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Invasion of *Prosopis juliflora* and its effects on soil physicochemical properties in Afar region, Northeast Ethiopia

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ABSTRACT

Woody species within pastures and savannas are often associated with 'resource islands' characterized by higher fertility under canopies trees. The aims of this study were to evaluate (1) the effects of *Prosopis juliflora* on some soil physicochemical properties and (2) the impacts of *Prosopis* invasion on soil salinity. For soil physicochemical analysis**,** a total of 104 soil samples from Teru and Yalo Districts were collected. The soil samples were collected from soil depths of 0–15 cm and 15–30 cm in *Prosopis* invaded and non-invaded open grazing lands. Invasion of *Prosopis* had significantly affected soil pH, exchangeable Na^+, water soluble $Ca^{2+} + Mg^{2+}$, water soluble Na^+, and exchangeable sodium percentage in Teru and Yalo Districts ($p < 0.05$). The invasion of *Prosopis* significantly increased soil pH (1.5%), but decreased exchangeable Na^+ (24.2%), exchangeable sodium percentage (21.6%), and water soluble $Ca^{2+} + Mg^{2+}$ (39.9%) than non-invaded lands. Clay content of *Prosopis* invaded lands was higher by 19% than non-invaded lands. However, sand content of soil was higher under non-invaded lands by 5.6% than *Prosopis* invaded lands. Most results indicated that invasion of *Prosopis* had positive effects on physicochemical properties and thus conducive for cereal crops and forages.

1. Introduction

Recently, global levels of biological invasions are increasing (Thapa et al., 2018). Invasive species are either indigenous or exotic plants, animals, and microorganisms which can heavily colonize a particular habitat (Ng'weno et al., 2009). Invasive alien plants are of great concern in Ethiopia, posing particular problems on biodiversity with great economic and ecological consequences (Shiferaw et al., 2018). Among invasive alien plants in Ethiopia, *Parthenium* weed (*Parthenium hysterophorus*), *Prosopis juliflora,* water hyacinth (*Eichhornia crassipes*), and lantana weed (*Lantana camara*) are the three severe invasive alien plants threatening different ecosystems (EBI, 2014).

Prosopis juliflora belongs to the family Fabaceae (Leguminosae), subfamily Mimosoideae. *Prosopis* is a shrub/tree native to Mexico, Central and Northern America. *Prosopis* spread to Africa, Asia and Australia from its native ranges (Pasiecznik et al., 2001). In Africa, *Prosopis* was first introduced to Senegal in 1822 and continued to establish in other countries in different times (Jama & Zeila, 2005).

In Ethiopia, *Prosopis* was said to have been introduced in the 1970s for reclamation of degraded areas in low lands (Abebe, 2012). *Prosopis* covered about 5 million hectares forming dense thicket in Africa. It was reported that 1.2 million hectares of *Prosopis* invaded lands constituted 12.3% of the land surface in Afar region (Shiferaw et al., 2019).

Woody species within pastures and savannas are often associated with 'resource islands' characterized by higher fertility and organic matter levels under the tree canopies. In silvopastoral systems, trees are included in cultivated fields or pastures in order to maintain soil fertility, cycle nutrients, improve microclimate, manage water table and improve overall system productivity (Tiessen et al., 2003). Improved fertility under tree canopies can result from litter fall or dung inputs from sheltering animals (Tiedemann & Klemmedson, 1973).

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Prosopis invaded habitats in the Afar region are river banks, irrigated croplands, wildlife conservation areas, roadsides, and around settlements (Shiferaw et al., 2018). In addition, the ameliorating effects of *Prosopis* also involve in reducing soil salinity, neutralizing alkaline soils, sodic and improving soil nutritional status and physical properties. These are primarily due to complex interactions between the effects of floral and soil microbial populations (Pasiecznik et al., 2001; Ahirwal et al., 2017). However, so far no researches were reported from Teru and Yalo plains of Afar region about the effects of *Prosopis* on soil physicochemical properties and soil salinity.

Therefore, this study aimed to analyze (1) the effects of *Prosopis* on some soil physicochemical properties and (2) the impacts of *Prosopis* invasion on soil salinity. In addition, the study attempted to answer the following questions: (1) what are the status of some soil physicochemical properties under the invaded and non-invaded lands by *Prosopis*? and (2) do *Prosopis* invasion alter soil salinity under the invaded and non-invaded lands in Teru and Yalo Districts? Thus, the hypotheses of the study were (1) Invasion by *Prosopis* did not alter soil physicochemical properties and (2) Invasion by *Prosopis* did not alter soil salinity in the study areas.

