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Effect of soil organic amendments on sorption behavior of two insecticides and two herbicides

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A B S T R A C T

The effect of biochar, compost, peat and wheat straw at 1 and 5% on adsorption isotherm of chlorantraniliprole, dinotefuran, bispyribac-sodium, and metribuzin was studied in clay loam soil and sandy loam soil. Biochar, compost, peat and wheat straw (at a rate of 1 % in soil) improved the adsorption capacity of chlorantraniliprole and metribuzin in sandy loam soil. The sorption coefficients are higher for chlorantraniliprole and metribuzin whereas lower for dinotefuran and bispyribac-sodium in amended soil compared to unamended sandy loam soil. There is not a clear direct correlation between Freundlich parameters as well as Kd or Koc and type of organic amendment. The sorption of all tested pesticides on biochar was increased, whereas on compost was decreased. The order of pesticides sorption in soils and different organic amendments is generally inversely proportional to their aqueous solubilites. Adsorption of chlorantraniliprole increases on the sandy loam soil amendment at the rate of 1% in the following order: peat > compost > biochar > original soil. Also, the magnitude of adsorption on soil A amendment at the rate of 5% can be arranged for dinotefuran in the order; peat > biochar > compost > original soil and for bispyribac-sodium and metribuzin peat = wheat straw > biochar > original soil.

1. Introduction

Soil amendments can cause changes in soil structure and transport characteristics, including increased porosity, decreased bulk density, increased water retention, and changes in pore size distribution. Soil amendment also affects pesticide binding.[1-3] Organic amendments used to enrich soils of low organic matter (OM) contents can affect sorption and movement of pesticides in soils.[4,5] Several studies demonstrated that the application of organic amendments onto soils improved their physical properties and increased their OM content and thus may greatly affect their capacity for pesticide sorption-desorption processes.[6-8] Soil amendments can play an important role in the management of runoff and leaching losses of pesticides. Any amendment to soil changes its physico-chemical properties, which in turn, affect the sorption, transport and degradation of the soil-applied pesticides.[9-12]

Development of low-cost adsorbent for pesticide retention is an important area of research in environmental sciences.[13] Application of organic carbon (OC) in the form of compost, sludge, effluent and crop residues is a common agronomic practice followed in agriculture to increase the soil fertility and crop productivity. Generally, with increase in OM content of soil retention of pesticide on soil particles increases, thus, downward mobility of pesticide in soil profile decreases.[14] But, application of compost can lead to a substantial amount of dissolved and colloidal organic material in the soil solution that may have an impact on the subsequent pesticide binding and transport behaviour.[9] Field burning of crop residues incorporates resulting chars into soil and may thus influence the environmental fate of pesticides in the soil. Recent work on potential pesticide sorbents found that biochar has a high affinity for sorbing organic contaminants, thereby reducing adverse impacts of pesticide residues on the environment and the ecosystem functionality.[15] Biochars produced at different

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heat treatment temperatures are molecularly distinct and thus expected to show variable sorbent characteristics.[16] Biochar is produced from the pyrolysis of OM, carbon-rich plant- and animal-residues under low oxygen and high temperature conditions and has been increasingly used for its positive role in soil compartmentalization through activities such as carbon sequestration and improving soil quality. Biochar is also considered a unique adsorbent due to its high specific surface area and highly carbonaceous nature. Therefore, soil amendments with small amounts of biochar could result in higher adsorption and, consequently, decrease the bioavailability of contaminants in the soil. However, the mechanisms affecting the environmental fate and behaviour of organic contaminants, especially pesticides in biochar-amended soil, are not well understood. Therefore, biochar has demonstrable effects on the fate and effects of pesticides and has been shown to affect the degradation and bioavailability of pesticides for living organisms. An increase in surface area and/or hydrophobicity of the biochar results in an enhanced sorption affinity and capacity towards hydrophobic organic contaminants.[16] Soil biochar applications have significant agricultural benefits, such as stabilizing the carbon and modifying soil physico-chemical properties altering the soil nutrient availability and increasing crop production,[17] improving soil microbial activity,[18] and strengthening mycorrhizal associations.[19] In addition, biochar has been proven to be particularly effective in sorption and immobilization of organic contaminants in soils,[20] and markedly influence their environmental fate in soil.[21-24] It has been also shown that biochar and other biochar-like materials effectively sorb pesticides and they are responsible for their increased sorption by soils amended with these types of organic materials. Various studies have documented that the increased sorption of pesticides by biochar- or ash-amended soils may result in a decrease of their degradation, desorption, leaching and uptake by plants when compared to the non-amended soils. Moreover, toxicity and efficacy of soil- applied pesticides may be also reduced significantly in biochar- or ash-amended soils and this is due to high sorption capacity of biochars and biochar-like materials.[15]

The increased pesticides sorption by biochar could potentially decrease pesticide leaching to groundwater.[20,25] Application of pine chip biochar reduced cumulative atrazine leaching by 52% in packed soil columns.[26] The addition of biochar (5%, w/w) to soil increased the sorption of atrazine and acetochlor compared to non-amended soils, resulting in decreased dissipation rates of these herbicides.[25] Leaching experiments with hand-packed soil columns indicated that the fresh and composted olive mill waste amendments significantly reduced the amount of metribuzin (MBZ) leached due to the higher sorption capacity and the faster degradation of the pesticide. It may be useful management practice for reducing the risk of groundwater contamination by MBZ in soil.[27] Sorption of MCPA ionizable herbicide by biochar and biochar-amended soil (1%, w/w biochar) was 82 and 2.53 times higher than that by the non-amended soil, respectively. The adsorption and desorption isotherms of terbuthylazine in the soils with or without biochar amendment were well described by the Freundlich model.[28,29] The sorption behaviour of chlorantraniliprole (CAP) by biochar and effect of soil extracts on sorptivity in soil-biochar systems were examined. The biochar amendment could enhance the sorption of CAP in soils, but the magnitude of the sorption enhancement by biochar amendment among the soils was varied, presumably due to the attenuation of the sorptivity of the biochar when amended in the soil. The amendment with biochars leads to a decrease in the availability of CAP in the soils. Aging of biochar in soil extract reduced CAP sorption by up to 85 %.[22,30]

In this study, the focus was on the effect of biochar, compost, peat, and wheat straw on the adsorption of the pesticides; CAP, dinotefuran (DNF), bispyribac-sodium (BPS), and MBZ into clay loam soil (soil A) and sandy loam soil (soil B), in order to reach the best agricultural practices with less environmental pollution.

