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The effects of polyacrylamide on the parameters of physical quality in a clay loam soil selected from semiarid region

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Abstract

In semiarid regions, physical quality of fine-textured soils is generally poor due to low rate of organic matter and consequently weak stability of aggregates. A greenhouse experiment was conducted to evaluate the effects of anionic polyacrylamide (PAM) on some physical quality indices and also their temporal variability in a clay loam soil which was selected from a semiarid region in the west of Iran. These indices were mean weight diameter (MWD) of aggregates, dispersible clay ratio (DC), saturated hydraulic conductivity (K_s), and total porosity (n). The rates of PAM including 0 (control), 0.125, and 0.25 g kg^{-1} of air dry soil were mixed with the soil and uniformly packed into plastic pans, and incubated in a greenhouse at 0.7 to 0.8 field capacity moisture content (0.123-0.14 g g^{-1}) and 22 ± 4 ºC for 6 months . MWD, DC, K_s, and n were measured for the soil taken from the 10–15 cm layer of pans at 30, 90, and 180 days. The results showed that both low and high rates of PAM significantly increased the means of MWD by 83 and 127 % and n by 8.75 and 7.75 %, respectively compared with the control even 6 months after the start of the experiment. Also, both low and high rates of PAM significantly decreased the mean of DC by 31 and 43 % and increased the mean of K_s by 11.5 and 14.5 %, respectively relative to the control. The beneficial effects of PAM on soil physical quality were reduced with time. By considering the application cost of PAM, it can be suggested that in semiarid regions, 0.125 g PAM kg^{-1} of air dry soil is a suitable application rate for improving physical quality of fine-textured soils.

***Keywords*:** Polyacrylamide, Soil physical quality, Semiarid regions, Incubation time.

1. Introduction

Soil quality is considered to be a important issue in identifying appropriate management practices for sustainable land use (Dexter, 2004). There are many indices for the assessment of soil physical quality. Some of them are: soil texture, density, porosity, hydraulic conductivity, infiltration, moisture curve slope, aggregate stability, and dispersible clay ratio.

In arid and semiarid regions of Iran, the physical quality of fine-textured soils (clay and clay loam) is often poor due to the low organic matter content and weak stability of aggregates (Tajik, 2004; Sepaskhah and Mahdi-Hosseinabadi, 2008). For example, Tajik (2004) reported that in 30 soils selected from different places of semiarid regions in Iran, the ranges of organic carbon (OC), water aggregate stability (WAS), and dispersible clay ratio (DC) varied from 0.38 to 2.48 %, 12.05 to 59.92 %, and 0.705 to 0.83 g $100g^{-1}$, respectively. Moreover, in these regions, the residues of wheat and barley crops are utilized for feeding animals. Therefore, it is not available for improving physical quality of soils (Sepaskhah and Bazrafshan-Jahromi, 2006).

Recently, water-soluble, high molecular weigh, anionic polyacrylamide (PAM) has been used as a synthetic organic soil conditioner for improving physical quality of fine-textured soils. For example, in several medium- and fine-textured soils taken from arid and semiarid regions, PAM increased aggregate stability and hydraulic conductivity (Bryan, 1992) and infiltration rate (Tumsavas and Kara, 2011). Santos and Serralheiro (2000) reported that PAM application at the rate of 10 g m^{-3} increased average saturated hydraulic conductivity (K_s) of a Mediterranean soil by 168 % in a furrow experiment. Sepaskhah and Bazrafshan-Jahromi (2006) found that in a soil selected from semiarid regions of Iran, 6 kg ha^{-1} of PAM was required for improving infiltration and reducing soil losses on 7.5 % soil surface slope under rainfall simulator. Tumsavas and Kara (2011) found that PAM application with a rate of 3.333 kg ha^{-1} reduced surface runoff and soil losses by 23.1 and 18.5 %, respectively and increased infiltration rate by 24 % relative to the control. Also, they concluded that the effectiveness of PAM was higher in clay and clay loam soils than sandy clay loam soil. Bryan (1992) showed that the application of anionic PAM at the concentration of 0.5 g kg^{-1} of air dry soil on several medium- and fine-textured soils significantly ($P < 0.05$) increased water aggregate stability (WAS), saturated hydraulic conductivity (K_s), and available water capacity (AWC). Zahow and Amrhein (1992) reported that the addition of PAM at a rate of 50 mg kg^{-1} in conjunction with gypsum on a heavy-textured saline sodic soil increased K_s from 0.0 to 0.28 mm hr^{-1}. In a field study, Gorbani Vaghei et al. (2009) showed that the application of PAM at the concentration of 10 mg L^{-1} on a clay loam soil increased the final infiltration rate by 33 % compared with the control. Asghari at al. (2009) indicated that in a sandy loam soil prepared from semiarid region of Iran, the addition of PAM at the rates of 0.25 and 0.5 g kg^{-1} of air dry soil enhanced mean weight diameter (MWD) of aggregates (wet sieving method) by 500 and 1000 % respectively, relative to the control.