2. Materials and methods

2.1. Description of the study area

Teru District is located 12°38′03.95″N to 13°0′.00″N and 39°55′.00″E to 40°18′00.0″E and at an altitude of 354 m.a.s.l. Whereas Yalo District is located between 12° 40′ 0″ N to12° 45′ 0″ N, and 39°65′0.00″ E to 40°25′.00″ and at altitude of 826 m.a.s.l. (Fig. 1). Climate data were taken from the nearest Chifira Meteorology Station in Afar region (EMA, 2018). The mean annual temperature of the study site was 27.5 °C. The mean annual temperature ranged from 16.8 °C to 39.9 °C. The annual precipitation in the study site was 173 mm (Fig. 2).

The dominating feature of geology is intense slicing of the Afar Neogene volcanic by early Pleistocene fault-belts ((Mohr, 1972). According to FAO soil classification and ISRIC-world soil information, the soil of the Afar Floristic region was Lithic, Eutric leptosols, and Eutricfluvisols (Friis et al., 2010). *Acacia-Commiphora* woodland and bushland are among vegetation types in Ethiopia which is characterizing the floristic region (Friis et al., 2010). Ninety percent of Afar people were pastoralists, while another ten percent were considered agro-pastoralist (Wakie et al., 2014).

2.2. Sampling design

Prosopis invasions sites were categorized during preliminary reconnaissance survey. The study sites were stratified into approximately homogeneous units based on the following parameters such as invasion levels of *Prosopis*, the age of the species, land use and land cover, and physiography of the area. Soil samples were collected in August 2018 after rainy season.

A total of 104 soil samples were collected i.e., 52 samples each in Teru and Yalo Districts in the 0–15 and 15–30 cm soil depths under Prosopis invaded and non-invaded areas adjacent each other (10 m apart) were collected. The water scheme of test plots for *Prosopis* invaded areas in Teru District were near Teru River. But, the test plots for open grazing lands in Teru District were adjacent to *Prosopis* invaded lands. On the other hand, the water schemes for both