2. Materials and methods

2.1. Tested pesticides

Chlorantraniliprole-CAP

Pesticide type: Insecticide. Chemical class: Anthranilic diamide. Chemical structure: **Fig. 1.** Uses: in fruit, vegetables, cotton, grapes, potatoes, rice and landscaped areas.

Dinotefuran-DNF

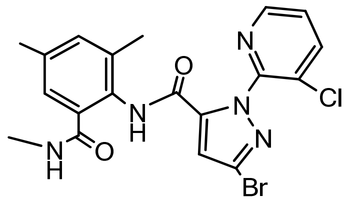
Pesticide type: Insecticide. Chemical class: Neo-nicotinoid. Chemical structure: Fig. 1. Uses: in fruit, vegetables, paddy rice and turf. It can be applied to foliage, soil, nursery boxes and to paddy water by spray, drench, broadcast and ‘pricking-in-hole’ treatment.

Bispyribac-sodium-BPS

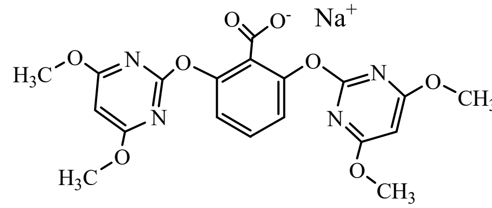
Pesticide type: Herbicide. Chemical class: Pyrimidinyloxybenzoic acid. Chemical structure: **Fig. 1.** Pesticide type: Herbicide. Uses: Control of grasses, sedges and broad-leaved weeds, especially *Echinochloa spp.*, in direct-seeded rice and weeds in non-crop situations.

Metribuzin-MBZ

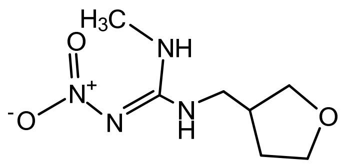
Pesticide type: Herbicide. Chemical class: Triazinone. Chemical structure: **Fig. 1.** Uses: for pre, and post-emergence control of many grasses and broad-leaved weeds in soya beans, potatoes, tomatoes, sugar cane, and cereals.



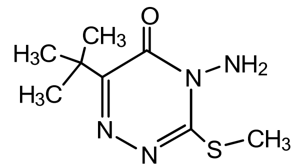
CAP



BPS



DNF



MBZ

Fig. 1. Chemical structures of pesticides

2.2. Tested soil

Two types of Egyptian soils: clay loam soil from Agricultural Research Station, Abis and sandy loam soil from Bangar Elsokar region were tested in the present study. The samples were collected from the top layers of the soil profiles from different locations. The physical properties and chemical properties of soils were presented in Table 1.

Table 1. Physiochemical properties of soils

Code	Texture class	OM (%)	pH	EC	Total carbonate (%)	Cations conc. (meq/L)	Anions conc. (meq/L)
A	Clay loam	3.3	8.3	1.3	7.9	18.7	13.3
B	Sandy loam	1.3	8.2	2.3	40.1	33.5	23.3

2.3. Tested soil amendments

Four amendment substances (biochar, peat, compost, and wheat straw) were tested in the study. The commercial form of substances was obtained from Faculty of Agriculture, University of Alexandria. Air-dried substances were ground and passed through a 5-mm sieve.

2.4. Sorption isotherm of pesticides

Adsorption isotherms by bulk soil and soil with amendments were quantified using the batch equilibration technique. Experiments were carried out in duplicate with a sorbent mass to pesticide solution ratio of 1:5. Initial pesticide concentrations of in 5-50 µg/mL range were prepared in 0.01 M $CaCl_2$. The pesticide solutions were equilibrated with soils in 20-mL polypropylene centrifuge tubes. The tubes were shaken mechanically at 125 rpm by orbital shaker, bibby steril, at room temperature for a time period to achieve equilibrium based (1 day) on its kinetics study and centrifuged at 3500 rpm for 20 min. The pesticide concentration in supernatants was determined by UV-Spectrophotometer at the proper λ_{max}. The amount of pesticide sorbed, C_s, by solid phase after equilibrium was calculated,

$$C_s = (C_i - C_e) \times \frac{V}{M_s}$$

C_s is the concentration or amount of pesticide sorbed per mass unit of adsorbent (µg/g), C_i is the initial concentration of pesticide (µg/mL), C_e is the equilibrium concentration of the pesticide per mass unit of solution (µg/mL), V is the volume of added solution (mL), and M_s is the weight of the adsorbent sample (g).[31]

2.5. Effect of soil amendments

The substance amendments (biochar, compost, peat, wheat straw) were amended to the soils at a rate of 1 and 5% (w/w). The samples of the amended soils were treated with known concentrations of tested pesticides in 0.01 M $CaCl_2$ solution.[32]

2.6. Freundlich model

The empirical formula of the Freundlich equation can be written as;

$$q_e = K_F {C_e}^{1/n}$$

K_F is a constant indicative of the adsorbent ($mg^{1-(1/n)}\ L^{-1/n}\ g^{-1}$) and 1/n is a constant indicative of the intensity of the adsorption.[33]

2.7. Statistical analysis

Experimental data are presented as mean ± standard error and the statistical analysis was performed by the Microsoft Excel 2010 program.

3. Results

The adsorption (µg/g ± SE) of tested pesticides; CAP, DNF, BPS and MBZ into soil A, soil B, and amended soils with 1% of biochar, compost, peat and wheat straw isotherms are given in **Fig. (2-5)**.

