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Correlations between Tree/Shrub Diversity and Herbaceous Biomass with Soil Physico-chemical Properties under *Acacia saligna* Canopy

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Authors contributions

This work was carried out in collaboration between both authors. Authors RN and KG designed the study and analyzed the data and wrote the manuscript. Author RN collected the vegetation data, herbaceous data and soil samples. Both authors read and approved the final manuscript.

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ABSTRACT

Acacia saligna (*A. saligna*) is originated from South Western Australia, and it was brought to the Tigray region of Ethiopia in 1972 with the intention of restoring the ecosystem and conserving soil and water. This study aims to evaluate the correlations between tree/shrub diversity and herbaceous biomass with some soil physico-chemical properties under *Acacia saligna* canopy and away from the canopy in Atsibi Wemberta district, Tigray, Ethiopia. For collecting of vegetation data, herbaceous cover and soil sample, twelve A.saligna tree stands were used as a replication.Woody

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species identification, herbaceous cover and biomass production were collected under the canopy of A.saligna and 50 m away from the canopy at 1 m^2 for woody species, and 0.25 m^2 for herbaceous cover, and biomass production. Soil samples were taken using auger at 20 cm soil depth under the canopy and in the canopy gap A.saligna. The species richness under the canopy of *A.saligna* was positively insignificant correlated with pH (r = 0.48, p = 0.11), availability of phosphorus (Av.P) (r = 0.16, p = 0.63), total nitrogen (TN (r = 0.12, p = 0.7) and Silt (r = 0.71, p = 0.009). However, it is also negatively correlated with soil organic carbon (SOC (r = -0.06, p = 0.85), and sand (r = -0.77, p = 0.003). The Pearson's correlation matrix in the canopy gap of *A.saligna* showed that, Shannon diversity index is insignificantly positively correlated with SOC (r = 0.19, p = 0.53), Av.P (r = 0.46, p = 0.12), availability of potassium (Av.K) (r = 0.43, p = 0.16) and TN (r = 0.13, p = 0.69). However, species richness and Shannon diversity index have insignificantly negatively correlated with pH(r = -0.13, p = 0.68, r = -0.15, p = 0.63) and sand (r = -0.23, p = 0.51, r = -0.44, p = 0.14), respectively. In the canopy gap of *A.saligna,* the herbaceous biomass was positively correlated with Av.K (r = 0.47, p = 0.12), silt (r = 0.39, p = 0.20), and clay(r = 0.37, p = 0.24), but the Pearson's correlation matrix between herbaceous biomass and some soil parameters in the canopy gap is observed to be insignificantly negatively correlated with pH (r = -0.24, p = 0.44), SOC (r = -0.04, p = 0.9), Av.P (r = -0.34, p = 0.28), and TN (r = -0.33, p = 0.31).The species richness, Shannon diversity indexes and herbaceous biomass were insignificantly positively correlated with pH under the canopy of A.saligna, but for similar parameters in the canopy gap was observed negatively insignificant correlated with pH. Overall, the small positive correlation found in the current study between same soil physico chemical and diversity indexes under the *A. saligna* canopy suggests that the presence of these large *A. saligna* trees may increase soil nutrient availability through litterfall. The study found clear relationships between plant density and Shannon diversity with herbaceous biomass in Acacia saligna's canopy gap and beneath its canopy. In particular, both settings showed a substantial negative connection between herbaceous biomass and plant density, suggesting that increased plant density tends to diminish herbaceous biomass. On the other hand, a strong positive association was seen between Shannon diversity and herbaceous biomass, indicating that higher species diversity is linked to higher herbaceous biomass. Therefore, it is imperative to manage and conserve *A. saligna* and the woody species growing beneath the canopy in order to preserve and strengthen the favorable connections that exist between diversity indexes and the physical and chemical characteristics of soil.

Keywords: Acacia saligna; correlation; soil physico-chemical; herbaceous; diversity.

