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Systematic review and meta-analysis

Black (*Acacia mearnsii*) and silver wattle (*Acacia dealbata*) invasive tree species impact on soil physicochemical properties in South Africa: A systematic literature review

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ABSTRACT

Invasive alien plant species are a problem to global biodiversity, ecosystem dynamics, and human livelihood. The risks and potential effects of invasive alien species on local vegetation are growing, particularly the potential loss of ecological services. Thus, this study aimed to synthesise the impacts of acacia 'species' on soil physicochemical properties in South Africa. A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework for conducting a systematic review was followed. A total of 16 studies that met the study selection criteria were used. Data were extracted and evaluated by checking if any soil physicochemical parameters increased (+) or decreased (−) the impacts on invaded and cleared soils. The results showed increased quantities of soil organic carbon, total nitrogen, and gravimetric water content in invaded soil than in cleared soil. Acacia species generally positively improved the soil's physical and chemical properties during their invasion, and some minor changes may occur after their clearance, such as a decrease in cations. The results of this study only explain how acacias affect soil physical and chemical properties in three provinces; therefore, there need to be more studies from other provinces which could have further given insights into a particular region.

1. Introduction

Invasive alien plant species are considered hazardous to global biodiversity, ecosystem dynamics, and human livelihood [1]. The spread of these species has been gradual, encompassing all biomes globally [2], and is projected to persevere harshly in invaded ecosystems in the long run [3]. Invasive alien plants have hindered the advancement towards several United Nations' Sustainable Development Goals [4] because of the multifaceted and complex economic implications they perpetuate. In the United States, estimates show that management of invasive plants costs approximately US$27 billion annually [5]. In the United Kingdom the cost of invasive plants was estimated to be US$1.3 billion between 1976 and 2020 [6], while in France the cost was US$0.75 billion between 1993 and 2018 [7]. In Africa, invasive plant costs have been estimated to be US$38.01 billion between 1976 and 2020, with the largest costs observed in the Southern Africa region [8].

In South Africa, invasive alien plant species have had far-reaching detrimental implications. Around 552 invasive plant species have been identified, covering approximately 13% of South Africa's land area [9]. This equates to 10–20 million ha of land area,

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mostly in the country's grasslands and savanna ecosystems [3]. The cost of clearing invasive species is estimated at about R6.5 billion annually [10]. These plants outcompete native vegetation, resulting in biodiversity loss and environmental deterioration [11]. They exacerbate water scarcity difficulties, increase the likelihood and intensity of wildfires, and place economic constraints on agricultural and water management [12]. Furthermore, they endanger indigenous flora by contributing to genetic contamination and the extinction of distinctive genetic features [13]. Invasive plants also impact ecosystem services such as water quality, pollination, and soil nutrient cycles [10,14]. While attempts to battle these invaders are underway, continued, and sustained action is required to maintain South Africa's ecosystems and alleviate the varied repercussions of invasive alien plant species.

Wattle (*Acacias)*, is a prominent invasive species in South Africa [15]. These species have short generation period and typically attain reproductive maturity within 2–3 years of their growth cycle [16] thereby significantly speeding up their invasion success and ultimately outcompete indigenous plants. Wattles occupies an estimated 400 000 ha of land area in South Africa [3] and largely found in Eastern Cape, Kwa-Zulu Natal, Gauteng and Limpopo provinces [17]. Initially, 141 acacia species were introduced to the country, though about 33 are still present [18]. The tree species were historically introduced in the country about 150 years ago for use in tannins and timber production [19]. They were later on used as stabilising method for dunes in the country's coastal regions [20] and also currently used for poles, planks, firewood, and charcoal in village communities [18]. *Acacia mearnsii* and *Acacia dealbata* are among the top 10 and 25 invading species, respectively, occupying approximately 2.5 million hectares of South African land [19]. Much research has focused more on these species due to their wider spread, rapid invasion rates, and potential environmental damage [14]. Determining the effectiveness of restoration efforts, assessing soil recovery, assisting in the establishment of native plants, managing soil nutrients, preventing reinvasion, and promoting long-term ecosystem resilience all depend on an understanding of the characteristics of the soil before, during, and after the removal of invasive species [21–23]. Numerous researchers have studied the

