Hindawi
International Journal of Ecology
Volume 2021, Article ID 6681577, 11 pages
https://doi.org/10.1155/2021/6681577

Research Article

Effects of *Prosopis velutina* Invasion on Soil Characteristics along the Riverine System of the Molopo River in North-West Province, South Africa

Alvino Abraham Comole[1,2] **Pieter Willem Malan,**[1] **and Makuété André Patrick Tiawoun**[1]

[1]*School of Environmental Sciences and Management, Department of Botany, North West University, Mafikeng, Private Bag X 2046, Mmabatho 2735, South Africa*
[2]*School of Natural Sciences in Education, North West University, Mafikeng, Private Bag X 2046, Mmabatho 2735, South Africa*

Correspondence should be addressed to Alvino Abraham Comole; 18045529@nwu.ac.za

Received 6 October 2020; Revised 21 January 2021; Accepted 14 February 2021; Published 4 March 2021

Academic Editor: Isabel Marques

Invasive alien plants are one of the major threats to ecosystems. Many invasive plant species, such as *Prosopis* species, have been introduced around the world and can alter the soil properties of invaded ecosystems. It is one of the most aggressive invasive plant invaders in the North-West Province of South Africa, but little information is available about their influence on soil properties. This study was conducted to investigate the effect of *Prosopis velutina* invasion on selected soil properties at five different sites along the riverine system of the Molopo River in North West Province. At each study site, soil characteristics were measured from soil samples taken under *P. velutina* canopies, between canopies and in the benchmark stands free of *Prosopis* species. The effect on selected soil properties of *P. velutina* invasion varied between the three stands and between sites. In all the sites, almost all soils collected from under the canopies had a significantly higher soil exchangeable Ca, K, Mg, and Na, organic matter (OM), total nitrogen (TN), available phosphorus (P), Electrical conductivity (EC), and cation exchange capacity (CEC) than the other sample positions, except for the pH which had the high value in intercanopies. Significantly higher ($p < 0.05$) values of almost all soil properties were found on the densely invaded sites (Tshidilamolomo I and Tshidilamolomo II) compared to lightly invaded sites (Mabule, Black Heat Farm, and Bray). However, it was difficult to generalise as the effects often appear to be site-specific. In addition, the findings also indicated that soils textural classes ranged between sand, silt, and clay in all study sites with a higher proportion of sand in the benchmark than in the soil under the canopies and intercanopies. Soil characteristics differed significantly more between sites than among positions. The site effects observed in this current study provide evidences that this species may occupy a relatively broad soil niche.

1. Introduction

Alien plants have consistently caused environmental changes worldwide and represent a frequent and widespread threat to natural ecosystems [1, 2] and to biodiversity conservation [3, 4]; these impacts are very often irreversible. Alien plant species can influence the plant-soil relationship in the invaded habitats [5, 6] modifying both biotic and abiotic elements of soil and diversity [7].

The spread of alien plant species in South Africa is an increasing concern because it leads to decreases in both surface water runoff and groundwater recharge, causing direct habitat destruction, intensifying flooding, and increasing the risk and intensity of wildfires [8]. Among the widespread alien plants in South Africa, *Prosopis* species cover very large areas of arid and semiarid parts of the country, causing severe threats to native plant communities in the Northern Cape and Western Cape provinces and in the North West Province as well [9, 10]. Moreover, these species are causing severe damage to the natural environment and habitats, threatening many plant species. It has been shown that in some cases, invasive plant species are capable of altering the characteristics of invaded soil and native species diversity to facilitate further invasion [11, 12]. A number of studies reported that *Prosopis* species can significantly alter soil properties, which may favour their own development and proliferation [13, 14].

Prosopis species, introduced to South Africa as agro forestry trees to provide wood, fodder, and shade, charcoal in the late 1800s [9, 15], have since been identified as a serious problem in parts of South Africa and become the second most widespread invasive alien plant after *Australian acacias* [16]. They are known to impact negatively on the conservation of biodiversity as well as the livelihoods of rural people that depend heavily on natural resources [17], such as overrunning grazing land, consuming excessive quantities of ground water, and disrupting ecosystem services [10, 18, 19].

Much work has been undertaken on the influence of invasive plants on soil properties [12, 14, 20]. Recently, many studies have increased interest in identifying appropriate indicators for describing soil characteristic changes [12, 21, 22]. Although much is well documented on the ecological impacts of *Prosopis* species, research exploring the effects of *Prosopis velutina* invasion on soil properties has received little attention and more particularly in the North-West Province of South Africa. The paucity of such important studies could be due to the high costs of conducting soil analyses, particularly of multiple soil samples collected across wider geographic areas over time. The documented impacts on soil properties are diverse. According to [20], *Prosopis* species may have different influences on soil properties, depending on local conditions. Therefore, this study was undertaken with the aim to investigate and compare the impact of *Prosopis* on selected soil properties at five sites with different *Prosopis velutina* density along the riverine system of the Molopo River in North-West Province of South Africa.

Soil properties are the essential factors that influence plant species distribution [23]. A better understanding of soil properties in different communities is crucial for clarifying the influence of *P. velutina* on soil characteristics. This study was therefore conducted to analyze and increase the understanding on the variability of soil properties as influenced by *P. velutina*. For this reason, two major objectives were addressed: (i) to compare the selected soil properties from under *Prosopis* canopy to soil from between canopies and adjacent benchmark stands and (ii) to examine the alterations in soil properties under *P. velutina* invasion across the five study sites.

2. Materials and Methods

2.1. Description of the Study Sites. The study was conducted in five sites in Tshidilamolomo I, Tshidilamolomo II, Mabule, Black Heat Farm, and Bray along the riverine system of the Molopo River in North-West Province of South Africa (Figure 1). Each site is more than 1500 m^2 in extent and was selected for the comparison of soil characteristics. The five study sites were selected using stratified purposive sampling [24]. These sites were paired to include one stand with *Prosopis velutina* and another without. In the present study, the uninvaded stands called benchmark stands were selected to be in close vicinity of the invaded stands. In addition, the criteria used to select the five sites were also based on the availability and abundance of *P. velutina* in invaded stands and the homogeneity of sites in terms of soil type under both the benchmark stands and invasive *Prosopis* stands. To clarify the difference in the soil characteristics between invaded and benchmark stands, the density of dominant vegetation in the five sampling sites was recorded (Table 1). The riverine system of the Molopo River in North-West Province of South Africa has a semiarid to arid climate and situated between the latitudes 23°20′ S and 28°30′ S and longitudes 20°15′ *E* and 26°10′ *E* [25], with an average annual precipitation of about 550 mm [26]. In the North-West Province, the daily temperature is about 42°C during summer months and often −9°C during winter months [26]. According to [27], soil in this province is sandy loam and is classified as a Hutton form [28] or Rhodic Ferralsol [29] or Chromic Luvisol [30].

2.2. Soil Sampling. At each sampling site, soil from the upper 15 cm in three replicates was collected from the under canopy (UC) and the intercanopy (IC) of five selected *P. velutina* in invaded patches located in the centre of the sites, mostly where the species were more dense; while in adjacent benchmark (BM) stands, soil from the upper 15 cm was collected in three selected 1 m × 1 m plots. All soil samples from UC of the five selected *P. velutina* in each site were pooled homogeneously into a single bulk sample as well as all soil samples from IC and BM. The effect of pooling samples on the efficiency of experiments was meant to detect the difference in soil properties between UC, IC, and BM in the same site and between sites. The pooling of samples is that it also reduces financial cost of analysis. These soil samples from UC, IC, and BM were air-dried separately at room temperature, passed through a 2 mm sieve to remove large particles and for homogenization before analyzing for various contents. For analysis, about 2 kg of soil samples from the same position and from each site were carried in brown paper bags to the laboratory at the Agricultural Research Council (ARC) in Pretoria (South Africa).

