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The Correlation between *Opuntia stricta* Distribution and Soil Chemical Composition in Tsavo East National Park

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Abstract: *Biological invasions have been observed in Kenya some of which are deemed to have significant socio-economic repercussions on affected communities altering the composition and structure of ecosystems. Data from the East African region indicates that Kenya has been invaded by 34 distinct species with notable examples including Opuntia stricta (Haw) and water hyacinth (Eichhornia crassipes). This study aimed to examine the relationship between the distribution of the invasive species O. stricta and the soil chemical composition in Tsavo East National Park, Kenya (TENP). The study area was divided into twelve 2km-long transects with ten 5m by 5m quadrats systematically established along each transect. Data on O. stricta coverage and soil chemical concentration were collected in each quadrat. Analysis of variance (ANOVA) was conducted on O. stricta coverage revealing significant differences in its distribution across the sampled transects. Correlation analysis between O. stricta and soil chemical composition was performed. Among the soil chemical components examined, phosphates exhibited a negative correlation with O. stricta cover at a significance level of $p=0.002$ for $\alpha=5\%$. Conversely, sodium content and O. stricta cover showed a positive correlation at a significance level of $P=0.039$ for $\alpha=5\%$. These findings are critical for guiding strategies aimed at controlling the rapid spread of O. stricta in Tsavo East National Park and similar ecosystems.*

Keywords: *Invasive Plants, Opuntia stricta, Soil chemical composition, Correlation, Ecosystems.*

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1. Introduction

Invasive Alien Species (IAS) pose significant threats to biodiversity loss (Witt, 2016). These plants exhibit a broader range of tolerances allowing them to adapt highly effectively compared to native species (Ivens, 1989). As they infiltrate native ecosystems, they displace indigenous plants upsetting the ecological balance between grasses and shrubs in both natural and agricultural environments (Pimentel, 2002). Consequently, these invasions induce changes in species composition, dominant life forms, nutrient cycling, hydrology and decomposition, altering the overall structure and function of ecosystems (Oba et al., 2000). Their rapid reproduction and dispersal capabilities enable them to out compete native species leading to significant economic losses estimated in the billions of USD (Richardson and Pysek, 2001; Wilcove et al., 1998; Yurkonis et al., 2005).

O. stricta stands out as one of the most pernicious invasive alien plant species worldwide posing a substantial menace to wildlife conservation and agricultural productivity across various regions (Bright, 1998). During the 1950s, the British colonial administration introduced three *Opuntia species* (*O. monacantha*, *O. ficus-indica*, *O. stricta*) into Kenya (Strum et al., 2015). Among these cactaceae species, *O. stricta* has aggressively spread, outcompeting indigenous flora and displacing them. Its proliferation has even resulted in the exclusion of browsing animals and forced local Maasai pastoralists in Laikipia to abandon their traditional lands (Witt, 2016).

Tsavo East National Park (TENP) hosts a rich diversity of species, including the iconic 'Big Five' and the endangered Hilora antelope. However, the park's ability to sustain such diversity is gradually eroding due to the rapid expansion of *O. stricta,* which is replacing crucial forage species vital for wildlife survival. Given the park's significance as a critical wildlife conservation area in Kenya, curtailing this invasion is imperative. Safeguarding its ecological integrity, processes and functions is paramount for maintaining viable and varied wildlife populations. This research was conducted to assess the influence of soil chemical composition on the spatial distribution and abundance of *O. stricta* within TENP. Such data is indispensable for effectively managing *O. stricta* in both the park and the broader Tsavo eco-region. Furthermore, this information could inform the development of management strategies for combating other invasive plant species.

1.1 Statement of the problem

The rapid encroachment of *O.stricta* is swiftly transforming TENP as noted by Witt (ABR, 2017), with detrimental effects on wildlife survival. As emphasized by Llewellyn et al. (2008), adept management of plant invasions necessitates precise spatial data regarding distribution patterns, presence/absence and abundance across affected areas. Such information is indispensable for devising management strategies, establishing achievable objectives and assessing the efficacy of control measures. Unfortunately, there is little comprehensive data regarding the occurrence, spread, intensity of invasion, correlation with soil chemical composition and management practices of *O. stricta* in Kenya. This knowledge vacuum hinders efforts to reclaim and restore the environmental integrity of TENP. Without this critical information, stakeholders may be hesitant to engage in effective management initiatives. Thus, this research aims to bridge these knowledge gaps furnishing scientifically sound data crucial for combating and managing the proliferation of this invasive plant species

1.2 Research Question

Is soil chemical composition correlated with spatial distribution of *O. stricta* in Tsavo East national park?