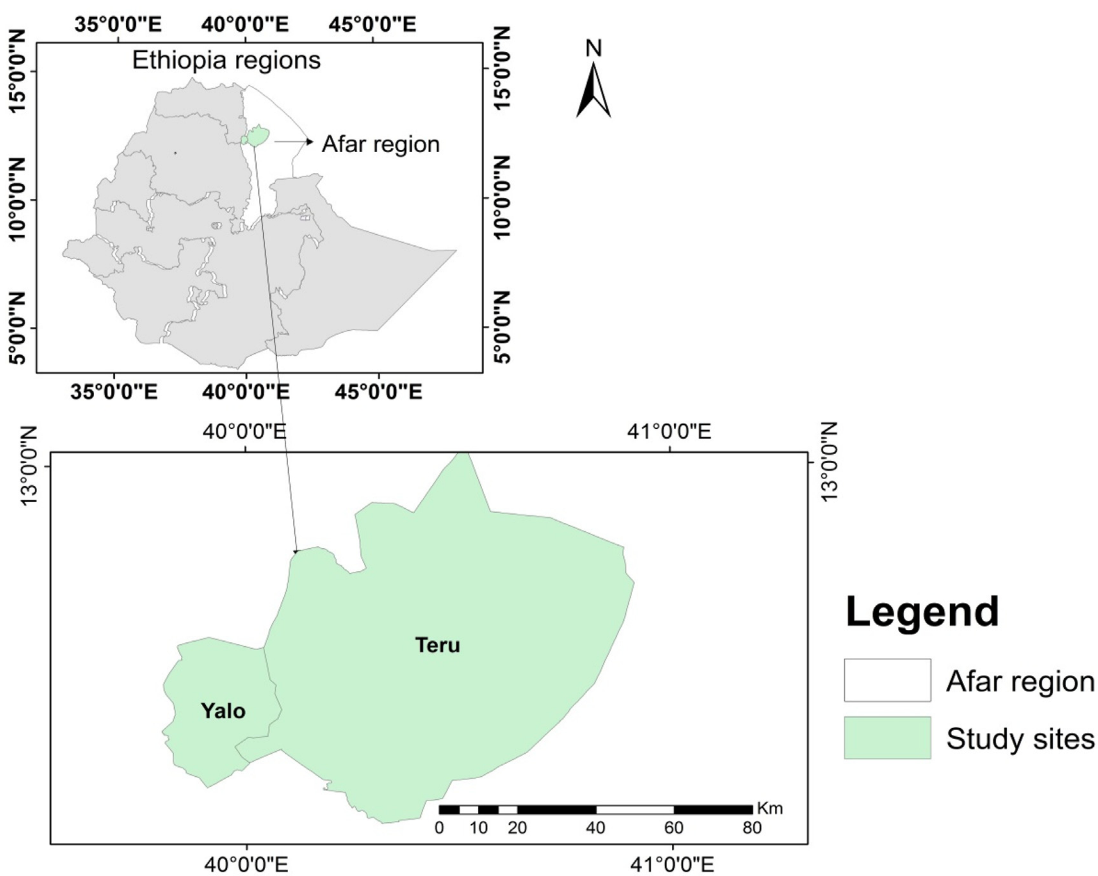

Fig. 1. Map the study areas.

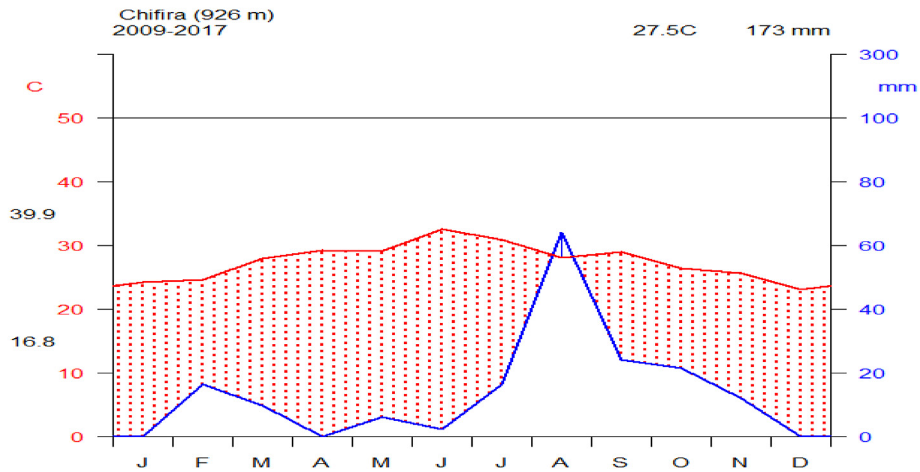

Fig. 2. Climate diagram for the study sites (Red dots indicate deficit in rainfall, blue solid line excess rainfall, C = degree Celsius, vertical left is rainfall (mm), vertical right is temperature (^{0}C)).

test plots of *Prosopis* invaded and adjacent non-invaded lands in Yalo District were distant from rivers but near villages. Then, composite soil samples were made for each soil depths. Finally, from the composite soil samples for each depth, 500g of the representative samples were labeled and sealed with a plastic bag and taken to a soil laboratory for physiochemical analysis. Near the center of all plots, representative soil bulk density was also being taken only for upper soil layer (0–15 cm) using core sampler.

Soil moisture content (SMC %) on a dry mass basis expressed as percentages by mass to an accuracy of 0.1% (m/m) was calculated using equation (1) which was analyzed from a soil sample taken for bulk density.

$$SMC\% = \frac{M1 - M2}{M2 - M0} \times 100 \quad (1)$$

Where M_0 mass of the empty container with a lid (g), M_1 mass of the container with air-dried soil or field-moist soil (g), M_2 mass of the container plus oven-dried soil (g) at 105 °C for 24hrs (Wilke, 2005).

Typical particle densities for soils range from 2.60 to 2.75 g/cm^3 for mineral particles (Globe, 2005). The amount of pore space or porosity of the soil was calculated according to the following equation (2):

Bulk Density = mass of dry soil/total volume of soil and air (g/cm^3).

Particle Density = mass of dry soil/volume of soil particles only (air removed) (g/cm^3)

$$porosty = \left[1 - \frac{Db}{Pd} \times 100\right] \quad (2)$$

Then,

$$\%pore\ \ space = 100 - \left[\left(\frac{Db}{Dp}\right) \times 100\right] \quad (3)$$

Where D_b = bulk density and D_p = particle density.

