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Influence of different organic materials on physical properties of desert and cultivated soils

G. Sokolov[1], *I. Michael*[2], *and N. Bambalov*[1]*

[1]Institute for Problems of Natural Resources Use and Ecology, National Academy of Sciences of Belarus, Minsk, Belarus
[2]Soils, Water and Environment, Research Institute, Agricultural Research Center, Giza, Egypt

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A b s t r a c t. The field and pot experiments were conducted in Belarus and Egypt to study the effect of different natural organic materials on physical properties of sandy and sandy loam soils. The following materials were studied: well known and widely distributed peat moos (PM), new Belarussian peat-sapropel ameliorant (PSA), ammonium humate (AH) and fulvic acid (FA).

The obtained results have shown that addition of studied organic materials decreased electrical conductivity (EC) and soluble cations and anions content in the soils, apart from soluble K which was increased on PSA variant. The highest increase in total soil aggregates was observed with PSA. Data of total soil porosity and pore size distribution confirmed again the superiority of PSA for improving soil properties. In spite of the small percentage value (0.1 and 0.5%), in contrast to the relatively high rates of PSA and PM (3 and 5%), AH showed a pronounced role in increasing total porosity and available water. Data of surface tension of soil solution showed a range of decrease from about 75 to 17% after treatments, reflecting improvement of soil wettability and capillary rise.

It was concluded that the best effect of PSA on soil properties is due to the presence of the organic-mineral and mineral components of sapropel. On the other hand, the effective role of the small amount of AH (0.5%) in increasing soil aggregation, available water, and plant growth, confirm that the effect of the other organic materials is basically due to humic acids.

K e y w o r d s: soil, agrophysical properties, humified organic materials

INTRODUCTION

Lack of food and starvations as a result of decreasing water resources and desertification is considered to be one of the most serious problems and a menace to the world today. During the last decade, agricultural investment in desert and low fertility soils increased, aiming at achieving food sufficiency. Now investors tend to use modern technology to produce high quantity and quality crops in the time of customer demand. The proper water supply for cultivated plants is an extremely acute problem under the conditions of arid, semiarid and even humid climates, especially during dry periods. To use irrigation water rationally, farmers have to improve substantially the agrophysical properties of soil, such as aggregate composition, porosity and its structure, water retention capacity, and other, in combination with the optimization of agrochemical ones. Manure and compost application is obligatory and has been used traditionally for this purpose. Alongside with that, some new soil improvers, based on peat, sapropel, brown coal, as well as preparations isolated from them, such as ammonia humates, fulvic acids *etc*. become more interesting to be investigated for the purposes mentioned previously. To improve seed bed as well as plant growth, the use of organic ameliorants in nursery production and green houses has increased greatly. The effect of manure, peat, composts and organic-mineral deposits on the chemical and physical properties of soil and on plant growth was studied by many investigators such as Bambalov and Sokolov (1993; 1998), Gliński and Walczak (1998), Jamroz and Drozd (1999), Tahara *et al*. (1994), Uomori *et al*. (1995), Yamaguchi *et al*. (1993), but multi-aspect investigations of new organic materials characteristics and estimation of their impact on soils properties studied are far from being completed.

The main objective of the current work is the comparative study of the impact of organic materials of different origin, treatment and structure on the improvement of the physical properties of low fertility soils in different climatic zones.

*Corresponding author's e-mail: agrico@ns.ecology.ac.by

MATERIALS AND METHODS

Field experiments with natural organic materials were carried out in the Central part of Belarus (Minsk region) and then in Northern part of Egypt (Wadi El-Natroun region, Bohera Governorate). Belarussian peat-sapropel ameliorant was tested in Egypt in comparison with local compost and peat moos. Those organic materials were incorporated into the arable layer of desert sandy soil in doses equal to 30 t ha^{-1} of dry matter, which made up 1% of soil weight. The wet weight of each organic material incorporated into the soil was different because the materials had different humidity. By analogy to that, the peat-sapropel ameliorant was tested in Belarus in comparison with cow manure on straw base. The areas of experimental plots were 50 m^2 in Egypt and 80 m^2 in Belarus, each with 4 replicates. General characteristics of the investigated organic materials are presented in Table 1. The amount of humic substances in cow manure was essentially less than that in peat moss and ameliorant.

A pot experiment was conducted to study the effect of fulvic acid (FA)and ammonium humate (AH), in comparison to the above mentioned peat moos (PM) and peat-sapropel ameliorant (PSA), on some chemical and physical properties of desert sandy soil, collected from the plots of the field experiment in Wadi El-Natroun, by growing wheat.

