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Effects of applications of synthetic polymer and humic acid on resistance to dispersion and mechanical forces

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Abstract

In this study, the effects of the addition of polyvinyl alcohol (PVA), polyacrylamide (PAM), and humic acid (HA) to soils in sandy loam, loam, and clay texture classes on their resistance to dispersion and mechanical forces were examined. The study was performed under greenhouse conditions using surface soil samples and 1.5 kg pots. Furthermore, the study was planned as an incubation experiment and the application of PVA, PAM, and HA at 500, 100, and 500 ppm doses for each soil texture class, respectively. During the incubation times (1 (0), 2 (15), 3 (30) 30, and 4 (45) days), the irrigation process was repeated as half of the available moisture in the soil was depleted. Ultimately, the applications of PVA, PAM, and HA on soils in sandy loam, loam, and clay textures increased the liquid limit/ pF'2 moisture ratio (LL/pF'2) values in them by 6.30%, 5.99%, and 7.30%, respectively, (reducing the tendency to dispersion) compared to the control. Furthermore, the applications increased the plastic limit/pF'2 moisture ratio (PL/pF'2) values (resistance to mechanical forces) by 22.31%, 16.50%, and 9.27%, respectively. Incubation time 1 was more effective in reducing dispersion and increasing resistance to mechanical forces, and the effects decreased over time. PVA was the most effective conditioner for all three soil groups.

Introduction

Soil structure is the arrangement and grouping of primary and secondary soil particles in certain shapes along weak surfaces that can be easily separated from each other and is a dynamic characteristic of the soil. This dynamic structure is crucial for creating an environment suitable for plant cultivation and a structure resistant to erosion (Özdemir and Canbolat, 1997; Özdemir and Bülbül, 2021). Soil texture, organic matter content, climatic conditions, land use, and conditioner practices significantly affect the resistance of the dynamic structure to dispersion and mechanical forces. Hacımüftüoğlu (2012) investigated the effects of plants grown under the conditions of the Erzurum region on the structural parameters of the soil and found that the structural parameters of the soil were significantly different depending on the plant pattern cultivated. In research under the conditions of the Turhal region, Bülbül (2019) found that basic soil properties and plant management practices were effective on structural durability and sensitivity to erosion and that the most appropriate parameters were in grassland areas, while the most negative parameters were in the soil in sugar beet cultivation areas.

Different methods can be employed to improve the soil structure and create soils that are resistant to mechanical forces, dispersion, and erosion and suitable

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for plant cultivation (Demir et al., 2022). These methods include conservation tillage (Busari et al., 2015), the addition of organic matter (Wuddivira and Camps-Roach, 2007) and green manure (Gao et al., 2018), biological fertilization (Lucas et al., 2014), and the addition of organic matter based synthetic environmental conditioners to the soil. Polyvinyl alcohol, polyacrylamide and humic acid are widely used for these purposes because they are effective at low doses (Tejeda and Gonzales, 2007; Hacımüftüoğlu and Canbolat, 2020).

Polyacrylamide application increases aggregate stability (Mamedov et al., 2007; Kassim and Özdemir, 2022), reduces water and soil loss (Bjorneberg et al., 2003; Sojka et al., 2007), prevents crust formation, and reduces plant nutrient loss (Sojka et al., 1998; Özdemir et al., 2014). In their study examining the effects of PAM and PVA applications on soil properties and NPK uptake in coarse and fine-textured soils, Çağlar and Demir (2021) found that the application positively affected the physical structure and NPK nutrition of the jute plant in both (loam, clayey) soil groups. Kassim and Özdemir (2022), on the other hand, evaluated the effect of PVA, PAM, and HA acid applications on aggregate stability and found that PVA was more effective than other conditioners and that the effect was at a proportionally lower level in clay soil.

