IMPACTS OF PARTHENIUM WEED (*PARTHENIUM HYSTEROPHORUS* L.) ON SELECTED SOIL CHEMICAL PROPERTIES IN HIDHABU ABOTE DISTRICT, ETHIOPIA

Abu Feyisa*[1] and Samson Shimelse[2]

[1]Fitche Duplicate Gene Bank, Ethiopian Biodiversity Institute, Fitche, Ethiopia.

[2] Ethiopian Biodiversity Institute, P.O.Box 30726, Addis Ababa, Ethiopia.

ABSTRACT: *Parthenium hysterophorus* L. has become a major environmental, social, and economic threat in Ethiopia. Therefore, examining its impacts on soil chemical properties is vital to designing future management strategies. A total of 36 soil samples were collected from *P. hysterophorus* invaded and non-invaded sites. A simple *t*-test was conducted to examine the impacts of *P. hysterophorus*'s invasion on soil chemical properties between invaded and non-invaded sites per depth. Significant pairwise differences (p<0.05) were observed among means of soil pH, calcium, electrical conductivity, phosphorus, and magnesium between invaded and non-invaded sites. The threats of this species on native biodiversity, soil chemical properties, and the economy will be high in the future unless management action is undertaken. This study suggests that all relevant stakeholders should be organized to combat the expansion of the species to new areas.

Keywords: Biological invasion, Impact of invasion; Parthenium hysterophorus, *Soil*

INTRODUCTION

Biological invasion is one of the main drivers of biodiversity loss and also the second most common threat next to habitat destruction and ecosystem degradation (Thapa et al., 2018). They have affected natural processes, homogenized flora caused the extinction of species, compromised agricultural production (Zuberi et al., 2014), and damaged ecosystem resources (Namkeleja et al., 2014).

Parthenium hysterophorus L. is an annual herb that aggressively colonizes disturbed sites (Zuberi et al., 2014). It is considered one of the '100 most invasive species in the world (GISD, 2018). It has accidentally been introduced into several countries and has become a series of agricultural and rangeland weeds in parts of Australia, Asia, Africa, and the Pacific Islands. In more than 45 countries, it is reported as a major weed in field crops (Bajwa et al., 2018), with yield losses estimated in millions of dollars (Saini et al., 2014).

---

*Corresponding author: abufeyisa151@gmail.com

Parthenium hysterophorus is one of the top 20 invasive alien plants found in Ethiopia (Shiferaw et al., 2018) and the high spread of *P. hysterophorus* in the country has become a major threat to the various ecosystems (Shiferaw et al., 2018) and socioeconomic welfare (Tewelde and Mesfin, 2018). It poses high negative impacts on native biodiversity, agricultural lands, soil physical and chemical properties, rangeland resources, national parks, waterways, roadsides, urban green spaces, therefore leading to economic and social consequences (Zuberi et al., 2014; Hundessa, 2016). Ethiopian farmers describe it using the term "Faramsisa" in Afan Oromo, meaning "sign off"/"leave your farm" (Zuberi et al., 2014; Fite, 2017) which shows how this invasive weed is economically important. *P. hysterophorus* also affects human and animal health (McConnachie et al., 2011). In humans, it causes problems like asthma, bronchitis, dermatitis, and pollinosis. It also causes dermatitis with pronounced skin lesions and a large amount of *P. hysterophorus* L. in feed can kill cattle and buffalo (Kaur et al., 2014).

Parthenium hysterophorus prefers neutral to alkaline pH soils although it reacts to a wide variety of soils. It tolerates infertile, shallow, saline, and sodic soils. Its invaded sites were identified as having mostly sandy loam soil with a pH ranging from 5.4 to 7.4 (Kaur et al., 2014). Seeds of *P. hysterophorus* can germinate during any season of the year if moisture is available. It can keep its viability for an extended period and may grow under very harsh environmental conditions. Etana et al. (2011) reported that *P. hysterophorus* can extract nutrients from nutrient-deficient soils leading to high tissue levels of nitrogen phosphorus, potassium, and other macro and micronutrients, and recommending its manure for field crops.