Application rates of the materials used in the pot experiment were 0.1% FA, 0.1% and 0.5% AH, 3% and 5% of both PM and PSA. The organic materials were mixed individually with 10 kg of soil in pots. Ten seeds of wheat (vt. Sakha 69) were planted in each pot and harvested after 45 days. All the treatments were fertilized with nitrogen (150 kg N ha^{-1}) in two doses, 7 and 30 days after sowing. Superphosphate (270 kg P_2O_5 ha^{-1}) and potassium sulphate (60 kg K_2O ha^{-1}) were added one time before sowing. Water was added to keep moisture level constant at 75% of field capacity. Disturbed and undisturbed soil samples and plant samples were taken from the pots after cultivation to determine the different characteristics under consideration. The chemical and physical properties of soil were determined according to Black (1965). Measurements of the surface tension of soil solution were performed using Surface Tensiomat Model 21 (Chen and Schnitzer, 1978).

T a b l e 1. General characteristic of investigated natural organic materials

Characteristics	Peat moss (PM)	Peat-sapropel ameliorant (PSA)	Cow manure (CM)
Moisture (%)	60	50	70
pH (KCl)	3.7	6.5	6.5
Organic matter (% of dry matter)	97.5	75	93.1
Humic substances (% of dry matter)	59	43	5.6*
Nutrient content (% of dry matter)			
total N	1.3	3	1.5
total P_2O_5	0.2	1	0.8
total K_2O	0.3	1.3	1.7
Dry matter added to soil (t ha^{-1})	30	30	30
Wet weight added to soil (t ha^{-1})	75	60	100
Water amount added to soil (t ha^{-1})	45	30	70

*Humus like substances.

RESULTS AND DISCUSSION

Pot experiment

The soil of the pot experiment was characterized by the texture of loamy sand (10% coarse sand, 69.6% fine sand, 7.6% silt and 12.8% clay), soil pH 7.8, and by low contents of organic matter (0.29%) and $CaCO_3$ (3.5%).

Data presented in Table 2 indicate that electrical conductivity (EC) values (dS m^{-1}) of the soil water extracts (1:5) decreased in all the treatments after the addition of the organic materials. Reduction of EC was proportional to increasing AH amount from 0.1 to 0.5%. This trend was less pronounced for PSA and PM, probably because of their containing some soluble salts. Generally, the decrease in EC by addition of the studied organic materials may be due to their effect on improving soil aggregation and consequently accelerated salt movement. Improvement of soil salinity by the addition of humic materials was detected by Yamaguchi *et al*. (1993).

Data in Table 2 shows that the content of bicarbonate increased slightly with FA and PM, while in the case of AH and PSA the increase in HCO_3^- became more evident and was proportional to the rate of addition. This may be due to the release of HCO_3^- as a result of carbonation process associated with the action of these materials on $CaCO_3$ (3.5%). In general, sulphate showed a clear decrease in all the treatments, but became less pronounced with 5% of PM and PSA.

Calcium and magnesium showed the same trend as sulphate.

T a b l e 2. Effect of studied organic materials on EC, soluble cations and anions, organic matter, and cation exchange capacity

Treatment	EC (dS m^{-1})	Soluble cations and anions (meq l^{-1})							OM (%)	CEC (meq 100 g^{-1})
		HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+		
Control	3.32	4.5	4.4	24.1	13.1	4.5	13.8	0.8	0.29	9.24
0.1% FA	3.20	4.6	4.2	23.3	13.0	4.4	13.9	0.8	0.34	9.98
0.1% AH	2.89	5.0	4.3	19.6	10.1	4.4	13.6	0.8	0.43	10.07
0.5% AH	2.60	5.6	4.2	16.5	7.8	4.3	12.4	0.8	0.49	11.70
3% PM	2.78	4.6	4.7	18.7	11.7	3.1	12.4	0.8	0.90	11.85
5% PM	3.18	4.6	4.9	20.2	11.2	4.2	13.5	0.8	1.98	15.10
3% PSA	2.55	5.2	4.8	16.2	8.4	2.7	13.9	1.2	2.36	15.03
5% PSA	3.18	5.4	6.0	20.4	13.4	2.9	14.0	1.5	4.13	19.60

A decrease in sodium was noticed for all the treatments, with the exception of PSA which exhibited a slight increase.

