International Journal of Environmental Science and Technology (2019) 16:4563–4570
https://doi.org/10.1007/s13762-018-1861-1

ORIGINAL PAPER

The impact of flood spreading and *Prosopis juliflora* on a loamy sand soil

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Received: 12 January 2018 / Revised: 28 May 2018 / Accepted: 13 June 2018 / Published online: 18 June 2018

Abstract

Loamy sand soils cannot hold considerable amounts of water and nutrients. A flood-spreading project generates fine particles, often stored in sediment. In addition, established plants have interactive effects on beneath-canopy. This research investigated the effects of flood spreading and *Prosopis juliflora* on soil characteristics. Fourteen years after the flood-spreading project was initiated, quality of soil was compared between FS and control sites, and the accumulation of nutrients in soil beneath the *P. juliflora* was compared to soil from between trees with *t* test. For soils, we analyzed texture, water infiltration, organic carbon, pH, total nitrogen, available phosphorus, available potassium, cation exchange capacity, calcium carbonate equilibrium, and soil microbial respiration, and for plants, we measured the below-ground root. Few variations were found in the soil characteristics as a result of flood-spreading establishment. The results indicated that fine fractions of soil in FS site were greater than that in control ($p < 0.05$). It was obvious that flood spreading and *P. juliflora* could alter soil infiltration rate. The soil infiltration rate of the under *P. juliflora* had the highest value (3.05 ± 0.22 cm h^{-1}), and in flood-spreading site without *P. juliflora* had the lowest value (2.48 ± 0.20 cm h^{-1}). FS had a significant improvement in soil nutrient concentration and soil microbial respiration. This research suggests that flood spreading in coarse texture soils provided a beneficial approach to remediation of sandy soil characteristics. In addition, *P. juliflora* had a significant effect on developing soil fertility under plant canopy.

Keywords Flood spreading · *Prosopis juliflora* · Loamy sand · Soil

Introduction

Loamy sand soils, of the coarse-textured class, generally have poor structure (Kolton et al. 2011). One of the most important problems of coarse-textured soils is undesirable physical conditions. Other problem of these soils is low nutrient storage and water-holding capacity (Jones et al. 2010). Arid and semiarid environments with coarse-textured soils cover > 35% of the lands in Iran. The rainfall in these areas is irregular and concentrated in a few floods. Floods transfer high amounts of soluble and insoluble materials to the spreading site. The Iranians had used floodwater as an important method for combating desertification. Basically, the flood-spreading (FS) project is a soil surface which has been prepared to generate flood to be utilized. This method is easy and cheap. The goal of this approach is to harvest runoff in arid and semiarid ecosystems. The FS has a profound effect on coarse-textured soil characteristics such as available water content (AWC). Soil texture is the main determinant of AWC (Gelsomino and Azzellino 2011). As a factor to restore soil quality, plant establishment is a continuous process for developing soil stability in long term. The development of plants on coarse-textured soils contributes to improve hydrological processes and soil properties, including soil infiltration rate, water content, and fertility (Ortiz et al. 2012). Several plant species were used for planting in study area. The plants cultivated in control site died after the rainy season. However, *Prosopis juliflora*, a genus of woody legumes, survived in FS sites. These plants influence soil development by changing the soil characteristics of under plant canopy. Soils in study area in southern Iran have coarse-textured class. The main problem of these soils is low

Editorial responsibility: M. Abbaspour.

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water-holding capacity and nutrient concentration. In order to reduce these limitations, FS has proposed for conditioning these soils. Observations under FS were conducted to determine the changes of soil physical and chemical properties compared with that of in control. The research was carried out in Mousian plain in southwestern Iran, and soil sampling was carried out from October 2010 to July 2012.