A high amount of above-ground biomass along with the upper decomposition rate within the *P. hysterophorus* invaded area may lead to the observed increase in organic matter and nitrogen content (Timsina et al., 2011). According to Timsina et al. (2011) the increase in soil pH within the *P. hysterophorus* invaded area is due to the allelopathic chemicals discharged by the species into the soil which has no direct effect on the rise in soil nutrients, like nitrogen and phosphorus. The allelopathic compounds may, however, kill different soil microorganisms, and also the decomposition of microorganisms may cause increases in the amount of nutrients within the soil. *P. hysterophorus* L. grows in a very large choice of habitats and causes changes in above-ground vegetation as well as in below-ground soil nutrients (Timsina et al., 2011). These all are reported as the results of its concreted traits or its considerable phenotypic variation that may potentially promote invasiveness and thus, colonizing ability on soils across a broad range of habitat conditions. There was no research done in the study area concerning *P. hysterophorus* invasion and its impacts. Therefore, the purpose of this study was to examine the impacts of *P. hysterophorus* on selected soil chemical properties.

MATERIALS AND MEHTHODS

Description of the study area

The study was conducted in the Hidhabu Abote woreda/district, Ethiopia. Hidhabu Abote Wereda is one of the 14 woredas of the North Shewa Zone of Oromia Regional State and is located 34 km from the zonal capital of Fitche, and 146 km from the capital Addis Ababa. Hidhabu Abote is located at 9° 50′ 0″ N, 38° 30′ 0″ E in Ethiopia (Figure 1). It is bordered on the south by Kuyu, on the west by Wara Jarso, on the north by the Jamma river which separates, and on the east by Degem woreda.

The study area is characterized by a bimodal rainfall pattern with the main rainy season extending from July to September and the short season extending from March to May. The average annual rainfall and mean annual minimum and maximum temperature of the area based on the last ten years (2009-2017) records were 1014 mm and 8.57°C and 20.87°C respectively (Ababu, 2022). The agroecological zone of the woreda stretches between *Dega* (cool, humid highlands), *Weyena-dega* (mild, sub-humid highlands), and *Kola* (warm, semi-arid, lowlands) which covers about 12%, 73%, and 13.7% respectively (Ababu, 2022). The study woreda has a very diverse slope, ranging from flat lands (< 3%), a slope that accounts for 8% up to a very steep (> 60%) slope although the proportion is too small (< 0.1%) (Ababu, 2022). The major soil type of the study area is Nitisols. The soil is clay textured with a pH of 5.56, low content of nitrogen (0.15%), organic matter (1.42%), available phosphorous (4.36pmm), and moderate CEC (21.67 MEQ/100 g soil).