Concentration of potassium appeared to be constant in all the treatments, except for the case of PSA, where its concentration increased with increasing rate of addition from 3 to 5%. This was due to the relatively high initial content of K_2O (1.3%).

Data in Table 2 reveal that readily oxidizable organic matter increased in all the treatments according to the added quantity of the materials used. The relatively high increase in organic matter in the case of PSA, which overcome the actual level of humus material added to the soil, could be attributed to its high potential in stimulating the growth of the root system and consequently organic matter content.

The data of the cation exchange capacity (CEC) (Table 2) indicate that it clearly increased in all the treatments. The rate of increase depended upon the kind and quantity of the organic materials. CEC values increased about 1.6 times with the addition of 3% PSA or 5% PM, and doubled with 5% PSA. The increase in soil CEC after the treatments can be attributed to the high CEC values of humic materials (200 - 300 meq 100 g^{-1}) (Russell, 1973).

A marked increase in CEC by incorporating different organic materials was reported by Matar *et al*. (1995).

The effect of the studied organic ameliorants on soil aggregation as expressed by water stable aggregates is shown in Table 3. The presented data clearly show that the effect of the used organic materials on soil aggregation depended upon its kind and quantity. The highest values of total water stable aggregates (TWSA) were observed with the treatment of PSA at rates of 3 and 5%, where the values increased from 12.63% (original) to 16.23 and 22.46%, respectively. Although very slight increases in total aggregates appeared with 0.1% of both FA and AH, their effect on 2-1 mm aggregates was almost similar to that of 3% PM. Increasing AH to 0.5% caused an increase in total aggregates approximately equivalent to that resulting from 5% PM.

The data in Table 3 also show that the clear increases in 2-1 mm aggregates were associated with the two treatments - 3 and 5% PSA and 0.5% AH - indicating the tendency of these materials towards cementation of small aggregates to form larger ones. The superiority of PSA in improving soil aggregation over AH and PM could be due to the sticky and plastic characteristics of sapropel which acts as a cementing material (Uomori *et al*., 1995). Generally, the previous results represented the important role of both sapropel (organic-mineral deposits) and humic acids on soil aggregation process. The increase of soil aggregation by organic matter treatments in sandy soils was reported by Abd-Elfatah *et al*. (1995).

Pore size distribution is one of the common criteria for soil structure status. From data of the soil moisture retention characteristics in the range 1-15 000 hPa (Table 4), total

T a b l e 3. Effect of the studied organic materials on soil aggregate size distribution

Treatment	TWSA* (%)	Soil aggregate size distribution (%, dia in mm)						
		>2	2-1	1-0.85	0.85-0.65	0.65-0.42	0.42-0.25	<0.25
Control	12.63	1.96	1.43	0.77	2.03	2.69	3.75	87.37
0.1% FA	12.68	2.30	1.69	0.98	1.92	2.32	3.65	87.12
0.1% AH	12.68	2.57	1.59	0.68	1.96	2.54	3.34	87.32
0.5% AH	14.32	3.41	3.38	1.43	2.27	2.08	2.75	85.68
3% PM	13.56	2.22	1.67	0.95	2.73	1.87	4.10	86.44
5% PM	14.56	3.89	1.78	0.67	1.92	2.49	3.81	85.44
3% PSA	15.56	7.18	4.19	2.56	1.08	0.32	0.20	83.47
5% PSA	22.46	13.55	5.63	2.64	0.33	0.19	0.12	77.54

*TWSA – total water stable aggregates.

T a b l e 4. Effect of the studied organic materials on the soil moisture retention under different pressure levels

Treatment	Soil moisture (%, vol.) at pressure levels (hPa)						
	1	100	330	660	1 000	3 000	15 000
Control	25.56	16.91	15.38	14.37	13.95	13.31	6.80
0.1% FA	27.79	18.45	17.66	16.50	15.50	14.80	7.72
0.1% AH	27.76	18.58	17.40	16.23	15.05	13.06	7.38
0.5% AH	36.33	26.56	22.56	20.33	19.02	18.25	9.56
3% PM	32.57	25.04	21.23	20.93	19.53	17.71	8.47
5% PM	39.12	28.68	23.72	21.42	20.42	18.89	10.17
3% PSA	40.19	28.08	23.51	20.29	19.54	18.20	10.24
5% PSA	50.99	35.04	29.31	28.31	25.87	21.19	13.09

T a b l e 5. Effect of the studied organic materials on total porosity and pore size distribution of the soil