The wheat straw displayed higher efficiency in improving adsorption capacity of soil A to CAP in the range of concentrations (20-40 µg/mL). However, all tested organic amendments significantly reduced the adsorption of soil A to CAP. Among the evaluated organic amendments, the peat demonstrated the most significant reduction on the adsorption. No significant differences were obtained between natural soil A and soil A amended with wheat straw and between soil amended with biochar and compost (**Fig. 2**). The isotherms presented in **Fig. 2** indicated that the soil B amended with peat, compost and biochar improved the CAP adsorption compared to natural soil B, the amendment with peat demonstrated the most significant enhancement whereas no significant differences were detected between the effects of compost and biochar amendments. The straw amended soil has the lowest sorption of CAP. Therefore, it was observed that all tested organic amendments (at rate of 1 % in soil) except wheat straw, reduced CAP adsorption in soil A while increased that in soil B. Among the soil amendments, the adsorption of CAP in straw amended soil A was the highest, whereas it was lowest in straw amended soil B. In contrast, the adsorption of CAP in peat amended soil A was the lowest whereas it was highest in peat amended soil B. also, the effect of biochar and compost on the CAP adsorption differed from soil A and soil B. Biochar amendment of the soils affected the sorption of CAP, but the magnitude of the sorption enhancement by biochar amendment among the soils was varied, presumably due to the attenuation of the sorpitivity of the biochar when amended in the soil.

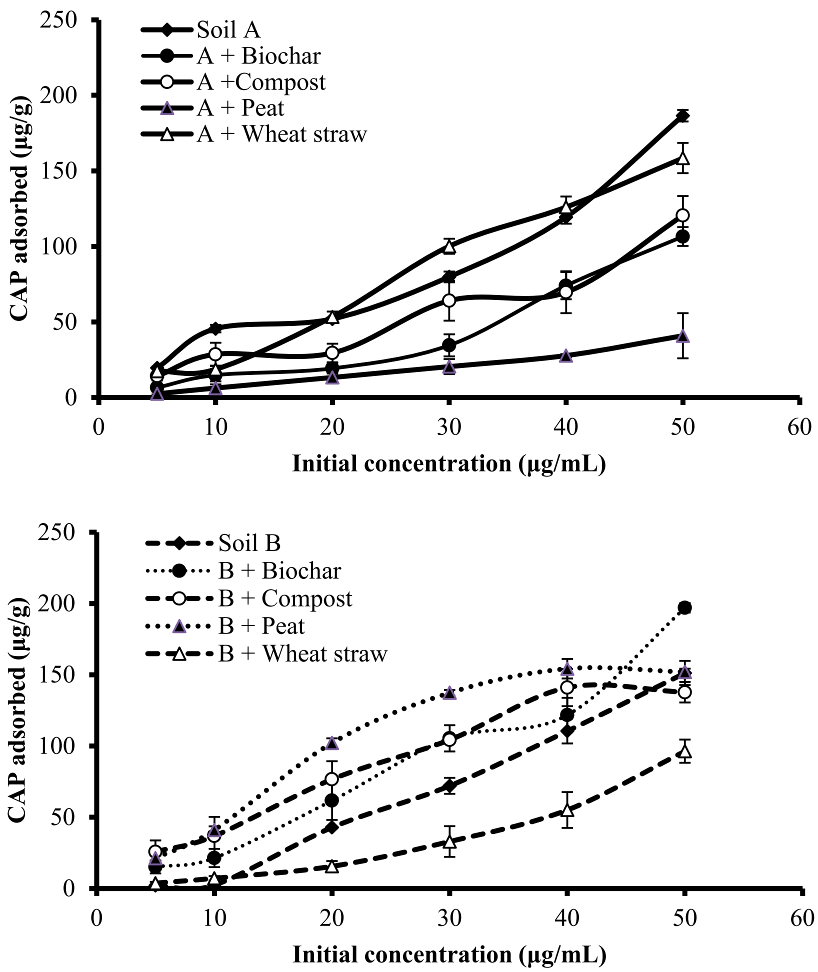


Fig. 2. Adsorption of CAP in soil A (upper) and soil B (lower) with 1% amendments
Error bars represent one standard error of the mean

Amendment of soil A with 1% of biochar, compost and wheat straw had non-significant influence on the adsorption of DNF (**Fig. 3**). No significant differences were obtained between natural soil B and wheat straw amended soil B and between biochar amended soil B and compost amended soil B. The adsorption of DNF was lowest in peat amended soil A and B. Therefore, the provirus studies showed that properties of organic amendments are an important factor in affecting pesticide sorption in amended soil.

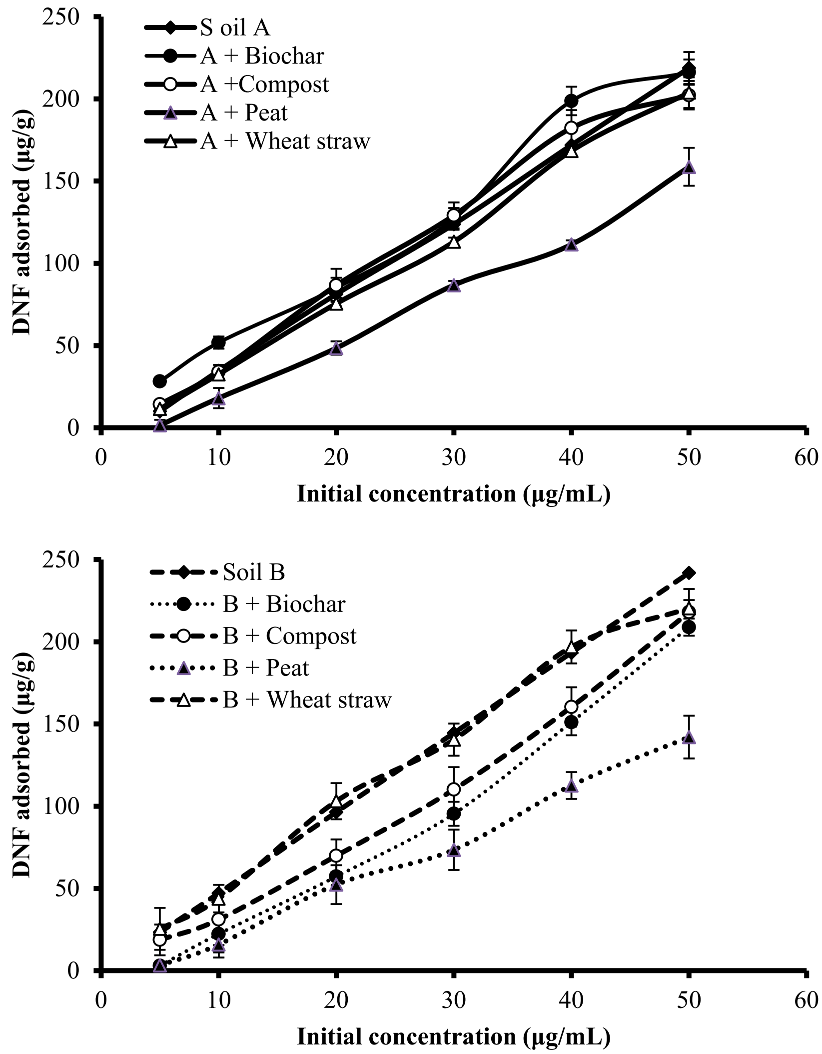
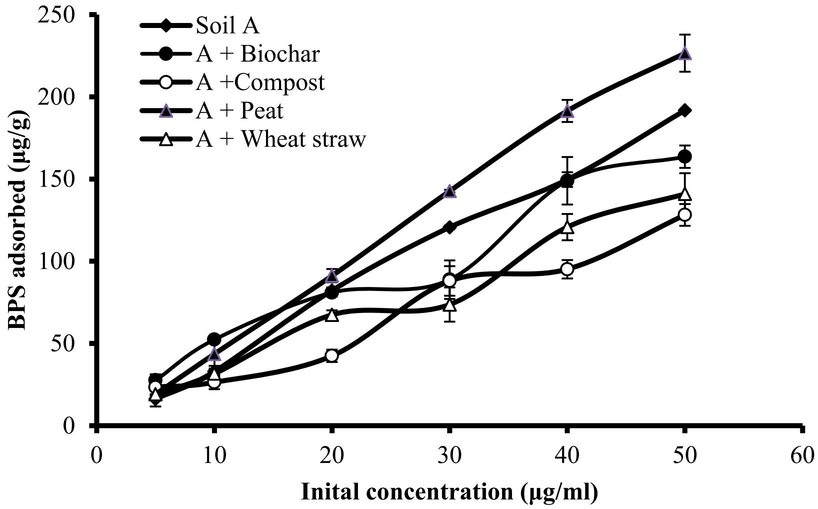