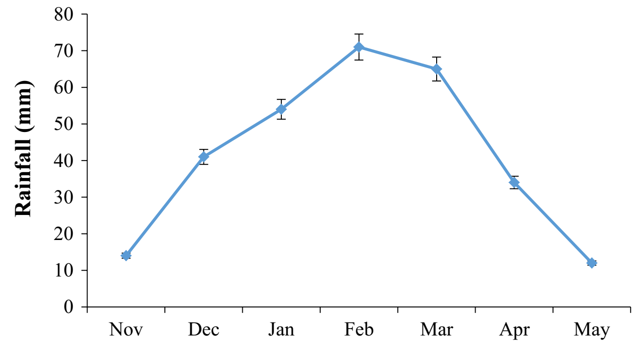


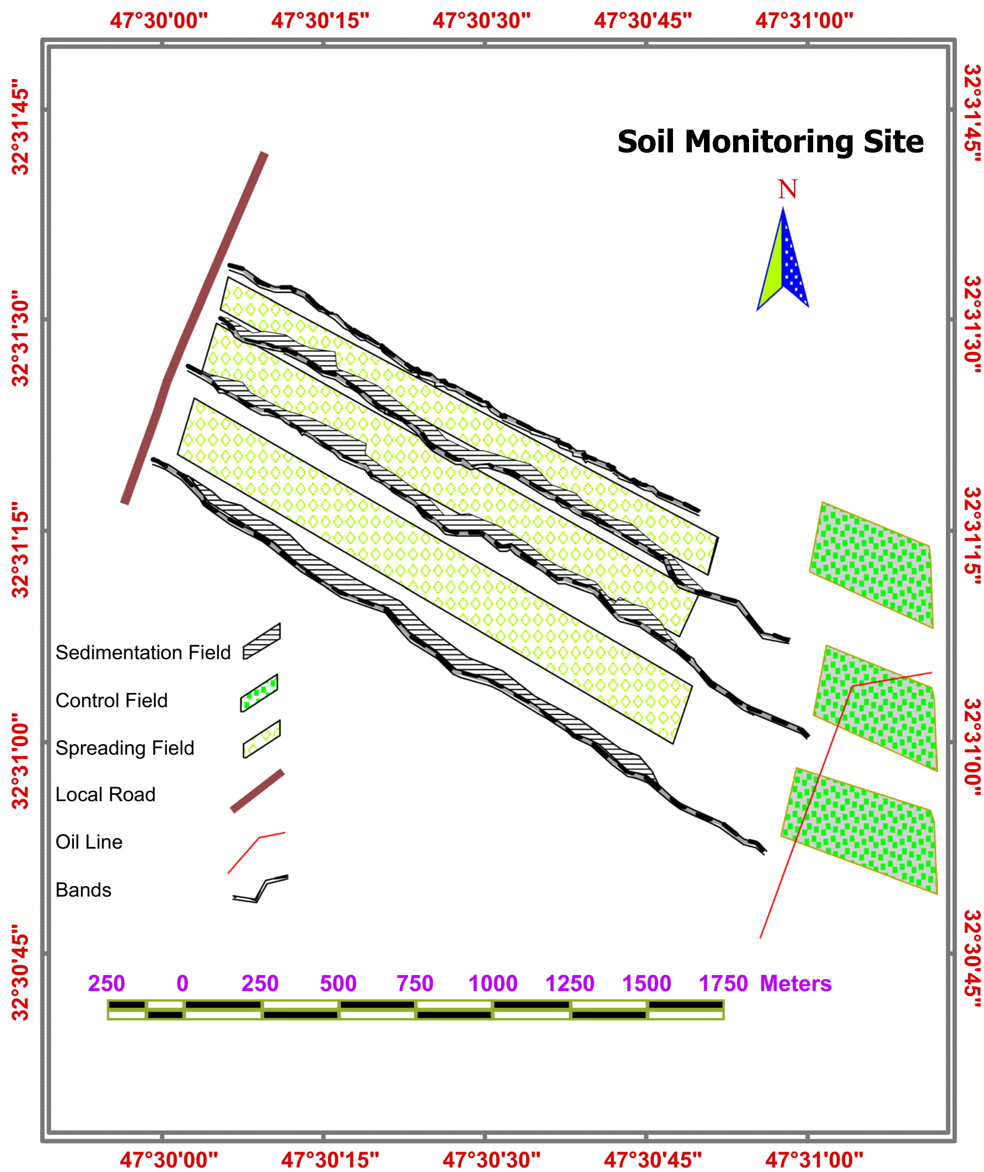
Fig. 2 Monthly rainfall of study area

Materials and methods

Study site

Mousian plain is located on a coarse texture soil (47°26′21″E 32°28′45″N) in southwestern Iran (Fig. 1). The elevation of study area from sea level is 65 m. The region has a semiarid climate with the mean annual precipitation of 271 mm that occurred in late autumn, winter, and early spring (Fig. 2). The study area received 302 mm of rainfall

Fig. 1 Location of flood-spreading project



in 2012. The mean annual temperature is 25 °C. The main formation of floodplain is alluvial sediment, and soils are classified as *Entisols*. This project was planned following the method Kowsar (1991). When the precipitation covers highland basin, the maximum flood occurred. Runoff from upper parts of the catchment distributes on FS sites with the slope of less than 1% from 2000. In FS site, *P. juliflora* plants had been established. These plants were planted at 5-m interval spacing, and their survival rate was 91% under FS condition. Control site (without spreading of flood) was located around the FS site that was similar to initial condition of area.