The exchangeable sodium percentage is the equivalent fraction of exchangeable Na + to cation exchangeable capacity multiplied by 100. It was computed using Cannon et al. (2007, p. 45).

$$ESP = \left(\frac{Exchangeable\ \ Na}{Cation\ \ excheange\ \ capacity}\right) \times 100 \quad (4)$$

Sodium absorption ratio (SAR) was also computed using Cannon et al. (2007, p. 45).

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (5)$$

Cation Exchangeable Capacity (CEC) was also be analyzed in the laboratory by adding basic cations. After Ca, Mg and K will be analyzed in the laboratory, CEC could be computed following (Ross & Ketterings, 2011):

$$CEC\left(\frac{meq}{100}g\ \ or\ \frac{cmol}{kg}\right) = \frac{(ppmCa)}{200} + \frac{(ppmMg)}{120} + \frac{(ppmK)}{390} \quad (6)$$

2.3. Laboratory analysis

The sieved and stored samples were analyzed for soil pH using saturated paste extract of 1:1 soil to water. Organic carbon was determined by wet oxidation method (Wakley & Black, 1934). Organic matter was estimated as organic carbon multiplied by 1.724. Soil organic carbon was calculated using Eq. (7):

$$SOC = BD \times d \times \%\, C \quad (7)$$

Soil electrical conductivity (ECe) was analyzed in the laboratory using saturated paste extract (ICARDA, 2013). Amount of Ca and Mg in the leachate were analyzed by 1 N NH4Ac extraction method (ICARDA, 2013). K and Na were analyzed by flame emission spectroscopy using flame photometer. The exchangeable Na^+ shown here was already after the subtraction of the soluble fraction. The textural analyses were analyzed using hydrometer method (g/cm) using USDA textural triangle (Bouyoucos, 1962). Soil sample parameters were analyzed at Melka Werer Research Center Soil and Plant Analysis Laboratory, Ethiopia Agricultural Research Institute.

2.4. Data analysis

All soil related data were statistically analyzed using the Analysis of Variance (ANOVA) procedures of the general linear model (GLM) procedures of SAS 9.0. Means separations were carried out using the Dennett's t-tests at $P < 0.05$ significant level between sites and different invasion levels.

3. Results

3.1. Prosopis and soil chemical properties

Invasion of *Prosopis* was significantly affected soil pH, exchangeable Na^+, water soluble $Ca^{2+} + Mg^{2+}$, water soluble Na^+, and ESP in Teru and Yalo Districts. On the other hand, the effects of *Prosopis* invasion on ECe, exchangeable $Ca^{2+} + Mg^{2+}$, Ex K^+, water soluble K^+, sodium absorption ratio, organic carbon, and total organic carbon were not statistically significant in Teru and Yalo Districts ($P < 0.05$). The mean values of pH under *Prosopis* invaded areas were increased by 1.5% than in non-invaded open grazing lands. But, the mean values of exchangeable Na^+ were decreased under *Prosopis* invaded lands by 24.2% than in non-invaded open grazing lands (Table 1).

In addition, results showed that under *Prosopis* invaded sites, the mean values of exchangeable $Ca^{2+} + Mg^{2+}$ decreased by 2.2% than under non-invaded open grazing lands. The mean values of water soluble $Ca^{2+} + Mg^{2+}$ were decreased by 39.9% in *Prosopis* invaded lands than in non-invaded grazing lands. Meanwhile, the mean values of ESP were decreased by 21.6% under *Prosopis* invaded areas. Moreover, the mean values of water soluble Na^+ was decreased by 21% than lands in non-invaded areas of open grazing (Table 1).

3.2. Effects of Prosopis on soil physical properties

It was found that clay and sand showed significant variations in the study areas. But, the silt content of the soils was not statistically significant with land use systems ($P < 0.05$). The mean value of clay content for *Prosopis* invaded lands was increased by 23.5% than in non-invaded open grazing lands. But, the mean value of sand content for *Prosopis* invaded areas was decreased by 16.3% than lands in non-invaded adjacent lands (Table 1).

In Teru District, bulk density and moisture content for *Prosopis* invaded lands were 1.1 g/cm^3 and 81% respectively. But, the mean values of bulk density and moisture content for non-invaded open grazing lands were 1.2 g/cm^3 and 97.7%. In Yalo District, bulk density and moisture content for *Prosopis* invaded areas were 1.2 g/cm^3 and 147.9% respectively. But, the mean values of bulk density and soil moisture content for non-invaded open grazing lands were 1.5 g/cm^3 and SMC of 87.5% (Table 2).