1.3 Hypothesis

There is no significant relationship between soil chemical composition and spread of *O. stricta* in TENP.

1.4 Objective

The main purpose of the study was to investigate spatial distribution of *O. stricta* in Tsavo East National Park and establish its relationship with soil chemical composition, presence of other woody plants and presence of elephants.

2. Literature Review

2.1 Invasive Species in Kenya and their Impact on Terrestrial Ecosystems

The World Conservation Union has identified 35 invasive alien species within Kenya with nine of these being plants (IUCN/SSC/ISSG, 2004). Among the prominent invasive plant species in Kenya are the Water hyacinth (*Eichhornia crassipes*), Water fern *(Salvinia molesta*), Wild garlic (*Allium vineale*), Prickly pear (*Opuntia species),* Mexican marigold (*Tagetes minuta*), Lantana camara, and Morning glory (*Ipomea species*) (Gichua et al., 2013).

O. stricta is listed as one of the top 100 worst invasive alien species in the Global Invasive Species Database (GISD) (Lowe et al., 2000). Its dense growth impedes movement and access across landscapes and is known to alter the characteristics of savannas and arid grasslands (Henderson, 2001).

2.2 Distribution and Spread of *Opuntia stricta* in Kenya

O. stricta was introduced to East Africa and specifically to Kenya during the colonial era of the 1950s initially as an ornamental plant prized for its ability to thrive in arid environments. Subsequently, it has spread across vast expanses of delicate rangelands in northern Kenya, posing a threat to the livelihoods of animal herders (Lazarides et al., 1997). Flourishing in arid and semi-arid regions, this species renders valuable pasture species inaccessible to livestock while also obstructing access to essential resources such as water (CABI, 2017)

The plant has extended its presence to the northern part of the country particularly thriving in the high-altitude semi-arid savanna of the Laikipia plateau where it is abundant. This area comprises valuable commercial rangelands and conservation zones (Kunyaga et al., 2009). Furthermore, it has established itself in Tsavo East National Park (TENP) and is believed to have encroached upon approximately 2000 km^2 of the park (Ross et al., 2017). It has also been reported in other regions of the country including the Coastal, Rift Valley, Nyanza regions and the Eastern shore of Lake Victoria (Mathews and Brand, 2004; Chenje and Katerere, 2006).

The invasion of *Opuntia stricta* in Kenya didn't present a challenge until the late 1990s when the rapid degradation of rangeland conditions provided an ideal environment for its quick proliferation (Bradley et al., 2010). This has resulted in a decline in pasture production posing a significant threat to livestock farming and wildlife conservation in Kenya's arid and semi-arid regions. Munyasi (2004) noted that areas suffering from degradation were more susceptible to being dominated by invasive plant species compared to bushed or wooded areas. Strum et al. (2015) also illustrated how range degradation, reduced ground vegetation cover and suppressed herb layers facilitate the growth of *O. stricta* in the Laikipia Plateau. Instances of this invasion have been recorded in various parts of Kenya (Western, 2009; Kioko et al., 2012; Groom and Western, 2013; Kaye-Zwiebel and King, 2014)

According to Strum et al. (2015), the invasion of *O. stricta* into the Laikipia Plateau stems from changes in land use, particularly the settlement of pastoralists resulting in overgrazing and subsequent ecological degradation of rangelands. This degradation has facilitated the proliferation of *O. stricta*. There exists a notable correlation between the intensity of livestock grazing and the presence of both native and non-native species of *O. stricta* (Pemberton and Liu, 2007). The selective consumption of palatable plant species by predominantly grazing herbivores in open grasslands has contributed to the increased spread of *O. stricta* which is less preferred (Hobbs and Huenneke, 1992; Mwangi and Western, 1998)

As an arid-adapted species, it thrives in environments with limited resources enabling it to out compete native species particularly during drought periods. Furthermore, its success is attributed to its dual reproductive modes (Padrón et al., 2011). It reproduces sexually and agents like mammals and birds disperse its seeds and asexually through the rooting and growth of dropped plant paddles (Strum et al., 2015). The plant bears fruits year-round providing sustenance for animals while its seeds remain viable for up to 15 years (Mandujno et al., 2001).