ABBREVIATIONS

SOC : Soil Organic Carbon
TN : Total Nitrogen
Av.P : Availability of phosphorus
Av.K : Availability of potassium

1. INTRODUCTION

Establishing quickly growing exotic tree species in tropically degraded land is a good way to increase biomass productivity per unit area and, as well as to catalyze the succession of native woody species in the understory [1]. As a tropical nation, Ethiopia has seen the majority of its native woody species regenerated or initiated, primarily through the integration of exotic species, in an effort to restore degraded areas [2,3]. Even though plantations of exotic species have played a crucial role for environmental rehabilitation, they are also widely viewed in a negative light in relation to native woody species diversity [4].

Acacia saligna (Labill.) Wendl. (A. cyanophylla Lindley) is originated from South Western Australia [5], which is considered as an exotic tree species in many parts of the world and an invasive species to some countries [6]. One of Ethiopia's exotic tree species, *Acacia saligna (A.saligna),* was brought to the Tigray region of Ethiopia in 1972 with the intention of restoring the ecosystem and conserving soil and water [7]. It is an evergreen tree/shrub species that is grown in a variety of agro-ecological zones [8]. According to [9], *A. saligna* grows quickly and may thrive in a variety of unfavorable environmental situations, including places that are prone to drought, waterlogged areas, and soil dominated by alkaline or saline.

A.saligna is one of the species from the genus of *Acacia* that spreads outside of their original range and they establish easily in new reas which threats the natural ecosystem functions by reducing the native biodiversity [10]. Similarly described by [11], large-scale plantation of alien species like *A.saligna species* in open areas have a negative impact on the regeneration potential and diversity of native woody vegetation, such as reducing species richness of native plants, disturbing nutrient cycling and altering the structure of the vegetation in adjacent native areas.

A. saligna tree plantation was practiced in the Tigray region in 1972 to restore degraded areas of the region [7]. Although *A. saligna* is commonly grown in different parts of the region, but the relationship between woody species diversity, herbaceous biomass with some soil physico-chemical properties under its canopy has been not studied yet for the semi-arid degraded ecosystem. Therefore, the present study was conducted to assess the correlation between woody species diversity, herbaceous cover and biomass with some soil physico-chemical properties under the canopy of *A. saligna* tree in semi-arid conditions of northern Ethiopia.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Atsbi-Womberta district, in the Eastern zone of Tigray, Ethiopia. The district is geographically bounded between 13º 36"North latitude and 39º 36``East longitude .The district has an altitudinal variation ranging from 988 to 3063 m a.s.l. Barka Adisebha is the particular study area, and geographically, it is situated between 39° 39'30"-39°47'0" East longitude and 13° 45'30"- 13° 51'30" North latitude and has an altitudinal range of 2171 to 2718 m a.s.l. with two agro-ecological zones (5.5% midland and (94.5%) highland (Fig. 1).

The consecutive eleven years (2006–2016) of the average monthly rainfall of Atsbi-Wemberta district was 613 mm, while the mean monthly temperature of the district varies from 6.4-22.8°C (Fig. 2). The detailed information regarding on the long term (11years) mean monthly temperature and rainfall of Atsbi-wenberta district is depicted (Fig. 2).