3.3. Spatial variations of soil chemical properties in Teru and Yalo Districts

It was found that ECe, exchangeable $Ca^{2+} + Mg^{2+}$, exchangeable Na^+ exchangeable K^+, water soluble $Ca^{2+} + Mg^{2+}$, water soluble K^+, SAR, OC, TOC, and ESP were significant variations between study districts ($P < 0.05$). But, spatially pH and textural class did not reveal significant variations between the study districts. In Teru District, the mean value of ECe was increased by 54.6% than in Yalo District. In addition, the mean values of exchangeable $Ca^{2+} + Mg^{2+}$ was increased by 17.8% than in Yalo District (Table 3).

Furthermore, the mean values of exchangeable Na^+ in Teru district was increased by 34% than in Yalo District. But, the mean values of exchangeable K^+ in Teru district was decreased by 20.8% than in Yalo District. In addition, the mean value of water soluble $Ca^{2+} + Mg^{2+}$ in Teru District was decreased by 36.2% than in soil of Yalo District. Moreover, the mean values of water soluble K^+ in Teru soil was decreased by 48.9% than in soil of Yalo District. In addition, the mean value of total organic carbon for Teru District was decreased by 20% than in Yalo District. The mean value of organic carbon in Teru District was decreased by 19.8% than in Yalo soils. But, the mean value of ESP in Teru District was increased by 11.4% than in Yalo District (Table 3).

3.4. Spatial variations of physical properties in Teru and Yalo Districts

In this study, sand and silt showed significant variations between districts. But, clay content of the soils was not statistically significant between the study sites ($P < 0.05$). In Teru District, the mean value of sand content was decreased by 29.3% than in the soil of Yalo District. But, the mean value of silt content in Teru District was increased by 20% than Yalo District (Table 3).

3.5. Vertical variations of soil physicochemical properties in Teru and Yalo districts

In both soil layers, 0–15 cm and 15–30 cm down the soil profile, except exchangeable K^+ the rest of soil physicochemical properties considered did not significantly vary across the soil depths. The trends of ECe dS/m, exchangeable $Ca^{2+} + Mg^{2+}$ meq/L, and water soluble $Ca^{2+} + Mg^{2+}$ meq/L decreased down the soil depth. On the other hand, results depicted that soil pH, exchangeable Na^+ cmol kg^{-1}, exchangeable K^+ cmol kg^{-1}, water soluble Na^+ meq L^{-1}, water

Table 1
Effects of *Prosopis* on soil physicochemical properties in Teru and Yalo Districts.

0–30 cm					% change (100%(A-B)/B)
Types and units	Soil properties	*Prosopis* invaded (A)	Non-invaded grazing land (B)	P value of *t*-test	
_	pH	8.15	8.03	0.0002	1.49
dS m^{-1}	ECe	1.17	1.35	0.36	−13.33
Exchangeable cations (Cmol kg^{-1})	$Ca^{2+} + Mg^{2+}$	47.17	48.25	0.45	−2.24
	Na+	0.5	0.66	<0.0001	−24.24
	K+	1.44	1.24	0.08	16.13
% wt/wt	Clay	21.44	17.36	0.003	23.50
	Sand	28.5	34.05	0.04	−16.30
	Silt	50.06	48.59	0.73	3.03
	Textural class	Loam	Silt loam	0.25	Silt loam
Water soluble cations (meq L^{-1})	$Ca^{2+} + Mg^{2+}$	4.32	7.19	0.004	−39.92
	Na+	1.83	2.32	0.002	−21.12
	K+	0.32	0.35	0.65	−8.57
_	SAR	1.35	1.4	0.38	−3.57
%	OC	0.76	0.78	0.10	−2.56
	TOC	1.02	1.04	0.1	−1.92
	ESP	1.05	1.34	0.48	−21.64

Table 2
Some soil physical properties of Teru and Yalo Districts.

District	Habitat	Bulk density (g/cm^3)	Soil moisture content (SMC %)
Teru	*Prosopis* invaded lands	1.1	81.0
	Non-open gazing lands	1.2	97.7
Yalo	*Prosopis* invaded lands	1.2	147.9
	Non-open gazing lands	1.5	87.5

Table 3
Spatial variations of soil physicochemical properties in Teru and Yalo Districts.