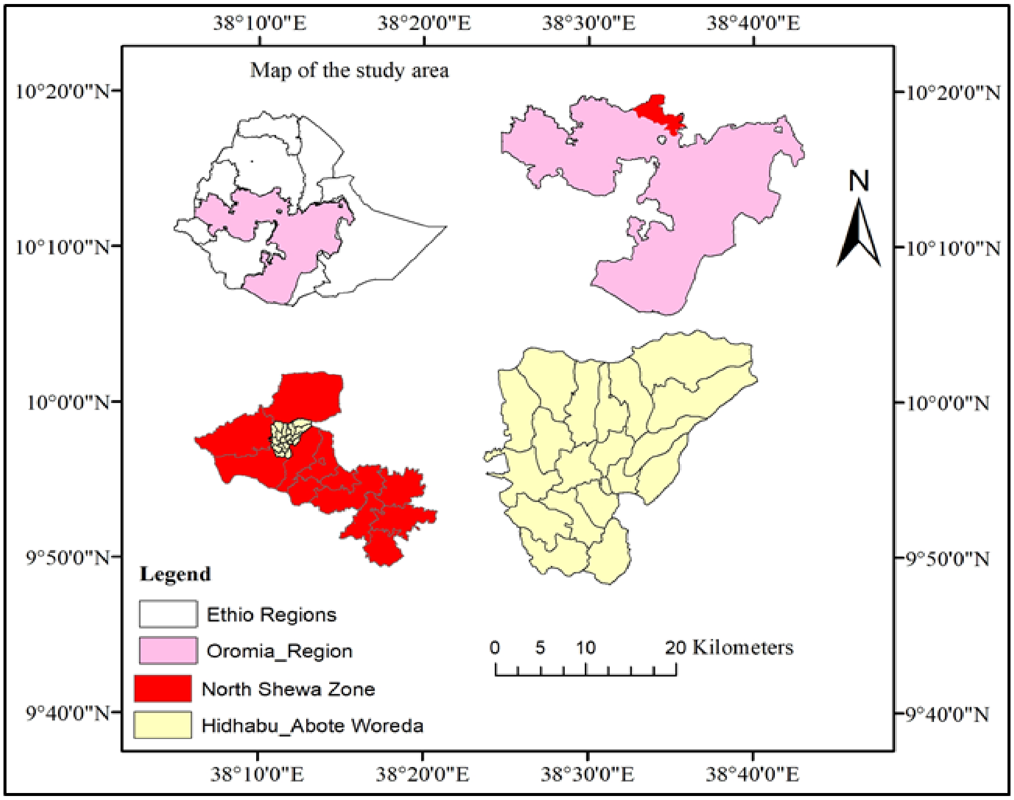

Figure 1. Map showing the study area.

Research design and sample collection methods

Reconnaissance survey

The reconnaissance survey was done to get information about the presence and the invasion area of *P. hysterophorus* in the study area. This was done by discussing with the Hidhabu Abote Agricultural office of the districts in the North Shewa Zone of the Oromia Region. This area was selected because it is one of the invaded areas in the North Shewa Zone. Field observation was also done to spot the invaded and non-invaded sites.

Sample collection

Soil samples were collected from invaded and non-invaded sites to test the soil pH, Nitrogen (N), carbon (C), phosphorus (P), electric conductivity (EC), exchangeable calcium (Ca^{2+}), and magnesium (Mg^{2+}) as these parameters used to determines soil fertility (Bai and Wang, 2011).

Sampling design

To examine the effect of *P. hysterophorus* on soil chemical properties, the study area was stratified into two categories (i) *P. hysterophorus* un-invaded site, and (ii) *P. hysterophorus* invaded site. The road is a means of entryway for invasive alien plant species due to the long-distance dispersal of propagules by vehicles (Ahmad et al., 2019). Therefore, sampling plots were laid on grazing land 10 m away from the road along a uniform slope gradient. In each category, three transects, 1 km long, were established. Within each transect, three 20 m × 20 m quadrats were established at every 500 m intervals making a total of 18 quadrates. Nested sub-plots of 1 m × 1 m (4 at the corner and 1 at the middle of the plot) were established to collect the soil sample.

Soil sample collection

In each subplot, using a core sampler auger, composite soil samples were taken at the depth of 0-20 and, 20-40 cm from the four corners and center of each quadrat after removing litter. Finally, 36 soil samples collected from each sub-plot were mixed homogenously and packed in a separate labeled plastic bag, and transported to Haramaya University soil laboratory for analysis.

Soil chemical analysis

The soil samples were oven-dried at 105°C for 24 h to remove the moisture of the sampled soil. Then, the grinded soil was passed through a 2 mm pore sieve for homogenization before being subjected to analysis. Soil pH, electrical conductivity and exchangeable basis were determined following the procedure of van Reeuwijk (2002. The pH of the soil was measured with a digital pH meter in the supernatant suspension in H_2O at the ratio of 1:2.5 (soil: water solution) using a combined glass electrode pH meter. The electrical conductivity (EC) of the soil 1:2.5 (soil: water) was measured by an EC meter. The organic carbon of the soil was also determined by the Walkley and Black (1934) method. The organic carbon was determined through wet oxidation of organic carbon with excess potassium dichromate ($K_2Cr_2O_7$) solution in the strong acid (H_2SO_4) rapid titration method. Total nitrogen was determined by the micro Kjeldahl digestion and titration method (Bremner and Hauck, 1982). Available phosphorus was analyzed using the Olsen sodium bicarbonate extraction solution (pH 8.5) (Olson et al., 1954) and the amount of available phosphorus was measured by spectrophotometer. Exchangeable bases (Ca^{2+} and Mg^{2+}) were extracted after leaching the soils with 1 N neutral ammonium acetate (NH_2OAc) solution. Exchangeable calcium and magnesium were determined by atomic absorption spectrophotometry (AAS).

Statistical analysis

A simple *t*-test was used to get the mean and the standard deviation of soil parameters in *P. hysterophorus* invaded and non-invaded grassland per soil surface separately. Using R statistical software, a paired samples *t*-test was used to compare the mean of each selected soil parameter in invaded and non-invaded sites per the two soil surfaces.