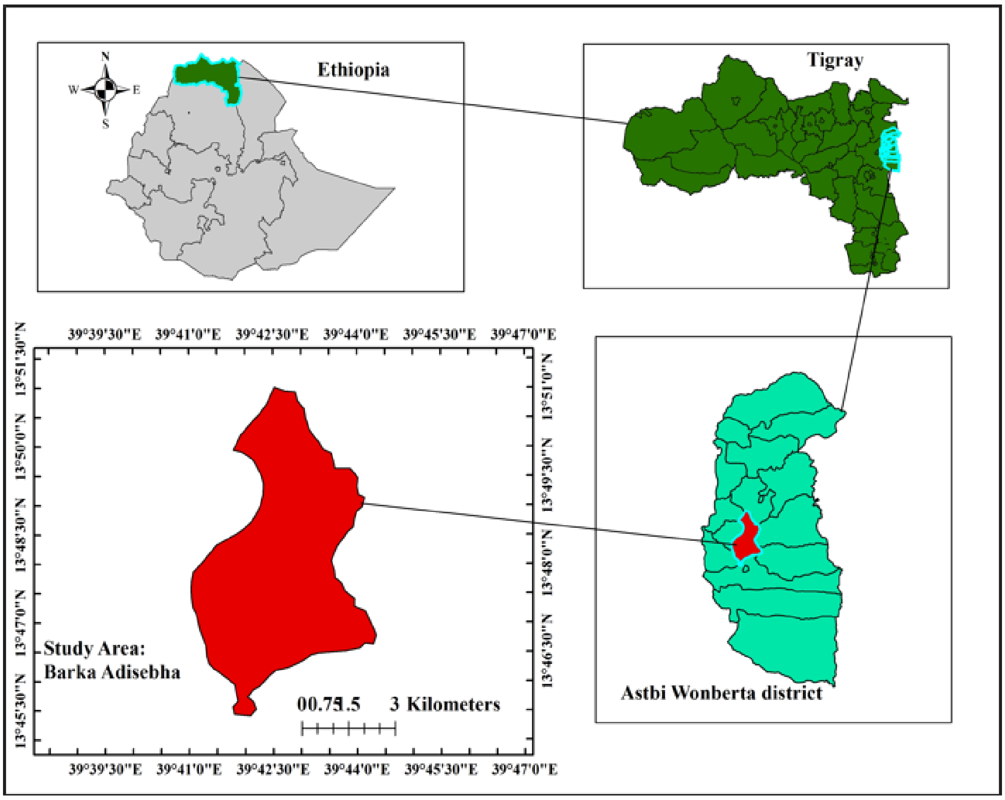

Fig. 1. Map of the study area

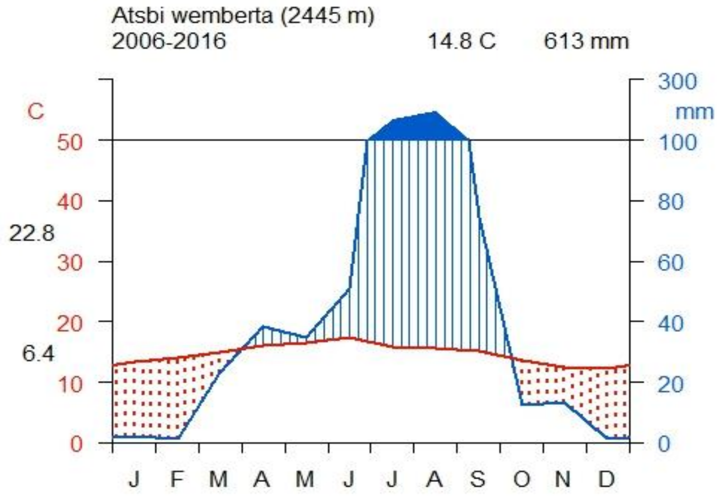

Fig. 2. Walter -Lieth climatic diagram for Atsbi wemberta district (Source; Tigray Regional Meteorological service center)

2.2. Sampling Design and Data Collection

Twelve exotic *A.saligna* tree stands were selected systematically with almost similar crown diameter, diameter at breast height, height and ages. Each *A.saligna* tree stands was considered a replication. The quadrates with a size of 1 m^2 were visually placed under the canopy of *A.saligna* tree stand and 50 m away from the stand, in which the sampling points were taken along the four directions under *A.saligna* canopy at a distance of 1 m away from the trunk, and from 50 m away (canopy gap). Briefly, the identification of all woody plants and the total number, as well as the height and dsh of individual seedlings and saplings of each species, were recorded. Individual woody categorizations were made as height <0.5 m and dsh < 2.5 for seedlings, h >0.5 m and dbh <5 cm for saplings [12].

The nested quadrate plot design was employed to sample the herbaceous biomass production. Accordingly, the sub plots with the size of 0.5 m x 0.5 m were established at the center of each main plot. In each sub plots destructive method was used to quantify the herbaceous biomass production. The harvested fresh herbaceous biomasses were weighted in each quadrats and sub sample from the fresh herbaceous biomass were oven dried at 65 ^{0}c for 24 hours and weighted again to determine the herbaceous biomass production.

The soil samples were taken from under canopy of *A.saligna* and 50 m away from the stand of *A.saligna* tree using an auger at fixed 0-20cm soil depth [13,14], and finally sub samples were pooled to obtain one composite soil sample. The soil samples were air-dried at room temperature of 19-21ºC, crushed, homogenized and passed through 2 mm sieve and subjected to analysis for soil texture, soil pH, soil organic carbon, available phosphorus, total nitrogen, available potassium, organic matter. The collected soil samples were analyzed in Tigray Agricultural Research Institute (TARI), Mekelle Soil Research.

