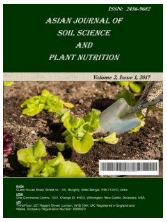

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Effect of Bio- and Synthetic- Polymers on Enhancing Soil Physical Properties and Lettuce Plant Production

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Most of new reclaimed soils in Egypt are light to medium in texture. They are mainly poor in physical and hydro-physical soil quality such as porosity, water retention capacity and available water content. The objective is to assess some bio-polymers and synthetic polymers to test their effects on the soil physical and hydro-physical properties and on Lettuce plant production.

Seven treatments were applied using bio-polymers (2%dextran, 3%alginate and 3% xanthan) and two synthetic polymers (2 and 3% polyacrylamide and 2 and 3% diaper). These polymers were cheeked for their efficiency in enhancing soil properties of Toshka soil and the growth performance of Lettuce plant (*Lactuca sativa*) grown in soil for 55 days under open field conditions was considered.

Fresh and dry weights of plant and nutrient contents were increased significantly with all bio-treatments amendment. Whereas, synthetic polymers caused negative effects on the previously mentioned parameters.

Concerning the effects on soil properties, dextran treatment recorded the lowest values of total drainable pores (TDP %), the highest values of porosity (%), and available water. Whereas, the

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synthetic polymers amended soil attained negative effect with all these measured parameters compared with control treatment.
The study declared beneficial order of enhancement of soil physical and hydro-physical properties and plant production as obtained with Dextran, followed by Alginate, and Xanthan bio-polymers, while synthetic polymers did not show such effects. Hence, the study recommend using bio-polymers instead of synthetic polymers.

Keywords: Biopolymers; synthetic polymers; soil physics; pore size distribution; soil conditioners; lettuce plant.

1. INTRODUCTION

The main production challenges of new reclaimed soils of Egypt, like Toshka region in Aswan Governorate are higher bulk density, poor water retention capacity, higher hydraulic conductivity, lower organic carbon content and lower biological activities. Physical quality of most of these soils is often poor due to high percentage of sand which causes macropores resulting in losses of water and nutrients from the root zone by deep percolation and preferential flow [1]. Therefore, producers and researchers alike are interested in improving the physical conditions of these soils and, thus, enhance crop production. These goals can be accomplished by using materials to improve the soil physical and hydro-physical conditions that called soil conditioners [2]. Soil conditioners vary greatly in their composition, application rate, and expected or claimed mode of action. They can be natural such as polysaccharides, humus, mulch and manure or synthetic such as polyacrylamide, polyvinyl alcohol, bituminous or asphalt emulsions, silicates of magnesium and aluminum in solution [3, 4].

Soil conditioners can improve soil quality for instance, structure and aeration; increased water-holding capacity (WHC) and availability of water to plants, release of what so called “locked” nutrients, better root development and higher yields and quality. Different soil types vary greatly in their physical, chemical, and biological properties, which influence the effectiveness of soil conditioners [2,5,6,7,8].

In a laboratory scale, Czarnes *et al*., [9] studied the efficacy in enhancing physical and hydro-physical properties and germination and seedling growth of the *Gossypium herbaceum* by using different biopolymers (i.e. xanthan, agar, cellulose, alginate, psyllium gaur gum, and other bacterial exopolysaccharide (EPS) powders. The efficacy of all biopolymers previously mentioned were found to increase more or less WHC, organic matter, total nitrogen, and PWP as compared to the control.

The objective of this study is to evaluate the effect of some biopolymers and some synthetic polymers on soil quality properties and Lettuce plant production in pot experiment under open field conditions.

2. MATERIALS AND METHODS

To investigate and compare between the effect of biopolymers and synthetic polymers in improving soil physical quality (e.g. the soil porosity, pore size distribution and available water) and Lettuce plant production. Soil samples were taken from Toshka region in Aswan governorate, Egypt to represent new reclaimed poor structure soils.

2.1 Soil Sampling and Characteristics

The soil samples were gently crushed and sieved to < 2 mm. Afterwards, the physical and chemical properties were determined according to the standard methods [10,11].

2.2 Polymeric Substances

In this study, two diversified types of extracellular polysaccharides (EPs) naturally produced by soil microbial cultures were used (i.e. xanthan from *Xanthomonas* isolates; dextran from *Leuconostoc* isolates, and alginate from *Azotobacter* isolates). Isolation of different isolates of *Xanthomonas*, *Leuconostoc* and *Azotobacter* were performed on specific media from various samples which were obtained from the unit of bio-fertilizers, Ain Shams Univ. The screening of potent cultures for each polymer was conducted based on their culture viscosities and on specific productive media. Five isolates of *Xanthomonas*, four *Leuconostoc* isolates and four *Azotobacter* isolates were cultured on different productive media to select the suitable medium for enhancing each polymer production.

