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Soil aggregate stability index and particulate organic matter in response to differently afforested lands in the temperate regions of Iran

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Abstract: Aggregate Stability Index (ASI) and particulate organic matter (POM) are strongly influenced by land use and management. This work illustrates the effects of plantations on ASI and POM-C and POM-N in northern Iran. Three plantations of *P. deltoides* (PD), *T. distichum* (TD), *A. subcordata* (AS), and a fourth site ‑ adjacent abandoned lands (BL, as control) were selected. Soil samples were taken within 16 quadrats of each plantation and BL from the two depths of 0–15 cm and 15–30 cm during the summer. Soil C was significantly higher under TD (2.10%) than under BL (2.02%) > PD (1.61%) > AS (1.30%). Soil N was found in ranked order of AS (8.99%) > TD (7.82%) > PD (5.30%) > BL (3.68%) ($P < 0.019$). The significantly higher ASI was found under TD (57.49) in comparison with PD (53.10), BL (51.23), and AS (36.57). The POM-C was as follows: TD (0.209%) > PD (0.141%) > AS (0.139%) > BL (0.075%) ($P = 0.020$). The highest POM-N was found under TD (0.035), followed by AS (0.0284%), PD (0.0288%), and BL (0.007%). The results indicate the positive effect of afforestation on soil ASI and POM-C and POM-N, especially in the surface layers of soil.

Keywords: afforestation; organic matter; soil properties; tree species; land use

Afforestation is defined as the conversion of non-forest lands to forested land (Berthrong, Finzi 2006) and is one of the ways of restoring degraded lands (Cannell 2003). Perhaps, one of the most important factors provided by forests is soil organic matter (SOM) accumulation and soil fertility maintenance (Boley et al. 2009). Besides the environmental and economic effects, the afforestation has an important impact on the soil physical and chemical properties (Xie et al. 2021). Thus, in addition to the major role of forest soil in creating change and diversity, forests, in turn, play a significant role in changing and developing forest soils (Fisher, Binkley 2000). Therefore, understanding the soil properties is considered as a basis for appropriate forest management. Many studies have indicated that planted forest trees change soil properties (Antunes et al. 2008; Vesterdal et al. 2008; Ayres et al. 2009; Luan et al. 2010; Mueller et al. 2012; Kooch, Zoghi 2014). The results of most of these studies indicate that afforestation can amend and modify soil physical and chemical properties of afforested lands through adding litter to the soil, decomposition of litter, and also microbiological phenomena such as nitrogen fixation and mycorrhizal activity (Evans 1992).

The soil aggregate stability index (ASI) is related to its ability to maintain particle and pore arrangement when faced with different environmental stresses

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(Angers, Carter 1995), and assessment of soil structure is usually expressed based on aggregate stability (Bronick, Lal 2005). ASI plays a significant role in the development of root systems, carbon and water cycles as well as resistance against erosion (Barthès et al. 2008). ASI can also be controlled by management practices (Oades 1993). Afforested lands impact on soil structure by distributing SOM through litter and recycling of roots and root exudates. Thus, vegetation and soil organic carbon are some of the most important factors determining ASI (Carpenter, Chong 2010; Fattet et al. 2011). However, any decrease of SOM can lead to reduced fertility, soil structure instability, and declined soil productivity potential (Obalum et al. 2017).

SOM is considered as one of the main indicators of soil quality because it strongly influences the soil chemical, physical, and biological processes (Spaccini et al. 2004). SOM consists of two parts, namely humus substances and labile compounds. Particulate organic matter (POM) is a part of the soil labile compounds (Yoosefi et al. 2008). In comparison with the total SOM, POM consisting of organic carbon and nitrogen is very sensitive to changes in management (Haynes 2005).