2.3. Soil Analyses. A total of 13 soil variables were estimated on each sample. The soil pH was determined using a glass electrode in a 1 : 2.5 soil-water suspension following equilibration for 16 h [31]. Soil organic matter (OM) content was determined using the WalkleyBlack method [32]. Total nitrogen (TN) was determined by the micro-Kjeldhal technique [33]. Exchangeable cations were extracted with 1 N ammonium acetate, and the concentration of potassium (K) was determined using a flame photometer and that of calcium (Ca) and magnesium (Mg) was determined with an atomic absorption spectrophotometer, while atomic emission spectrophotometry was used for sodium (Na). Available phosphorus (P) was measured using the Bray analysis method [34]. Soil texture (Sand %, silt % and clay %) was determined using hydrometer method [34]. Cation

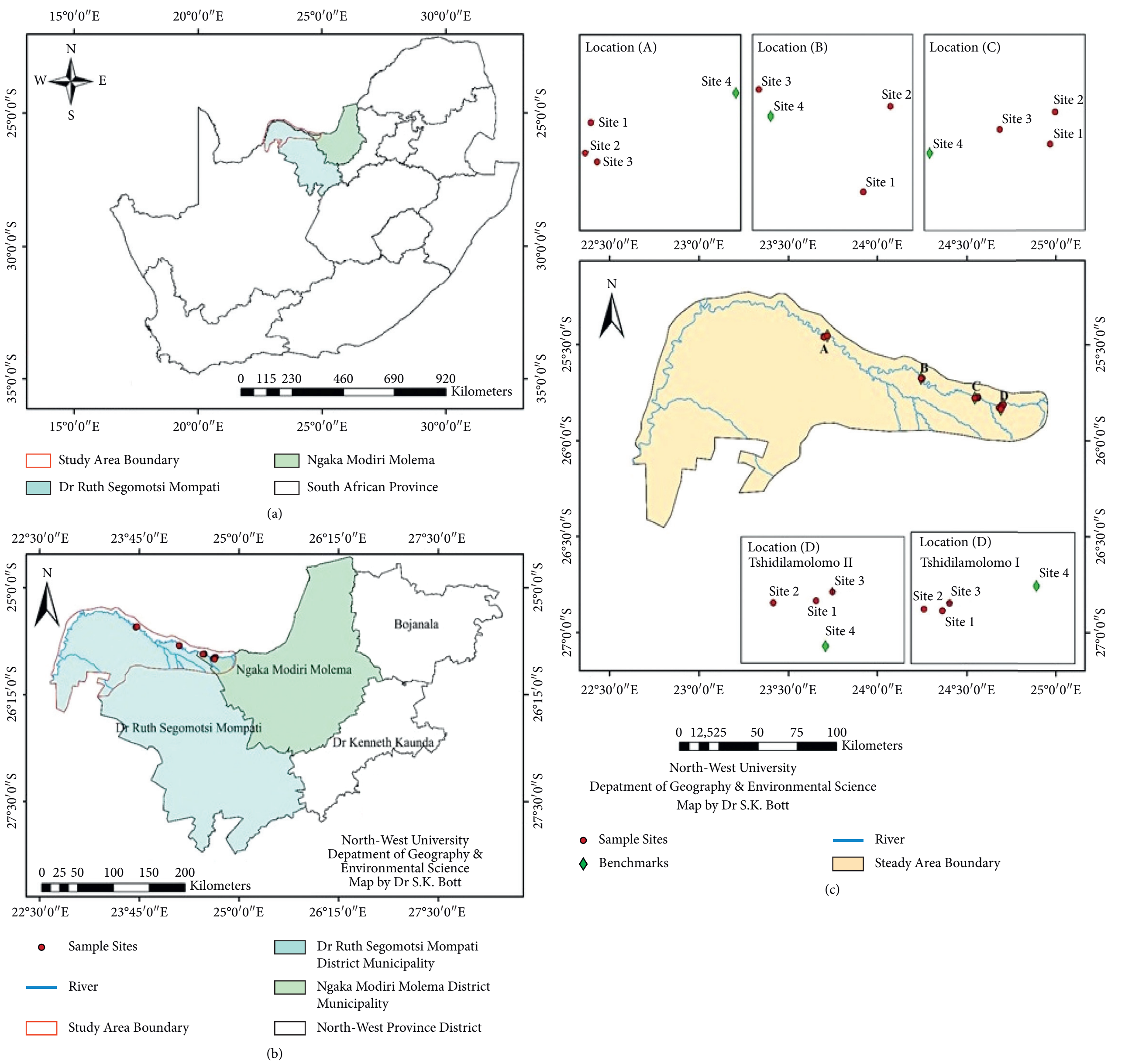

Figure 1: Map showing the location of the five study sites along the riverine system of the Molopo River in North-West Province, South Africa.

exchange capacity (CEC) was estimated by ammonium acetate extraction at pH 7 [35], and electrical conductivity (EC) was performed on a saturated extract of the soil [36].

2.4. Statistical Analysis. One way analysis of variance (ANOVA) was used to test and compare the differences among different soil parameters in different positions and at different sites. Statistical significance was determined at $p < 0.05$, and differences among soil properties were separated using Tukey's HSD (honestly significant differences) post hoc test. All statistical methods were computed using Excel 2013.

3. Results

3.1. Influence of Prosopis velutina on selected soil properties in three stands at five study sites. All selected soil properties were compared between soils under the canopies (UC) of *P. velutina,* with soil in intercanopies (IC) and soil in an adjacent benchmark (BM) in order to assess the difference between the five sites. Almost all soil properties measured were statistically different ($p < 0.05$) at different positions or stands (Table 2). While significant differences were found in selected soil properties in all the five sampling sites (Table 3). Soil characteristic differed significantly more between sites than among positions (Table 2 and 3).

Table 1: Site locations and dominated plants species at five sites of *Prosopis velutina* invasion.

Site	Coordinates	Dominant plant species	Site type
Tshidilamolomo I	25° 48′54.26″S 24° 41′50.57″E	*Prosopis velutina* *Senegalia mellifera* *Vachellia hebeclada*	Grazing, densely invaded with *P. velutina*
Tshidilamolomo II	25° 49′31.54″S 24° 40′58.01″E	*Prosopis velutina* *Senegalia mellifera* *Vachellia hebeclada* *Ziziphus mucronata*	Grazing, densely invaded with *P. velutina*
Mabule	25° 46′23.87″S 24° 33′14.93″E	*Prosopis velutina* *Vachellia hebeclada* *Vachellia tortilis* *Ziziphus mucronata*	Grazing, water point, lightly invaded with *P. velutina*
Black heat farm	25° 40′26.65″S 24° 14′33.74″E	*Grewia flava* *Prosopis velutina* *Vachellia hebeclada* *Ziziphus mucronata*	Rotational grazing, lightly invaded with *P. velutina*
Bray	25° 27′41.42″S 23° 42′05.05″E	*Mellia azedarach* *Prosopis velutina* *Vachellia erioloba*	Grazing lightly invaded with *P. velutina*