The biological activity of potent culture for each polymer was determined under optimal nutritional conditions. Whereas, the synthetic polymers; polyacrylamide and diaper polymer were obtained from the Technogene Company in Dokki, Egypt.

2.3 Seedlings

Seedlings of Iceberg Lettuce (*Lactuca Sativa*) 25 days old were used for pot experiment. These seedlings were obtained from private farm at El Khatatba, El- Monifia governorate, Egypt.

2.4 Experimental Design

Open field experimental conditions were performed using pots, with, diameter of 14 cm and height of 20 cm, using filter paper at the bottom to prevent the soil from falling out [12]. Three treatments were conducted using biopolymers at the efficient rates, namely; dextran (2%), alginate (3%) and xanthan (3%). These rater were recommended in a previous study by Sodaf Ahmed *et al.,* [13].

Two synthetic polymers, namely polyacrylamide and diaper which were used at two ratios (2 and 3%), with five replicates. So, forty pots were used and packed up with 2 kg of sandy clay loam disturbed soil, including five pots as a control treatment (without any treatment).

After preparing the pots, *lactuca sativa* seedlings (25 days old) were cultivated and irrigated to field capacity for fifteen days. After that water depletion processing was done till 80% of field capacity until plant harvest at 55 days. At the end of the experiment, soil particle density, soil bulk density and pore size distribution were determined using undisturbed soil samples to assess the efficiency of tested polymers on soil quality. Fresh and dry weights and plant nutrient content were recorded after plant harvest.

2.5 Plant Vegetative Parameter

Plants were harvested at the end of the experiment. Whole plant was dried at 70°C for 3 days in oven until constant weight was obtained to record its dry weight.

2.5.1 Soil analyses at the end of experiments

At the end of the experiments, undisturbed soil samples were collected from the pots. Bulk and particle density, porosity of soil were determined according to Mashhour *et al.,* [14]. Pore size distribution was determined according to Nimmo [15].

2.6 Statistical Analyses

The effect of different ratios of bio-polymers and synthetic polymers on soil physical and hydro-physical quality and plant growth were assessed by one-way ANOVA and the Tukey's multiple range tests at a level of significance of $P < 0.05$ using Costat program (version 6.400) described by Arun and Rattan [16].

3. RESULTS AND DISCUSSION

The efficiency of using some biopolymers and synthetic polymers for enhancing poor physical and hydro-physical soil properties, and Lettuce plant production showed the following results.

3.1 Characteristic of Soil Sample

Table 1 shows some physical and chemical properties of the studied soil sample. The obtained data indicated that the soil sample has sandy clay loam texture, 1.63 g/ cm^3 bulk density, low total porosity (35.12%) and particle density of 2.51 g/ cm^3. The percentage of organic matter and calcium carbonate content were very low. The soluble salts content was also low (less than 4.0 dS/ m at 25^{o}C). As such, the soil sample can be classified as non-saline [17].

3.2 Soil Structure as Affected by the Added Polymers

3.2.1 Soil porosity

Porosity is the fraction of the total soil volume that is occupied by the pore space. As a basic physical property of soil, bulk density not only affects the availability of soil moisture and nutrients, but also indirectly reflects on soil quality and productivity [18].

Data of the soil particle and bulk density as well as porosity as influenced by polymer treatments are shown in Table 2.

Data in Table 2 indicated that the highest values of porosity were recorded for dextran (39.13). On the other hand, the lowest values were recorded for daiper polymer ratios. Statistical analysis revealed that the soil porosity data show significant differences between every treatment with the control. This can be noticed easily where treatments have the same letter are not significant at the 5% level according to LSD-test.

Slight significant differences were found between DIP ratios and control, these findings agreed with several authors [5,19].

Generally, the beneficial order of enhancement soil porosity was in the order: biopolymers dextran > alginate > xanthan and synthetic polymers; daiper polymer, respectively.

3.2.2 Pore size distribution

Pore size distribution (PSD) and available water (AW) were concluded from soil water retention curves [15].

The changes in pore-size distribution arising from mechanical loading, chemical treatment, plant root growth, freezing and thawing, or other influences, often need to be taken into account in interpreting experimental results [20,21].