ASI and POM are two important properties that are strongly influenced by different land covers, but little attention has been paid to these properties concerning afforestation with different tree species in northern Iran. Due to the high amount of rainfall in the north of Iran and the increasing risk of water erosion, the necessity of afforestation on degraded lands is higher than ever before because trees due to creating higher infiltration capacities of water flow can prevent soil erosion (Kramer 2010). On the other hand, afforestation causes increasing POM in the soil (Mao, Zeng 2010), and POM affects ASI and soil fertility (Haynes 2005; Onweremadu et al. 2010). Little research has been done in this regard, and most research on the size and concentration of POM has been carried out for different management practices and land use (Meyer et al. 2012; Mujuru et al. 2013). Thus, the effect of different species on POM have been rarely studied (Yu et al. 2013), and little information is available. Nevertheless, the issue of which planted species can be more effective on ASI, POM-C, POM-N, and finally, soil protection remained unclear. This study aims to investigate the effect of the afforestation with different tree species on soil ASI, POM-C, and POM-N.

MATERIAL AND METHODS

Study area. The study was conducted on the southern coast of the Caspian Sea, Mazandaran Province, Northern Iran: Klodeh (36°35'N, 52°10'E)

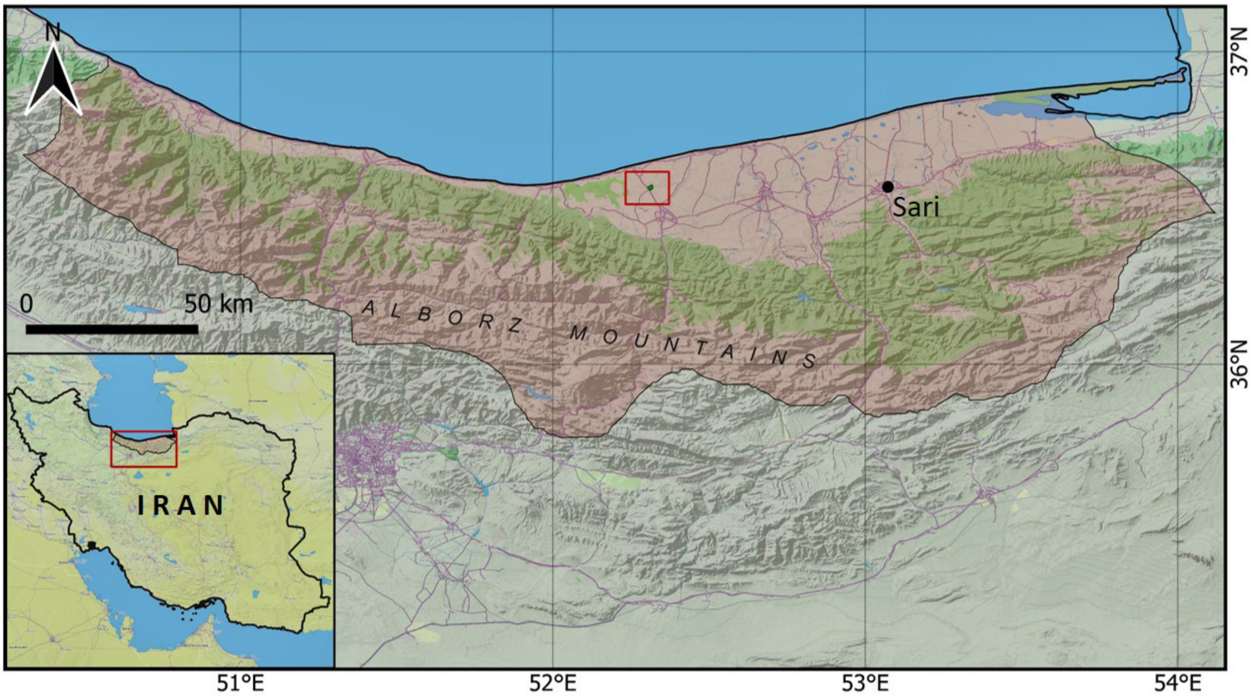

Figure 1. Location of the study area in the Mazandaran province, north of Iran

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(Figure 1). The region has a temperate climate, with the mean annual temperature of 16.9 °C. The mean annual precipitation of the last 10-year period is 802–823.5 mm and the majority of precipitation falls between September and March. This region has a distinct dry season that stretches from April to August. The topography is characterized by flatlands to low hills at an elevation of 5 m a.s.l. According to WRB (World Reference Base), the soil type is Dystric Cambisol (WRB, IUSS 2014). The soil texture is silty loam with poor drainage (Eslamdoust 2015). The average pH ranges between 7.6 and 8.1.