3.2. The concentration of exchangeable cations (calcium, potassium, magnesium and sodium). Overall, the concentration of exchangeable cations (Ca, K, Mg, and Na) was higher under canopies (UC) of *Prosopis velutina* than in the intercanopies (IC) and the benchmark (BM) (Table 2). The concentrations of exchangeable Ca, Mg, K, and Na in almost all the study sites showed a decreasing trend with increasing distance from tree canopies to nearby benchmark stand. In contrast, there was no regular pattern of exchangeable Ca, Mg, K, and Na with distance between IC and BM (Table 2). All concentrations of exchangeable Ca, K, Mg, and Na recorded significant differences ($p < 0.05$) between UC, IC, and BM in all sites, except for exchangeable Ca and Na in Bray and Black Heat Farm where the p value was ($p = 0.44$) and ($p = 0.37$), respectively (Table 2). The mean concentration of exchangeable Ca, Mg, K, and Na tended to be in the order of Ca > Mg > K > Na in all the five sites (Table 3). Among all sites, the greater concentration of exchangeable Ca, Mg, and Na was observed in Tshidilamolomo II, while the higher exchangeable K was recorded in Bray site. The range of exchangeable Ca, Mg, K, and Na was between 1.76 and 10.53 mg kg^{-1}, 0.77 and 3.35 mg kg^{-1}, 0, 22 and 0.68 mg kg^{-1}, and 0.02 and 0.05 mg kg^{-1}, respectively. The lowest concentration of exchangeable Ca, Mg, K, and Na was recorded in Black Heat Farm. Most particularly, the analysis of Variance (ANOVA) showed significant differences in soil exchangeable cations of Ca, Mg, K, and Na at all the five sites (Table 3).

3.3. Soil Organic Matter (OM). The soil organic matter content was significantly different ($p < 0.05$) between soils under canopy, intercanopies, and benchmark stands in all the five sites (Table 1). In all the five sites, soil OM declined with distance from under canopy (UC) to intercanopy (IC) and then increased from IC to the benchmark (BM) (Table 2). The maximum range of OM was recorded in Tshidilamolomo II which was from 0.36 to 7.29%, and the minimum range was recorded in Black Heat Farm between 0.2 and 1.5%. In addition, the overall mean value of OM proportion among the five different study sites varied between 0.30 and 3.82%. Among the study sites, the highest proportion of OM was recorded in Tshidilamolomo II, whereas the lowest percentage was observed in Black Heat Farm (Table 3). However, a one-way ANOVA test showed that OM was statistically significantly different ($p < 0.05$) between sites (Table 2).

3.4. Total Nitrogen (TN). Like soil organic matter, total nitrogen (TN) tended to be higher under *Prosopis velutina* canopies in all study sites except in Black Heat Farm where it was higher in the benchmark stand. The highest TN content in all sites was recorded under the canopies, which ranged from 0.02 to 0.11% followed by the benchmark, from 0.03 to 0.08% and then by intercanopies from 0.02 to 0.04% (Table 2). However, significant differences ($p < 0.05$) existed in TN percentage between the UC, IC, and BM. The overall mean value of TN percentages in all different sites varied between 0.02 and 0.07%. Among the five sites, the minimum mean values of TN percent were recorded in Black Heat Farm (0.02%), and the maximum mean value (0.07%) was recorded in Tshidilamolomo I and Bray. However, the difference among the different sites was significant ($p < 0.05$) (Table 3).

3.5. Soil pH. The maximum range of pH in all the study sites was recorded under the intercanopy (IC) which was between 7.4 to 8.3, and the minimum was recorded in the benchmark (BM) ranging from 6.5 to 8.3. However, no significant differences ($p < 0.05$) in pH were observed between under canopy UC, IC, and BM in Tshidilamolomo II, whereas there was a significant difference ($p < 0.05$) between UC, IC, and BM Tshidilamolomo I, Mabule, Black Heat Farm, and Bray (Table 2). The soil pH under the three positions (UC, IC, and

Table 2: Mean (±SEM) of selected soil properties in three soil stands at five study sites Influenced by *Prosopis* species.

Soil properties	Positions	Sites				
		Tshidilamolomo I	Tshidilamolomo II	Mabule	Black Heat Farm	Bray
Ca (mg kg^{-1})	UC	13.12 ± 2.8a	17 ± 5.8a	6.23 ± 1.8a	2.53 ± 0.3a	6.64 ± 1.3a
	IC	4.50 ± 0.4b	4.04 ± 0.2c	2.93 ± 0.6b	1.8 ± 0.2b	7.14 ± 0.6a
	BM	1.91 ± 0.9c	14.7 ± 1b	1.75 ± 0.2c	1.72 ± 0.4b	6.23 ± 1.2a
	p value	<0.05	<0.05	<0.05	0.003	**0.44**
K (mg kg^{-1})	UC	0.77 ± 0.3a	0.52 ± 0.16a	0.44 ± 0.09 a	0.22 ± 0.05b	0.70 ± 0.08a
	IC	0.16 ± 0.02b	0.29 ± 0.01b	0.41 ± 0.01a	0.22 ± 0.0b	0.70 ± 0.07a
	BM	0.18 ± 0.01b	0.16 ± 0.01c	0.18 ± 0.02b	0.67 ± 0.04a	0.30 ± 0.1b
	p value	<0.05	<0.05	<0.05	<0.05	<0.05
Mg (mg kg^{-1})	UC	3.57 ± 1.46a	4.63 ± 0.07a	2.17 ± 0.60a	0.82 ± 0.01b	0.47 ± 0.03a
	IC	0.48 ± 0.05b	0.86 ± 0.08b	2.15 ± 0.08a	0.72 ± 0.01b	0.15 ± 0.02a
	BM	0.57 ± 0.07b	4.60 ± 0.23a	1.13 ± 0.08b	0.94 ± 0.08a	0.29 ± 0.05b
	p value	<0.05	<0.05	<0.05	<0.05	<0.05
Na (mg kg^{-1})	UC	0.05 ± 0.03a	0.02 ± 0.0b	0.06 ± 0.01a	0.02 ± 0.0a	0.04 ± 0.01ab
	IC	0.02 ± 0.0b	0.02 ± 0.0b	0.04 ± 0.0ab	0.02 ± 0.0a	0.04 ± 0.0a
	BM	0.02 ± 0.0b	0.13 ± 0.01a	0.02 ± 0.0b	0.02 ± 0.02a	0.02 ± 0.0b
	p value	0.01	<0.05	<0.05	**0.37**	<0.05
OM (%)	UC	2.37 ± 1.5a	7.29 ± 5.5a	1.72 ± 0.6a	0.4 ± 0.2a	1.91 ± 1.3a
	IC	0.30 ± 0.01c	0.36 ± 0.06c	0.24 ± 0.04b	0.2 ± 0.03b	0.24 ± 0.04b
	BM	1.66 ± 0.3b	2.50 ± 0.2b	0.48 ± 0.06b	1.5 ± 033b	0.20 ± 0.02b
	p value	0.007	<0.05	<0.05	<0.05	0.005
TN (%)	UC	0.09 ± 0.01a	0.06 ± 0.01a	0.07 ± 0.01a	0.02 ± 0.0b	0.11 ± 0.03a
	IC	0.03 ± 0.0b	0.03 ± 0.0b	0.02 ± 0.0b	0.02 ± 0.0b	0.04 ± 0.0b
	BM	0.03 ± 0.0b	0.02 ± 0.0b	0.03 ± 0.0b	0.08 ± 0.01a	0.04 ± 0.0b
	p value	<0.05	<0.05	<0.05	<0.05	<0.05
pH	UC	8.2 ± 0.34a	8.1 ± 0.3a	7.8 ± 0.17a	7.4 ± 0.07b	7.6 ± 0.20b
	IC	8.2 ± 0.31a	8.2 ± 0.2a	8.3 ± 0.06a	7.4 ± 0.04b	8.0 ± 0.07ab
	BM	7.3 ± 0.09b	8.2 ± 0.1a	6.9 ± 0.14b	6.5 ± 0.14a	8.3 ± 0.07a
	p value	<0.05	**0.85**	<0.05	<0.05	<0.05
P (mg kg^{-1})	UC	11.25 ± 4.44a	14.27 ± 4.65b	7.84 ± 0.17a	23.19 ± 0.12c	57.40 ± 15.6b
	IC	7.17 ± 0.08b	13.70 ± 2.54b	4.82 ± 0.06b	31.78 ± 0.42b	74.24 ± 1.15a
	BM	7.31 ± 0.05c	46.26 ± 0.45a	4.34 ± 0.14b	79.61 ± 0.37a	12.65 ± 0.45c
	p value	<0.05	<0.05	<0.05	<0.05	<0.05
EC (mS m^{-1})	UC	1.09 ± 0.37a	1.26 ± 0.43a	1.12 ± 0.44a	0.22 ± 0.04b	2.01 ± 0.20a
	IC	0.39 ± 0.05ab	0.55 ± 0.07b	0.64 ± 0.25ab	0.22 ± 0.04b	1.49 ± 0.21ab
	BM	0.23 ± 0.03b	0.54 ± 0.28b	0.29 ± 0.03b	1.40 ± 0.32a	0.89 ± 0.12b
	p value	<0.05	<0.05	0.002	<0.05	<0.05
CEC (cmolc kg^{-1})	UC	13.18 ± 1.8a	10.48 ± 3.8b	7.5 ± 1.8a	4.68 ± 0.2a	5.19 ± 0.5b
	IC	8.18 ± 0.3b	4.58 ± 0.1c	5.6 ± 0.1ab	4.31 ± 0.2ab	6.47 ± 0.1a
	BM	3.16 ± 0.0c	17.15 ± 0.3a	3.0 ± 0.0b	3.76 ± 0.09b	6.51 ± 0.1a
	p value	<0.05	<0.05	<0.05	<0.05	<0.05
Sand (%)	UC	78 ± 3.5b	75 ± 7.8b	84 ± 2.8b	90 ± 1.0a	88 ± 0.7ab
	IC	88 ± 1a	88 ± 1.2a	88 ± 1.4a	90 ± 0.0a	86 ± 1.4b
	BM	88 ± 0.7a	**67 ± 2c**	88 ± 0.7a	90 ± 0.7a	90 ± 0.7a
	p value	<0.05	<0.05	0.02	**0.07**	<0.05
Silt (%)	UC	3 ± 1a	2 ± 0b	1 ± 1a	1 ± 1a	1 ± 1a
	IC	2 ± 0b	2 ± 0b	0 ± 0b	0 ± 0b	0 ± 0b
	BM	2 ± 0b	4 ± 0a	0 ± 0b	0 ± 0b	0 ± 0b
	p value	0.02	<0.05	0.02	0.02	0.02
Clay (%)	UC	19 ± 2.2a	23 ± 8.4b	16 ± 3a	10 ± 1.4a	14 ± 1.0a
	IC	10 ± 0.7b	10 ± 1.2c	14 ± 2a	10 ± 1.2a	14 ± 0.0a
	BM	10 ± 1.4b	34 ± 0.7a	12 ± 1a	10 ± 1.4a	10 ± 1.4b
	p value	<0.05	<0.05	0.05	**1**	<0.05