In the North-Eastern region of Kenya's Laikipia Plateau encompassing Dol Dol and Ol Jogi ranches, *O. stricta* dispersal agents were identified as elephants, baboons, humans and livestock (Witt, 2017). Elephants were observed to transport *O. stricta* seeds the farthest distance exceeding 53 km from their original location (Strum et al., 2015). Similarly, in South Africa's Kruger National Park, baboons and elephants known for extensively consuming ripe fruits have played a significant role in the rapid spread of the plant (Hoffmann et al., 1998). Seed dispersal by these animals through their faecal matter, enhances germination rates as the seeds undergo scarification during digestion (Kunz and Linsenmair, 2008)

Figure 1: ***Opuntia stricta***

3. Methodology

3.1 Study Area

TENP, located in the South Eastern region of Kenya and situated opposite Tsavo West National Park (Figure 2) shares borders with Chyulu Game Reserve, South Kitui National Reserve and Mkomazi Game Reserve in Tanzania. Encompassing an area of 11,747 $km^{2,}$ it is characterized by low-lying, semi-arid terrain with altitudes ranging from 150 m to 1,200 m above sea level, positioned at coordinates 2.77861°S and 38.77167 °E (Ayieni, J., 1975). It spans across four counties, Kitui, Taita Taveta, Tana River and Makueni. Tsavo East was designated as a National Park in 1948 and stands as the largest protected area and most frequented park in Kenya (Tsavo Conservation, 2008-2018). Notably, it hosts the largest elephant population (Ngene, 2011) and attracts approximately 75,000 tourists annually with the majority drawn by the presence of the "Big Five" mammalian species (KNBS, 2015).

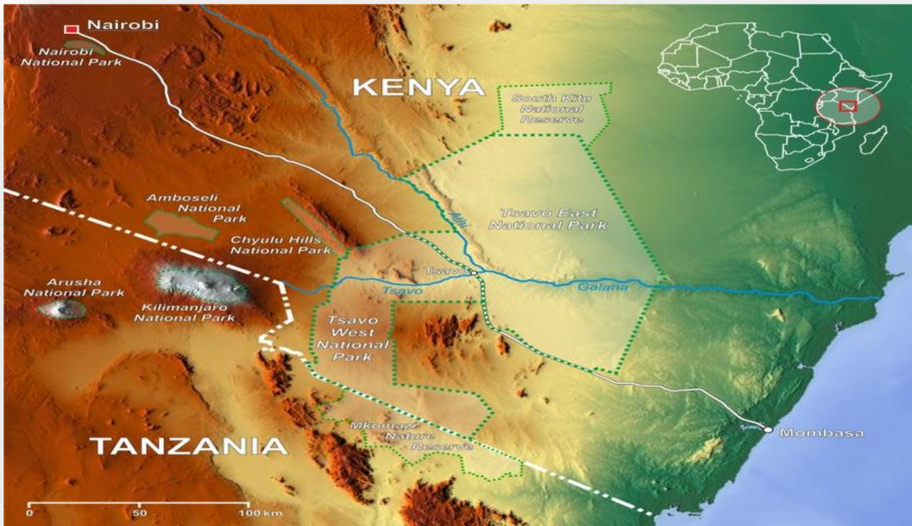

Figure 2: Map of Kenya in relation to TENP

TENP is predominantly populated by hardy, drought-resistant thorny-bush shrubs intermittently interrupted by verdant patches of vegetation along the River Galana and smaller seasonal rivers traversing the national park (Patterson et al., 2004). The vegetation within the region is closely linked to the soil composition and prevailing climatic conditions with its makeup mirroring the physical environment. The primary vegetation type consists of *Acacia commiphora,* incorporating diverse densities of trees and shrubs ranging from open plains to bushed grasslands shrub lands and woodlands.