The study plantations are composed of *Alnus subcordata* L. (AS), *Populus deltoides* L. (PD), and *Taxodium distichum* L. Rich. (TD). These treatments were planted in 2001. A description of the study sites is presented in Table 1 (Eslamdoust, Sohrabi 2018). An adjacent abandoned land (BL) was also selected as control.

Soil sampling and laboratory analysis. Due to the homogeneity of each afforestation in the study site, a network with dimensions of 200 m × 200 m with systematic random sampling was used. Soil samples (25 cm × 25 cm × 15 cm) were taken within 16 quadrats of each plantation and BL from two depths of 0–15 cm (D_1) and 15–30 cm (D_2) during the summer. The soil samples were stored at 4 °C for two weeks. Soils were air-dried and passed through a 2-mm sieve (aggregates were broken to pass through a 2-mm sieve) to laboratory analysis. Soil texture was measured using the Bouyoucos hydrometer method (Bouyoucos 1962). Bulk density was measured by the clod method. Soil organic C was determined using the Walkley-Black technique (Allison 1975). Total N was measured using a semi-micro Kjeldahl technique (Bremner, Mulvaney 1982). Available P was determined with a spectrophotometer and by the Olsen method (Homer, Pratt 1961). POM-C and POM-N were determined by physical fractionation. 25 g of air-dried soil samples were dispersed with 100 mL of 5 $g \cdot L^{-1}$ of sodium hexametaphosphate. The soil solution mixture was shaken for 1 h at high speed (= 500 rpm) on an end-to-end shaker and poured over a 0.053-mm sieve with several deionized water rinses. The soil remaining on the sieve was washed into a pre-weighed aluminium dish and dried at 60 °C for 24 h, then ground and analysed for C and N (Kooch et al. 2019).

Data analysis. The normality of variables was checked by the Kolmogorov-Smirnov test. The equality of the variances was checked using Levene's test. Two-way analysis of variance (ANOVA) was used to compare data on soil properties among plantations and depths. Duncan's test was employed to test for differences at the $P = 0.05$ level. All statistical analyses were conducted using the SPSS statistical software package (Version 19.0; 2010).

RESULTS

Clay and sand contents were not significantly different between afforested sites (Table 2). However, the highest value of clay and sand content was found under PD and AS, respectively. Soil silt contents decreased significantly in the order BL > TD > PD > AS. Soil bulk density was significantly higher in the AS treatment (1.58 $gr \cdot m^{-3}$) compared with PD, TD, and BL. Soil C was significantly higher under TD (2.10%) than under BL (2.02%) > PD (1.61%) > AS (1.30%). Soil N was found in ranked order of AS > TD > PD > BL with more than twofold value in the AS treatment (8.99%) compared to BL (3.68%). Higher values

Table 1. Site properties and plantation characteristics (Eslamdoust, Sohrabi 2018)

Plantation types		AS	PD	TD
DBH (cm)		31.32 ± 7.68 (15.92–50.96)*	27.43 ± 6.34 (12.42–43.94)	28.44 ± 6.83 (17.83–47.04)
Tree height (m)		21.98 ± 4.38 (10.1–31.8)	29.79 ± 4.77 (16.9–39.5)	17.74 ± 2.66 (9.8–24.1)
Crown height (m)		8.91 ± 2.69	11.45 ± 3.30	6.67 ± 1.94
Crown diameter (m)		4.02 ± 1.38	3.12 ± 1.20	4.25 ± 0.96
Stem density (trees·ha^{-1})		459	556	556
Main understory vegetation	shrubs	*Ruscus hyrcanus*; *Smilax excels*	*Ruscus hyrcanus*; *Smilax excels*	–
	herbaceous plants	*Carex remota*; *Carex sylvatica*; *Poa* sp.	*Carex remota*; *Carex sylvatica*; *Poa* sp.	