Different superscript letters within each column indicate significant differences ($p < 0.05$) in soil properties between UC, IC, and BM according to Tukey's HSD test.

Table 3: Mean (±SEM) of selected soil properties in invaded *Prosopis* stands at five study sites.

Soil properties	Site: Tshidilamolomo I	Tshidilamolomo II	Mabule	Black heat farm	Bray	p value
Ca (mg kg^{-1})	8.80 ± 1.3ab	10.53 ± 2.8a	4.80 ± 0.9c	1.76 ± 0.2d	6.70 ± 0.8bc	<0.05
K (mg kg^{-1})	0.46 ± 0.1b	0.40 ± 0.0b	0.42 ± 0.0b	0.22 ± 001c	0.68 ± 0.0a	<0.05
Mg (mg kg^{-1})	2.02 ± 0.7b	3.35 ± 1.8a	2.26 ± 0.3b	0.77 ± 0.0c	1.47 ± 0.0bc	0.002
Na (mg kg^{-1})	0.03 ± 0.0b	0.02 ± 0.1b	0.05 ± 0.0a	0.02 ± 0.0b	0.03 ± 0.0b	<0.05
OM (%)	1.32 ± 0.7b	3.82 ± 1.6a	0.98 ± 0.3c	0.30 ± 0.1d	1.06 ± 0.7c	<0.05
TN (%)	0.07 ± 0.0a	0.04 ± 0.0b	0.04 ± 0.0b	0.02 ± 0.0c	0.07 ± 0.0a	<0.05
pH	8.1 ± 0.3a	8.2 ± 0.2a	8.1 ± 0.0a	7.4 ± 0.0b	7.8 ± 0.1ab	<0.05
P (mg kg^{-1})	9.21 ± 2.2d	13.98 ± 3.2c	9.65 ± 0.1d	27.54 ± 0.2b	65.82 ± 8a	<0.05
EC (mS m^{-1})	0.74 ± 0.2b	0.9 ± 0.2a	0.88 ± 0.3b	0.23 ± 0.1b	2.04 ± 0.1a	<0.05
CEC (cmolc kg^{-1})	10.59 ± 1.0a	7.52 ± 1.9b	6.56 ± 0.9c	4.50 ± 0.2d	5.84 ± 0.3c	<0.05
Sand (%)	83.0 ± 1.7d	81.7 ± 4.1d	85.0 ± 1.2c	89.5 ± 0.5a	87 ± 0.6b	<0.05
Silt (%)	2.5 ± 0.6a	2.0 ± 1.2a	0.2 ± 0b	0.3 ± 0.6b	0.3 ± 0.6b	<0.05
Clay (%)	13.5 ± 1.7a	16.5 ± 4.0a	15 ± 1.9a	10 ± 0.9a	12.5 ± 0.5a	<0.05

Different superscript letters within each row indicate significant differences ($p < 0.05$) in soil properties between the five sites according to Tukey's HSD test.

BM) was alkaline but nearly neutral under the BM in Mabule and Black Heat Farm. The overall mean value of pH in the soil under each of the five different sites was moderately alkaline and was observed in the range between 7.4 and 8.2. Among the five study sites, the minimum and maximum pH in soil was recorded in Black Heat Farm and Tshidilamolomo II, respectively (Table 3). However, the difference in pH was significant ($p < 0.05$) between the different sites (Table 3).

3.6. Available Phosphorus (P). The analysis of variance (ANOVA) for available phosphorus revealed that there were significant differences ($p < 0.05$) among the three positions under canopy (UC), intercanopy (IC), and the benchmark (BM) across the five study sites (Table 1). The maximum range of P concentration was recorded under the BM, which ranged from 7.31 to 79.61 mg kg^{-1} followed by the IC from 7.17 to 74.24 mg kg^{-1} and then followed by UC from 7.84 to 57.40 mg kg^{-1} (Table 2). It is clear that concentrations of soil available phosphorus increase with increasing distance from under *Prosopis* canopies to open areas benchmark. The mean available phosphorus concentration under different sites was observed ranging from 9.21 mg kg^{-1} in Tshidilamolomo I to 65.82 mg kg^{-1} in Bray (Table 3). However, significant differences ($p < 0.05$) regarding the concentration of available phosphorus were recorded between the five study sites.