Data of the pore size distribution; FCP, WHP and TDP of soil cultivated with *Lactuca sativa* in the presence of different bio and synthetic polymers are shown in Fig. 1. These data indicated that the lowest values of TDP% were recorded for dextran (28.7%) against 58.29% for the control treatment. On the other hand, the highest values of TDP% were recorded for synthetic polymers and ranged from 50.65, with 3% to 52.15 with 2% of DIP, respectively. Various effects were noted by increasing both synthetic polymers from 2 to 3%. Decreases in TDP% in cultivated soil indicated a good effect which means improving soil structure. Also, data indicated that the highest values in WHP% were recorded for dextran. On the other hand, the lowest values were recorded for synthetic polymers from 4.67, with 3% DIP to 5.4 in presence of 3% PAM. Increasing in WHP% in sandy clay loam soil occurred which means improving soil structure.

Also, data indicated that the highest values in FCP% were recorded by dextran (19.46%) increased by 70.0% than control. On the other hand, the lowest values were recorded by synthetic polymers being 6.10 and 6.55% for DIP at 3% and PAM at 3%. Various effect were noticed by increasing the ratios of both synthetic polymer from 2 to 3%. These results agreed with those obtained by Green and Juniper [5].

In general, statistical analysis of measured parameters (FCP, WHP and TDP) stated significant differences between all treatments and control indicating positive effects when biopolymers were used and negative effect with synthetic polymers. The used of biopolymers increased WHP% and decreased TDP% and FCP%, total drainable pores TDP %, and vice versa when using synthetic polymers.

3.2.3 Available water content

Available water content (AW) calculated from subtraction of volumetric water content at field capacity from that at permanent wilting point. Data of the available water content are presented by Fig. 2. Data indicated that the highest values of AW% were recorded for dextran (24.71%). On the other hand, the lowest values were recorded for synthetic and polymers ranged from 2.4, with 3% DIP to 3.13 with 2% DIP. On top of the immense water holding capacity of the biopolymer itself, which increases the soil water content, Martinez and Zinck [6] suggested that this increase can be partly attributed to the biopolymer separating soil particles and consequently maintaining a more open pore structure.

Statistical analysis of AW% showed significant differences between all treatments and control; but the positive effects were obtained by using biopolymers. This agreed with the results of Barthes and Roose [22]. Increasing in AW% values in sandy clay loam (cultivated soil) is beneficial effect which means enhancing water holding capacity, and hence improve soil hydro-physical quality and vice versa, when using synthetic polymers.

Generally, increasing in soil porosity and AW beside enhancing PSD values due to using biopolymers in sandy clay loam (cultivated soil) is considered good effect. It means that improving physical and hydro-physical soil properties. Vice versa effects were obtained when using synthetic polymers. These results may be attributed to the effect of organic matter content of microbial biomass and microbial byproducts including cell wall residues and extracellular polysaccharides [2,14,23].

Based on the above, biopolymers had positive effect in improving the physical and hydro-physical soil properties, this was consistent with [24,25,26,27,28], While the results were not agree with [29,30], might be due to the high percentages used from synthetic polymers in this study, where the recommended rates in their researches were from 0.001 to 1%.

3.3 Growth Response of Lettuce (*Lactuca sativa*) as Affected by the Polymers

Seedling developments are critical phases in the early growth and establishment of any plant. In arid and semiarid environments, water retention capacity plays a key role in the growth and establishment of crops.

It was observed that addition of biopolymers to sandy clay loam showed potential effects on seedling growth and biomass production (Table 3).

Data in this Table present the dry and fresh weight and nutrient content of *Lactuca sativa* plant as affected by polymers treatments. Obviously results indicated stimulatory response of dry and fresh weights of plant due to the amendment with biopolymer compared with synthetic polymer and control treatments. In this respect, fresh and dry weights of *Lactuca sativa* plants were increased significantly from 470.3 and 17.5 g/ plant the control treatment to 655.2 and 28.5 g/ plant for dextran and to 560.3 and 21.1 g/ plant for alginate treatments, respectively. Dextran at ratio of 2% exhibited the highest effect on fresh and dry weights of plants followed by alginate (3%) treatments.

Moreover, it was observed that the studied synthetic polymers gave significantly the lowest values of fresh and dry weights of plant. Dextran improved the plant growth by 39.34% and 62.86% in fresh and dry weights of plant compared to the untreated soil (control).