Type and unit	Soil properties	Teru (A)	Yalo (B)	P value of *t*-test	% change 100%(A-B)/B)
–	pH	8.11	8.06	0.25	0.62
dS m^{-1}	ECe	1.53	0.99	0.02	54.55
Exchangeable cations (cmol kg^{-1})	$Ca^{2+} + Mg^{2+}$	51.56	43.77	0.0002	17.80
	Na^+	0.67	0.5	<0.0001	34.00
	K^+	1.18	1.49	0.01	−20.81
% wt/wt	Clay	20.15	18.21	0.27	10.65
	Sand	26.24	37.13	<0.0001	−29.33
	Silt	53.61	44.67	<0.0001	20.01
	Textural class	Silt loam	Silt loam	0.61	Silt loam
Water soluble cations (meq L^{-1})	$Ca^{2+} + Mg^{2+}$	4.62	7.24	0.03	−36.19
	Na^+	2.25	1.94	0.03	15.98
	K^+	0.23	0.45	<0.0001	−48.89
–	SAR	1.6	1.14	<0.0001	40.35
%	OC	0.69	0.86	0.002	−19.77
	TOC	0.92	1.15	0.002	−20.00
	ESP	1.27	1.14	0.04	11.40

soluble K^+ meq L^{-1}, SAR, % organic carbon (OC), % total organic carbon (TOC), and % ESP increased down the soil depths. Both % clay and % silt increased down the soil profile, but contents of % sand decreased. The textural classes across the soil depths showed that varied from silt loam to loam in 0–15 cm to loam in the lower 15–30 cm (Table 4).

3.6. Correlation coefficients among soil physicochemical properties

It was fund that soil silt showed significant and strong negative correlation (r = −0.85) with sand ($P < 0.01$). On the other hand, the correlation between textual class were not significant and very week negative correlations with soil reaction (pH) and exchangeable $Mg^{2+} + Ca^{2+}$ (r = −0.03). Moreover content of % silt and ECe dS/m; and % OC and clay showed insignificantly very week correlations (r = 0.02). Nevertheless, % ESP had shown strong significant correlation (r = 0.75) with exchangeable Na^+ ($P < 0.01$) (Table 5).

4. Discussion

4.1. Effects of Prosopis on soil chemical properties

The invasion of *Prosopis* was changed the physicochemical properties of Teru and Yalo districts. The overall soil pH in *Prosopis* invaded was higher than non-invaded grazing lands. The increase of pH in *Prosopis* invaded lands reason could be due to the proximity of river particularly in Teru district that declined organic carbon stock due to runoff (Morrissey et al., 2014). Soil pH of the soil was thus rated as moderate salinity in both *Prosopis* invaded and adjacent non-invaded open grazing lands (Beernaert and Bitondo 1992 cited in Asongwe et al., 2016). Similar results were indicated by Edrisi et al. (2020) that pH under non-invaded lands is lower than under *Prosopis* invaded lands in North India.

Though the soil pH critical level varies, the trend of soil pH under *Prosopis* invaded and open grazing lands were similar to findings by Menezes and Salcedo (1999) in the semi-arid of

Table 4
Effects of soil depth on soil physicochemical properties in Teru and Yalo Districts.

Type and unit	Soil properties	0–15 cm (A)	15–30 cm (B)	P value of *t*-test	% change (100%(A-B)/B)
–	pH	8.12	8.06	0.07	0.74
dS m^{-1}	ECe	1.09	1.36	0.32	−19.85
Exchangeable cations (cmol kg^{-1})	$Ca^{2+} + Mg^{2+}$	47.1	48.16	0.62	−2.20
	Na^+	0.59	0.57	0.61	3.51
	K^+	1.48	1.22	0.04	21.31
% wt/wt	Clay	20.39	18.53	0.15	10.04
	Sand	30.27	32.63	0.29	−7.23
	Silt	49.34	48.84	0.81	1.02
	Textural class	Loam	Silt loam	0.69	Silt loam
Water soluble cations (meq L^{-1})	$Ca^{2+} + Mg^{2+}$	4.8	6.21	0.07	−22.71
	Na^+	2.07	2.06	0.95	0.49
	K^+	0.36	0.31	0.09	16.13
–	SAR	1.44	1.31	0.16	9.92
%	OC	0.82	0.73	0.1	12.33
	TOC	1.09	0.97	0.09	12.37
	ESP	91.29	76.66	0.22	19.08

Table 5
Pearson correlations among soil physicochemical properties in Teru and Yalo Districts.