3.7. Electrical Conductivity (EC). The value of soil electrical conductivity in Tshidilamolomo I, Tshidilamolomo II, Mabule, and Bray ranges from 0.23 to 1.09 mS m^{-1}; 0.54 to 1.26 mS m^{-1}; 0.29 to 1.12 mS m$^{- ;1}$ and 0.89 to 2.01 mS m^{-1}, respectively. The results showed that these values decrease from under canopy (UC) to intercanopy (IC) and then to benchmark (BM). Soil EC was higher in UC followed by IC and BM. However, significant differences ($p < 0.05$) in EC were found between UC, IC, and BM, but no differences ($p > 0.05$) in EC were recorded between IC and BM in these sites except in Black Heat Farm (Table 2). In Black Heat Farm, EC ranged from 0.22 to 1.40 mS m^{-1} and tended to increase from UC to BM (Table 2). The mean values of soil EC distribution under different sites varied and were recorded in the range of 0.232.04 mS m^{-1}. Among all the sites, the minimum and maximum mean values of soil EC were observed in Black Heat Farm and Bray, respectively (Table 3). There was a significant ($p < 0.05$) difference in EC between all sites.

3.8. Soil Cation Exchange Capacity (CEC). Soil cation exchange capacity (CEC) was significantly higher under the canopies (UC) of *Prosopis* compared to soil CEC in intercanopies (IC) and benchmark (BM). It ranged from 3.16 to 13.18 cmolc kg^{-1}; 3 to 7.5 cmolc kg^{-1}; and 3.76 to 4.68 cmolc kg^{-1} in Tshidilamolomo I, Mabule, and Black Heat Farm, respectively. Whereas, in Tshidilamolomo II and Bray, the higher value of CEC was recorded in the BM and IC (Table 2). However, across all sites, the CEC values were significantly ($p < 0.05$) affected by different positions or distance (UC, IC, and BM). The mean values of CEC distribution under different sites varied from 4.50 to 10.59 cmolc kg^{-1}. Among all sites, the minimum mean value of soil CEC was recorded in Black Heat Farm, while the maximum concentration was observed in Tshidilamolomo I (Table 3). The analysis of variance (ANOVA) for CEC revealed a significant variation ($p < 0.05$) between the sites.

3.9. Soil Texture (Sand, Silt, and Clay). The results of this study showed that sand had the dominant proportion in soils in all the sites (Table 2). Analysis of variance for soil sand content revealed that it was significantly affected by the position, i.e., by under canopy (UC), intercanopy (IC), and benchmark (BM) ($p < 0.05$) in all sites except in Black Heat Farm where the soil sand content was not affected by the position ($p = 0.07$). However, maximum sand content was recorded in IC between the range of 86 and 90% followed by UC from 75 to 90% and by BM from 67 to 90%. The values for clay content were higher UC and tended to decline from UC to IC and to the BM (Table 2). Across sites, significant differences ($p < 0.05$) in clay percentage were recorded between UC, IC, and BM except in Black Heat Farm ($p = 1$). The results also revealed that the proportion of silt was slightly higher UC than that of IC and BM. Silt soil texture decreases with distance from the trunk of *Prosopis* trees towards the open area benchmark, but its proportions did not significantly vary ($p > 0.05$) between the IC and the BM in Tshidilamolomo I, Mabule, Black Heat Farm, and Bray, while no significant difference was recorded between UC and IC in Tshidilamolomo I site (Table 2). However, the textural analysis from different sites was classified as followed sand >clay >silt (Table 3). Significant difference ($p < 0.05$) between the mean values of sand clay and silt were recorded between the sites.

4. Discussion

In this study conducted along the riverine system of the Molopo River in North-West Province of South Africa, the selected soil properties from each site were compared between under canopy (UC), intercanopy (IC), and benchmark (BM) in order to assess the difference in soil characteristic among the five sites. The results of this study revealed a strong effect of *Prosopis velutina* on the properties of the soil. These outcomes are generally consistent with other studies on invasive species, which indicate significant effects of invasive species on different soil properties [13, 37, 38]. In this research, soil UC of *P. velutina* consistently had higher value of soil properties compared to soil in IC and BM stands (Table 2), which is in agreement with many earlier report where the soil characteristics decline from the base of the tree to adjacent open areas [39, 40]. Table 3 shows that the site effect was highly significant ($p < 0.05$) for all the soil parameters analysed, indicating that *P. velutina* can adapt to and thrive in sites with a significant variation in soil characteristics. This is in line with earlier studies reported by [38]. Furthermore, the results of this study reveal that *P. velutina* has a significant effect on all the soil properties, indicating that the influence on soil characteristic varied widely depending on the existing site conditions. Soil properties differed significantly across sites and this could reveal that the five study sites covered a wide range of different soil conditions.

The present study showed varied effects of *P. velutina* on soil exchangeable Ca, Mg, K, and Na with significant differences between UC, IC, and BM stands in all the five sites. Most exchangeable Ca, Mg, K, and Na were higher under *P. velutina* than in IC and BM. Similar to this result, in [41, 42], significant decreases in exchangeable Ca, Mg, K, and Na in soils from under canopies to open areas of *P. juliflora* and *P. laevigata* have been reported. Likewise, in [43], significant differences in exchangeable Ca, Mg, K, and Na between soil under and outside *Celastrus orbiculatus* canopies have been reported. The high value of exchangeable cation under the canopy of *P. velutina* could be ascribed to the high accumulation of litter under the tree canopies as the cations are released when the accumulated litters from the canopies of the trees undergo microbial decomposition followed by mineralization. Unlike to this study, in [44], no significant differences are shown in the levels of Na and Ca between soil within the canopy *P. juliflora* and the open areas in the deserted rangelands of Bahrain.

The relative higher accumulation of soil organic matter (OM) under *P. velutina* canopies than in inter canopy and benchmark in all the sampling sites indicated the soil enriching capacity under this tree. As reported by [45], mesquite (*P. juliflora*) trees enrich the soil under their canopies at the expense of the soil nutrient capital in the open areas. The higher percentage of OM under tree canopy could be attributed to the leaf litter deposition, higher organic matter production by trees and its slower rate of mineralization, root turnover, and animal defecation as they stay under shade for browsing. This result is in line with [13], who also reported that OM was significantly higher under than outside *P. flexuosa* canopies. Similarly, many authors, such as [46, 47], have also reported gradual decreases in soil organic matter with increasing distance from tree base. The lower soil OM content in adjacent open areas could be attributed to the fact that the main source of organic matter there is grass. Similarly to this study, in [48], higher OM under canopies of *Prosopis juliflora* than outside canopies is reported. Contrary to the findings of this study, in [49], higher soil organic matter stocks in the perennial grasses than in the shrubs are observed; this might be attributed to both greater inputs of poor quality litter that is relatively resistant to decay and the lower ability of microorganism to decompose these organic matter.

Soil total nitrogen (TN) was significantly higher under *P. velutina* canopies than the outside of the canopy in all the five sites. The higher percentage of total nitrogen under this species may be attributed to the accumulation of leaf litter within the crown limits and also to the N-fixing capabilities of the *Prosopis* species. However, the results of this study were in accordance with those of [13] who also observed higher value of TN in under than outside *P. flexuosa* canopies. This is consistent with the previous studies that have reported increased fertility under the canopy of *P. glandulosa* [50] and *P. cineraria* [51]. Furthermore, for other trees species, [52] found higher value of TN in soil under the canopies of *Hieraciurn* species than in stands outside. Similar trends were also reported for *Millettia ferruginea* and *Cordia africana* on the topsoil properties in agroforestry practices in Sidama, Southern Ethiopia [53].

