly, the increase in the concentration of dissolved potassium by sulfur supplementation might be the oxidation of sulfur resulting in sulfuric acid formation, that works to reduce soil degree of interaction and increase the solubility of some potassium-bearing soil minerals. The results agree with what is reported by Asadi *et al.* (2018), Belal *et al.* (2019) and Brownrigg *et al.*, (2022) that a significant increase in potassium concentration in the soil solution was observed when sulfur supplement was added to soil.

Regarding best results by the fourth batch application recorded for all soil characteristics might be due to the fact that when compost is applied in batches, the soil is continuously supplied with nutrients and the degree of soil interaction is reduced in the long term, as well as making the soil fertile by providing microorganisms and improving soil construction, which facilitates the penetration of plant roots, and providing the plants with adequate nutrients throughout the growth period (Al-Zahra, 2019; Barrow and Hartemink, 2023; Oyege and Bhaskar, 2023).

Conclusions and Recommendations

Overall study results have demonstrated that EC and CEC characteristics of the soil were significantly affected by the application of soil conditioners under this pot experiment. The agricultural sulfur had a strong effect on almost all soil chemical and nutritional profiles. While, the application of citric acid in soil had a minute and insignificant impact on final soil EC when applied in fourth batch. Similarly, soil EC and CEC as well as the monovalent cation concentrations were decreased in the soil at experiment end.

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Novelty Statement

This research presents fresh insights into the effects of these conditioners on soil chemistry in wheat farming, contrasting with findings from other crops or soils.

Author's Contribution

Bayan Habeeb Kadim and Ghassan Adnan Abdulameer: Conceived of the original idea, developed the experimental protocol, performed experiment, and collected and processed the experimental data.
Ghassan Adnan Abdulameer: Supervised the research work and technically proofread the manuscript.
Bayan Habeeb Kadim: Discussed the results and wrote the preliminary manuscript.

Generative AI and AI-assisted technology statement

The authors state that the manuscript was not created with Generative AI or AI-assistance.

Conflict of interest

The authors have declared no conflict of interest regarding the submission and publication of this research work.

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