PAM degradation in soil does not occure as quickly as organic matter. When incorporated into soil, PAM degraded at the rate of 10 % per year as a result of physical, chemical, and biological processes (Tolstikh at al., 1992). Busscher, et al. (2009) found that the improvement effect of PAM on soil penetration resistance was diminished with time during the 3 years of experiment. Asghari et al. (2009) reported that although MWD of the aggregates in PAM treatments was reduced from 7 to 180 days in a sandy loam soil, its values were higher than control and other treatments (biological sludge, vermicompost, and cattle manure) during the 6 months of study.

Limited information is available about the time variability of PAM effects on physical quality parameters of fine-textured soils especially in semiarid regions. Therefore, the objectives of this research were: (1) to determine the impact of PAM on physical quality parameters of a clay loam soil selected from semiarid region as mean weight diameter (MWD) of aggregates, dispersible clay ratio (DC), saturated hydraulic conductivity (K_s), and total porosity (n); and (2) to investigate the temporal variability of PAM effects on the soil physical quality parameters.

2. Materials and methods

2.1. Soil

In this research, a clay loam soil was taken from 0-30 cm depth of a follow farm in Grizeh Agricultural Research Station located about 12 km of Sanandaj city, the west of Iran (E 47˚ 2′ , N 35˚ 17′). Some physical and chemical properties of the soil were determined according to the procedures described by Klute (1986) and Page (1982).

2.2. Treatments

Three treatments were replicated 3 times in 9 plastic pans with 50 cm diameter and 25 cm height. The experiment was organized in a factorial with randomized complete block design. The two factors of experiment were: (1) three rates of PAM (an anionic polyacrylamide with a molecular weigh of 18×10^6 g mol^{-1}, supplied by the Polymer Researches Center of Iran) application including 0 (control), 0.125, and 0.25 g kg^{-1} of air dry soil; and (2) three incubation times including 30, 90, and 180 days. PAM application rates were solved in water and mixed with soil at 0.75 FC (field capacity) moisture content. FC was determined as the gravimetric water content at h = 30 kPa obtained by pressure plate apparatus. The treated moist soils were uniformly packed into plastic pans with bulk density of 1.2 g cm^{-3} (according to the initial soil bulk density of field where soil samples were taken). In order to create suitable conditions for aggregation, pans were incubated in a greenhouse at moisture and temperature conditions of 0.7 to 0.8 FC and 22 ± 4 ºC, respectively (Paul and Clark, 1996) for 6 months. Time domain reflectometer (TDR) probe was installed in 10-15 cm layer of pans in order to control soil moisture content in a range of 0.7-0.8 FC, with timely irrigation of the pans.

2.3. Parameters measurement

To measure MWD of aggregates, DC, and particle density (D_p), soil samples with minimum distribution were taken from the 10-15 cm layer (having the least variations in moisture and temperature) of pots; For measuring bulk density (D_b) and K_s, undisturbed soil samples using steel cylinders (5.1 cm diameter and 5.0 cm height) were taken from the same layer. All parameters were measured 30, 90, and 180 days after the start of incubation.