Today, humic acid, polyacrylamide, and polyvinyl alcohol are the most commonly used synthetic improvers. The effectiveness of these conditioners varies depending on the application doses, application time, application method, climatic conditions, and the effect of soil properties on polymer degradation (Blanco-Canqui and Lal, 2008). Various test techniques may be employed to evaluate the effect of these conditioners on soil structure (Özdemir, 2013). This study examines the effect of the application of humic acid (500 ppm), polyacrylamide (100 ppm), and polyvinyl alcohol (500 ppm) on sandy loam, loam and clayey soil's resistance to mechanical forces and its dispersion in water over time.

Materials and Methods

Three different soil types with sandy loam, loam and clayey textures were used in this study (Table 1). They were obtained from three different locations (41°50'-35°82'; 41°55'-35°86'; 41°36'-36°18') in the research area of Ondokuz Mayıs University. Soils were ready for use after drying and sifting processes. Three different commercial conditioners, namely, polyvinyl alcohol (PVA), polyacrylamide (PAM), and humic acid (HA) were employed in the study. Polyacrylamide ($CH_2CHCONH_2$) was a 98% hydrolysis commercial product with a molecular weight of 10000 mg/mol, and Polyvinyl alcohol (C_2H_4O) was a 98% hydrolysis commercial product with a molecular weight of 72000 g/mol. The humic acid used had a 15% humic and fulvic acid content.

Soils were weighed based on their kiln-dried weights and transferred to 1500 g pots. Afterward, PAM, PVA, and HA were added to the pots at doses of 500, 100, and 500 ppm, respectively (Kassim and Özdemir, 2022; Yakupoğlu and Öztaş, 2016; Yakupoğlu et al., 2019). After the addition process, the pots were left to incubate in the greenhouse (25 ^{0}C) for 0, 15, 30, and 45 days. During this period, irrigation was done when 50% of the ideal moisture in the soil was exhausted. After the end of each period, soil samples were dried in the air and crushed by hand and made ready for analysis.

In the laboratory analyses, texture (% sand, silt, clay) was determined based on the hydrometer method (Demiralay, 1993); soil reaction (pH) based on pH-meter in 1:1 (w/v) soil:pure water mixture (Kacar, 2016);

Table 1. Some of the physical and chemical properties of the soils

Soil num.	Soil properties								
	Sand %	Silt %	Clay %	Tekture	pH (1:1)	EC dS/m	$CaCO_3$ %	OM %	CEC me/100g
1	58.88	29.36	11.76	SL	7.90	0.118	8.23	0.80	31.69
2	36.40	41.60	22.00	L	7.45	0.492	8.42	2.98	38.28
3	31.72	23.17	45.11	C	6.95	0.149	2.20	1.59	65.40
	Parameters								
				LL/pF'2	PL/pF'2				
1				0.70	0.58				
2				0.82	0.64				
3				0.98	0.69				

OM: organic matter, CEC: cation exchange capacity, CaCO3: lime content, EC: electrical conductivity, LL: liquid limit, PL: plastic limit electrical conductivity (EC) based on EC-meter in 1:1 (w/v) soil:pure water mixture (Kacar, 2016); lime content ($CaCO_3$) based on Scheibler calcimeter (Rowell, 1996); cation exchange capacity (CEC) based on Bower method (Kacar, 2016); organic matter content based on Walkey-Black method (Kacar, 2016); field capacity based on pressure table (Demiralay, 1993); PF'2 moisture content based on Pressure table (Demiralay, 1983); liquid limit (LL) based on Casagrande's method, (Demiralay, 1993); plastic limit (PL) based on plastic limit roller method (Demiralay, 1993), and finally, LL/pF'2 and PL/pF'2 moisture contents ratio based on (Özdemir, 2013).

Results and Discussion

Soil Properties

Some of the physical and chemical properties of the soils used in the study conducted under greenhouse conditions are given in Table 1. As can be seen in Table 1, sandy loam (1) textured soil has a moderately alkaline reaction and a moderately calcareous structure with low organic matter content. Loam-textured (2) soil has a slightly alkaline reaction and a moderately calcareous structure with high organic matter content. Clay-textured (3) sample has a neutral reaction and a less calcareous structure with moderate organic matter content. The pH values of the soils are below 8.5 and there is no alkalinity problem in the soils (Soil Survey staff, 1993).