Soil sampling and analysis

For comparing the variations induced by *P. juliflora,* 30 soil samples under canopy, as well as 30 soil samples between trees were taken from depth of 0–15 cm. After preparation of soil samples, they were analyzed by following procedures: soil texture by the Bouyoucos hydrometer procedure (Liqiong 2010), organic carbon (OC) by the modified Walkley–Black method (Gelman et al. 2012), the total nitrogen by the Kjeldahl procedure (Bremner 1996), the available phosphorus by using 0.5 $NaHCO_3$ (Olsen et al. 1954), and the available potassium by NH4OAc method (Knudsen et al. 1982). Values of soil pH were determined in saturated pastes by using pH meter. Cation exchange capacity (CEC) and calcium carbonate equivalent (CCE) were determined by using N NH4OAc (Polemio and Rhoades 1977) and hydrochloric acid (Allison and Moodie 1965), respectively. Infiltration rate was determined using double rings with inner and outer ring diameters of 25 and 50 cm, respectively. The volume of water requirement to maintain water head was added at different time intervals. For determining the trend of infiltration rate, three initial lines of FS system were studied. Four pairs of plants were selected in each site. Each pair of plants consisted of a FS-affected plant and a non-FS-affected plant. For measuring the infiltration rates, a total of 30 points in FS site, next to *P. juliflora* and control sites (without FS), were selected. Below-ground biomass (BGB) was harvested at subsoil and placed into an envelope. Each sample was weighed after drying at 65 °C for 36 h. The soil surface was about 15 cm, and the plant roots were distributed in the 0–15 cm soil layer in the FS project site. Soil samples were collected from 0 to 15 cm and passed through a 2-mm sieve. The water content was determined by using time domain reflectometry (TDR) instrument (Noborio 2001). For assessing the soil microbial respiration, the CO_2 release method was used. A *t* test analysis was used for comparing the soil characteristics of FS and the control site. A Pearson's correlation method was used to determine the relationship between some soil characteristics (Ahlgren et al. 2003). For analysis of data, SAS v.9.4 was employed (SAS Institute 2017).

Results and discussion

The soils in FS sites were mainly classified as Entisols. The soils had high water infiltration and low nutrients concentration because they had a high sand fraction (Hamza and Anderson 2003). High soil pH may decline uptake of some nutrient elements such as phosphorus by trees.

The effect of FS on soil physical characteristics

The soil physical characteristics of the different locations in the FS project are shown in Table 1. The soil moisture under FS site (8.37 ± 0.15%) was significantly higher than that in the control site at early spring (4.07 ± 0.12%). The changes in water content under FS condition are obviously evident (Table 1). The reason for the low water content may be attributed to low water-holding capacity of soil in control site compared to FS site. These results agreed with the findings of (Saxton and Rawls 2006). The results of soil texture are shown in Table 1. The analysis of soil particle size indicated higher than 65% sand, less than 25% silt, and less than 10% clay in all samples. The results show a coarse texture in soil surface of research region. The differences in sand, silt, and clay percent between FS and control site were significant ($p < 0.01$).