In this study, there was a variation ($p < 0.05$) in soil pH between soil under canopies, between canopies, and the benchmark stands. The measured soil pH was alkaline resulting in soil pH above 7.0. The higher value of pH was recorded in intercanopy than that under the canopy. The lower pH value under the canopy could be attributed to accumulation of organic matter under the trees through litter fall and root decay [54]. According to [55, 56], the high soil pH may be attributed to the invasive plants having high nitrate uptake rates and may play also a critical role in the regulation of nutrient cycles [57]. In line with this finding, several studies have also found significant differences in pH when comparing soil from under canopies and open areas of invasive plants. Kahi et al. [37] found significant differences in pH between the soils within and outside the canopies of *P. juliflora* and *Acacia tortilis*. However, this work was inconsistent with the findings of [58] who found pH values not statistically different when comparing the soil samples in the areas with and without *Prosopis*. Witkowski 59 also found no significant differences in pH when comparing soil from under *Acacia cyclops* canopies with soils from outside their canopies. However, it is clear that both high and low pH have also been reported following plant invasions [60]. According to [56], the variation of soil pH is also dependent on the degree of invasion.

The results of this study showed significant differences in available phosphorus (P) between UC, IC, and BM and among the different sites. Furthermore, no clear trend in available phosphorus was detected by [61] who found that available phosphorus levels are usually highest under shrubs. However, there are exceptions. The results of this study recorded the decrease of p value from the canopies to the open areas (BM) in Tshidilamolomo I, Mabule, and Bray, whereas, in Tshidilamolomo II and Black Heat Farm, the value of P increased from the canopies to open areas. This is consistent with other studies which reported that P was significantly higher under than outside the canopy of *P. flexuosa*, *P. juliflora, Acacia tortilis* [13, 37], and *Cordia africana* [62]. In contrast to these findings, [63] found an increase in p value as the distance increased from the canopies of *Faidherbia albida* to outside of the canopies. These differences may be due to specific factors at the different sites.

The results pertaining to the high soil electrical conductivity (EC) content under *Prosopis* canopies in almost all the sites compared to intercanopies and benchmarks are in agreement with that of [12] who also observed increasing beneath rather than outside *Prosopis juliflora* canopies on the native flora and soils of the UAE. In a similar study, Mussa et al. [64] found higher values for EC under woody plants canopies compared to the open grasslands, and Hailemariam et al. [65] also reported higher EC value under the canopy than the open field of *Balanites aegyptiaca* at Limat in northern Ethiopia.

The cation exchange capacity (CEC) of the soils revealed significant variation ($p < 0.05$) between UC, IC, and BM across the five sites. The high CEC under canopies may be ascribed to the higher soil organic matter concentration under the tree canopies than the open areas [66]. The value of CEC was lower in IC and BM stands as compared to UC tree.

Based on the result of the study, variations in soil texture were observed between the three positions of all the study sites. These variations may be attributed to the increasing of biological activity which may have improved weathering process and favorable moisture provision under the tree canopy [67]. This study revealed that silt content was slightly higher under canopy than open area whereas the sand and clay content was higher in open area than under the canopy. This finding is in agreement with the study of [68] who reported the same trend in *Faidherbia albida* and *Cordia africana* studies in different sites. Furthermore, Sharma and Gupta [69] in India revealed increases in silt proportions under the tree canopies and decreases in sand proportion.

The comparisons for the soil properties between sites showed significant ($p < 0.05$) differences. The results of this study are important because they show the variation in selected soil characteristics on five different sites invaded by *P. velutina*. The differences in the soil characteristics between the five sites could be the result of various factors such as anthropogenic activities, grazing which alters soil properties and to difference in other plant species occurring in the sites. Descriptive statistics showed that the variable of all soil properties in the densely invaded sites (Tshidilamolomo I and Tshidilamolomo I) was relatively higher, while the variation in lightly invaded sites (Mabule, Black Heat Farm, and Bray) was relatively limited, but with some exception in sand proportion, P and Na values. The observed variations soils characteristics are similar to studies on other invasive plant species that suggest that invasive species may modify soil properties [70, 71]. The higher values of soil properties obtained in the densely invaded sites of *P. velutina* had also been reported in many other invasive species. For example, Mandal and Joshi [72] reported that soil TN, OM, P, and K levels increased with increase in *Lantana* density.

5. Conclusion

Based on the result of this study, variations in soil properties were observed not only between the three stands (under canopy, inter canopy, benchmark) but also between different sites invaded by *Prosopis velutina*. This study demonstrates that the three stands showed significant effects of *P. velutina* on soil properties, and most of the soil properties were higher under canopies but the lower values did not show consistent trends between inter canopies and the benchmark stands. However, the highest value of pH was observed in inter canopies. The results highlight the importance of sites as a most important source of variation in the impacts of *P. velutina* on soil properties. Due to variability of soil properties values among different sites, it was difficult to confirm the significant impact of the invader *P. velutina* on the selected soil properties. Despite a number of studies on *Prosopis* species, there is no consensus on the predictability of the impact of this species on soil characteristics. As *P. velutina* invasions are still increasing in different sites, more attention should be paid to studying this problem over a wider spectrum of invaded sites. This study provides a valuable pattern for future studies in order to achieve successful control of *P. velutina*.

Data Availability

All data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors would like to acknowledge the North West University of South Africa for providing financial support and logistics to conduct this research. They also thank the farmers and the community chiefs who granted us to access to their land.

References

[1] D. D. Buhler, M. Liebman, and J. J. Obrycki, "Theoretical and practical challenges to an IPM approach to weed management," *Weed Science*, vol. 48, no. 3, pp. 274–280, 2000.

[2] J. G. Ehrenfeld, "Effects of exotic plant invasions on soil nutrient cycling processes," *Ecosystems*, vol. 6, no. 6, pp. 503–523, 2003.

[3] O. E. Sala, F. S. Chapin, J. J. Armesto et al., "Global biodiversity scenarios for the year 2100," *Science*, vol. 287, no. 5459, pp. 1770–1774, 2000.

[4] M. Vilà, J. L. Espinar, M. Hejda et al., "Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems," *Ecology Letters*, vol. 14, no. 7, pp. 702–708, 2011.

[5] J. M. Levine, M. Vilà, C. M. D. Antonio, J. S. Dukes, K. Grigulis, and S. Lavorel, "Mechanisms underlying the impacts of exotic plant invasions," *Proceedings of the Royal Society of London. Series B: Biological Sciences*, vol. 270, no. 1517, pp. 775–781, 2003.

[6] A. Kulmatiski, K. H. Beard, J. R. Stevens, and S. M. Cobbold, "Plant-soil feedbacks: a meta-analytical review," *Ecology Letters*, vol. 11, no. 9, pp. 980–992, 2008.

[7] T. F. J. Van De Voorde, W. H. Van Der Putten, and T. Martijn Bezemer, "Intra- and interspecific plant-soil interactions, soil legacies and priority effects during old-field succession," *Journal of Ecology*, vol. 99, no. 4, pp. 945–953, 2011.

[8] A. H. M. Görgens and B. W. Van Wilgen, "Invasive alien plants and water resources: an assessment of current understanding, predictive ability and research challenges," *South African Journal of Science*, vol. 100, no. 1-2, pp. 27–34, 2004.

[9] C. Zachariades, J. H. Hoffmann, and A. P. Roberts, "Biological control of mesquite (ProsopisSpecies) (fabaceae) in South Africa," *African Entomology*, vol. 19, no. 2, pp. 402–415, 2011.

[10] R. T. Shackleton, D. C. Le Maitre, N. M. Pasiecznik, and D. M. Richardson, "Prosopis: a global assessment of the biogeography, benefits, impacts and management of one of the world's worst woody invasive plant taxa," *AoB PLANTS*, vol. 6, pp. 1–18, 2014.

[11] N. R. Jordan, D. L. Larson, and S. C. Huerd, "Soil modification by invasive plants: effects on native and invasive species of mixed-grass prairies," *Biological Invasions*, vol. 10, no. 2, pp. 177–190, 2008.