Fig. 3. Adsorption of DNF in soil A (upper) and soil B (lower) with 1% amendments
Error bars represent one standard error of the mean

It was observed that at low concentrations of BPS, there are no significant differences between the organic amended-soil A and soil B. Amendment of soil A with 1 % of peat had a significant increase whereas, amendment with compost and wheat straw had a significant decrease on the adsorption of BPS. The wheat straw amended soil B at rate of 1% was the lowest one compared to other amendments. Almost non-significant differences were detected between natural soil B and biochar, compost and peat-amended soil B. However, the adsorption of BPS at low initial concentrations was higher in compost amended soil B than in biochar amended soil B, this trend was reversed under high concentrations (**Fig. 4**).

MBZ sorption isotherms of unamended soil A and B and amended soil with biochar, compost, peat and wheat straw are given in **Fig. 5**. All evaluated organic amendments displayed higher efficiency in improving adsorption capacity of soil A and B to MBZ except peat and wheat straw at high concentrations of herbicide in the case of soil A. The differences between effect of compost and biochar also, between peat and wheat straw on the soil A adsorption capacity were almost equal at all initial concentrations of MBZ. Both organic amendments, wheat straw and peat increased the adsorption of MBZ in soil B compared to biochar and compost.



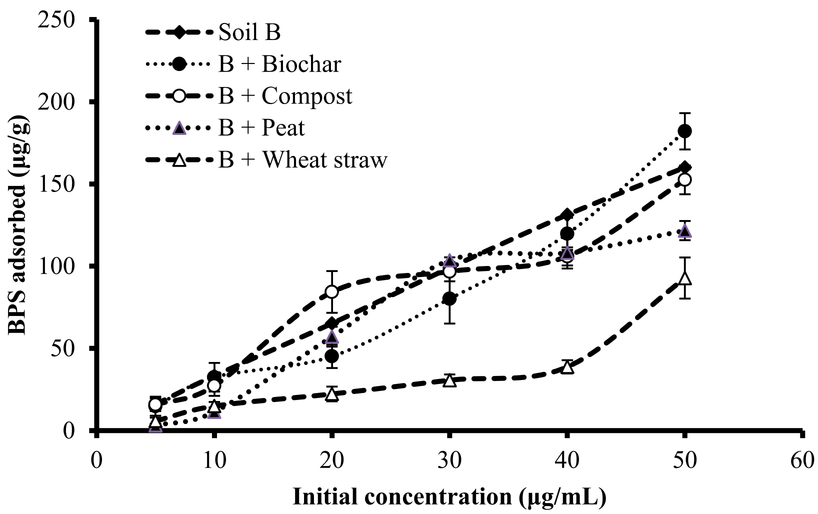
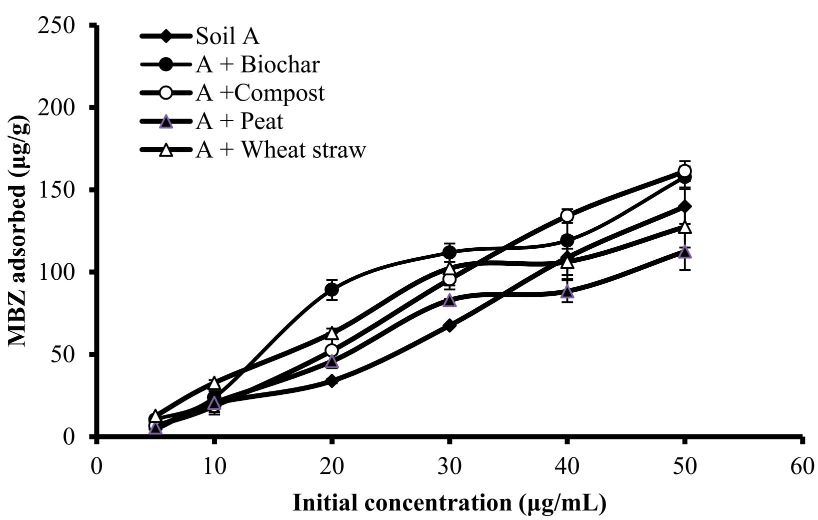


Fig. 4. Adsorption of BPS in soil A (upper) and soil B (lower) with 1% amendments Error bars represent one standard error of the mean