The clay percent increased as affected by FS. The mean clay percent in the 15 cm of soil surface in control and FS sites were 5.41 ± 0.72 and 10.21 ± 1.03, respectively. This is a beneficial factor for coarse texture soils. The FS site had a

Table 1 Soil physical characteristics in different sites of the FS project

Location	Soil moisture (%)	Sand (%)	Silt (%)	Clay (%)	Texture	Infiltration rate ($cm\ h^{-1}$)
FS site	8.37 ± 0.15^a	65.25 ± 5.12^b	24.54 ± 1.93^a	10.21 ± 1.03^a	Sandy loam	2.45 ± 0.11^b
Control	4.07 ± 0.12^b	85.02 ± 6.33^a	9.57 ± 1.93^b	5.41 ± 0.72^b	Loamy sand	4.13 ± 0.12^a

FS Flood spreading

[a,b] Means followed by the same letter are not significantly different from each other based on paired *t* test ($p < 0.05$)

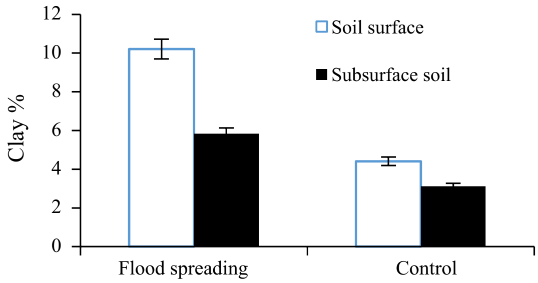


Fig. 3 Differences of clay content between soil surface and subsurface

sandy loam texture (65% sand, 25% silt, and 10% clay), and the control had a sand texture (91% sand, 5% silt, and 4% clay). The mixture of the loamy sand soils and fine particles (in flood) has produced an acceptable medium for tree establishment than loamy sand soils. The topsoil removal in FS sites is confirmed by having the same soil texture in the soil surface of the control with the subsoil of FS site. But, clay percent in subsoil of FS site was higher than that in the soil surface of the control site. This could be explained by illuviation of the clay particles (Fig. 3). The role of clay content in maintaining nutrient elements in loamy sand soils is very important for soil fertility (Buri et al. 2010).

The soil infiltration rates without FS were very high (4.13 ± 0.12 cm h^{-1}). The linear curve of the infiltration rate shows that soils in control site were well drained. The final infiltration in FS sites had lower rates in comparison with control. Control sites had the low clay and silt percentage. There were not enough fine particles to ban pores. With increase in clay percentage, the drop rate of infiltration rate decreased. Fine soil particles are substrates for closing pores in loamy sand soils. Spreading of flood on the plain resulted in deposition of large amounts of fine particles on the surface of soil. The decrease in infiltration rate was related to increase in clay + silt fraction up to the sandy loam. These amounts were in the range of amounts reported in the past researches for the similar conditions (Fashi et al. 2014). Researchers had reported a negative relation between infiltration and sand fraction of soil surface (Bean et al. 2007).

The effect of FS on soil chemical characteristics

There were no significant differences in pH among different sites in FS project (Table 2). Flood had OC and spreading of it raised the soil OC percent from 0.12 ± 0.03 to 0.31 ± 0.05. Soil OC percent was correlated with clay percent ($r = 0.81$, $p < 0.01$) and silt percent ($r = 0.72$, $p < 0.05$) (Fig. 4).

Table 2 Soil chemical characteristics in different sites of the FS project

Location	pH	OC (%)	Total nitrogen (%)	Phosphorus (mg kg^{-1})	Potassium (mg kg^{-1})	CEC (cmol kg^{-1})	CCE (%)
FS site	7.37 ± 0.20^a	0.31 ± 0.05^a	0.029 ± 0.004^a	3.25 ± 0.33^a	47.5 ± 5.24^a	4.11 ± 0.37^a	4.12 ± 0.38^a
Control	7.40 ± 0.21^a	0.12 ± 0.03^b	0.013 ± 0.002^b	1.47 ± 0.12^b	22.4 ± 2.06^b	2.39 ± 0.20^b	1.67 ± 0.11^b
Sig.	ns	**	**	*	*	*	**
CV%	9.19	8.29	8.81	7.33	9.83	6.58	9.17

FS Flood spreading

* Significant at the 0.05 probability level

** Significant at the 0.01 probability level

[a,b] Means followed by the same letter are not significantly different from each other based on paired *t* test ($p < 0.05$)