Data in Table 3 represent the nutrient content as percentage and plant uptake as influenced by biopolymers and synthetic polymers treatments. In general, plants grown with biopolymers treatments contained high amounts of nitrogen, phosphorus and potassium than control and synthetic polymer treatments. The most pronounced effect of this application was manifested in plants grown with dextran treatment giving 30mg N/ plant ، 20mg P/ plant and 60mg K/ plant for plant uptake. Synthetic polymers at different ratios recorded significantly the lowest values of nitrogen, phosphorus and potassium uptake which ranged from 3 to 5, 4 to 7 and 7 to 10 mg/ plant, respectively. Alginate treatment at 3% gave less nitrogen and phosphorus uptake for *Lactuca sativa* plant than that obtained with xanthan (3%) treatment, whereas xanthan recorded potassium uptake higher than alginate treatment. It was observed that synthetic polymers gave high values of nitrogen, phosphorus and potassium uptake at ratio of 2% than 3% of polymer ratio.

The superiority of nutrient uptake was recorded for dextran treatment which increased nitrogen, phosphorus and potassium uptake by 3, 2.5 and 2.5 fold as compared with the control treatment. In this concern, Patil *et al.,* [31] found that addition of biopolymer showed high potential effects on seedling growth of *Gossypium herbaceum* plant and biomass production.

Table 1. Some physical and chemical properties of the studied soil sample

% Particle size distribution *				Texture class	ρ_s g/cm^3	ρ_b g/cm^3	% *f*	% OM	$CaCO_3$ %	EC_e ** (Sd/m)	pH (paset)
Clay	Silt	Fine Sand	Coarse Sand								
30.11	5.17	42.81	21.91	Sandy Clay Loam	2.51	1.63	35.12	0.17	1.54	1.35	7.90

Each value is the mean of three replicates.
ρ_s is the Particle density.
ρ_b is the Bulk density. f % is the percentage of porosity.
*According to ISSS classification. ** Electrical conductivity at 25^{0}C in soil paste extract*

Table 2. Particle and bulk density, and percentage of porosity of studied soil samples cultivated with *Lactuca sativa* and treated by bio and synthetic polymers

Type of polymer	Ratio of polymer (%)	ρ_s (g/cm^3)	ρ_b (g/cm^3)	*f* %
Control	0	2.47	1.6	35.22 a
Dextran	2	2.3	1.4	39.13 e
Alginate	3	2.33	1.42	39.06 d
Xanthan	3	2.36	1.49	36.86 c
Polyacrylamide (PAM)	2	2.46	1.59	35.26 a
	3	2.45	1.55	35.20 a
Daiper polymer (DIP)	2	2.45	1.56	35.99 b
	3	2.45	1.55	35.36 b

Each value is the mean of five replicates.
Means having the same letter in each separate column are not significantly different at the 5 % level according to LSD-test.

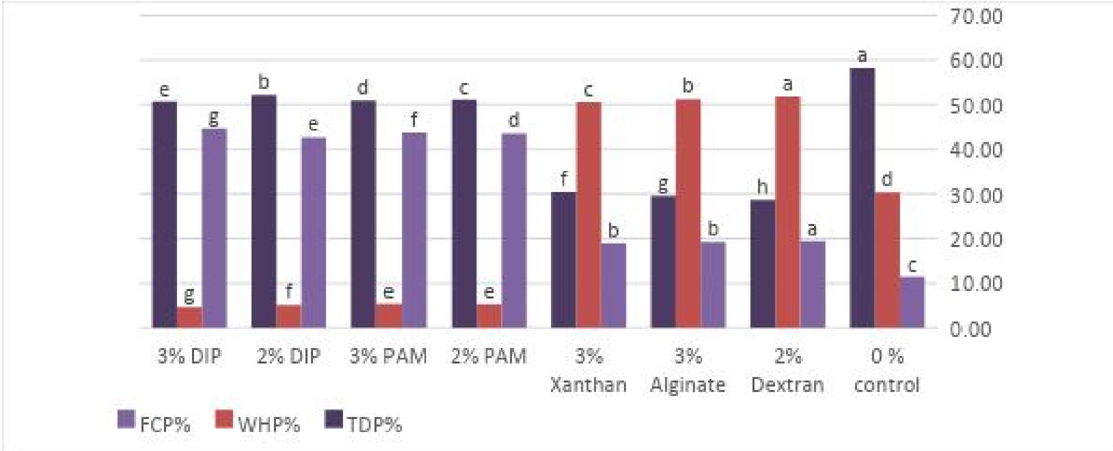

Fig. 1. Pore size distribution of sandy clay loam soil cultivated with *Lactuca sativa* and treated by bio and synthetic polymers