2.3 Data Analysis

Shannon diversity, Margalef (Richness), Simpson (dominance) and Equitability (evenness) were calculated using Paleontological STatistics (PAST) software version 1.93.The assumption of normality data on species diversity and herbaceous biomass were checked using the Shapiro – Wilk test. The correlation between indigenous woody species diversity indexes and herbaceous biomass with some soil physico-chemical parameters, was tested using the matrix Pearson correlation methods using SPSS for windows version 20.

3. RESULTS AND DISCUSSION

3.1 Correlation between Some Soil Physicochemical Parameters and Woody Species Diversity Indexes

The species richness under the canopy of *A.saligna* was positively insignificant correlated with pH ($r = 0.48$, $p = 0.11$), Av.P ($r = 0.16$, $p = 0.63$),TN ($r = 0.12$, $p = 0.7$) and Silt ($r = 0.71$, $p = 0.009$).However, it is also negatively correlated with SOC (r = -0.06, p = 0.85), and sand (r = -0.77, p = 0.003, Table 1).Similarly, Shannon diversity indexes were insignificantly positively correlated with pH (r = 0.09, p = 0.78), SOC (r = 0.54, p = 0.07), and TN (r = 0.27, p = 0.39) ,but negatively insignificant correlated with sand (r = -0.24, p = 0.46, Table 1). The herbaceous biomass was insignificantly positively correlated with pH (r = 0.001, p = 0.99), SOC (r = 0.16, p = 0.63), TN (r = 0.29, p = 0.36) and Av.P (r = 0.34, p = 0.28), but negatively insignificant correlated with Av.K (r = -0.06, p = 0.88), silt (r = -0.04, p = 0.9) and clay (r = -0.04, p = 0.9) (Table 1).

Similarly, the Pearson's correlation matrix in the canopy gap of *A.saligna* showed that, Shannon diversity index is insignificantly positively correlated with SOC (r = 0.19, p = 0.53), Av.P (r = 0.46, p = 0.12), Av.K (r = 0.43, p = 0.16) and TN (r = 0.13, p = 0.69) (Table 1). However, species richness and Shannon diversity index have insignificantly negatively correlated with pH(r = -0.13, p = 0.68, r = -0.15, p = 0.63) and sand (r = -0.23, p = 0.51, r = -0.44, p = 0.14), respectively (Table 1).

In the canopy gap of *A.saligna,* the herbaceous biomass was positively correlated with Av.K (r = 0.47, p = 0.12), silt (r = 0.39, p = 0.20), and clay(r = 0.37, p = 0.24), but the Pearson's correlation matrix between herbaceous biomass and some soil parameters in the canopy gap is observed to be insignificantly negatively correlated with pH (r = -0.24, p = 0.44), SOC (r = -0.04, p = 0.9), Av.P (r = -0.34, p = 0.28), and TN (r = -0.33, p = 0.31) (Table 1).

In this study, woody species richness was found insignificant positive correlation with Av. K and silt in the canopy gap and under the canopy of *A.saligna.* Similarly, other studies showed that some positive kind of relationships between woody species richness and soil nutrient availability such as soil fertility index like,. Ca, P and K contents [15]. On the contrary, many researchers reported that species richness decreases at higher soil fertility [16]. That difference in pattern between woody species richness and some soil factors may be caused by the different type of species found at different agro ecology zones of the world. Additionaly, the canopy cover of *A.saligna* has no an effect on the correlation between species richness and some soil parameters like., With Av. K and silt.

Species richness was not correlated with total N under the canopy and in the canopy gap of *A.saligna*. This result in lines with [17] that tree species richness was not correlated to Mg, Fe, Cu, Zn, and Mn contents, C/N ratio, and total N. However, this is also in contrary with the findings of [18], who found that total N was highly positively related to tree species richness. This difference might be generated due to the difference annual rain fall available and the rainfall itself affects the availability of nutrient cycling.