The species of trees found in the area comprise *Acacia tortilis, Acacia nilotica, Commiphora africana, Commiphora campestris* and *Commiphora confusa*. Additionally, sporadic taller hardwood tree species and shrubs such as *Terminalia spinosa, Melia volkensii, Boscia coracea*, various *Grewia species*, different *Lannea species*, *Premna resinosa* and *Cassia abbreviata*, are present (Wijngaarden et al., 1985). The dense *Acacia-Commiphora* forest gradually thins out and transitions into patches of grassland.

3.2 Study Site

The study was conducted between Bachuma and Ndara plains

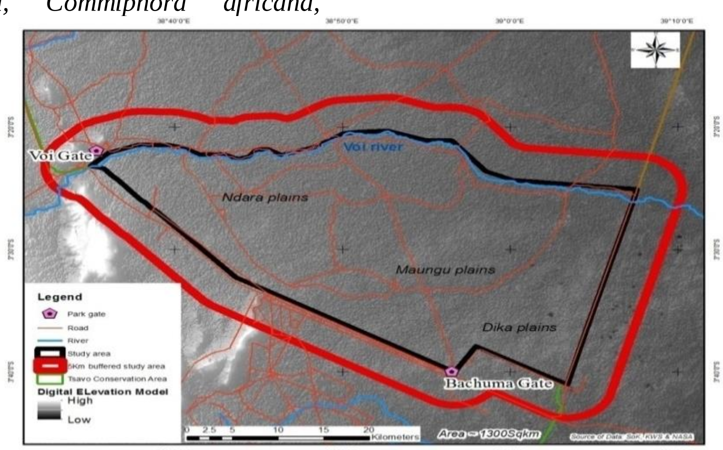

Figure 3: Satellite image of the study area (Wright and David, 2005).

3.3 Survey and Sampling Strategy

Data collection took place during the rainy and dry seasons to identify seasonal fluctuations and was carried out over a period of six months. The survey encompassed a total area of 24 square kilometers. Utilizing GPS technology, 12 linear transects each spanning 2 kilometers were established between Bachuma and Ndara plains. Along each transect, 10 quadrats each measuring 5 meters by 5 meters were systematically positioned at intervals of 200 meters. All transects and quadrats were geo referenced using handheld GPS units placed between successive transects and quadrats.

3.4 Spatial Analysis of *Opuntia stricta* Cover

The Braun-Blanquet cover abundance scale commonly employed in vegetation science to measure plant cover based on percentage ranges was used. In this study, the scale was utilized to assess percentage coverage where 5 represents 75% to 100%, 4 corresponds to 50% to 75%, 3 denotes 25% to 50%, 2 indicates 5% to 25% and r signifies less than 5% (Braun-Blanquet, 1932). These ratings were recorded for all 120 quadrats. The data collected was then utilized to illustrate the spatial distribution of *Opuntia stricta*, with coordinates captured using handheld GPS units.

3.5 Collection and Chemical Analysis of Soil Samples

Ten soil samples were gathered from each transect at a depth of 15cm precisely from the center of each quadrat. Following collection, the samples underwent three days of sun-drying. Subsequently, 15 grams of soil from each quadrat were packed into khaki bags and stored in a well-ventilated room. From each transect, five soil samples were chosen at random and subjected to analysis for nitrates, phosphates, calcium, magnesium, sodium, and potassium. Thus, a total of 60 samples were analyzed for each soil element.

3.6 Determination of the Concentration of Nitrates

Five soil samples were chosen randomly from the quadrats within each transect then prepared and analyzed employing a UV-VIS spectrophotometer. UV-VIS measurements were conducted across a spectrum ranging from 350 to 700 nm utilizing 3 cm^3 quartz cuvettes with the Nicolette Evolution 100 Spectrometer (Thermo Electron Corporation, UK). Concentration levels of the solutions were directly recorded from the calibrated UV-VIS spectrophotometer (Amponsah et al., 2014).

3.7 Determination of the Concentration of Phosphates

The five prepared soil samples were analyzed utilizing a UV-VIS spectrophotometer. Measurements were taken across the 350-700 nm spectrum using 3 cm3 quartz cuvettes with the Nicolette Evolution 100 Spectrometer (Thermo Electron Corporation, UK). The concentration levels of the solutions were directly recorded using a calibrated UV-VIS spectrophotometer (Amponsah et al., 2014).