Variables	pH	ECe	$Ca^{2+}+Mg^{2+}$	Na^+	K^+	Clay	Sand	Silt	TC	SAR	SOC	TOC	ESP
ECe	−0.3**												
$Ca^{2+}+Mg^{2+}$	−0.10	0.04											
Na^+	−0.22*	0.20	0.36**										
K^+	0.32**	−0.04	−0.26*	−0.34**									
Clay	0.20	0.14	0.10	−0.30**	0.35**								
Sand	−0.26*	−0.10	−0.24*	−0.11	−0.08	−0.49**							
Silt	0.18	0.02	0.21	0.30**	−0.12	−0.1	−0.85**						
TC	−0.03	0.25*	−0.03	−0.08	0.05	0.33**	0.05	−0.26*					
SAR	0.37**	−0.16	0.17	0.31**	−0.26*	−0.1	−0.2*	0.35**	−0.3**				
SOC	0.31**	−0.11	−0.11	−0.14	0.38**	0.02	0.18	−0.22*	0.03	−0.11			
TOC	0.31**	−0.11	−0.11	−0.14	0.38**	0.02	0.18	−0.22*	0.03	−0.11	1.0**		
ESP	−0.18	0.19	−0.31**	0.75**	−0.25*	−0.4**	0.1**	0.13	−0.07	−0.13	−0.13	−0.13	

** Correlation is significant at the 0.01 level. TC is textural class.
* Correlation is significant at the 0.05 level.

Northeastern Brazil. The pH of the soil under *Prosopis* was similar to research made by Cibichakravarthy et al. (2011) near the Wetland Experimental Station of Tamil Nadu Agricultural University of India, and Mesene and Kabtamu (2017) for the case of Dupti in Afar region of Ethiopia. However, the average value of soil pH under *Prosopis* invaded lands in comparison to non-invaded grazing lands contradicts findings of Kahi et al. (2009) in Njemps Flats at the Baringo district of Kenya but similar to findings of Vallejo et al. (2012) in intensive silvopastoral systems of Colombia. Exchangeable Na^+ (Ex Na^+) is the sodium content in the resulting solution and ready for uptake by plant roots in the soil. Excess Ex Na^+ destroys soil structure by causing the individual soil particles to repel each other (Harron et al., 1983). Moreover, Elbashier et al. (2016) pointed out that soluble salts affect the productivity of soils in changing the osmotic potential of soil solution and increasing the content of Ex Na^+. Na improves the growth of Na-liking plants such as sugar beets, spinach, cabbage and barley and the Ex Na^+ concentrations only in the leaves of such plants should be 0.01–0.03 $cmolkg^{-1}$ (FAO, 2006) which is higher than total Na^+ in the soil of study sites.

The higher Ex Na^+ under *Prosopis* invaded lands in comparison to non-invaded grazing lands might be due to the amelioration effects of *Prosopis* that lessen Ex Na^+ (Maghembe et al., 1983; Nisar et al., 2013). In this study, the critical values of Ex Na^+ in the soil for both land use systems were rated as medium (Munjeb et al., 2018). Ex Na^+ under *Prosopis juliflora* invaded lands and non-invaded lands were less than the same land uses in semiarid northeast of Brazil (Menezes & Salcedo, 1999). On the other hand, it was found that the mean value of Ex Na^+ was similar to 7 years old of *Prosopis* invaded lands of India, but less than 5 years age of *Prosopis* (Bhojvaid, 1998).

The increase in the mean values of water soluble $Ca^{2+}+Mg^{2+}$ under non-invaded open grazing lands in comparison to *Prosopis* invaded lands might also be due to the reducing effects of *Prosopis* (Basavaraja et al., 2007). According to Munjeb et al. (2018), the critical value was rated as low for Ca^{2+} and medium for Mg^{2+} in both the land uses. However, soluble Na^+ was declined under *Prosopis* invaded lands was possibly due to the uptake of water soluble Na^+ by *Prosopis* (Basavaraja et al., 2007). In addition, the mean value of ESP under *Prosopis* was lower than the soils under open grazing lands. The reason was due to the reclaiming capacity of salt concentrations namely Na^+ relative to Ca^{2+} and Mg^{2+} by *Prosopis* (Maghembe et al., 1983; Nisar et al., 2013; Tiedemann & Klemmedson, 1973). The soil of both *Prosopis* invaded and non-invaded open grazing lands were non-saline (Qadir & Schubert, 2002; Gonzalez et al., 2004). It was found that salinity status of the study areas was also varied from that of Mishra et al. (2003) at Uttar Pradesh, in Dehra Dun of India. For both study sites, the trends of SOC were increased under *Prosopis* invaded lands than non-invaded lands though insignificantly varied. In soils of the current study, although total nitrogen was not analyzed, the increase of SOC which directly correlated with total nitrogen and the species is the Fabaceae family (nitrogen-fixer); total nitrogen could be predicted and increase under *Prosopis* invaded lands (Ahirwal et al., 2017; Edrisi et al., 2020).