MWD of aggregates was measured by a modified Yoder wet sieving machine (Yoder, 1936). Briefly, 50 g air dry soil samples (< 4.75 mm) were gently transferred to the top of the sieves set with pore size of 2, 1, 0.5, 0.25, and 0.106 mm, and sieving was performed. Vertical sieving oscillation was 37 mm at 30 rpm for 5 min. the fractions remaining on the sieves were oven-dried at 105 ˚C for 24 hr, weighed, and corrected for the sand fractions. Finally, the MWD was calculated according to the van Bavel equation (1950). To determine the dispersible clay ratio, turbidimetric analysis was performed with 20 g oven-dried aggregates (2-4.75 mm) after shaking end-over-end in 100 ml 2 mM $Na_4P_2O_7$ for 3 hr (Pojasok and Kay, 1990). Particle density was measured by pycnometer method (Blake and Hartge, 1986b).

Soil bulk density (D_b) was calculated from cylinder volume and oven dry (105 ˚C) soil mass (Blake and Hartge, 1986a). Total porosity (n) was calculated using D_b and Dp (n = 1- $\frac{D_b}{D_p}$) (Danielson and Sutherland, 1986). K_s was also measured in cylinders by the falling head method (Klute and Dirksen, 1986).

2.4. Statistical analyses

The normality test of data distribution was done by Kolmogorov-Smirnov test using Minitab software (MINITAB, 2003) before analyzing with ANOVA. Variance analyses of data and comparison of means by Duncan' s multiple range test was carried out using MSTATC (1988) software.

3. Results and discussion

Table 1 shows that in the studied clay loam soil, MWD of aggregates is small (MWD = 0.306 mm) due to the low rate of organic carbon (1.06 g $100g^{-1}$). These conditions were resulted in unstable soil structure and consequently low (6.2 %) soil available water capacity (AWC = FC – PWP). Therefore, it was expected that PAM application increases aggregate stability of the examined soil by increasing MWD and decreasing DC.

Table 1. Some physical and chemical properties of the examined soil.

Property	Soil
pH^*	7.62
EC_e (dS m^{-1})	1.32
OC (g $100g^{-1}$)	1.06
CCE (g kg^{-1})	131
30 kPa WC (FC) (% w/w)	17.5
1500 kPa WC (PWP) (% w/w)	11.3
AWC (% w/w)	6.2
MWD (mm)	0.306
Sand (g kg^{-1})	200
Silt (g kg^{-1})	520.4
Clay (g kg^{-1})	279.6

*, saturated paste; OC, organic carbon; CCE, calcium carbonate equivalent; WC, water content; FC, field capacity; PWP, permanent wilting point; AWC, available water content; MWD, mean weight diameter of aggregates.

Table 2 indicates the analyses of variance for measured parameters in the experiment. According to this table, the main effects of PAM used rate (A) and incubation time (B) on MWD, DC, K_s, and n parameters and also their interaction effects (A × B) on MWD and n parameters were significant. Some descriptive statistics as mean, range, and standard deviation of the measured soil physical quality parameters are shown in Table 3.

Table 2. Analysis of variance (F value) for measured parameters.

Source	Df	MWD	DC	K_s	n
PAM rate (A)	2	1489.74^{**}	726.32^{**}	494.19^{**}	105.61^{**}
Time (B)	2	235.2^{**}	26.79^{**}	25.46^{**}	8.8^{*}
A × B	4	61.7^{**}	$2.28^{n.s}$	$0.568^{n.s}$	6.24^{*}
Error	16	-	-	-	-

Df, degree of freedom; MWD, mean weight diameter of aggregates; DC, dispersible clay ratio; K_s, saturated hydraulic conductivity; n, total porosity; n.s, not significant; *, $P < 0.05$; **, $P < 0.01$.

Table 3. Description statistics of soil physical quality parameters measured in the study.

	Mean	Range	Standard deviation
MWD (mm)	0.665	0.298 – 1.13	0.285
DC (g $100g^{-1}$)	0.512	0.357 - 0.729	0.129
K_s (cm hr^{-1})	0.566	0.492- 0.612	0.037
n (%)	55.1	51.3 – 56.9	1.687

MWD, mean weight diameter of aggregates; DC, dispersible clay ratio; K_s, saturated hydraulic conductivity; n, total porosity.