RESULTS

Impacts of *P. hysterophorus* on soil chemical properties

The row data value of the selected soil chemical properties obtained from the laboratory analysis was shown (Appendix 1). The mean and the standard deviation (SD) of the selected soil chemical properties in the invaded and non-invaded sites are presented in Table 1 and Table 2 respectively. The mean of soil pH (H20) in both the invaded and non-invaded sites was slightly lower in the upper soil surface. The result also showed that there was a significant mean difference in the amount of soil Ca ($p = 0.00$) and EC ($p = 0.04$) on lower soil surface. Similarly, a significant mean difference was observed in the score of soil Mg ($p = 0.02$) in the upper soil surface.

The mean of organic carbon varied from 1.52 to 1.75% on the upper soil and from 0.48 to 1.74 % on the lower surface in invaded and non-invaded sites, respectively. The mean of total varied from 0.11 to 0.11% on the upper soil and from 0.12 to 0.12 % in invaded and non-invaded sites respectively. The mean of available phosphorus values in invaded and non-invaded sites varied from 9.43 to 5.38 mg/kg on the upper soil surface respectively. Similarly, the mean of available phosphorus in invaded and non-invaded sites for lower surface ranged from 19.41 to 4.52 mg/kg. The mean of soil electric conductivity (EC) of the invaded and non-invaded sites ranges from 0.08 to 0.02 dS/mol in the upper soil surface whereas 0.05 to 0.03 dS/mol in invaded and non-invaded sites per lower surface. The mean value of exchangeable calcium in invaded and non-invaded sites varied from 8.83 to 5.638 cmol (+) kg^{-1} in the upper soil layer respectively. In addition, the mean of soil exchangeable calcium content in invaded and non-invaded sites in the lower soil surface varied from 9.98 to 5.94 cmol (+) kg^{-1}. The mean values of exchangeable magnesium (Mg) in invaded and non-invaded sites varied from 1.62 to 2.79 cmol (+) kg^{-1} in the upper soil surface respectively. Similarly, the mean of Mg content in invaded and non-invaded sites in the lower soil surface varied from 2.09 to 2.59 cmol (+) kg^{-1} respectively.

Table 1. Mean and the standard deviation (SD) values for the selected soil parameters in P. hysterophorus L. invaded site per upper (0 - 20 cm and lower (20-40 cm) soil surface.

soil parameters	Depths in cm	Stats	
		Mean	Sd
soil pH (H_20)	0 - 20	7.05	0.24
	20 – 40	7.12	0.87
OC %	0 - 20	1.52	1.08
	20 – 40	1.48	1.07
Total N %	0 - 20	0.11	0.04
	20 – 40	0.12	0.02
P (mg/kg)	0 - 20	9.43	13.92
	20 – 40	19.41	18.72
EC (dS/m)	0 - 20	0.08	0.08
	20 – 40	0.05	0.03
Ca (cmol(+)/kg	0 - 20	8.83	5.59
	20 – 40	9.98	4.16
Mg (cmol(+)/kg	0 - 20	1.62	0.77
	20 – 40	2.09	0.81

Table 2. Mean, and the standard deviation (SD) values for the selected soil parameters in P. hysterophorus L. non-invaded site per upper (0 - 20 cm and lower (20-40 cm) soil surface.

Soil parameters	Depths in cm	Mean	Sd
soil pH (H20)	0 - 20	6.78	0.15
	20-40	6.74	0.32
OC %	0 - 20	1.75	0.70
	20-40	1.74	0.58
Total N %	0 - 20	0.11	0.03
	20-40	0.12	0.01
P (mg/kg)	0 - 20	5.38	3.48
	20-40	4.52	2.44
EC (dS/m)	0 - 20	0.02	0.01
	20-40	0.03	0.02
Ca (cmol(+)/kg	0 - 20	5.68	3.28
	20-40	5.94	5.39
Mg (cmol(+)/kg	0 - 20	2.79	0.92
	20-40	2.59	1.00

A paired samples t-test showed that there is a significant mean difference in the soil pH (*p* = 0.02 and 0.001) in the upper and lower soil surface respectively (Table 3).

Table 3. Paired t-test mean comparison of the selected soil parameters from *P. hysterophorus* L. in invaded (IN) and non-invaded (NI) sites per soil depth (0-20 cm and 20-40 cm).