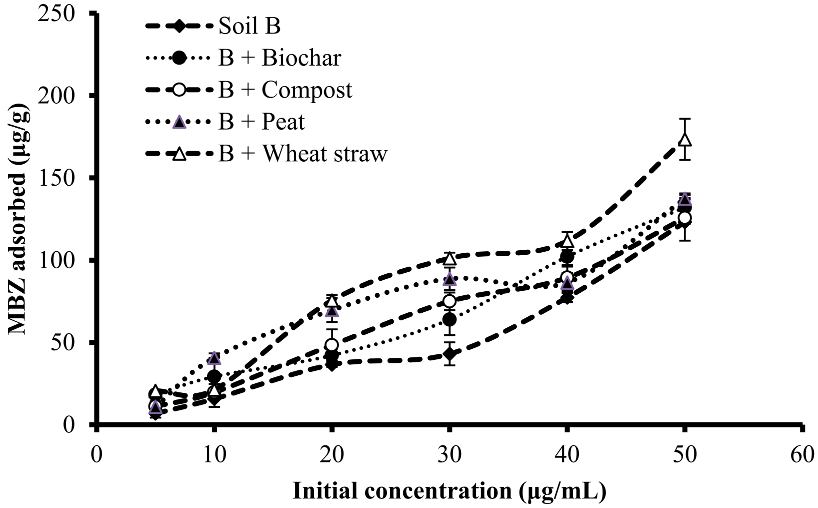


Fig. 5. Adsorption of MBZ in soil A (upper) and soil B (lower) with 1% amendments
Error bars represent one standard error of the mean

The adsorption isotherms of tested pesticides; CAP, DNF, BPS, MBZ in both studied soils A and B amendment with 1% of biochar, compost, peat and wheat straw were satisfactorily described by the Freundlich model (**Table 2**). K_F values which measure relative sorption capacity, are higher in the amended soils with all tested organic amendments than in the original soil A except peat in the case of DNF sorption and compost in the case of BPS and MBZ sorption. The K_F value of CAP adsorption was reduced in soil A amended with different organic amendments compared to that in original soil A. In the case of soil B, CAP and MBZ sorption coefficients are higher in different substance amended soil than in original soil B. While, DNF and BPS sorption coefficients are lower in amended soil A compared to soil B. However, K_F values cannot be statically compared because the corresponding 1/n values were not equal.

The Kd (partition coefficient) values are calculated (**Table 2**), differences were more significant and similar to that in the K_F values. Kd values were normalized to OC content to get Koc values. This normalization assumes that OC content is the primary component of the soil controlling adsorption. As shown in **Table 2**, Koc values for DNF of biochar and compost amended soil A are higher than those of peat and wheat straw amended soil A as well as original soil A. Also, Koc values for MBZ of all organic substances amended soil were higher than that of original soil A and soil B. Biochar, compost and peat amended soil B had Koc values much greater than those of the original soil A in the case of CAP sorption.

The slope (1/n) values for CAP in soil A, compost amended soils A and B, and wheat straw amended soils A and B, for DNF in biochar amended soil A and wheat straw amended soils B, for BPS in biochar and compost amended soils A and for MBZ in biochar and peat amended soil B and wheat straw amended soils A and B were <1 suggesting nonlinear adsorption isotherms. It indicated L-type isotherm, which is characterized by the decrease in the adsorption at higher aqueous concentration of compounds, thus, sorption of all tested pesticides under these conditions was concentration dependent. The values of (1/n) of tested pesticide adsorption isotherms in other treatments were >1 indicating S-type isotherm.

The results of the adsorption of tested pesticides at 40 µg/mL on soils, A and B and organic amendments, biochar, compost, peat and wheat straw. It was showed that the adsorption of CAP on biochar and peat were statistically higher whereas, on compost and wheat straw were lower than those on soil A and B. The adsorption of DNF at 40 µg/mL on both compost and wheat straw were lower compared to the adsorption on soil A and B. No significant in adsorption of DNF were obtained between neither biochar and soil A nor peat and soil B. It was exhibited that the adsorption of BPS on compost was lower than those on other tested adsorbents. No significant differences were observed among soil A, soil B, biochar, peat and wheat straw. The adsorption of MBZ at 40 µg/mL on biochar was higher than those on other adsorbents. Statistically, the adsorption on peat equals that on soils A and B. Adsorption of MBZ on compost and wheat straw was significantly lower than that on both tested soils, A and B and both tested organic amendments, biochar and peat.

Comparison of organic amendments sorption capacity for all tested pesticides indicated that the adsorption of all tested pesticides was lowest on compost. Also, the adsorption of DNF and MBZ was lower on wheat straw compared to other adsorbents. Also, soil B the sorption capacity of soil A, biochar and peat was highest for CAP and DNF. In addition, biochar improved the sorption capacity of all tested pesticides compared to other adsorbents (**Table 3**). The order of pesticides sorption in soils and different organic amendments can be explained by their aqueous solubility as sorption of organic compounds is generally inversely proportional to their aqueous solubilities. MBZ is characterized by its high-water solubility.

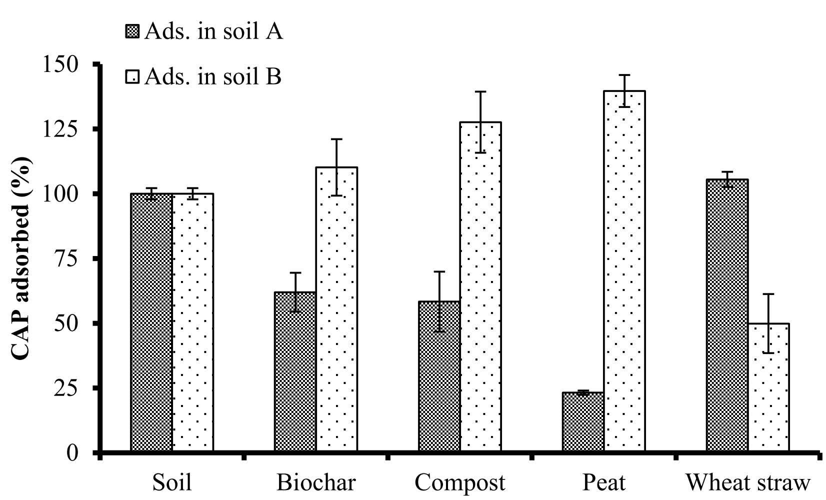
Table 2. Freundlich parameters and partition coefficient of soil and soil amendment