3.1. Mean weight diameter (MWD) of aggregates

Fig. 1 shows that both low and high application rates of PAM significantly increased MWD compared with the control at all incubation times; This increase was about 83 and 127 % for low and high application rates of PAM, respectively relative to the control. Also, the increase of PAM rate from 0.125 to 0.25 g kg^{-1} significantly increased MWD value. Apparently, PAM formed water stable aggregates by cementing primary soil particles together. Although negatively charged polymers as anionic PAM that have the same charge as clay surfaces tend to be repelled, anionic polymers can still be attached to clay through bridging between the anionic groups and negatively charged clay surfaces in the presence of polyvalent cations (Inyang and Bae, 2005). Similarly, Levy and Miller (1999) indicated that the application of anionic PAM on a sandy loam soil significantly increased MWD (wet sieving method) relative to the control.

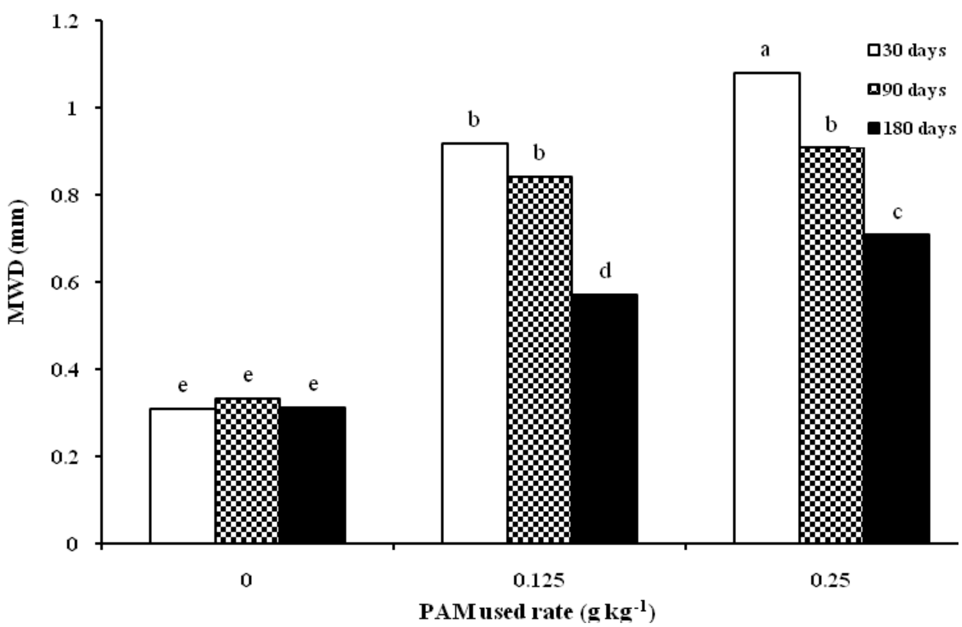

Figure 1. Interaction effects of polyacrylamide (PAM) used rate and incubation time on mean weight diameter (MWD) of aggregates. Values with common letters are not significantly different at P < 0.05 (Duncan’s multiple range test).

According to Fig. 1, although MWD of aggregates in PAM treatments significantly decreased from 30 to 180 days after the start of incubation probably due to gradually degradation of PAM (Tolstikh at al., 1992) and/or leaching of PAM from soil particles surface, however, its values were still significantly higher than control at 180 days. These results agree with the findings of Asghari et al. (2009) who reported that although MWD of PAM treatments remained unchanged from 7 to 60 days after adding PAM to a sandy loam soil, but its values significantly decreased from 120 to 180 days relative to the 7 days.

3.2. dispersible clay ratio (DC)

Fig. 2A shows that both low and high application rates of PAM significantly decreased DC by 31 and 43 %, respectively compared with the control due to the increase of MWD (Fig. 1). Also, DC significantly decreased by increasing PAM application rate. Shainberg et al. (1992) expressed that anionic PAM formed strong aggregates and decreased dispersion clay. The findings of Nadler et al. (1996) indicated that application of PAM at used rates of 0.025, 0.05, and 0.075 g kg^{-1} on a sandy loam soil significantly increased the percentage of water stable aggregates because of decreasing dispersion clay. Shahbazi et al. (2006) mentioned that in their experimental study, adding of PAM at the rate of 30 kg ha^{-1} on 4 clay soils with different rates of salinity and alkalinity significantly decreased runoff and soil losses at 40 mm hr^{-1} rainfall rate relative to the control.