Treatment	Total porosity (%)	Pore size distribution (%, dia in μ)				Increase available water (%)
		> 28	28-9	9-0.2	< 0.2	
Control	25.56	8.65	1.53	8.58	6.80	0
0.1% FA	27.79	9.34	0.79	9.94	7.72	15.8
0.1% AH	27.76	9.18	1.18	10.02	7.38	16.8
0.5% AH	36.33	9.54	4.23	13.00	9.56	51.5
3% PM	32.57	9.53	3.81	12.76	8.47	48.7
5% PM	39.12	10.44	4.96	13.55	10.17	57.9
3% PSA	40.19	12.11	5.57	13.27	12.24	54.7
5% PSA	50.99	15.35	6.33	16.44	13.09	91.6

porosity and pore size distributions were calculated for the studied samples (Table 5). Equivalent pore size distribution is classified according to Kohnke (1968).

The results showed that total porosity increased with the additions of organic materials in all the treatments. The highest increase (about 99%) was associated with 5% PSA, whereas the lowest one (about 7%) was detected with 0.l% of both FA and AH treatments. Also, the data revealed that the increase in total porosity resulting from 0.5% AH was about 1.5 times less than that resulting from 3% PM.

Data of micropores (9-0.2 μ) reflect the effectiveness of PSA in increasing available water. Available water showing the highest value of about 91% was associated with the addition of 5% PSA, whereas the in crease did not exceed about 58% when using 5% PM.

Also, the increase of available water which occurred with the addition of 0.5% AH was about 52%, which exceed that obtained from the addition of 3% PM (about 48%) and nearly approached that of 3% PSA (about 54%). EI-Hady *et al*. (1995) found that the addition of 4% organic matter increased available water of sandy soil 1.5 times.

It is worthwhile to mention that the increase in available water is not only due to the effect of organic matter on improving the soil structure, but also to the hydrophilic characteristics of the humic materials. Chen and Schnitzer (1976) attributed the hydrophilic characteristics of HA and FA to their relatively large concentration of oxygen-containing functional groups (COOH, -OH and C=O) per unit weight. The increase in soil water retention by the application of organic composts was mentioned by Abdel-Sabour and El-Gandi (1995).

Both wettability and capillary rise of water are affected by the liquid-gas interfacial surface tension. In general, as the surface tension of liquid decreases, the liquid-solid contact angle decreases (Zisman, 1964).

Surface tension values of the studied soil (paste extract) are illustrated in Table 6. The data show that the values of soil solution decreased after all the treatments, depending on the type and amount of the added material. The highest depression of about 17% was detected with 5% PSA. Also, 0.5% of AH caused about 11% depression in surface tension which was nearly close to that for 3% PM. These data are in agreement with those obtained by Chen and Schnitzer (1978). Generally, the decrease in surface tension of soil solution in water repellent soil as a result of humic material treatments should cause a corresponding decrease of contact angle (θ), thus improving soil wettability (Schnitzer and Khan, 1972).

T a b l e 6. Effect of the studied organic materials on the surface tension of soil solution

Treatment	Surface tension (mN m^{-1})	Depression (%)
Water	72.2	-
Control	70.5	2.35
0.1% FA	67.2	6.93
0.1% AH	66.2	8.31
0.5% AH	64.0	11.35
3% PM	63.8	11.63
5% PM	62.0	14.12
3% PSA	62.8	13.02
5% PSA	60.0	16.89

Field experiments

The results of the field experiments conducted in Belarus (Table 7) showed that the most essential increase of pore volume occupied by water in the arable layer of soil took place under PSA influence (from 21% on the control to 33%), whereas the application of manure increased the volume of such pores only by 2%. Accordingly, the pore volume occupied by air decreased from 25% on the control to 13% on the PSA variant and only to 23% on manure. Total porosity and the volume of solid phase did not change.

The field experiment in Egypt (Table 7) showed the same trends, although absolute indexes of soil properties differed substantially. For example, only 2% of pores were occupied by water in the original sandy desert soil and their volume was increased 4 times (to 8%) after PM application and 6 times (to 12%) after PSA application. The pore volume occupied by air decreased from 45% in the original desert soil to 37% after PM application and to 31% after PSA application. The volume of solid phase changed only a little: from 53 to 55% with the use of PM and to 57% with the use of PSA.