3.8 Acid Digestion of Soil Samples to Determine the Concentrations of Calcium and Magnesium

From each transect, five samples were randomly chosen for analysis resulting in a total of 60 samples. In a beaker, 30 ml of dilute hydrochloric acid was added followed by the addition of the weighed soil sample. The mixture was heated on a low-temperature hot plate until it reached boiling point (Anderson et al., 1993). After boiling, the mixture was allowed to cool before being filtered into a 100 ml volumetric flask using medium filter paper (Whatman 540). The residue was rinsed with distilled water until the volume reached approximately 80 ml. The volume was then adjusted to 100 ml using distilled water and thoroughly mixed by shaking. Subsequently, 100 ml of the mixture was transferred into 60 cuvettes.

Standards of Calcium and Magnesium were prepared and subjected to analysis using Atomic Absorption Spectrometry (AAS). Similarly, the samples were analyzed using AAS. In the analysis for Calcium in the air-acetylene flame, silicon was eliminated due to its potential to modify the soil composition resulting in the formation of new clay minerals characterized by heightened biogeochemical activity. The presence of magnesium ions was also determined using the flame method as outlined (Talanta, 1999).

3.9 Flame Photometer Method for Extraction of Sodium and Potassium

From each transect, five dry soil samples weighing 2 grams was measured and placed into a clean, dry glass beaker, to which 30 ml of dilute hydrochloric acid was added. The mixture was gently heated to boiling over low heat and then allowed to cool to room temperature before being filtered. The filtrate was rinsed and transferred into a 100 ml volumetric flask, which was subsequently filled to the mark. Distilled water was used for aspiration, and the flame photometer scale was adjusted to zero deflection (0% reading).

Calibrated solutions containing sodium and potassium at concentrations of 2 mg/L, 4 mg/L, 6 mg/L, 8 mg/L, and 10 mg/L were aspirated sequentially starting from the lowest concentration and progressing to the highest with the addition of water between each measurement. The corresponding deflection for each standard was recorded. Each sample solution was also aspirated and its corresponding deflection was recorded. The chemical properties of all samples were analyzed in total.

3.10 Data Analysis

The data regarding the percentage coverage of *O. stricta* within the sampled area underwent transformation prior to analysis to fulfill the parametric statistical assumptions necessary for inference purposes or to enhance the interpretability and presentation of the findings. The transformation utilized the arcsine formula. Analysis of Variance (ANOVA) was employed to assess whether the distribution of *O. stricta* varied significantly across the transects. Subsequently, a post hoc multiple comparisons (Tukey's HSD test) was conducted to identify means that exhibited significant differences among them.

To ascertain the correlation between the soil chemical components and the cover of *O. stricta*, a Pearson Correlation test was performed. This analysis aimed to determine if a relationship existed between *Opuntia* and the specified factor. A correlation coefficient of 1.00 indicated a perfect positive correlation. , -1.00 perfect negative correlation while zero implied no correlation. Statistical significance in both directions was tested using two- tailed test.

4. Results and Discussion

4.1 Spatial Distribution of *Opuntia stricta*

Spatial distribution of *Opuntia stricta* cover was determined in the 12 transects. Transect one, two, three and six recorded high cover of *O. stricta* (Figure 4) while the rest recorded low percentages and there was no *O. stricta* cover in transect nine.