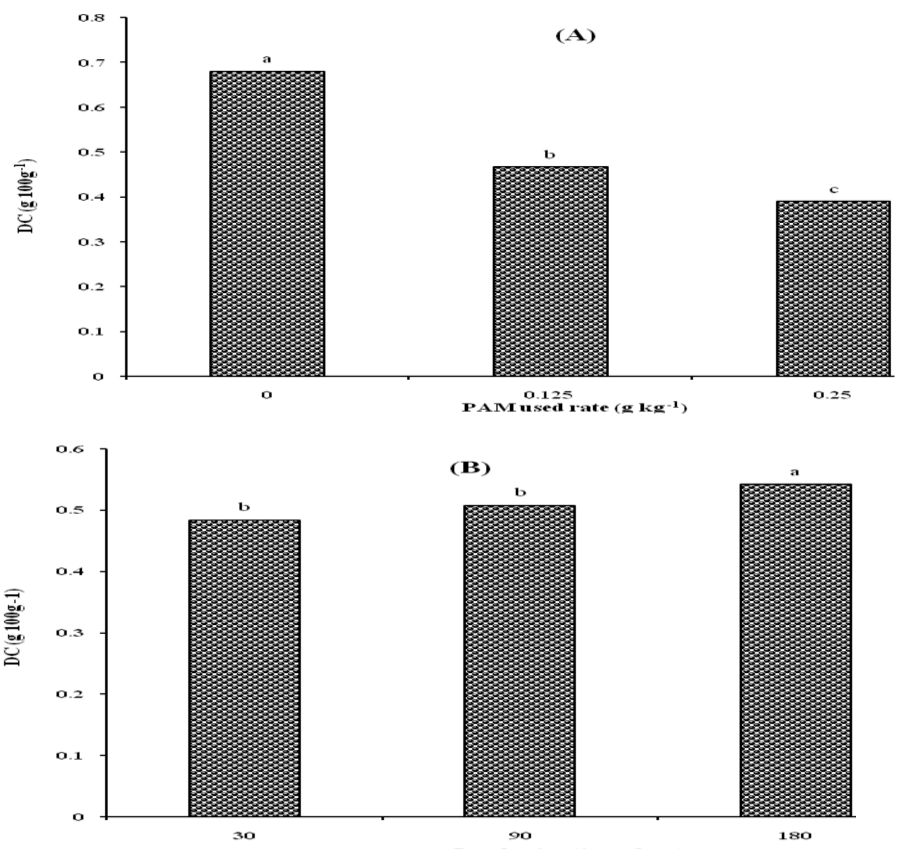

Figure 2. Main effects of polyacrylamide (PAM) used rate (A) and incubation time (B) on dispersible clay ratio (DC). Values with common letters are not significantly different at P < 0.05 (Duncan's multiple range test).

According to Fig. 2B, DC significantly increased from 90 to 180 days due to the break down of aggregates and consequently the decrease of MWD (Fig. 1). Therefore, it can be postulated that there was a negative correlation between MWD and DC. Tajik (2004) also obtained a significant negative correlation between the percentage of water stable aggregates (WSA) and dispersible clay ratio (DC) for 54 soil samples taken from semiarid regions of Iran. No other reports about the effect of PAM on DC were found in the literature for comparison.

3.3. Saturated hydraulic conductivity (K_s)

Fig. 3A shows that both low and high application rates of PAM significantly increased K_s by 11.5 and 14.5 %, respectively compared with the control. The highest K_s value (0.6 cm hr^{-1}) was obtained for PAM treatment at high used rate and it significantly differed from K_s value at low used rate of PAM. It seems that PAM by creating water stable aggregates (Fig. 1) and decreasing dispersible clay ratio (Fig. 2A) prevented pore clogging in the examined fine-textured soil and finally increased K_s. Neyshabouri et al. (2007) found that adding PAM at the concentration of 50 mg L^{-1} on a sandy loam soil significantly increased K_s from 4.42 to 8.89 cm hr^{-1}. The increase of K_s in PAM treated fine-textured soils has also been reported by Bryan (1992), Santos and Serralheiro (2000), and Ghorbani Vaghei et al. (2009).