Parameters	**depth**	**Mf**	**t-value**	**Df**	**p-value**	**(95%) confidence**		**Significance**
pH	0-20	0.27	2.82	8	**0.02****	0.04878	0.4867	SS
	20-40	0.43	5.01	8	**0.001***	0.2304	0.6229	SS
N	0-20	0.00	-0.05	8	0.94	-0.052	0.0505	NS
	20-40	0.00	0.512	8	0.62	-0.02152	0.03383	NS
C	0-20	-0.23	-0.49	8	0.64	-1.3208	0.85718	NS
	20-40	-0.26	-0.75	8	0.47	-1.0587	0.5387	NS
P	0-20	4.053	0.86	8	0.4132	-6.7766	14.883	NS
	20-40	14.89	2.36	8	**0.046****	0.3178	29.467	SS
EC	0-20	0.060	2.12	8	0.06	-0.00616	0.12771	NS
	20-40	0.033	2.4	8	**0.04****	0.001152	0.06462	SS
Ca	0-20	3.15	1.436	8	0.188	-1.910005	8.21600	NS
	20-40	-2.53	-7.67	8	**0.00*****	-3.3022	-1.7756	SS
Mg	0-20	-1.17	-2.89	8	**0.02*****	-1.0842	0.0865	SS
	20-40	-0.49	-1.97	8	0.085	-1.3180	0.32051	NS

* Mf= mean difference, IN = invaded, NI = non-invaded, SS = statistically significant, NS = statistically not significant.

DISCUSSION

This study intended to compare the means of selected soil chemical properties between invaded and non-invaded sites to examine the variability caused by *P. hysterophorus L*. invasion. The pH of the soil in the invaded site is higher than the pH of non-invaded sites in both soil layers. The higher soil pH in the invaded site could be due to the increased concentration of calcium recorded in the site (Behera and Shukla, 2015) and the lower amount of soil carbon. The soil pH content in the invaded site in both depths was significantly higher than non-invaded site. Similar results were reported by Ojija and Manyanza (2021). Therefore, *P. hysterophorus* invasion affects the soil pH in the study area which in turn will have an effect on solubility and availability of nutrients in the soil.

The soil carbon values in the non-invaded site had more variability than the soil carbon values in the invaded site in both soil layers. However, there was no significant mean difference in invaded and non-invaded sites in both soil layers. Similar results were reported by Etana et al. (2015) and Ojija and Manyanza (2021) who found an insignificant effect of *P. hysterophorus L.* on soil organic carbon. The lower soil organic carbon content in the invaded site may be due to the lower decomposition rate and amount of above-ground biomass of *P. hysterophorus*. The high amount of above-ground biomass together with the higher decomposition rate in the invaded plots may lead to an increase in organic matter and nitrogen content of the soil (Timsina et al., 2011).

The soil total nitrogen values had no variability between invaded and non-invaded sites. As per total nitrogen ratings suggested by Landon (2014), the total soil nitrogen in non-invaded and invaded sites was rated very low and low in the upper soil surface whereas low in the lower soil surface. There was no significant difference ($p < 0.05$) in total soil nitrogen between invaded and non-invaded sites on both soil surfaces. Similarly, Etana et al. (2015) and Ojija and Manyanza (2021) reported non-significant differences in total soil nitrogen in invaded and non-invaded sites.

The available phosphorus content in the non-invaded site was lower than the available phosphorus in an invaded site in both soil layers. This may be because *P. hysterophorus* resulted in a high amount of soil phosphorus released back to the soil surface by decomposition as suggested by Masum et al. (2013). This finding is contrary to that of Ojija and Manyanza (2021) who reported a low amount of phosphorous in the invaded site in 10 cm soil cover. Timsina et al. (2011) reported that soil phosphorus content was higher in the *P. hysterophorus* invaded site at 15 cm soil cover. Similarly, our study revealed that the amount of phosphorus in the invaded site was significantly ($p < 0.05$) higher than the amount of phosphorus in non-invaded sites in 20-40 cm soil cover. The result showed that the invasion of *P. hysterophorus* increased soil phosphorus in the invaded area.