[12] S. Ruwanza and C. M. Shackleton, "Effects of the invasive shrub, Lantana camara, on soil properties in the Eastern Cape, South Africa," *Weed Biology and Management*, vol. 16, no. 2, pp. 67–79, 2016.

[13] B. E. Rossi and P. E. Villagra, "Effects of *Prosopis flexuosa* on soil properties and the spatial pattern of understorey species in arid Argentina," *Journal of Vegetation Science*, vol. 14, no. 4, pp. 543–550, 2003.

[14] A. El-Keblawy and A. Al-Rawai, "Impacts of the invasive exotic Prosopis juliflora (Sw.) D.C. on the native flora and soils of the UAE," *Plant Ecology*, vol. 190, no. 1, pp. 23–35, 2007.

[15] S. Shackleton, D. Kirby, and J. Gambiza, "Invasive plants-friends or foes? Contribution of prickly pear (Opuntia ficus-indica) to livelihoods in Makana Municipality, Eastern Cape, South Africa," *Development Southern Africa*, vol. 28, no. 2, pp. 177–193, 2011.

[16] B. W. Van Wilgen, G. G. Forsyth, D. C. Le Maitre et al., "An assessment of the effectiveness of a large, national-scale invasive alien plant control strategy in South Africa," *Biological Conservation*, vol. 148, no. 1, pp. 28–38, 2012.

[17] R. T. Shackleton, T. Adriaens, G. Brundu et al., "Stakeholder engagement in the study and management of invasive alien species," *Journal of Environmental Management*, vol. 229, pp. 1–14, 2018.

[18] D. C. Le Maitre, D. B. Versfeld, and R. A. Chapman, "The impact of invading alien plants on surface water resources in South Africa: a preliminary assessment," *Water SA*, vol. 26, pp. 397–408, 2000.

[19] S. Dzikiti, K. Schachtschneider, V. Naiken, M. Gush, G. Moses, and D. C. Le Maitre, "Water relations and the effects of clearing invasive *Prosopis* trees on groundwater in an arid environment in the Northern Cape, South Africa," *Journal of Arid Environments*, vol. 90, pp. 103–113, 2013.

[20] N. Dassonville, S. Vanderhoeven, V. Vanparys, M. Hayez, W. Gruber, and P. Meerts, "Impacts of alien invasive plants on soil nutrients are correlated with initial site conditions in NW Europe," *Oecologia*, vol. 157, no. 1, pp. 131–140, 2008.

[21] D. C. Le Maître, M. Gaertner, E. Marchante et al., "Impacts of invasive Australian acacias: implications for management and restoration," *Diversity and Distributions*, vol. 17, no. 5, pp. 1015–1029, 2011.

[22] T. E. Marler, "Three invasive tree species change soil chemistry in Guam forests," *Forests*, vol. 11, no. 279, pp. 1–13, 2020.

[23] P. M. S. Rodrigues, J. O. Silva, and C. E. G. R. Schaefer, "Edaphic properties as key drivers for woody species distributions in tropical savannic and forest habitats," *Australian Journal of Botany*, vol. 67, no. 1, pp. 70–80, 2019.

[24] J. W. Creswell, *Qualitative Inquiry and Research Design: Choosing Among Five Traditions*, Sage, Thousand Oaks, CA, USA, 1998.

[25] C. S. Bootsman, *The Evolution of the Molopo Drainage*, PhD thesis, University of the Witwatersrand, Johannesburg, South Africa, 1998.

[26] Mahikeng Local Municipality, *Mahikeng Local Municipality Audited Annual Report 2012/2013*, City Council of Mahikeng, Mmabatho, South Africa, 2013.

[27] S. A. Materechera, "Soil properties and subsoil constraints of urban and peri-urban agriculture within Mahikeng city in the North West Province (South Africa)," *Journal of Soils and Sediments*, vol. 18, no. 2, pp. 494–505, 2018.

[28] Soil Classification Working Group, *Soil Classification: A Taxonomic System for South Africa", Memoirs on the Agricultural Natural Resources of South Africa*, Department of Agriculture and Development, Pretoria. South Africa, 1991.

[29] IUSS Working Group WRB, "World reference base for soil resources 2014, update 2015", international soil classification system for naming soils and creating legends for soil maps," World Soil Resources Report no. 106, FAO, Rome, Italy, 2015.

[30] FAO/UNESCO, "FAO/UNESCO Soil map of the world, revised legend World Soil Resources," Report 60, FAO, Rome, Italy, 1998.

[31] FSSA (Fertilizer Society of South Africa), *Fertilizer Society of South Africa Fertilizer Handbook*, Society of South Africa, Lynnwood Ridge, Pretoria, South Africa, 5th edition, 2003.

[32] D. W. Nelson and L. E. Sommers, "Total carbon, organic carbon and organic matter," in *Methods of Soil Analysis*, A. L. Page, Ed., Agronomy Monographs 9.ASA and SSSA, Madison, WI, USA, Part 2, 1982.

[33] L. P. Van Reeuwijk, *Procedures for Soil analysis International Soil Reference and Information Center (ISRIC)*, ISRIC, Wageningen, Netherlands, 2002.

[34] I. I. Bashour and A. H. Sayegh, *Methods of Analysis for Soils of Arid and Semi-arid Regions*, FAO, Rome, Itay, 2007.

[35] D. L. Rowell, *"Soil Science: Methods and Applications" Third Drive Avenue*, Routledge Publications, New York, NY, USA, 2014.

[36] F. Khorsandi and F. A. Yazdi, "Estimation of saturated paste extracts' electrical conductivity from 1 : 5 soil/water suspension and gypsum," *Communications in Soil Science and Plant Analysis*, vol. 42, no. 3, pp. 315–321, 2011.

[37] C. H. Kahi, S. M. Mureithi, and J. C. Ng'ethe, "The canopy effects of *Prosopis juliflora* (DC.) and *Acacia tortilis* (Hayne) trees on herbaceous plants species and soil physicochemical properties in Njemps flats, Kenya," *Tropical and Subtropical Agroecosystems*, vol. 10, pp. 441–449, 2009.

[38] P. G. Soti and K. Jayachandran, "Effect of exotic invasive old world climbing fern (*lygodium microphyllum*) on soil properties," *Journal of Soil Science and Plant Nutrition*, vol. 16, no. 4, pp. 930–940, 2016.

[39] A. J. Belsky, S. M. Mwonga, R. G. Amundson, J. M. Duxbury, and A. R. Ali, "Comparative effects of isolated trees on their undercanopy environments in high-and low-rainfall savannas," *The Journal of Applied Ecology*, vol. 30, no. 1, pp. 143–155, 1993.

[40] C. P. Mugunga and D. T. Mugumo, "*Acacia sieberiana* effects on soil properties and plant diversity in songa pastures, Rwanda," *International Journal of Biodiversity*, vol. 2013, Article ID 237525, 11 pages, 2013.

[41] R. S. C. Menezes and I. H. Salcedo, "Influence of tree species on the herbaceous understory and soil chemical characteristics in a silvopastoral system in semi-arid northeastern Brazil," *Revista Brasileira de Ciência do Solo*, vol. 23, no. 4, pp. 817–826, 1999.

[42] R. García-Sánchez, S. L. Camargo-Ricalde, E. García-Moya, M. Luna-Cavazos, A. Romero-Manzanares, and N. M. Montaño, "*Prosopis laevigata* and *Mimosa biuncifera* (Leguminosae), jointly influence plant diversity and soil fertility of a Mexican semiarid ecosystem," *International Journal of Tropical Biology and Conservation*, vol. 60, no. 1, pp. 87–103, 2012.