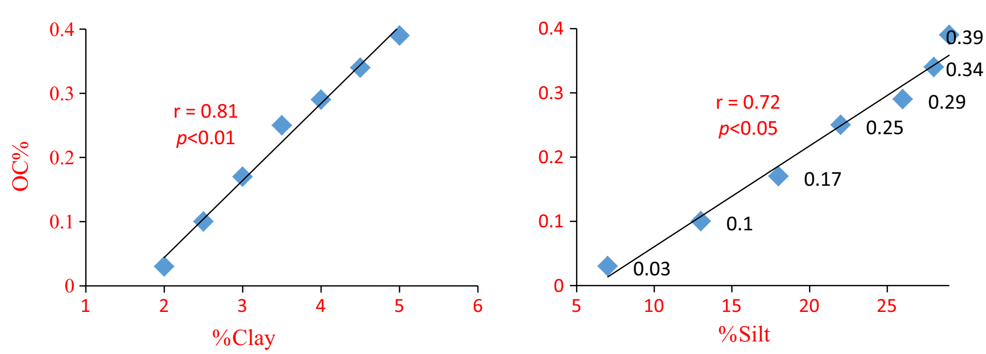


Fig. 4 Relationship between OC% and fine particles

The total nitrogen, available phosphorus, and potassium increased under FS condition respect to control, significantly (Table 2). In addition, the cation exchange capacity (CEC) of soils increased significantly (71.9%, $p<0.05$) under FS compared to control. Increase in CEC reflects the fine particles and OC variations under FS condition. In the FS site, there was the higher calcium carbonate equivalent (CCE) compared to control ($p<0.01$). The sediment in the region contains 4.12 ± 0.38 of CCE%. The similarity of the CCE percent in sediment and FS sites could be an indication for outcropping of sediment and soil surface of FS region (Karimi et al. 2011).

Interaction of *P. juliflora* and FS on soil characteristics

In the FS sites, soil water percent under canopy of *P. juliflora* (8.32 ± 0.13%) was significantly higher than that of in the between trees (6.35 ± 0.11%). The infiltration rate of soils under canopy and out of canopy of *P. juliflora* as affected by FS is presented in Table 3. The soil infiltration rate under canopy of *P. juliflora* was higher than that obtained in control. It is indicated that this increase is due to macropores occurrence. Root channeling of *P. juliflora* caused the soil infiltration rate to increase from 2.58 cm h^{-1} in the control to 3.08 under canopy of *P. juliflora*. Researchers have reported that introduction of some plants increases infiltration by more macropores (Lipiec et al. 2006).

The results indicated an obvious change in the infiltration rates as affected by FS. Some evidence of increase in clay percent may interpret the decrease in infiltration rates of FS area. In this condition, fine pores of soil are closed (Pla et al. 2017). Also Viglione et al. (2016) reported a decrease in soil infiltration as affected by flood. Ghazavi et al. (2010) reported that FS decreased significantly the soil infiltration. This result was in agreement with results of present research. One of the clear improvements under FS condition was found in root yield of *P. juliflora*. This is due to the increase in soil moisture around *P. juliflora* stands. Development of plant root production as affected by FS has reported by other researchers (Ghahari et al. 2014). Researchers had reported a direct relation between infiltration and plant cover (Frouz et al. 2011).

The pH values were lower under *P. juliflora* in the FS than in the control site ($p<0.05$). Soil organic carbon was significantly higher in samples collected next to *P. juliflora* under FS (0.72 ± 0.06%) than from between trees (control) (0.41 ± 0.05%). In comparison with soil between trees, nitrogen, phosphorus, and potassium were significantly higher under *P. juliflora* (Table 3). Woody legumes such as *P. juliflora* have the ability to symbiotically fix atmospheric N_2 (Bruning and Rozema 2013). In addition, it is obvious that distribution pattern of nutrients followed that of the soil organic matter (OM).

The soil under canopy of some plants shows higher rates of nutrients than soil of between the plants. Johnson et al. (2014) reported that increase in nutrients under canopy is due to the lower leaching of nutrient elements under plants and increase in nutrient capturing by plant roots from the lower soil layers. There were no significant differences in potassium values between control and under *P. juliflora* (Table 3). In the FS site, CEC increased significantly ($p<0.05$) next to canopy of *P. juliflora* (6.67 ± 0.54 cmol kg^{-1}) compared to between trees (4.25 ± 0.41 cmol kg^{-1}), which could be related to its high clay percent and OC. The biological soil properties can play an important role in the study of the effects of FS on soil quality. The soil microbial respiration (SMR) is an indicator of soil quality increased from 0.04 mg CO_2/g day in the between trees to 0.09 mg CO_2/g day under canopy of *P. juliflora* ($p<0.01$). According to some investigations, there are the direct correlations among soil physical characteristics and microbial activity (Zornoza et al. 2008). Fine particles and OC could be responsible for the increase in the SMR under canopy of *P. juliflora*. According to Straathof et al. (2014) the higher SMR of soils is explained by their high OC percent. Gougoulias