The study showed a significant difference ($p < 0.05$) in soil electric conductivity (EC) between non-invaded and invaded sites. This means that the soil in the invaded site had higher salt content than the soil in non-invaded sites. Hence this invasive species affects soil in the invaded site increasing salinity which in turn affects other living things such as flora and fauna. Electric conductivity is a measure of the contents of salts in the soil and EC of soil is directly affected by the soil's water contents, texture, and proportion of soluble salts (Winegardner, 2019). An EC that is too high in the soil can result in a physiological drought which restricts root water uptake by the plant, even when the substrate is moist (reference?). It results in salt toxicity which burns plant leaves.

The invaded site had higher soil exchangeable calcium content than non-invaded sites in both soil layers which indicated that *P. hysterophorus* had affected the soil calcium in the study site. This maybe because *P. hysterophorus* results in a high amount of soil calcium that it takes from the soil itself (Masum et al., 2013). The higher soil calcium content in the lower soil layer can be related to the nutrient movement to the lower soil surface. There was a significant difference ($p < 0.05$) in soil calcium between invaded and non-invaded sites in the 20-40 cm soil cover. Ojija and Marco Manyanza (2021) found a significant difference between *P. hysterophorus L.* invaded and non-invaded sites in 10 cm soil cover.

Soil-exchangeable magnesium was affected by *P. hysterophorus* in the study site as the exchangeable magnesium content was higher in the non-invaded site than exchangeable magnesium content in the invaded site on both soil surfaces.

CONCLUSION AND RECOMMANDATION

The majority of selected soil fertility parameters showed the trend of enhancement whereas decrease and no change for others because of *P. hysterophorus* L. invasion. But its invasion did not bring adverse impacts on soil based on the current findings in the study area even if reported otherwise by different researchers in different areas. This led to the conclusion that the adverse impact of Parthenium weed on the soil may depend on the duration of its invasion in the given area. *P. hysterophorus L*. may affects plant species either through its allelopathic chemicals discharged or altering the suitable range of soil fertility parameters.

Though *P. hysterophorus* had already been distributed in different parts of the country causing adverse effects on biodiversity, ecosystems, agriculture, food security, and the economy, its impact on parameters like biodiversity (above ground and below) need to be evaluated further. Preventing the spread of this invasive species into more susceptible environments requires an awareness of the distribution of the species and the impacts posed or a threat to a particular ecosystem. Policymakers should commit to developing management strategies that help to interact with local communities in managing this species.

ACKNOWLEDGEMENTS

The financial support granted to the author from the Africa Centre of Excellence for Climate Smart Agriculture and Biodiversity Conservation is gratefully acknowledged. The Author also sincerely thanks those who provided support during sample collection and reviewed the manuscript.

REFERENCES

Ababu, D. (2022). the role of watershed management practice for livelihood of smallholder farmers: evidence from Hidhabu Abote Woreda of North Shoa Zone in Oromia Region, Ethiopia. *Ethiopian Journal of Environmental Studies and Management*, **15(3):386–398**.

Ahmad, R., Khuroo, A.A., Hamid, M., Charles, B., and Rashid, I. (2019). Predicting invasion potential and niche dynamics of *Parthenium hysterophorus* (Congress grass) in India under projected climate change. Biodiversity and Conservation, pp.1-26.

Bai, Y., and Wang, Y. (2011). Spatial Variability of Soil Chemical Properties in a Jujube Slope on the Loess Plateau of China. *Soil Science*, **176:550–558**. https://doi.org/10.1097/SS.0b013e3182285cfd.

Bajwa, A. A., Tamado Tana, Chauhan, B. S., and Adkins, S. W. (2018). Effect of parthenium weed on maize yield at different competition durations in Ethiopia. 21st Australasian Weeds Conference September, 3–6.

Behera, S. K., and Shukla, A. K. (2015). Spatial distribution of surface soil acidity, electrical conductivity, soil organic carbon content and exchangeable potassium, calcium and magnesium in some cropped acid soils of India. *Land Degradation and Development*, **26(1):71–79**.

Bremner, J. M., and Hauck, R. D. (1982). Advances in methodology for research on nitrogen transformations in soils. In Nitrogen in Agricultural Soils (pp. 467–502). John Wiley and Sons, Ltd.

Etana, A., Kelbessa, E., and Soromessa, T. (2011). Impact of *Parthenium hysterophorus* L. (Asteraceae) on herbaceous plant biodiversity of Awash National Park (ANP), Ethiopia. *Management of Biological Invasions*, **2(1):69–80.** https://doi.org/10.3391/mbi.2011.2.1.07.