Pesticides	Adsorbents	Soil A					Soil B				
		K_F	1/n	R^2	Kd	Koc	K_F	1/n	R^2	Kd	Koc
CAP	Soil	23.77	0.49	0.80	12.39	645.51	0.01	3.21	0.81	3.05	395.82
	Soil + Biochar	1.32	1.17	0.85	1.90	98.56	4.85	1.27	0.85	8.05	1015.22
	Soil + Compost	8.66	0.68	0.81	4.35	225.16	24.78	0.62	0.87	13.41	1692.55
	Soil + Peat	0.42	1.21	1.00	0.72	37.85	0.32	1.53	0.93	31.26	4052.60
	Soil + Wheat straw	11.51	0.87	0.93	8.96	466.53	54.24	0.41	0.50	1.19	152.14
DNF	Soil	0.57	3.31	0.83	18.10	942.57	125.78	1.49	0.98	113.25	14708.02
	Soil + Biochar	103.02	0.24	0.85	31.58	1634.49	0.01	4.43	0.95	7.49	944.29
	Soil + Compost	4.80	1.88	0.82	20.35	1054.13	10.68	1.22	0.84	14.19	1790.41
	Soil + Peat	0.03	2.97	0.89	4.20	219.80	0.17	2.27	0.94	3.96	513.61
	Soil + Wheat straw	1.83	2.14	0.96	12.92	673.21	116.07	0.34	0.96	72.71	9305.87
BPS	Soil	9.88	1.25	0.88	15.49	806.60	9.41	1.00	1.00	9.51	1234.93
	Soil + Biochar	77.81	0.18	0.83	12.36	639.56	7.81	0.98	0.93	7.14	900.87
	Soil + Compost	7.00	0.91	0.94	5.74	297.40	10.92	0.85	0.97	8.55	1079.04
	Soil + Peat	24.40	1.61	0.87	40.50	2120.67	0.13	2.19	0.98	2.70	349.52
	Soil + Wheat straw	16.07	0.67	0.93	9.55	497.30	1.64	1.01	0.87	1.53	196.44
MBZ	Soil	0.47	1.81	0.93	3.42	178.23	1.31	1.28	0.94	2.45	317.89
	Soil + Biochar	3.28	1.38	0.87	7.80	403.96	12.99	0.63	0.88	6.65	837.98
	Soil + Compost	0.36	2.22	0.97	5.83	301.75	3.30	1.11	0.98	4.20	529.84
	Soil + Peat	1.24	1.44	0.91	3.86	202.36	32.87	0.39	0.86	11.07	1435.58
	Soil + Wheat straw	8.46	0.92	0.87	7.89	410.95	22.73	0.66	0.96	13.37	1711.63

Table 3. Adsorption of tested pesticides (µg/g ±SE) in soils (clay loam, A and sandy loam, B) and organic amendments

Initial con. (µg/mL)	CAP	DNF	BPS	MBZ
Soil A	335.153 ± 2.586	315.805 ± 7.185	309.936 ± 4.781	267.153 ± 7.301
Soil B	307.950 ± 2.395	375.575 ± 3.161	301.074 ± 9.668	297.810 ± 22.631
Biochar	388.506 ± 0.767	333.046 ± 5.460	311.815 ± 1.074	366.058 ± 9.125
Compost	103.161 ± 3.161	55.172 ± 11.496	108.593 ± 16.436	47.445 ± 7.301
Peat	375.862 ± 1.916	370.115 ± 2.874	328.034 ± 16.006	267.518 ± 3.281
Wheat straw	270.881 ± 3.832	108.046 ± 4.598	320.838 ± 25.890	198.540 ± 11.680

Date of the adsorption percentage of tested pesticides at 40 µg/mL on tested soils A and B and tested organic substances amended soil (at the rates of 1% and 5% w/w) are presented in **Fig. (6-9).**



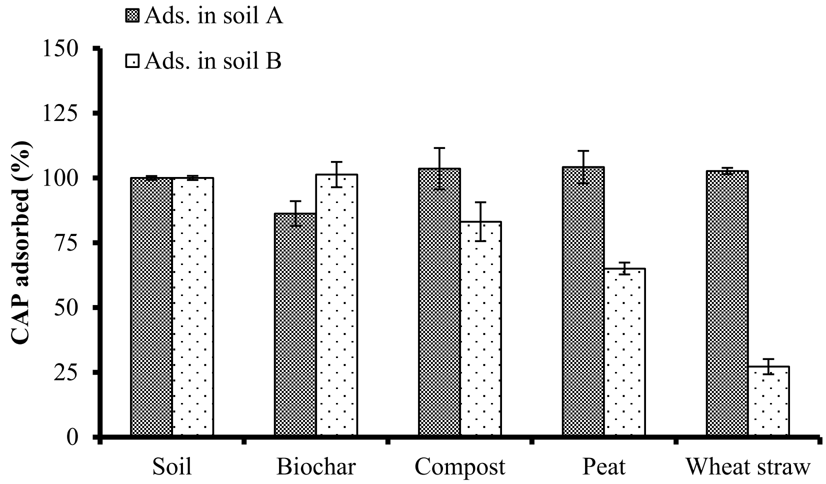


Fig. 6. Adsorption percentage of CAP at 40 µg/mL in soil A and B with 1% amendments (upper) and 5% (lower). (Adsorption in soil as 100%)