Table 3 Effect of *P. juliflora* establishment on soil characteristics

Soil characteristics	Under canopy	Between trees	CV%	ANOVA
Soil water content (%)	8.32 ± 0.13	6.35 ± 0.11	8.52	**
IR (cm h^{-1})	3.05 ± 0.22	2. 48 ± 0.20	7.83	*
pH	7.21 ± 0.62	7.35 ± 0.53	6.14	*
OC (%)	0.72 ± 0.06	0.41 ± 0.05	8.27	**
Total nitrogen (%)	0.064 ± 0.007	0.039 ± 0.004	9.08	**
Phosphorus (mg kg^{-1})	5.78 ± 0.52	3.89 ± 0.41	7.51	*
Potassium	49.1 ± 4.18	47.5 ± 5.24	8.37	ns
CEC (cmol kg^{-1})	6.67 ± 0.54	4.25 ± 0.41	6.34	*
SMR (mg CO_2/g day)	0.09 ± 0.008	0.04 ± 0.005	8.07	**
Root yield (g m^{-2})	537.2 ± 9.16	311.6 ± 5.28	9.45	**

IR infiltration rate, *OC* organic carbon, *CEC* cation exchange capacity, *SMR* soil microbial respiration

* Significant at the 0.05 probability level

** Significant at the 0.01 probability level et al. (2014) believe that OC and plant residue under plant canopy are important for increase in SMR. Loamy sand soils have low OC and caused a decrease in microbial respiration. The accumulation of plant residue under canopies is responsible for the formation of “fertile patches” in semiarid ecosystems. The root yield in the subsurface of *P. juliflora* under FS site (537.2 ± 9.16 g m^{-2}) was significantly higher than that of in the control site (311.6 ± 5.28 g m^{-2}) ($p < 0.05$). The presence of plants and their plant residues are responsible for changes in soil characteristics. Woody legumes such as *P. juliflora* have the ability to develop a vast root system (Van Auken 2009).

Conclusion

FS system has been accepted as a practical way for controlling the runoff in Iran. The success of FS project depends on understanding of relations among the soil, water, and plant. In areas where the soils are loamy sand, plants could be grown only after remediation of their characteristics. The results of soil characteristics suggested that the FS improved the soil quality such as soil OC and fertility. It is obvious that the nutrient contents followed the distribution pattern of the soil OC in all sites, and those under *P. juliflora* canopies were well pronounced. The similar measurements have been reported for some plant species in dry area (Sameni and Soleimani 2006). In addition, relationship between soil texture and OC% was evident under FS. These findings are attributed to the higher clay and silt percent under FS and the fact that OC is bounded to the fine particles. In the loamy sand soils, increasing clay can develop soil texture and water storage capacity. Soil infiltration has a role in status of water storage that is important for the plant survival in semiarid lands. Some investigations have reported the interaction between soil infiltration rate and texture. Importantly, the clay content was significantly and negatively related to the infiltration rate. Soil infiltration rates were influenced by the soil texture. The soil infiltration under canopy of *P. juliflora* was 32% higher than out of the canopy. The introduction of *P. juliflora* increased infiltration by more macro pores. The decrease/increase of infiltration rate is depended on the particle size of the suspended materials in the flood water. This change can be beneficial to improve plant growth. Our results indicated that *P. juliflora* had the significant effects on OC and soil fertility. The suspended OM and fine particles in flood increased the soil fertility of FS project and under canopy of *P. juliflora*. Our study show that spreading of flood water was beneficial for correction of loamy sand soils and we suggest that *P. juliflora* should be closely considered for using in FS projects. These trees as affected by FS less suffer from water scarcity of semiarid lands. Furthermore, the main factor that influenced soil infiltration rate was fine particle fractions in soil surface. Future studies should be on changes in soil biological characteristics under FS.

Acknowledgements The managing director of Ilam Agricultural and Natural Resources Research and Education Center is highly appreciated for their cooperation in conducting this investigation. This research was supported by Agricultural Research, Education and Extension Organization (Code: 90862541).

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