Etana, A., Kelbessa, E., and Soromessa, T. (2015). Impact of *Parthenium hysterophorus* L. (Asteraceae) on soil chemical properties and its distribution in a reserve area: A case study in Awash National Park (ANP), Ethiopia. *Journal of Soil Science and Environmental Management*, **6(5):116–124**. https://doi.org/10.5897/JSSEM12.015.

Fite, T. (2017). Distribution and Spread of Parthenium Weed [*Parthenium hysterophorus* L.) Infestation in Western Oromiya, Ethiopia. *Agricultural Research and Technology: Open Access Journal*, **11(4)**. https://doi.org/10.19080/artoaj.2017.11.555818.

Hundessa, N. (2016). Distribution and Abundance of Parthenium (*Parthenium hysterophorus* L.) in East Shewa and West Arsi Zones of Ethiopia. *Journal of Biology, Agriculture and Healthcare*, **6(5):65–71**.

Kaur, M., Aggarwal, N. K., Kumar, V., and Dhiman, R. (2014). Effects and management of *Parthenium hysterophorus*: A weed of global significance. *International Scholarly Research Notices*, **1–12**. https://doi.org/10.1155/2014/368647.

Landon, J. R. (2014). Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Taylor and Francis.

Masum, S. M., Hasanuzzaman, M., and Ali, M. H. (2013). Threats of *Parthenium hysterophorus* on agroecosystems and its management: a review. *International Journal of Agriculture and Crop Sciences*, **6(11):684–697**.

Mcconnachie, A. J., Strathie, L. W., Mersie, W., Gebrehiwot, L., Zewdie, K., Abdurehim, A., Abrha, B., Araya, T., Asaregew, F., Assefa, F., Gebre-Tsadik, R., Nigatu, L., Tadesse, B., and Tana, T. (2011). Current and potential geographical distribution of the invasive plant *Parthenium hysterophorus* (Asteraceae) in eastern and southern Africa. *Weed Research*, **51(1):71–84**. https://doi.org/10.1111/j.1365-3180.2010.00820.x.

Namkeleja, H. S., Tarimo, M. T. C., and Ndakidemi, P. A. (2014). Allelopathic effects of *Argemone mexicana* to growth of native plant species. *American Journal of Plant Sciences*, **05(09):1336–1344**. https://doi.org/10.4236/ajps.2014.59147.

Ojija, F., and Marco Manyanza, N. (2021). Distribution and impact of invasive *Parthenium hysterophorus* on soil around Arusha National Park, Tanzania. *Ecology and Evolutionary Biology*, **6(1):8**. https://doi.org/10.11648/j.eeb.20210601.13.

Olson, R. A., Rhodes, M. B., and Dreier, A. F. (1954). Available phosphorus status of nebraska soils in relation to series classification, time of sampling, and method of measurement. *Agronomy Journal*, **46(4):175–180**.

GSID (2018). Global Invasive Species Database (GISD). http://www.iucngisd.org/gisd/, accessed on 12 August 2022.

Saini, A., Aggarwal, N. K., Sharma, A., Kaur, M., and Yadav, A. (2014). Utility Potential of Parthenium hysterophorus for Its Strategic Management. *Advances in Agriculture*, Article ID 381859, **1–16**. https://doi.org/10.1155/2014/381859.

Shiferaw, W., Demissew, S., and Bekele, T. (2018). Invasive alien plant species in Ethiopia: ecological impacts on biodiversity a review paper. *International Journal of Molecular Biology*, **3(4):169–176**. https://doi.org/10.15406/ijmboa.2018.03.00072.

Tewelde, F., and Mesfin, M. (2018). Dominant Invasive species and their management practice in Tigray province, Northern Ethiopia. *Journal of Ecology and Environmental Sciences*, **6(2):50–57**. https://doi.org/10.5829/idosi.ajps.2018.11.2.11.18.

Thapa, S., Chitale, V., Rijal, S. J., Bisht, N., and Shrestha, B. B. (2018). Understanding the dynamics in distribution of invasive alien plant species under predicted climate change in Western Himalaya. *PLoS ONE*, **13(4):1–16**. https://doi.org/10.1371/journal.pone.0195752.