Dispersion and Resistance to Mechanical Forces

The following parameters were used to evaluate the effects of the applications and processes on the soil's dispersion and resistance to mechanical forces.

LL/pF'2 Moisture Ratio

Table 2 shows the effects of PVA, PAM, and HA added to soil samples with sandy loam, loam, and clay textures on soil resistance to dispersion (LL/pF'2 moisture ratio) and the results of the variance analysis test for related of this resistance values over time (0, 15, 30, 45 days), while Table 3 shows the average changes related to these values and the results of the multiple compare test. The changes in the said ratio compared to the control are shown in Figures 1 and 2. As can be seen in the variance analysis test results, the mean value of the squares of the LL/pF'2 moisture ratio values were significant ($p<0.01$). In other words, the soils differed in terms of their sensitivity to dispersion at the end of the experiment.

The same data indicates that the effects of the three conditioners and the application times are also significant ($p<0.01$). The results of the analysis also indicated that the interactions between soil x conditioner (A*B), soil x period (A*C), conditioner x period (B*C), and soil x conditioner x period (A*B*C) for LL/pF'2 values were significant.

Significant changes were observed in LL/pF'2 value compared to control (Table 3). The change varied depending on the time, conditioner type, and soil texture. Considering the increases compared to control, PVA was the most effective conditioner in all three soil classes.

A multiple compare test (Duncan) was performed using the values to compare the effects of soils, conditioners, and application periods on the LL/pF'2 moisture ratio at the end of the experiment. These test data indicate that the soils are significantly different from each other in terms of the average LL/pF'2 moisture ratio at the end of the experiment. The said evaluation also indicated that the conditioner periods were ranked, as shown in Table 3, based on the average LL/pF'2 moisture ratios at the end of the experiment. In this multiple-compare test, the differences between the application times were significant ($p<0.01$), and the effectiveness decreased over time (Table 3).

On the other hand, according to the same test results, the differences between PVA, PAM, and HA were significant ($p<0.01$) in terms of average LL/pF'2 moisture contents at the end of the experiment.

Considering the rate changes (%) in LL/pF'2 moisture contents compared to the control (Figure 1), PVA, PAM, and HA caused increases in LL/pF'2 moisture rate

Table 2. The results of the variance analysis of LL/pF'2 moisture ratio values

Sources	Degrees of freedom	Sum of squares	Mean of squares.	F value	Level of significance
A*	2	0.176	0.088	220.121	0.000
B	2	0.185	0.092	230.992	0.000
C	3	0.211	0.070	175.502	0.000
A*B	4	0.022	0.006	14.017	0.000
A*C	6	0.276	0.046	114.877	0.000
B*C	6	0.013	0.002	5.403	0.000
A*B*C	12	0.056	0.005	11.573	0.000
Mistake	72	0.029	0.000		
General	108	108.992			

A: Soils, B: Conditioners, C: Periods

Table 3. LL/pF'2 moisture ratio values of soils and multiple comparison test (Duncan) results

Soils	Conditioners	Periods				Soil averages
		1	2	3	4	
	PVA	0.826	0.782	0.750	0.746	
SL	PAM	0.765	0.741	0.730	0.726	0.745 a
	HA	0.756	0.738	0.690	0.685	
	PVA	0.950	0.930	0.897	0.850	
L	PAM	0.919	0.862	0.842	0.839	0.869 b
	HA	0.896	0.845	0.819	0.781	
	PVA	1.164	1.193	1.099	1.033	
C	PAM	1.068	1.062	1.002	0.996	1.050 c
	HA	1.035	1.015	0.987	0.965	
Period averages		0.931 a	0.908 b	0.868 c	0.847 d	
Conditioners averages	PVA	0.935 a				
	PAM	0.879 b				
	HA	0.851 c				

The difference between the mean values shown with different letters are significant at the 1%.

depending on the application times. The change was 6.30 in SL class soil, 5.99 in L class soil and 7.30 in C class soil. In other words, the activities of the conditioners changed depending on the texture and the effect on the soils was C>SL>L in this respect. On the other hand the respective effect of different conditioners were: PVA: C soil (14.51)> SL soil (10.85)> L soil (10.58); PAM: SL soil (5.78)> L soil (5.54)> C soil (5.30); HA: SL soil (2.46) >C soil (2.09) >L soil (1.86) (Figure 1). Conditioners may have been more effective in increasing the stability in clay soils due to the combined effects of the clay and the conditioners.