AS – *Alnus subcordata*; PD – *Populus deltoides*; TD – *Taxodium distichum;* * (min-max)

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Table 2. Means (± SE, n = 16) of the soil variables analysed in the studied land covers and depths

Properties	Depth	AS	PD	TD	BL	Statistic description	
Clay (%)	D_1	33.5 (± 4.03)	35.7 (± 3.51)	26.5 (± 1.76)	33.3 (± 2.16)	Land cover: F = 1.003; P = 0.398	PD > AS > BL > TD
	D_2	32.3 (± 5.61)	33.0 (±4.72)	3.7 (±3.02)	27.5 (±2.16)	Depth: F = 0.289; P = 0.593 L×D: F = 0.672; P = 0.769	$D_1 > D_2$
Silt (%)	D_1	34.3 (± 1.82)	38.3 (± 4.14)	41.0 (± 4.50)	42.8 (± 2.90)	Land cover: F = 3.643; P = 0.018	$BL^a > TD^{ab} > PD^{ab} > AS^b$
	D_2	35.0 (± 5.69)	41.3 (± 4.30)	43.8 (± 2.25)	50.8 (± 2.60)	Depth: F = 1.863; P = 0.178 L×D: F = 0.337; P = 0.798	$D_2 > D_1$
Sand (%)	D_1	32.3 (± 4.70)	26.0 (± 5.14)	32.5 (± 5.23)	24.0 (± 2.61)	Land cover: F = 1.191; P = 0.321	TD > AS > PD > BL
	D_2	32.8 (± 6.16)	25.8 (± 6.95)	25.5 (± 4.74)	21.8 (± 2.80)	Depth: F = 0.353; P = 0.555 L×D: F = 0.198; P = 0.897	$D_1 > D_2$
Bulk density ($gr \cdot m^{-3}$)	D_1	1.58 (± 0.07)	1.41 (± 0.08)	1.42 (± 0.11)	1.35 (± 0.05)	Land cover: F = 4.308; P = 0.008	$AS^a > TD^{ab} > PD^b > BL^b$
	D_2	1.61 (± 0.09)	1.48 (± 0.09)	1.28 (± 0.10)	1.23 (± 0.07)	Depth: F = 0.500; P = 0.482 L×D: F = 0.648; P = 0.578	$D_1 > D_2$
C (%)	D_1	1.30 (± 0.03)	1.61 (± 0.14)	2.10 (± 0.20)	2.02 (± 0.21)	Land cover: F = 6.65; P = 0.001	$TD^a > BL^{ab} > PD^{bc} > AS^c$
	D_2	1.25 (± 0.07)	1.37 (± 0.03)	1.49 (± 0.13)	1.49 (± 0.07)	Depth: F = 14.427; P = 0.000 L×D: F = 1.910; P = 0.138	$D_1^a > D_2^b$
N (%)	D_1	8.99 (± 1.33)	5.30 (± 1.42)	7.82 (± 2.07)	3.68 (± 0.64)	Land cover: F = 3.588; P = 0.019	$AS^a > TD^a > PD^{ab} > BL^b$
	D_2	5.10 (± 1.92)	6.27 (± 0.69)	6.51 (± 1.11)	2.88 (± 0.73)	Depth: F = 1.74; P = 0.19 L×D: F = 1.11; P = 0.35	$D_1 > D_2$
C.N	D_1	3.87 (± 0.49)	4.29 (± 0.37)	5.36 (± 0.72)	10.87 (± 1.41)	Land cover: F = 17.37; P = 0.00	$BL^a > TD^b > PD^b > AS^b$
	D_2	6.20 (± 0.79)	5.16 (± 0.47)	3.96 (± 0.34)	9.18 (± 1.55)	Depth: F = 0.002; P = 0.965 L×D: F = 2.32; P = 0.085	$D_2 > D_1$