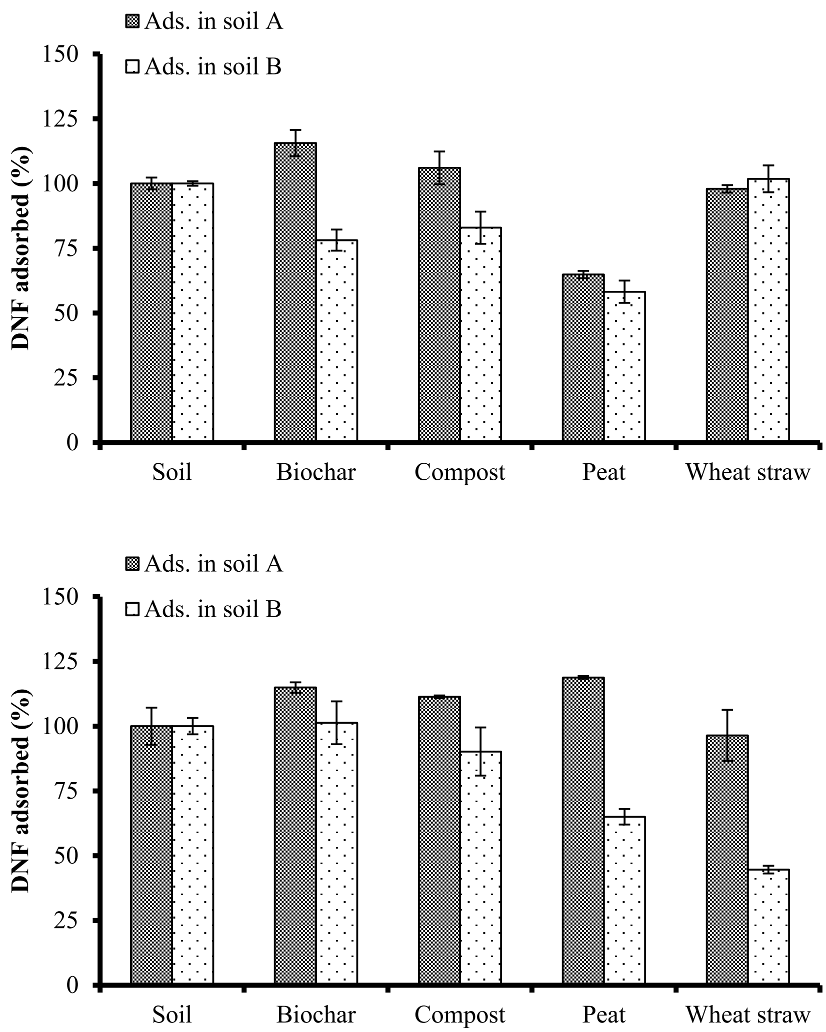


Fig. 7. Adsorption percentage of DNF at 40 µg/mL in soil A and B with 1% amendments (upper) and 5% (lower). (Adsorption in soil as 100%)

The adsorption percentage of CAP was increased significantly on compost and peat amended soil B at the rate of 1% and on compost, peat and wheat straw amended soil A at the rate of 5%. While biochar, compost and peat amended soil A and wheat straw amended soil B at the rate of 1% and biochar, compost, peat and wheat straw amended soil B at rate of 5% significantly reduced the adsorption of CAP compared to the adsorption on the original soil (**Fig. 6**). The adsorption percentages of DNF were significantly equal on the rate 1% of compost amended soil A and wheat straw amended soil A and B. Whereas, 1% of biochar, amended soil A and peat compost and biochar amended soil B increased DNF adsorption percentage compared to the original soils. Amendment of soil A at the rate of 1% and 5% of peat amended soil A and B reduced the adsorption of DNF (**Fig. 7**). Also, amendment of soil B at with of 5% of peat and wheat straw decreased the DNF sorption.

The amendment of soil A with of 1% of peat and 5% of peat and wheat straw increased the adsorption of BPS compared to that on soil A and B (**Fig. 8**). Whereas, the compost and wheat straw (1%) amended soil A and B and peat and wheat straw (5%) amended soil B caused significant reduction of BPS sorption. The adsorption of MBZ in soil A amendment with compost (1%) and biochar, peat and wheat straw (5%) was significantly increased. Also, the MBZ adsorption was significantly increased in soil B amendment with 1% of all tested organic substances. In contrast, all tested organic amendments at rate of 5% except biochar, significantly reduced the MBZ adsorption in soil B (**Fig. 9**).

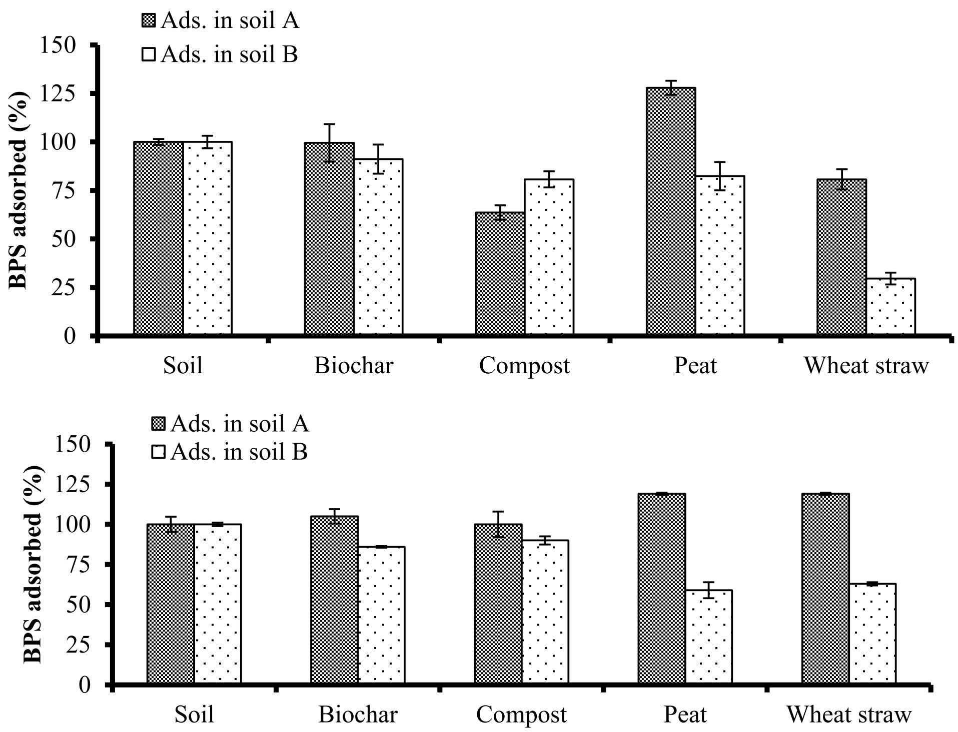
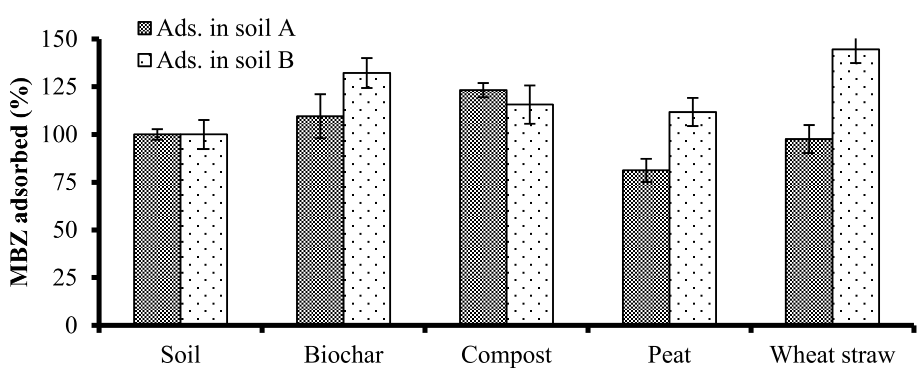