PVA, PAM, and HA applications created significant time-dependent differences in the LL/pF'2 moisture ratiot of the soil compared to the control (%) (Figure 2). As the figure shows, the differences varied depending on the texture of the soil, and the ranking of the periods based on the effectiveness was, 1st period (12.36) > 2nd period (9.03) > 3rd period (4.12) > 4th period (1.82).

The LL/pF'2 moisture content value reflects the resistance of the soils to dispersion when wet, and if the ratio is greater than 1, there is no risk of deterioration of the structure through dispersion when wet. On the other hand, the soil will be easily dispersed when wet if the said value is less than 1 (de Boodt et al., 1967; Demiralay, 1983; Karagöktaş and Yakupoğlu, 2014; Özdemir and Bülbül, 2021). An evaluation of the research data would suggest that the soils were structurally sensitive to dispersion before the

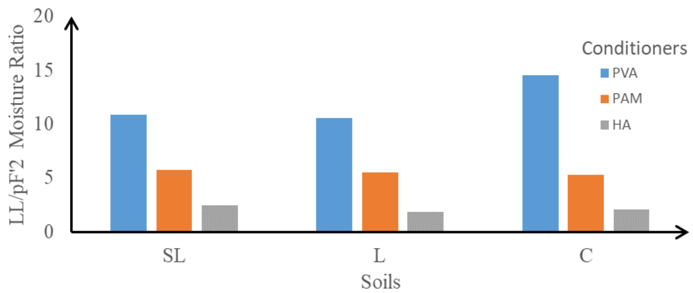

Figure 1. Changes in LL/pF2' moisture ratio values of soils depending on conditioners

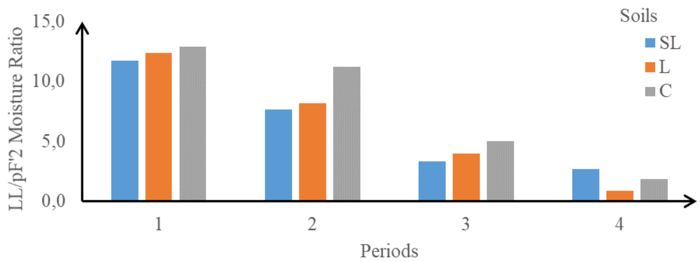

Figure 2. Changes in LL/pF'2 moisture ratio values according to periods

experiment, PVA, PAM, and HA added to the soils increased the LL/pF'2 moisture ratio, thus making them more stable compared to the initial conditions, the effectiveness decreased over time, and the applications were insufficient in terms of limit value in the two soil groups, except those in C class. In a study examining the effects of PVA, PAM, and HA applications on structural stability, Aksakal and Öztaş (2010) emphasized that synthetic conditioners increase stability and PVA is more effective within this scope. In a similar study, Kassim and Özdemir (2022) indicated that synthetic conditioner applications increase stability and their effect varies depending on the textural structure of the soil.

PL/pF'2 Moisture ratio

Table 4 shows the effects of PVA, PAM, and HA added to soil samples with sandy loam, loam, and clay textures on soil resistance to mechanical forces (PL/pF2 moisture content) and the results of the variance analysis test performed to examine the change of this resistance values over time (0, 15, 30, 45 days), while Table 5 shows the average changes related to these values and the results of the multiple compare test. The changes in the said ratio compared to the control are shown in Figures 3 and 4. As can be seen in the variance analysis test results, the mean value of the squares of the PL/pF'2 moisture ratio values were significant ($p<0.01$). In other words, the soils differed in terms of the ratio at the end of the experiment.