D1 – 0–15 cm soil depth; D2 – 15–30 cm soil depth; AS – *Alnus subcordata*; PD – *Populus deltoides*; TD – *Taxodium distichum;* C.N – carbon to nitrogen ratio; BL – bare land; L × D – Land cover × Depth; F – F-statistic; different letters indicate significant differences (P < 0.05 by Duncan test) between land covers

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of C/N were observed in the BL treatment (10.87) compared with TD (5.36), PD (4.29), and AS (3.87). Values of clay, silt, sand, bulk density, N and C/N were not found significantly different between the studied depths. However, soil C was significantly higher at D_1 (1.76%) than at D_2 (1.40%).

Our results showed that there were significant differences in ASI, POM-C, and POM-N between AS, PD, TD, and BL (Table 3). A significantly higher ASI was found in TD (57.49) in comparison with PD (53.10), BL (51.23), and AS (36.57) (Figure 2). ASI was insignificantly higher at D_1 (53.18) than at D_2 (46.01). POM-C was as follows: TD (0.209%) > PD (0.141%) > AS (0.139%) > BL (0.075%) (Figure 3). POM-C was significantly higher at D_1 (0.244%) than at D_2 (0.098%). The highest POM-N was found under TD (0.035), followed by AS (0.0284%), PD (0.0288%), and BL (0.007%) (Figure 4). POM-N was significantly higher at D_1 (0.039%) than at D_2 (0.021%).

ASI had a positive correlation with C and POM-N (Table 4). Soil clay and silt had a negative correlation with soil sand. Soil silt was positively correlated with C. C was positively correlated with POM-C.

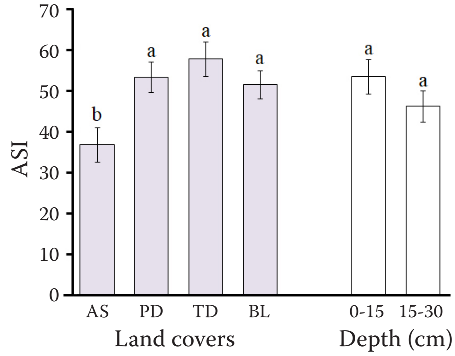

Figure 2. Mean (± SE; n = 16) of Aggregate Stability Index (ASI) under different land covers

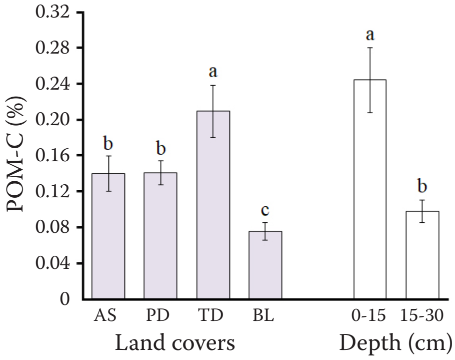

Figure 3. Mean (±SE; n = 16) of particulate organic carbon (POM-C) under different land covers

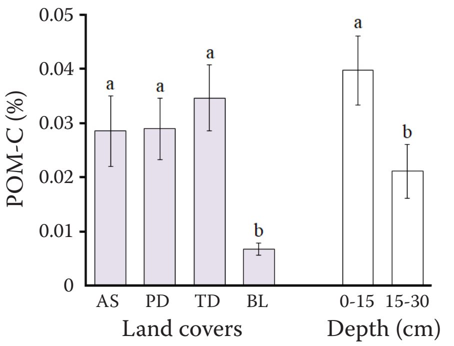

Figure 4. Mean (±SE; n = 16) of particulate organic nitrogen (POM-N) under different land covers