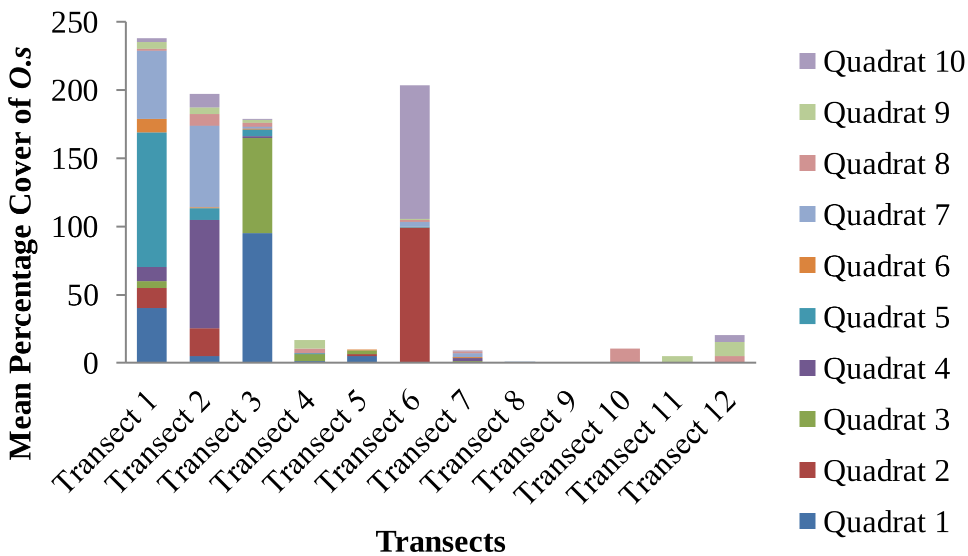

Figure 4. Mean Percentage cover of *Opuntia stricta* in the sampled area

4.2 Descriptive Statistics of *Opuntia stricta* Percentage Cover

The study carried out the descriptive analysis for the *O. stricta* distribution per the sampled transects and the findings summarized in the table below (Table 1).

From Table 1 below, the highest percentage mean was observed in transects one, two, three and six while the lowest were recorded in transects eight, nine and eleven. The maximum percentage was 99 percent in transect one and zero percent in transect 9

Table 1: Descriptive statistics of *Opuntia stricta* percentage cover

Transect	Mean	Std Dev
1	23.800	9.844
2	19.700	8.691
3	17.850	10.944
4	1.700	0.790
5	0.810	0.552
6	20.350	13.029
7	1.810	0.608
8	0.010	0.010
9	0.000	0.000
10	1.000	1.000
11	0.500	0.500
12	2.000	1.105

Table 2: Transformed data of the *Opuntia stricta* percentage cover

Transects	1	2	3	4	5	6	7	8	9	10	11	12
Opuntia stricta	23	19.7	17.9	1.7	0.4	20.4	0.9	0.1	0	1	0.5	2
log10(*O.s*)	1.36	1.29	1.25	0.23	-0.4	1.3	-0.05	-1		0	-0.3	0.5
Arcsine	0.50	0.59	0.51	0.30	0.20	0.48	0.32	0.10	0.00	0.10	0.10	0.27

As the log transformation approach yielded negative and undefined values, this study opted to utilize the arcsine-transformed values for subsequent data analysis. The application of the arcsine formula facilitated the conversion of the raw data into radians, enhancing its interpretability and presentation.

$$y = \arcsin e\sqrt{p} = \sin^{-1}\sqrt{p}$$

From the formula, P is the proportion or the percentage of the variable of interest while y is the transformed value of the observation.

The study conducted the Analysis of Variance (ANOVA) to establish whether the *O. stricta* percentage cover differed significantly per the sampled transects

Table 3: Analysis of variance

Source of Variance	Sum of Squares	Df	Mean Square	F	Sig
Between	10313.789	11	937.617	2.416	.010
Within	41917.057	108	388.121		
Total	52230.846	119			

From Table 3 above, *O. stricta* mean percentage cover differed significantly among different transects at $p < 0.05$ level with the computed $F = 2.416 > F_{0.05}(11,108) = 1.38$.

A post hoc multiple comparison (turkeys HSD test) was used to find means that were significantly different from each other in the transects and the results shown in the table 4 below.

Significant variations were observed between the means of quadrats 1.00 and 8.00, 2.00 and 9.00, 2.00 and 6.00, as well as 10.00 and 6.00. Consequently, the null hypothesis (H_O) was rejected, leading to the conclusion that there existed differences in the percentage cover of *O. stricta* among the 12 sampled transects (refer to Table 4).

Table 4: Separation of Means
Cover of *Opuntia stricta*

Turkey B[a]

Quadrat	N	Subset for alpha =0.05
		1
6.00	12	1.4167
8.00	12	2.7500
9.00	12	2.8750
3.00	12	6.7500
4.00	12	7.7500
7.00	12	9.7500
10.00	12	9.7917
5.00	12	10.3333
2.00	12	11.4167
1.00	12	11.7750

Means for groups in homogenous subsets were displayed

a. Uses Harmonic Mean sample size = 12.000

4.3 Correlation between the Soil Chemical Composition and *Opuntia stricta* Percentage Cover

The study sought to establish the relationship between some selected soil chemical composition and the *O. stricta* percentage cover. The results were summarized in Table 5 below.