[43] S. A. Leicht-Young, H. O'Donnell, A. M. Latimer, and J. A. Silander, "Effects of an invasive plant species, *Celastrus orbiculatus*, on soil composition and processes," *The American Midland Naturalist*, vol. 161, no. 2, pp. 219–231, 2009.

[44] M. A. M. Sadeq, M. S. Abido, A. A. Salih, and J. A. Alkhuzai, "The effects of mesquite (*Prosopis juliflora*) on soils and plant communities in the deserted rangelands of Bahrain," *International Journal of Forestry Research*, vol. 2020, pp. 1–8, 2020.

[45] A. R. Tiedemann and J. O. Klemmedson, "Responses of desert grassland vegetation to mesquite removal and regrowth," *Journal of Range Management*, vol. 57, no. 5, pp. 455–465, 2004.

[46] A. J. Belsky, "Influences of trees on savanna productivity: tests of shade, nutrients, and tree-grass competition," *Ecology*, vol. 75, no. 4, pp. 922–932, 1994.

[47] P. E. V. Charman and M. M. Roper, "Soil Organic Matter," *in Soils: Their Properties and Management*, pp. 276–285, Oxford University Press, Melbourne, Australia, 2007.

[48] M. Brehanu and W. Ashenafi, "Impact of tree species in different sub-habitats on soil physico-chemical properties of allaidege rangeland, Southern Afar, Ethiopia," *Asian Journal of Science and Technology*, vol. 9, pp. 7338–7346, 2018.

[49] Y. Zhou, Z. Pei, J. Su et al., "Comparing soil organic carbon dynamics in perennial grasses and shrubs in a saline-alkaline arid region, northwestern China," *PLoS One*, vol. 7, pp. 1–9, 2012.

[50] J. Franco-Pizaña, T. E. Fulbright, and D. T. Gardiner, "Spatial relations between shrubs and Prosopis glandulosacanopies," *Journal of Vegetation Science*, vol. 6, no. 1, pp. 73–78, 1995.

[51] R. K. Aggarwal, "Physico-chemical status of soil under khejri (*P. cineraria* linn.)," in *Khejri (P. cineraria) in the Indian Desert- its role in Agroforestry*, H. S. Mann and S. K. Saxena, Eds., CAZRI, Jodhpur, India, 1980.

[52] A. S. Neal, S. Saggar, and P. D. McIntosh, "Biogeochemical impact of *Hieracium* invasion in New Zealand's grazed Tussock grasslands: sustainability implications," *Ecological Applications*, vol. 11, pp. 1311–1322, 2001.

[53] Z. Asfaw and G. I. Agren, "Farmers' local knowledge and topsoil properties of agroforestry practices in Sidama, Southern Ethiopia," *Agroforestry System*, vol. 71, no. 1, pp. 35–48, 2007.

[54] K. N. Desta, N. Lisanenwork, and M. Muktar, "Physico-chemical properties of soil under the canopies of *Faidherbia albida* (Delile) A. Chev and *Acacia tortilis* (Forssk.) Hayen in park land agroforestry system in Central Rift Valley, Ethiopia," *Journal of Horticulture and Forestry*, vol. 10, no. 1, pp. 1–8, 2018.

[55] J. G. Ehrenfeld, P. Kourtev, and W. Huang, "Changes in soil functions following invasions of exotic understory plants in deciduous forests," *Ecological Applications*, vol. 11, no. 5, pp. 1287–1300, 2001.

[56] C. Si, X. Liu, C. Wang et al., "Different degrees of plant invasion significantly affect the richness of the soil fungal community," *PLoS One*, vol. 8, no. 12, pp. 1–9, 2013.

[57] M. N. N. Wekhanya, *The Effect of Invasive Species Lantana Camara on Soil Chemistry at Ol-DonyoSabuk National Park, Kenya*, Kenyatta University, Nairobi, Kenya, 2016.

[58] G. Zelalem, "Spatial variation in range dynamics in relation to Prosopis juliflora invasion along river awash, gewane district, North east Ethiopia," MSc thesis, 2007.

[59] E. T. F. Witkowski, "Effects of invasive alien *Acacias* on nutrient cycling in the coastal lowlands of the Cape Fynbos," *The Journal of Applied Ecology*, vol. 28, no. 1, pp. 1–15, 1991.

[60] P. S. Kourtev, J. G. Ehrenfeld, and M. Häggblom, "Exotic plant species alter the microbial community structure and function in the soil," *Ecology*, vol. 83, no. 11, pp. 3152–3166, 2002.

[61] J. L. Charley and N. E. West, "Plant-induced soil chemical patterns in some shrub-dominated semi-desert ecosystems of Utah," *The Journal of Ecology*, vol. 63, no. 3, pp. 945–963, 1975.

[62] Y. Abebe, I. Fisseha, and O. Mats, "Contribution of indigenous trees to soil properties: the case of scattered trees of *Cordia africana* Lam. in croplands of western Oromia," *Ethiopian Journal Natural Resource*, vol. 3, no. 2, pp. 245–270, 2002.

[63] C. S. Kamara and I. Haque, "Faidherbia albida and its effects on Ethiopian highland Vertisols," *Agroforestry Systems*, vol. 18, no. 1, pp. 17–29, 1992.

[64] M. Mussa, H. Hashim, and M. Teha, "Rangeland degradation extent, impacts and alternative restoration techniques in the rangelands of Ethiopia," *Tropical and Subtropical Agroecosystems*, vol. 19, pp. 305–318, 2016.

[65] K. Hailemariam, G. Kindeya, and Y. Charles, "*Balanite aegyptica*, a potential tree for parkland agroforestry systems with sorghums in Northern Ethiopia," *Journal of Soil Science Environment and Management*, vol. 1, no. 6, pp. 107–114, 2010.

[66] T. A. Zeleke, ""Effects of scattered *Acaciatortilis* (Forssk) hayne on soil properties in different land uses in Central Rift Valley of Ethiopia'," *Journal of Sustainable Forestry*, vol. 36, no. 2, pp. 164–176, 2017.

[67] A. D. Roba1, M. Mohammed, and L. Nigatu, "Evaluation of soil physicochemical properties under the canopy of coffee shade trees effect (*Cordia africana* and *Erythrina abyssinica*) in arsi golelcha district, Ethiopia," *Journal of Resources Development and Management*, vol. 32, pp. 80–91, 2017.

[68] M. Abdella, L. Nigatu, and A. Akuma, "Impact of," *Agriculture Forestry and Fisheries*, vol. 9, no. 3, pp. 54–66, 2020.

[69] B. D. Sharma and I. C. Gupta, "Effect of tree cover on soil fertility in Western Rajasthan," *Indian Forester*, vol. 115, no. 5, pp. 348–354, 1989.

[70] L. Chapuis-Lardy, S. Vanderhoeven, N. Dassonville, L.-S. Koutika, and P. Meerts, "Effects of the exotic invasive plant *Soildago gigantea* on soil phosphorus status," *Biology and Fertility of Soils*, vol. 42, pp. 481–489, 2006.

[71] L.-S. Koutika, S. Vanderhoeven, L. Chapuis-Lardy, N. Dassonville, and P. Meerts, "Assessment of changes in soil organic matter after invasion by exotic plant species," *Biology and Fertility of Soils*, vol. 44, pp. 331–341, 2007.

[72] G. Mandal and S. P. Joshi, "Biomass calculation and carbon sequestration potential of *Shorea robusta* and *Lantana camara* from the dry deciduous forests of Doon Valley, western Himalaya, India," *International Journal of Environmental Biology*, vol. 4, no. 2, pp. 157–169, 2014.