AS – *Alnus subcordata*; PD: *Populus deltoides*; TD – *Taxodium distichum*; BL – bare land; different letters indicates significant differences and same letters indicates non-significant differences

DISCUSSION

Afforestation improves soil quality by supplies of nutrition resources and reduces soil erosion (Berthrong et al. 2009). Our findings showed that soils under coniferous TD have a significantly higher C than soils under broadleaved AS and PD. The changes in C in different land cover also reflect the differences in quantity and quality of litter inputs, litter decomposition rates, and root biomass C (Zheng et al. 2008). Contrary to our findings, previous reports (Salamon et al. 2004; Wardle et al. 2006) claimed that the type of aboveground vegetation has no remarkable effect on the soil features. According to Kooch et al. (2012), soil total N content is the main factor that affects the decomposition of litter, and the litter decomposition rate is a source of soil CO_2 emission. In the present study, N values were in ranked order

Table 3. Statistical descriptions of Agregate Stability lindex (ASI), POM-C and POM-N in the studied land covers and depths

Properties	Land cover		Depth		Land cover × Depth	
	F	*P*	*F*	*P*	*F*	*P*
ASI	5.78	0.01	3.68	0.06	1.97	0.13
POM-C	1.59	0.02	7.91	0.01	0.55	0.07
POM-N	3.28	0.03	4.01	0.05	0.56	0.67

POM-C – particulate organic matter-carbon; POM-N – particulate organic matter-nitrogen; *F* – F-statistic

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Table 4. Pearson correlation coefficients (r) of soil properties across diffrent land covers

	ASI	Clay	Silt	Sand	Bulk Density	C	N	POM-C	POM-N
ASI	1	0.10	0.22	−0.24	−0.08	0.25*	0.07	0.20	0.25*
Clay		1	0.02	−0.65**	0.03	0.007	0.15	0.007	−0.09
Silt			1	−0.73**	0.01	0.30*	0.05	0.02	−0.14
Sand				1	−0.03	−0.23	−0.06	−0.24	0.17
Bulk Density					1	−0.10	0.15	0.04	−0.02
C						1	−0.02	0.35**	−0.01
N							1	−0.09	0.11
POM-C								1	0.19
POM-N									1

*correlation significant at the 0.05 level (2-tailed); **correlation significant at the 0.01 level (2-tailed); ASI – Aggregate Stability Index; POM-C – particulate organic matter-carbon; POM-N – particulate organic matter-nitrogen

of TD > PD > AS, which may be related to soil silt. The C/N ratio did not significantly differ between the coniferous TD and deciduous AS and PD at 0–15 cm depth. Different results have been reported based on a research review on the variability of soil C and N under various land covers. Soil chemical features are the influential factors affecting surface soil C and N (Zhou et al. 2015). Afforested lands with different species produced litterfall with various litter mass and chemicals that can affect C and N concentrations (Van den Berg et al. 2012).

Higher ASI in PD and TD compared to BL was expected because of conditions of undisturbed lands. The results of Nael et al. (2004) are consistent with our findings. Afforested lands influence soil structure by adding SOM to the soil through litterfall (Tajik 2004; Khazaee et al. 2008; Carpenter, Chong 2010; Fattet et al. 2011). However, lower ASI under AS is probably more related to the soil texture. The factors affecting ASI have been reported in numerous studies. Soil texture and clay content (Kemper, Koch 1966), acidity, SOM content (Kandiah 1976), and management practices and land use (i.e. natural forest, afforested lands, or agricultural lands) (Emadodin et al. 2009; Oades 1993) are among the factors influencing the aggregate stability. Thus, according to the above-mentioned factors and the effect of soil texture on aggregate stability, reduced ASI in AS could be explained by higher sand content (light texture) in soil under AS (Pearson correlation results). Based on the Pearson correlation, ASI is more closely related to soil C and POM-N. Studies of Khazaei et al. (2008) and Onweremadu et al. (2010) indicate a positive effect of C on ASI. It is well-known that there is a direct linear relationship between ASI and soil C (Six et al. 2002; Carpenter, Chong 2010). Higher ASI at the depth of 0–15 cm compared to 15–30 cm can be pertinent to higher accumulation of SOM in the soil surface layers. SOM is considered a dominant indicator that is influencing aggregate stability (Cantón et al. 2009). Soil dispersion decreases significantly with increasing SOM and ASI (Emadi et al. 2009).