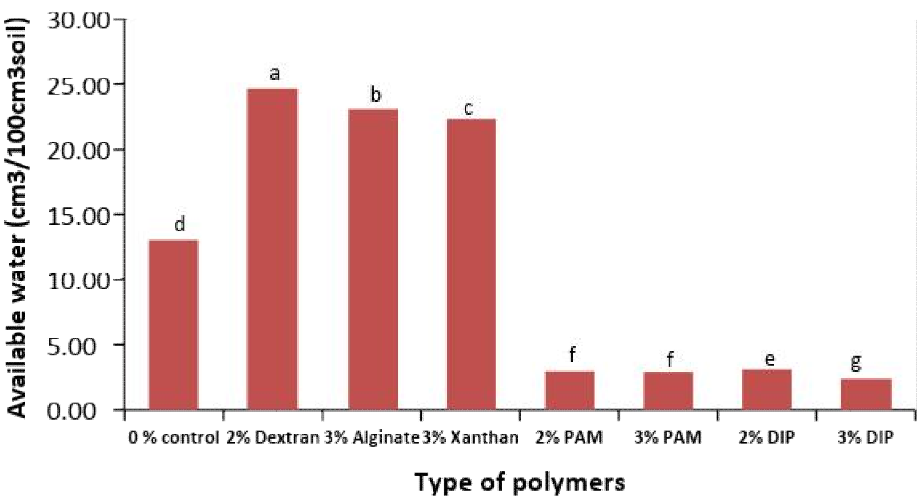

Fig. 2. Available water (cm^3/ $100cm^3$ soil) of sandy clay loam soil cultivated with *Lactuca sativa* and treated by bio and synthetic polymers

Table 3. Effect of bacterial and synthetic polymers amendment on plant growth and nutrient content of *Lactuca sativa* plant grown in sandy clay loam

Polymer type	Concentration used	Total plant mass g/plant		Plant nutrient content					
		Dry weight	Fresh weight	Total nitrogen		Total phosphors		Total potassium	
				N %	Uptake mg/plant	P %	Uptake mg/plant	K %	Uptake mg/plant
Control	0	17.5d	470.3	0.63	1c	0.46	0. 8bc	1.10	2c
Dextran	2%	28.5a	655.2	1.05	3a	0.84	2a	1.95	6a
Alginate	3%	21.1b	560.3	0.84	2b	0.55	1b	1.60	3b
Xanthan	3%	19.6c	530.1	0.91	2b	0.66	1b	1.49	3b
Polyacrylamide	2%	16.0e	370.2	0.35	0. 5e	0.27	0. 4c	0.65	1c
Polyacrylamide	3%	13.0g	350.4	0.28	0. 3f	0.24	0. 7bc	0.55	0. 7d
Diaper polymer	2%	14.4f	349.6	0.49	0. 7d	0.35	0. 5c	0.75	0. 1c
Diaper polymer	3%	12.0h	330.3	0.42	0. 5e	0.33	0. 4c	0.63	0. 7d

Based on the above, biopolymer addition showed positive significant effects, while synthetic polymers had negative significant effects on the physical properties of soil. This was reflected on the growth performance and lettuce plant production, this was consistent with [32,33,34].

4. CONCLUSION

In our study summary, we found that the addition of biopolymers treatments (i.e. Dextran, 2%, Alginate, 3% and Xanthan, 3%; these percentages are recommended) to poor structural soil cultivated with Lettuce plant in open field pots experiments, enhanced soil physical and hydro-physical properties (i. e. the soil bulk density, the porosity, Pore size distribution and available water) relative to control. Whereas, using of synthetic polymers treatments (i.e. polyacrylamide, 2 and 3%, and diaper, 2 and 3 %; to simulate previous ratios) caused inversely effect on the previous parameters of soil quality. Moreover, the effects of biopolymers and synthetic polymers treatments on soil properties were reflected on the growth performance and lettuce plant production. Fresh and dry weights of plant and nutrient contents were increased significantly with all bio-treatments amendment. Whereas, synthetic polymers treatments caused negative effects on the previously mentioned parameters compared with control treatment.

Consequently, the study declared beneficial order of enhancement of soil physical and hydro-physical properties and lettuce plant production as obtained with Dextran, followed by Alginate, and Xanthan bio-polymers, while synthetic polymers did not show such effects.

Through the benefit/ cost analysis one may recognize in the presented study that the use of naturally produced bio-polymers can give a higher and maybe more save healthy product (Lettuce) than the artificial polymers. As such, cost calculation showed that production of 5 lettuce plants due to bio-polymers application at the lowest used rate costs 1.1 US$ compared to 1.4 US$ when using artificial polymers. Therefore, it may be advisable to apply the used bio-polymers under commercial large scale production conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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