The soil pH showed several insignificant positive correlations with species richness, Simpson, Shannon diversity index and herbaceous biomass under the canopy of *A.saligna.* The reason for the low correlation of woody species diversity and soil pH might be due to the negative effect of soil pH for the important nutrients. This result disagrees with [19], higher species diversity was observed at high pH value. However, the correlation of soil pH with species richness, Simpson, Shannon diversity index and herbaceous biomass in the canopy gap of *A.saligna* was observed negatively insignificant correlation. Similar result was reported by [20], that soil pH negatively affected the availability of essential nutrients like: N and P, which correlated negatively with the essential nutrients at high rainfall availability.

On this study, the Av.P was positively insignificant with species richness and diversity in the canopy gap and under the canopy of *A.saligna*. This might be due to the available of optimum soil nutrients for providing plant nutrition and their distribution. This is similarly reported by [21], highest number of species in grasslands was recorded below the optimum soil phosphorus level and at the optimum soil potassium level; beyond this optimum, species richness decreased.

3.2 Correlation between Some Woody Species Parameters and Herbaceous Biomass

In this study, the woody species density was negatively correlated with herbaceous biomass under the canopy (r = -0.63, p = 0.01) and in the canopy gap (r = -0.49, p = 0.04) (Table 2). However, Shannon diversity shows a positively significant correlation with herbaceous biomass under the canopy (r = 0.35, p = 0.02) and in the canopy gap (r = 0.36, p = 0.01) (Table 2). We observed no significant correlation between species richness and herbaceous biomass under the canopy (r = 0.25, p = 0.052) and in the canopy gap (r = 0.29, p = 0.053) (Table 2).

Table 1. Pearson's correlations between soil physicochemical parameters, woody diversity, and herbaceous biomass

	Under the canopy of *A.saligna*				In the canopy gap			
	Species Richness	**Simpson_D**	**Shannon**	**Herbaceous biomass**	**Species Richness**	**Simpson_D**	**Shannon**	**Herbaceous biomass**
pH	0.48	0.15	0.09	0.001	-0.13	-0.06	-0.15	-0.24
P_value	0.11	0.65	0.78	0.99	0.68	0.85	0.63	0.44
SOC	-0.06	0.42	0.54	0.16	0.18	0.10	0.19	-0.04
P_value	0.85	0.17	0.07	0.63	056	0.75	0.53	0.9
Av.P	0.16	0.48	-0.07	0.34	0.42	0.34	0.46	-0.34
P_value	0.63	0.11	0.83	0.28	0.17	0.27	0.12	0.28
Av.K	0.19	-0.35	0.18	-0.06	0.36	0.43	0.41	0.47
P_value	0.54	0.25	0.56	0.88	0.24	0.16	0.18	0.12
TN	0.12	0.47	0.27	0.29	0.04	0.28	0.13	-0.33
P_value	0.7	0.12	0.39	0.36	0.91	0.37	0.69	0.31
Sand	-0.77**	-0.35	-0.24	0.04	-0.23	-0.52	-0.44	-0.43
P_value	0.003	0.26	0.46	0.89	0.51	0.08	0.14	0.16
Silt	0.71**	0.52	0.20	-0.04	0.37	0.56	0.56	0.39
P_value	0.009	0.08	0.5	0.9	0.23	0.06	0.06	0.20
Clay	0.64*	0.03	0.21	-0.04	-0.12	0.28	0.12	0.37
P_value	0.02	0.9	0.51	0.9	0.72	0.36	0.70	0.24

*R: Pearson's coefficient of correlation; P: significance; *P<0.05*

Table 2. Correlation between some woody species parameters and herbaceous biomass quantities

Vegetation parameters under canopy	Correlation with herbaceous biomass	P_value	Vegetation parameters in the canopy gap	Correlation with herbaceous biomass	P_value
Density	-0.63*	0.01	Density	-0.49*	0.04
Shannon	0.35*	0.02	Shannon	0.36*	0.01
Richness	0.25	0.052	Richness	0.29	0.053