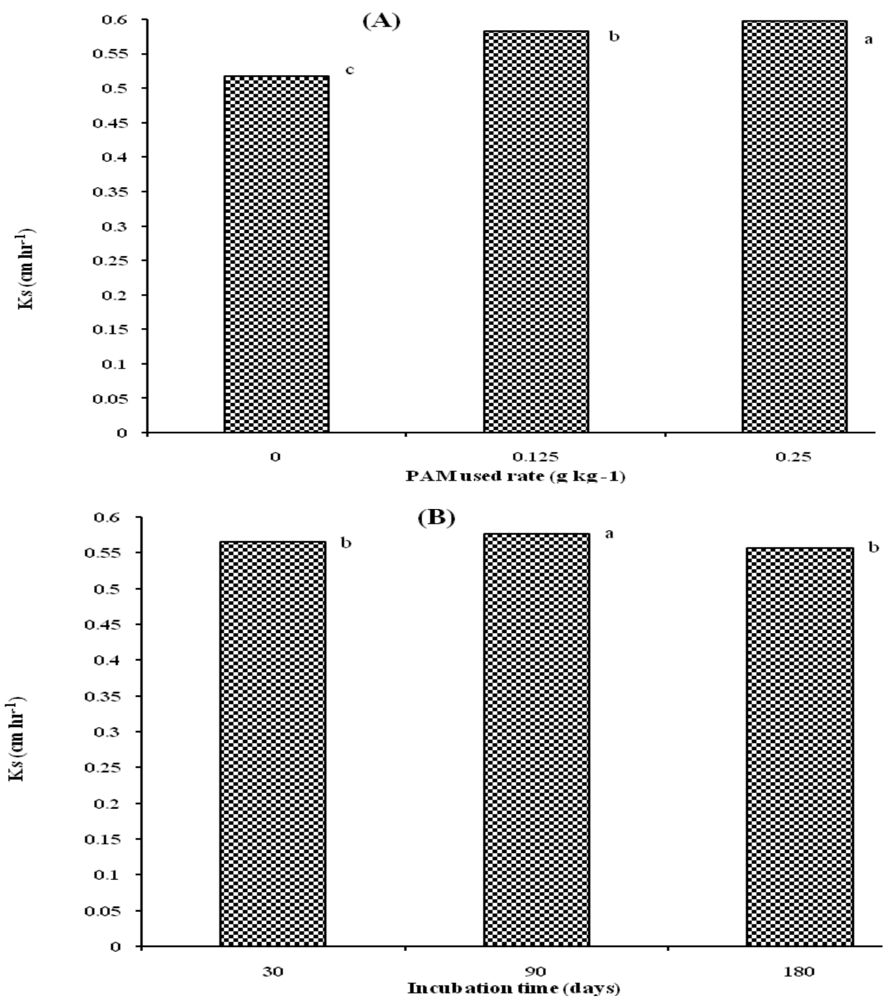

Figure 3. Main effects of polyacrylamide (PAM) used rate (A) and incubation time (B) on saturated hydraulic conductivity (K_s). Values with common letters are not significantly different at $P < 0.05$ (Duncan's multiple range test).

According to Fig. 3B, at all treatments (control and PAM used rates), K_s significantly increased from 30 to 90 days due to the creation of suitable temperature and moisture conditions that enhanced microbial activity of native microorganisms (Paul and Clark, 1996) and temporary improved K_s of the studied fine-textured soil by aggregation (Fig. 1). Then, K_s decreased at 180 days probably because of sealing soil pores due to the increase of DC (Fig. 2B). These findings are similar to the results of Asghari et al. (2011) who reported that K_s of a sandy loam soil treated with anionic PAM decreased 1.8-fold in 180 days relative to 7 days due to the gradually leaching of PAM and consequently the decrease of PAM effect on aggregation.

3.4 Total porosity (n)

Fig. 4 shows that both low and high application rates of PAM at all incubation times significantly increased the total porosity (n) compared with the control; The total porosity of PAM treatments was still higher than the control by 8.75 and 7.75 % at 180 days, respectively. It seems that PAM, by creating coarse and stable aggregates, increased soil volume and decreased soil bulk density (D_b), and consequently increased n (n = 1- $\frac{D_b}{D_p}$). These findings agree with the results of Sadegian et al. (2006) who reported that PAM application at the concentration of 50 mg L^{-1} significantly decreased D_b and increased n of a sandy loam soil.