The same data indicates that the effects of the three conditioners and the application times are also significant ($p<0.01$). The results of the analysis also revealed that the interactions between soil x conditioner (A*B), soil x period (A*C), conditioner x

Table 4. The results of the variance analysis of PL/pF'2 moisture ratio values

Sources	Degrees of freedom	Sum of squares	Mean of squares.	F value	Level of significance
A	2	0.073	0.037	218.640	0.000
B	2	0.056	0.028	168.497	0.000
C	3	0.035	0.012	70.031	0.000
A*B	4	0.010	0.003	15.271	0.000
A*C	6	0.057	0.010	56.854	0.000
B*C	6	0.006	0.001	6.201	0.000
A*B*C	12	0.023	0.002	11.579	0.000
Mistake	72	0.012	0.000		
General	108	58.146			

A: Soils, B: Conditioners, C: Periods

Table 5. PL/pF'2 moisture ratio values of soils and multiple comparison test (Duncan) results

Soils	Conditioners	Periods				Soil averages
		1	2	3	4	
SL	PVA	0.783	0.745	0.707	0.682	0.709 a
	PAM	0.748	0.727	0.716	0.673	
	HA	0.742	0.711	0.657	0.622	
L	PVA	0.800	0.787	0.777	0.752	0.746 b
	PAM	0.785	0.745	0.711	0.692	
	HA	0.776	0.721	0.717	0.685	
C	PVA	0.827	0.787	0.768	0.747	0.754 c
	PAM	0.769	0.761	0.742	0.727	
	HA	0.739	0.722	0.755	0.707	
Periods averages		0.774 a	0.740 b	0.727 c	0.698 d	
Conditioner averages	PVA	0.763 a				
	PAM	0.733 b				
	HA	0.713 c				

The difference between the mean values shown with different letters are significant at the 1%.

period (B*C), and soil x conditioner x period (A*B*C) for PL/pF'2 values were significant.

Significant changes were observed in PL/pF'2 value compared to the control (Table 5). The change varied depending on the time, conditioner type, and soil texture. Considering the increases compared to control, PVA was the most effective conditioner for all three soil texture classes.

A multiple compare test (Duncan) was performed using the values to compare the effects of soils and application periods of PVA, PAM, and HA on the PL/pF'2 moisture ratio at the end of the experiment. An evaluation of the test results indicates that the soils are significantly different from each other in terms of the average PL/pF'2 moisture ratio at the end of the experiment. The said evaluation also indicated that the conditioner periods were ranked, as shown in Table 5, based on the average PL/pF'2 moisture ratios at the end of the experiment. In this multiple-compare test, the differences between the application times were significant ($p<0.01$), and the effectiveness decreased over time. On the other hand, according to the same test results, the differences between PVA, PAM, and HA were significant ($p<0.01$) in terms of average PL/pF'2 moisture contents at the end of the experiment.

Considering the rate changes (%) in PL/pF'2 moisture contents compared to the control (Figure 3), PVA, PAM, and HA caused increases in PL/pF'2 moisture rate values depending on the application times. The mean change was 22.31 in SL class soil, 16.50 in L class soil, and 9.27 in C class soil. In other words, the activities of the conditioners changed depending on the texture and the effect on the soils was SL>L>C in this respect. On the other hand the respective effect of different conditioners were: PVA; SL soil (25.73)> L soil (21.71)> C soil (13.32); PAM: SL soil (23.47)> L soil (14.53)>C soil (8.70); HA: SL soil (17.73)>L soil (13.28)>C soil (5.80) (Figure 1). Conditioners may have been less effective in increasing the mechanical resistance in clay soils due to the combined effects of the clay and the conditioners.

PVA, PAM, and HA applications created significant time-dependent differences in the PL/pF'2 moisture content of the soil compared to the control (%) (Figure 4). As can be seen in Figure 4, the differences varied depending on the texture class of the soil and conditioner type, and the ranking of the periods based on the effectiveness was, 1st period (12.80) > 2nd period (9.71) > 3rd period (9.27) > 4th period (5.22), meaning that the effects decreased over time.