Table 5: Correlation between *Opuntia stricta* percentage cover and soil chemical composition

Soil Chemical Composition	*Opuntia* Pearson Correlation	Sig. (2-tailed)	Soil Samples
Opuntia s. cover	1.000	.	60
Nitrates	-.014	.918	60
Phosphates	-.404	.002	60
Calcium	.062	.636	60
Magnesium	-.044	0.369	60
Sodium	.247	.039	60
Potassium	.008	.476	60

The strength of the Pearson correlation values were based on the Cohen (1988) guidelines where;

$\text{Small} = |0.10 < r < 0.29|$,

$\text{Medium} = |0.30 < r < 0.49|$ and

$\text{Large} = |0.50 < r < 1.00|$ Therefore, from the results in Table 5, there was a small negative correlation between nitrate and the *O. stricta* at $\alpha = 5\%$ given that $[r = -0.014$ $p = 0.918$ and $n = 60]$. Phosphate concentration showed a moderately medium negative correlation at $\alpha = 5\%$ $[r = -0.404$, $p = 0.002$ and $n = 60]$. There was moderately medium positive correlation between *O. stricta* percentage cover and sodium at $\alpha = 5\%$ $[r = 0.247$, $p = 0.039$ and $n = 60]$. Calcium and potassium was positively correlated at p=0.636 and p= 0.476 respectively though it was not significant. Nitrates and magnesium correlated negatively with *O. stricta* at P=0.918 and 0.369 which was insignificant.

4.4 Discussion

In the present investigation, transects one, two, three, and six situated in Ndara plains and the Mackinon road area within the southern regions of TENP, exhibited the highest mean percentage cover of *O. stricta*, with values of 23.80, 19.70, 17.85, and 20.35 respectively. Conversely, the remaining transects displayed lower mean cover (refer to Table 2). There was a significant divergence in the spatial distribution of *O. stricta* cover among the various transects (p-value < alpha). The Southern portion of the study area exhibited extensive invasion whereas the Northern areas showed minimal *O. stricta* infestation. These results are consistent with the findings of Foxcroft et al. (2004) which suggest that the proliferation of prickly pear *(O. stricta)* is predominantly influenced by propagule pressure encompassing factors such as propagule size, quantity, as well as the temporal and spatial patterns of propagule arrival with environmental factors playing a lesser role.

The findings of this study reveal a notable negative correlation between phosphate concentration and *O. stricta* cover reaching statistical significance at p=0.002 for α=5%. Conversely, nitrates and magnesium exhibited negative correlations with *O. stricta*, though these associations were not statistically significant with p-values of 0.918 and 0.369 respectively. On the other hand, sodium concentration demonstrated a positive correlation with *O. stricta* cover achieving statistical significance at p=0.039 for α=5%. Meanwhile, calcium and potassium exhibited positive correlations with *O. stricta*, although these relationships were not statistically significant with p-values of 0.636 and 0.476 respectively (refer to Table 5). Consequently, it remains challenging to pinpoint the precise soil minerals influencing the distribution of *O. stricta.*

5. Conclusion and Recommendations

The analysis revealed that there is no significant correlation between the soil chemical composition and the prevalence of *O. stricta* in TENP. The impact of soil chemical composition on the distribution of *O. stricta* was found to be minimal. Consequently, it proved difficult to identify any specific soil factor that significantly influenced the prediction of *O. stricta* population density leading to the acceptance of the null hypothesis.

During the time of this study, it was observed that *Opuntia stricta* was present in TENP and was having a detrimental impact on biodiversity. The spread rate of this species was particularly high in the Southern regions of the park. If this trend persists, it is anticipated to result in more severe consequences for wildlife survival. Consequently, this could lead to negative implications for Kenya's tourism sector potentially resulting in significant financial losses for the country. Therefore, there is an urgent need to implement measures to control the spread of this invasive species in order to enhance the health and sustainability of national parks. It is imperative to conduct further detailed research to develop a management strategy for dealing with *Opuntia stricta* in TENP and similar ecosystems.

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