Fig. 8. Adsorption percentage of BPS at 40 µg/mL in soil A and B with 1% amendments (upper) and 5% (lower). (Adsorption in soil as 100%)



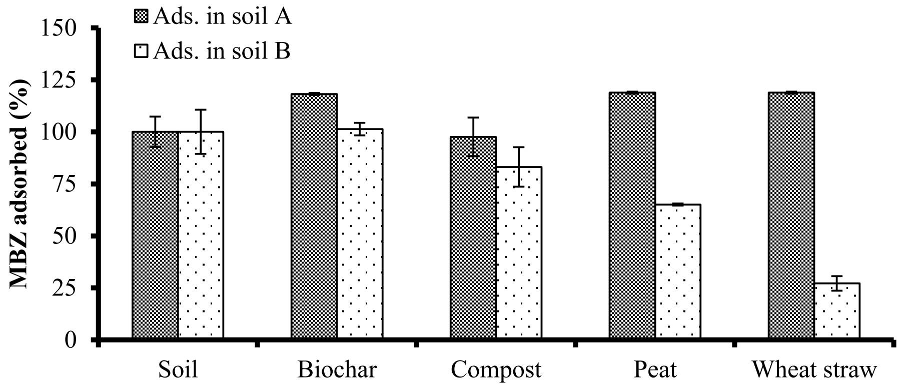


Fig. 9. Adsorption percentage of MBZ at 40 µg/mL in soil A and B with 1% amendments (upper) and 5% (lower). (Adsorption in soil as 100%)

4. Discussion

Non-significant differences were obtained between the effect of biochar and compost on the adsorption capacity of soil B to MBZ. This is in agreement with the results of other studies such as Majumdar and Singh [9] they indicated that application of manure and fly ash to a sandy loam soil increased the MBZ sorption capacity of the soil. Also, addition of a small amount of crop residue chars to soil greatly enhanced the sorption of atrazine and simazine.[20] In general, the Koc coefficient represents the sorption on a unit carbon basis and allows a comparison of sorption on compounds with different OM content.[34] Accordingly, it could be suggested that the adsorption efficiency of OM increased with OM content decrease. The results of the previous study indicated that the adsorption isotherm forms on various organic amendments; litter, compost and sludge were S-type.[35]

An increase in pesticide adsorption in response to the addition of an organic amendment to soil has been demonstrated in several studies.[36,37] The increase in herbicide ethametsulfuron-methyl adsorption by organic amendment (commercial peat) addition to soil was attributed the high adsorptive capacity of the insoluble OM added to the soil.[1] The sorption coefficient for alachlor and atrazine increased on carbon-rich materials amended versus un amended soils.[38] Similar results were obtained by Barriuso et al for eight pesticides,[34] and by Sluszny et al for three pesticides.[37] Besides the OM, the soil clay should be another important factor that affects the sorptivity of organic amendment in soil. The small particle of clay sheet might deposit on the surface of organic amendment such as biochar, block the pore and reduce the surface area.[30] However, the addition of organic amendment in soil may result in an increase in pesticide adsorption.[39] Although there is an overall increase in some pesticide upon amendment, there is not a clear direct correlation between Freundlich parameters as well as Kd and Koc and type of organic amendment. Therefore, more relationships were studied to show the results clearly.

Therefore, low adsorption on soil and organic amendments.[13,24] In contrast, CAP is characterized by its low water solubility (1.023 mg/L).[22,30] The adsorptions of each tested pesticide on both tested soils, A and B and both tested amendments, biochar and peat were almost the same. In fact, the actual impact of an organic amendments depends on the type and characteristics of organic material, as well as on the pesticides molecular configuration, polarity, and size.[36] Biochar is one of the most efficient sorbents for several groups of pesticides.[40] Moreover, a number of studies have demonstrated that biochar has a high capacity to adsorb pollutants, especially for organic contaminants,[41] therefore, is known as a "super sorbent".[42]

In general, the soil amendment improved sorption of tested pesticides. However, adsorption of CAP increases on the soil B amendment at the rate of 1% in the following order: peat > compost > biochar > original soil. Also, the magnitude of adsorption on soil A amendment at the rate of 5% can be arranged for DNF in the order; peat > biochar > compost > original soil and for BPS and MBZ peat = wheat straw > biochar > original soil. Addition of animal manure and its compost to soils increased their sorption capacity for pesticides and improved many chemical and physical factors necessary for establishment of agronomic crops on soils as well as might solve environmental pollution.[35] The predominant role of biochar in sorption by biochar amended soils was observed for cholrantraniliprole,[30] isoproturon,[43] and acetamiprid.[44] Moreover, soil biochar applications have significant agricultural benefits, such as stabilizing the carbon and modifying soil physicochemical properties,[45] altering the soil nutrient availability and increasing crop production,[17,25] improving soil microbial activity,[18] and strengthening mycorrhizal associations.[19] In addition, biochar has been proven to be particularly effective in sorption and immobilization of organic contaminants in soils,[20] and markedly influence their environmental fate in soil.[46] Soil organic amendments can modify the soil's physicochemical and biochemical properties, which in turn can affect the behavior of any pesticide applied.[24] Soil amendment also affects pesticide binding,[47] and increases retention of organic pollutants.[48] However, it is difficult to determine accurately the behavior of a particular pesticide in a specific soil under different organic amendment conditions. Indeed, different studies report different responses.[49] It is well known, for example, that organic amendments may under some conditions enhance the retention, persistence, and mobility of pesticides in the soil profile, and under others decrease them.[17]

Author contribution

MRF edited the manuscript, read, and approved the final version. AFE conceived of and designed the study. MEIB collected the input data and performed the calculations. MIA adapted.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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