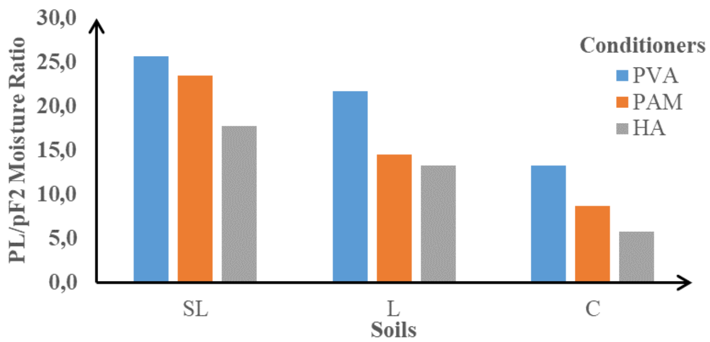

Figure 3. Changes in PL/pF2' moisture ratio values of soils depending on conditioners

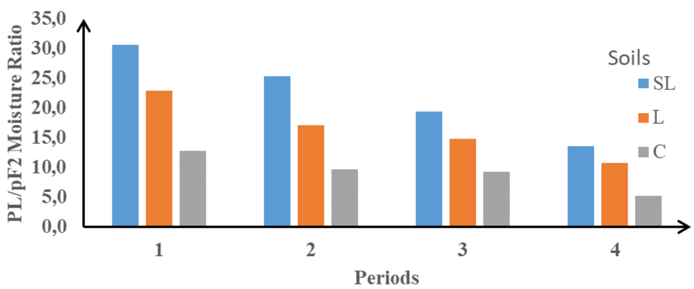

Figure 4. Changes in PL/pF'2 moisture ratio values according to periods

The PL/pF'2 moisture content ratio reflects the resistance of the soils to mechanical forces, and if the rate is greater than 1, the soil is considered to be resistant to mechanical forces, while values less than 1 (0.6-0.7) indicate sensitivity to the mechanical forces (de Boodt et al., 1967; Demiralay, 1983; Karagöktaş and Yakupoğlu, 2014; Özdemir and Bülbül, 2021). An evaluation of the research data would suggest that the soils were sensitive to mechanical forces before the experiment, PVA, PAM, and HA added to the soils increased the PL/pF'2 moisture ratio, thus making them more stable compared to the initial conditions, the effectiveness decreased over time, and the conditioners were insufficient in terms of limit value in all three soil groups. In a study examining the effects of PVA, PAM, and HA applications on structural stability, Aksakal and Öztaş (2010) emphasized that synthetic conditioners increase stability and PVA is more effective within this scope. In a similar study, Kassim and Özdemir (2022) indicated that synthetic conditioner applications increase stability and their effect varies depending on the textural structure of the soil. Examining the durability of the soil against grazing, Sönmez (1978) found that there was a positive relationship between the PL/pF moisture ratio and the criteria based on structural stability.

Conclusions

As a result of this study performed under greenhouse conditions to determine the effects of synthetic polymer and humic acid applications on dispersion and resistance to mechanical forces, it was found that;

Polyvinyl alcohol, polyacrylamide, and humic acid applied to the soil samples significantly increased the resistance to dispersion values of the soil, PVA was more effective than other conditioners, and the said increases in resistance were affected by the texture, and the soils were ranked as C>SL>L in this respect. On the other hand, the effectiveness of conditioners decreased as the period length increased. The applications were insufficient in terms of the recommended limit value for durability in two soil groups, except in the clay (C) texture class.

The application of polyvinyl alcohol, polyacrylamide and humic acid significantly increased the resistance to mechanical forces values of the soils, PVA was more effective than other conditioners, the said increases were affected by the texture and the soils were ranked as SL>L>C in this respect. On the other hand, the effectiveness of conditioners decreased as the period length increased, and the conditioners were insufficient in terms of the limit value related to durability in all three soil groups.

In conclusion, the effects of polyvinyl alcohol, polyacrylamide, and humic acid applications improved the resistance to dispersion and mechanical forces values of soils, and the effectiveness varied depending on the properties of the conditioners, soil texture class, and duration. It would be helpful to pay attention to these issues in practice.

Conflict of Interest

There is no conflict of interests at all.

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