4.2. Effects of Prosopis on soil physical properties

In the study landscapes, the clay content of *Prosopis* invaded lands was higher by 19.03% than non-invaded open grazing lands. But, sand content of soil was higher under non-invaded grazing lands by 5.6% than *Prosopis* invaded lands. The reason might be due to the invasion effects of *Prosopis* which in the long run modified soil texture (Mesene & Kabtamu, 2017) and low Ex Na^+ under *Prosopis* invaded lands could also reduce the dispersion of clay materials. However, it was found that a finding of the effects *Prosopis* on clay content contradicts research report by Andersson (2005) in the Lake Baringo area of Kenya. Moreover, due to the invasion of *Prosopis* in the periphery of rivers and in the lower slopes clay sized materials might be transported by soil erosion as well as gravitational forces deposited in these areas (Fan & Wu, 2001; Lawal et al., 2014; Nguyen & Pham, 2018).

The mean value of clay content under *Prosopis* canopy was higher by 20% than under non-invade open grazing lands. The reason probably due to soil long run soil forming factors such as increase in SOC due to soil biota (Ahirwal et al., 2017; Plante et al., 2006), inherited parent materials (Anderson 1988), and soil erosion which could cause for the raise of clay content (Lyles & Tatarko, 1986). Thus, the clay content of *Prosopis* invaded areas was higher, but similar to non-invaded areas for 5 and 7 years old invasion of *Prosopis* in sodic soils of Haryana of India (Bhojvaid, 1998). Moreover, the mean value of clay content in the soil for both *Prosopis* invaded and non-invaded lands were less than finding by Vallejo et al. (2012) in all the chrono-sequences that were considered in Colombia.

In Yalo district, the mean values of soil moisture and soil compaction were declined, but soil water content was affinity to be raised under open grazing lands than *Prosopis* invaded lands. These could be due to inputs of animal manures around homestead where the soil samples were collected (Morrissey et al., 2014; Su et al., 2016). This could probably the cause for the decline of soil bulk density and soil moisture content in Yalo District. In the study sites, the mechanisms behind the changes of soil properties under *Prosopis* invaded lands than non-invaded areas could be due to the N-fixation of the species and its litter biomass that increased SOC thus improve soil physicochemical and biological properties (Ahirwal et al., 2017).

5. Conclusion

The overall pH statuses were moderate salinity ranges for conducing agriculture practices. The decline in Exchangeable Na^+ under *Prosopis* invaded lands imply that invasion of lands by *Prosopis* had contributed for reduction of salinity problems. In this study, soils under invaded and non-invaded lands were rated as non-saline for food, feed and fiber productions. The rise of ECe in Teru District showed that high moisture content of the soil. This had implications for better crop and forage productions. Higher amounts of exchangeable Na^+ in Yalo than Teru District revealed symptoms for salinity problems. High Na^+ concentration is thus the cause for soil structure deteriorations. This will in turn hamper plant growth problems for susceptible forage, cereal, and fiber crop varieties. Higher soil organic carbon in Teru than Yalo District implied that soil in the district was suitable for cereal and forage establishment during rainy seasons or supplemental irrigation.

In Teru District, the overall salinity status under both *Prosopis* and grazing lands were none of salinity for conducing agricultural activities. In this particular study, soil of Teru District could be better suited for agriculture than Yalo District. Clay contents under *Prosopis* invaded sites were higher than non-invaded sites. But, the bulk density of soils under *Prosopis* invaded lands was lower than under non-invaded lands. Soils under *Prosopis* invaded lands were thus conducive for crop and forage production if the lands will be changed to crop lands. In most of our findings, the invasion of *Prosopis* had positive effects on physicochemical properties. However, in the future, studies of soil qualities in relation to different ages of *Prosopis* against native species are paramount importance for study.

Authors' contributions

All authors have equally contributed the inputs for the manuscript.

Declaration of competing interest

The authors declare that they have no competing interests.

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