Land use changes individually the cultivation operations and land covers can differently affect SOM compounds in temperate regions. POM-C like SOM, are indices of soil sensitivity to land-use changes (Hajabbasi, Fallahzadeh 2010). In AS, PD, and TD, a higher value of POM (POM-C and POM-N) identifying aboveground litter was found through different land covers considering an influential POM source (Poeplau, Don 2013; Kooch et al. 2019). However, the differences were probably majorly due to the physical and chemical nature of the litterfall inputs by different tree species (Mendham et al. 2004). Increased POM-C in forested lands usually results from adding organic materials from trees of large size because entirely different from SOM of bare lands (and agricultural lands) in terms of diverse chemical composition and particle size (Mokhtari Karchegani et al. 2011). The measured POM values were reported to vary considerably in different soils (Christensen 2001). However, generally soils with perennial vegetation and a more prolonged period of litter return into the soil (e.g. forest soils) show the highest POM. Mokhtari Karchegani et al. (2011) reported a 60–70% reduction in SOM in bare lands compared to afforested lands. Thus, higher POM in afforested lands compared to bare lands is predictable due to the influence of tree cover and litter from the trees. In the present study, the highest

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ASI was below TD, followed by PD. According to the Pearson correlation results, the higher ASI under TD and PD may be associated with higher POM. Also, the highest POM-C and POM-N were under TD, which in turn may impact on ASI. However, inconsistently with our results Soucémarianadin et al. (2019) indicated that soils under deciduous trees were significantly higher in POM than under coniferous trees.

POM-C and POM-N were significantly higher at 0–15 cm soil depth than at 15–30 cm depth. It is not surprising given the higher SOM in the soil surface layers due to litter presence. Generally, it has been reported that the soil surface behaves more actively in terms of the fertility parameters while not so accurate for the deeper layers (Rumpel, Kogel-Knabner 2011). Soil C and N are the most labile C and N fractions in the biogeochemical cycling of topsoil (Zhou et al. 2015) while being affected by vegetation type and litter quality (Kooch et al. 2021). POM in topsoil is more likely to originate from the organic layers than directly from fresh leaves/needles (Soucémarianadin et al. 2019). Thus, the topsoil functions as nutrient provision, storage, and finally, increased stand growth is clear (Wang et al. 2014).

CONCLUSION

POMs are intermediate matters between newly shed litter and decomposed SOM while a source of SOM determining the future status of nutrient and soil quality is considered. POM can play a significant role as a sensitive indicator reflecting negative impacts of forest degradation on soil quality. Based on our findings, ASI decreased in ranks order of TD > PD > BL > AS, which can be assigned to the lower values of soil silt and C. Our results revealed a positive effect of afforestation with AS, PD, and TD on POM-C and POM-N. Afforested lands have more remarkably enhanced POM-C and POM-N compared to BL. Especially in terms of POM-N, there were significant differences between afforested lands and BL. Our findings indicate that afforestation with this species improves the properties of soil fertility and stability. Thus afforestation is recommended to increase soil quality and prevent erosion caused by rainfall in these areas. It can be concluded that afforested lands increase soil ASI and POMs, finally ensuring future soil fertility.

Contribution of the authors: Masoomeh Soleimany: field works and collecting the data, the laboratory analysis; Jamshid Eslamdoust: running the data analysis, writing the paper; Moslem Akbarinia: designing the experiment; Yahya Kooch: designing the experiment, writing the paper, supervising the work.

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