So, the best characteristics of soil water-air properties were reached on variants with PSA in both field experiments. The differences between the results of these two field tests consist only in quantitative estimation of indexes. For example, the cultivated Belarussian soil had 21% of pores occupied by water and only 2% of those were in the original Egyptian soil. Such essential difference can be explained by the fact that the humus content in Egyptian desert soil was too low (0.29%), but in the Belarussian old cultivated soil the humus content was about 10 times higher before the application of the investigated organic materials. That is why the pore volume occupied by water increased 4-6 times in the desert soil and only 1.1-1.5 times in the old cultivated one after the application of the organic materials.

Water retention capacity in the arable layer of the old cultivated soil in Belarus was 62.0 mm on the control variant and after the application of manure increased up to 67.9 mm and reached 87.0 mm after the use of PSA. Water retention of the original desert soil was very small at only 4.3 mm, but it increased after PM application to 24.3 mm and after PSA application to 36.9 mm (increase of 20.0 and 32.6 mm, correspondingly).

It is worthwhile to notice that the pore volume occupied by water increased 4-6 times and water retention capacity 5.6-8.7 times in the desert soil, whereas in the old cultivated soil the water retention capacity increased proportionally to the increase of pore volume occupied by water. Probably, that could be explained by considerable improvement of structure in the desert soil in comparison to the old cultivated one after the application of the organic materials that linked with the different humus contents in these two original soils.

So, the increase of water retention capacity under the influence of organic materials had common trends both in the desert and the old cultivated soils. Application of organic materials was rather prospective from the point of view of phase ratio improvement and the increase of moisture stock in soils. Peat-sapropel ameliorant showed much better results in comparison to manure and PM in this context.

T a b l e 7. Influence of natural organic materials on soil phases and water retention capacity

Variant	Total porosity	Liquid phase	Gas phase	Solid phase	Water retention capacity	
	(%)				(t ha^{-1})	(%)
Field experiment in Belarus						
Control (cultivated soil)	46	21	25	54	62.0	100
Local manure	46	23	23	54	67.9	110
PSA	46	33	13	54	87.0	140
Field experiment in Egypt						
Control (desert soil)	47	2	45	53	4.3	100
PM	45	8	37	55	24.3	565
PSA	43	12	31	57	36.9	858

Table 8. Influence of PSA on granulometric composition of cultivated sandy loam soil in Belarus

Variant	Granulometric compositon (%, dia in mm)			
	1-0.25	0.25-0.05	0.05-0.01	<0.01
Control (original soil)	25.11	44.59	17.73	12.57
PSA	30.57	42.93	9.41	17.07

Table 9. Influence of PSA on aggregate composition of cultivated sandy loam soil in Belarus

Variant	Aggregates of air-dried soil (%, dia in mm)		Water-resistant aggregates (%, dia in mm)	
	>0.25	<0.25	>0.25	<0.25
Control (original soil)	53.9	46.1	34.7	65.3
PSA	69.4	30.6	44.5	55.5

The above mentioned regularities were explained by the results of investigations of the granulometric and aggregate composition of the old cultivated soil in Belarus (Tables 8 and 9). The amount of particles with size less than 0.01 mm increased by 36%. There is the need to notice that PSA contains 3 kinds of particles, namely: organic, organic-mineral and mineral ones. Organic particles are mineralized in soil mostly within 2-3 years, organic-mineral ones are much more resistant to mineralization and can be present in soils for decades of years, and mineral particles persist in soil indefinitely long, making a positive influence on the soil properties. PSA differs beneficially from peat and manure thanks to the content of mineral and organic-mineral particles, in fact.

Improvement of soil aggregation and granulometric compositions after PSA application led to improvements of porosity, phase composition and water-physical properties of soil in Belarus.

So, both the Egyptian and Belarussian field experiments showed considerable advantages of PSA in improvement of structure and water-physical properties of soils in comparison with peat and manure compost application.

CONCLUSIONS

1. As the results of the pot and field experiments showed, peat-sapropel ameliorant was the most effective means for prompt and substantial improvement of physical properties of desert sandy and low fertile sandy loam soils in comparison to manure, peat moos, ammonia humate and fulvic acid.

2. Peat-sapropel ameliorant possess the ability of complex improvement of the soil agrophysical properties including aggregate composition, porosity, its structure and water retention capacity, which is especially important in conditions of arid and semiarid climates and even humid zone in cases of unequal distribution of rainfalls and droughts.

3. Ammonium humate is a promising material for the improvement of the agrophysical properties of soils due to the comparatively low rates of its application, but its influence on soil properties change is much weaker if compared to the peat-sapropel ameliorant.

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