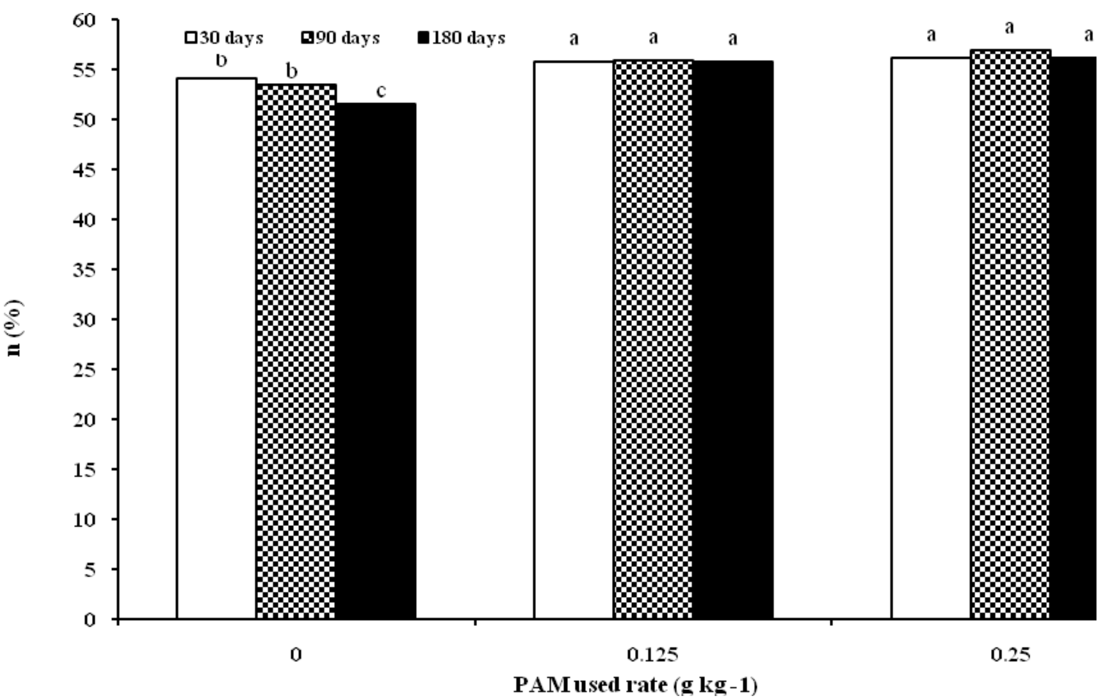

Figure 4. Interaction effects of polyacrylamide (PAM) application rate and incubation time on total porosity (n). Values with common letters are not significantly different at $P < 0.05$ (Duncan's multiple range test).

According to Fig. 4, n was significantly decreased from 90 to 180 days at the control treatment due to break down of aggregates, while n was not changed from 30 to 180 days at PAM treatments because of the formation of stable aggregates (Fig. 1). Asghari et al. (2009) also reported that PAM application in a sandy loam soil modified pore size distribution by the significant increase of mesopores (d = 30-75 μm) relative to the control. Seyed Dorraji et al. (2010) indicated that adding 0.6 % (w/w) of a superabsurbent polymer on a clay soil increased capillary and aeration porosity by 28.8 and 33.33 %, respectively relative to the control.

4. Conclusions

According to the results of this study, application of anionic polyacrylamide (PAM) at the rates of 0.125 and 0.25 g kg^{-1} on a clay loam soil with low organic matter (1.06 g $100g^{-1}$) increased mean weight diameter of aggregates, saturated hydraulic conductivity, and total porosity, and decreased dispersible clay ratio. Therefore, lower rates of PAM (0.125 g kg^{-1}) can be used for improving physical quality of fine-textured soils because of its low cost. It is proposed that in semiarid regions, the effect of PAM on physical quality of fine-textured soils is also investigated at lower rates of PAM application especially in the field scale.

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