Timsina, B., Shrestha, B. B., Rokaya, M. B., and Münzbergová, Z. (2011). Impact of *Parthenium hysterophorus* L. invasion on plant species composition and soil properties of grassland communities in Nepal. *Flora: Morphology, Distribution, Functional Ecology of Plants*, 2**06(3): 233–240**. https://doi.org/10.1016/j.flora.2010.09.004.

Van Reeuwijk L.P.(2002). Procedures for soil analysis. 6th Edition, ISRIC, FAO, Wageningen pp. 869–879.

Walkley, A., and Black, I. A. (1934). an examination of the degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science,* **37(1)**.

Winegardner, D. L. (2019). An introduction to soils for environmental professionals. Routledg, Tailor and Francis group.

Zuberi, M. I., Gosaye, T. and Hossain, S. (2014). Potential threat of alien invasive species: *Parthenium hysterophorus* L. to subsistence agriculture in Ethiopia. *Sarhad Journal of Agriculture,* **30(1):117-125**.

Appendix 1: The row data values obtained from laboratory analysis for the selected soil parameters.

Site	Depth*	soil pH(H_20)	Organic C%	Total N%	P (mg/kg)	Ca (cmol(+)/k	Mg (cmol(+)/k	EC (dS/m
IN	1	7.02	1.23	0.11	5.32	7.42	1.37	0.06
NI	1	6.53	2.40	0.15	10.14	5.47	2.98	0.04
NI	1	7.03	1.07	0.10	10.14	4.17	3.30	0.02
NI	1	6.72	2.26	0.11	2.99	2.73	3.31	0.03
NI	1	6.76	0.29	0.02	2.74	4.30	3.09	0.02
IN	1	7.36	0.88	0.11	4.40	5.99	2.37	0.05
NI	1	6.73	2.18	0.15	0.17	2.73	3.50	0.02
IN	1	7.27	0.76	0.11	3.74	6.38	1.38	0.04
IN	1	7.24	1.44	0.12	7.48	4.30	0.63	0.05
IN	1	7.15	0.21	0.02	5.57	9.50	2.08	0.06
IN	1	6.71	2.79	0.10	46.12	11.33	2.86	0.23
NI	1	7.02	1.95	0.11	5.90	10.15	2.56	0.02
IN	1	6.65	3.71	0.20	0.00	18.88	2.08	0.24
IN	1	6.97	1.56	0.13	5.32	15.10	1.15	0.03
NI	1	6.72	1.35	0.12	2.66	8.59	2.16	0.02
NI	1	6.70	2.11	0.12	6.98	2.34	0.64	0.02
IN	1	7.08	1.11	0.11	6.98	0.65	0.66	0.04
NI	1	6.83	2.16	0.14	6.73	10.67	3.61	0.05
NI	2	6.86	2.24	0.12	2.66	1.95	2.92	0.03
IN	2	6.96	0.68	0.10	42.71	9.24	3.23	0.11
NI	2	6.06	2.07	0.14	7.73	0.13	3.11	0.03
NI	2	6.82	2.32	0.13	2.08	1.43	4.12	0.02
IN	2	6.85	1.62	0.13	37.97	7.68	2.98	0.14
IN	2	7.18	1.31	0.11	3.57	5.47	2.05	0.04
IN	2	7.48	1.07	0.12	50.27	6.25	1.34	0.03
IN	2	7.16	1.52	0.13	7.23	6.12	1.40	0.04
IN	2	7.11	0.86	0.10	8.48	10.28	2.21	0.05
NI	2	7.01	1.35	0.12	3.82	0.91	2.17	0.02
IN	2	7.30	1.50	0.13	12.30	15.62	1.57	0.04
NI	2	6.45	2.16	0.13	8.14	9.63	2.33	0.06
NI	2	7.01	1.62	0.11	1.83	14.32	1.96	0.03
NI	2	7.06	1.35	0.12	3.16	12.11	1.61	0.02
IN	2	7.22	4.19	0.19	10.64	16.79	1.08	0.03
NI	2	6.81	2.07	0.12	4.49	3.78	1.21	0.02
NI	2	6.63	0.55	0.10	6.81	9.24	3.94	0.00
IN	2	7.29	0.64	0.11	1.58	12.37	3.02	0.04

*1= 0-20 cm soil surface; *2 = 20-40 cm soil surface; *IN = Invaded site; *NI = Non-invaded site.