** shows that the significant value at (P< 0.05)*

The Pearson correlation matrix shown that, the density of woody species have a significant negatively relationship with herbaceous biomass quantities ($p<0.05$) and Shannon diversity index have also a positive significant relationship with herbaceous biomass under the canopy of *A.saligna* and in the canopy gap ($p<0.05$) (Table 2), whereas, herbaceous biomass and woody species richness had non-significant relation. Another research done by [22], indicates that, isolated individual trees had positive effects on herbaceous biomass, most likely trees could be enrich soil organic matter, but the effects of individual trees could explain the effects of increasing tree density for low biomass of herbaceous production, because the more woody species density leads to depressed of herbaceous biomass productivity. In the area where, trees are widely spaced, many inter-canopy areas are remained entirely unshaded by trees, whereas at high tree densities the shadows cast by individual trees may overlap ,so that grass/herbaceous species in most of the inter-canopy zone is shaded and have a negative relationship with tree densities [23]. Similarly, herbaceous species biomass might be affected by dense tree roots that extend beyond the canopy radius and deplete water or nutrients in the inter-canopy zone [24]. This study suggests that woody species density can progress markedly reduce the herbaceous biomass, because the more density plant community components was either severely reduced or completely absent of herbaceous species, such effect could become increasingly important at high tree densities. As a result the herbaceous biomass exhibits negatively relationship with the increasing woody species density due to low level of plant and herbaceous species interaction. Adding to the fact that, evapotranspiration is also another factor for increasing herbaceous biomass, and the moderate density of woody species could be contributed to reduce the amount of evapotranspiration that leads to increase the herbaceous biomass .Similar study conducted by [25,26], low tree density can also facilitate herbaceous biomass by reducing sub-canopy evapotranspiration.

The positive correlation between woody species diversity and herbaceous biomass under the canopy and in the canopy gap was due to the diverse plant community that exerts a prevailing influence on the herbaceous biomass quantities. The diverse plant community has diverse characteristics in increasing and/or decreasing in herbaceous biomass [27]. Even though, the correlation was very weak, the diverse plant community which provides to increases the herbaceous biomass production might have a better distribution. Consistent result had been reported by [28], which indicates that, the optimum conservation biodiversity provides high herbaceous biomass production. However, the insignificant correlation between woody species richness and herbaceous biomass suggests that, woody species richness at the initial establishment rate of herbaceous species couldn't be play a crucial role to be correlated more positively. It is also similarly suggested by [29], the direction for the total species richness and biomass were nearly perpendicular, indicating that species richness and biomass was not strongly linearly related. The reason for the productivity of woody species richness for maintaining optimal herbaceous biomass might be sustained by the climatic factor, which causes high inter annual variability of herbaceous biomass. Another study by [30,31], indicates that, in the unproductive areas, external factors such as moisture or other environmental factors are thought to be much more important than internal interactions between the relationship of species richness and herbaceous biomass. In addition to this, the important species in the sites might have in the process of succession.

4. CONCLUSION AND RECOMMENDATION

The results of this study provided with evidence that, the correlation made between species diversity and soil physico-chemical parameters under the canopy of *A.saligna* and in the canopy gap showed that diversity of indigenous woody species and herba ceous biomass was insignificantly negative correl ated with pH in the canopy gap, but for similar pa rameters were insignificant positively correlated with pH under the canopy of A.saligna. Generally, the insignificant positive correlation between Ph and diversity indexes under the canopy of A.saligna in the current study indicates that the presence of these large A.saligna trees might increase the availability of pH through litterfall and more number of nutrient-competent indigenous woody species are available. However, the connection between SOC,Av.K,Av.P and TN with diversity indices and herbaceous biomass in the canopy gap and under the canopy of *A. saligna*'s did not differ noticeably. The results indicated that there were no significant differences in these parameters between the two environments. This suggests that the presence of *A. saligna* does not markedly alter the soil nutrient dynamics, biodiversity, or herbaceous biomass.

The study revealed distinct correlations between plant density and Shannon diversity with herbaceous biomass in both the canopy gap and under the canopy of *Acacia saligna*. Specifically, herbaceous biomass exhibited a significant negative correlation with plant density in both environments, indicating that higher plant density tends to reduce herbaceous biomass. Conversely, Shannon diversity showed a significant positive correlation with herbaceous biomass, suggesting that greater species diversity is associated with increased herbaceous biomass. Thus, proper management and conservation of *A. saligna* and the woody species growing under the canopy is very crucial to maintain and enhance the positive correlations between diversity indexes and soil physico-cemical properties for the benefit of present and future generations.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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