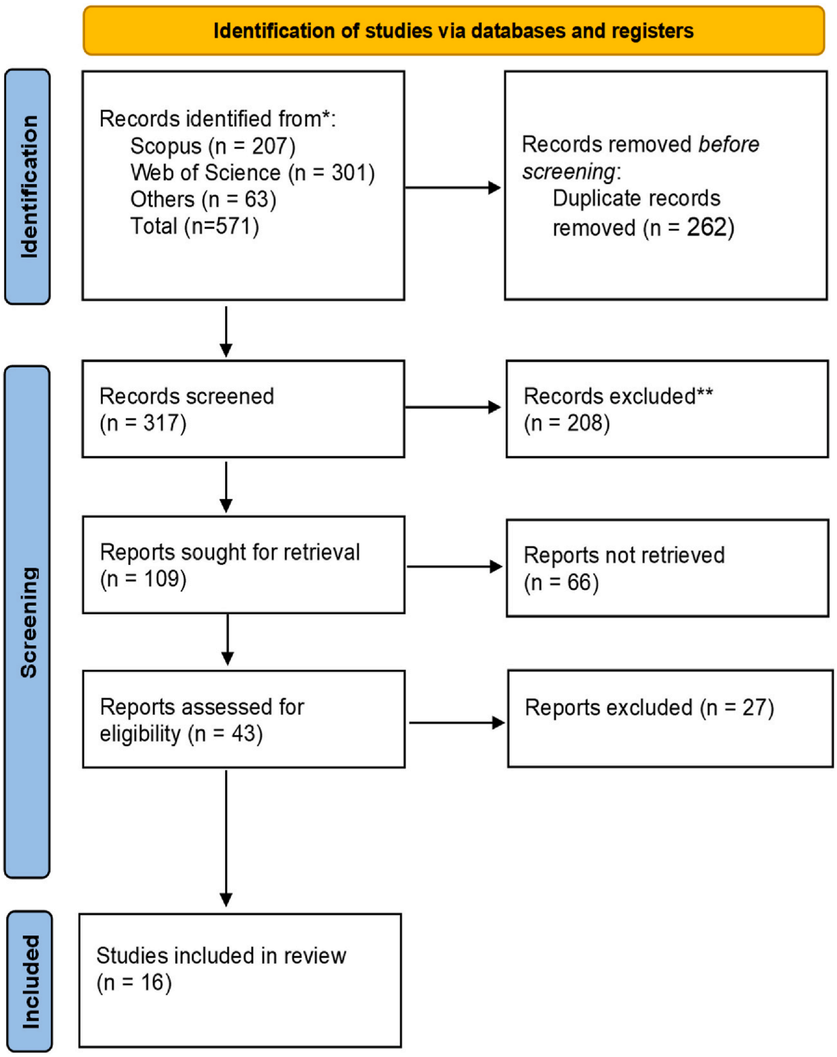

Fig. 1. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) [32] for impacts of wattle species on soil physical and chemical properties.

impact of wattle trees on the physicochemical characteristics of the soil [14,19,24–26]. Nevertheless, the outcomes differ, which makes formulating specific suggestions for crucial ecosystem restoration tactics challenging. Ruwanza [14] reported that soil pH was significantly higher in uninvaded (4.64) as compared to *Acacia mearnsii* invaded soils (4.05). Similarly, Balintulo [18] found significantly higher pH levels in uninvaded compared to both *Acacia dealbata* cleared and invaded soils in the Tsitsa catchment of the Eastern Cape. In contrast, a study by Fourie [27] in the Western Cape under clay soils showed no significant difference between the *Acacia mearnsii* invaded and uninvaded. Wiener et al. [28] reported that total nitrogen under loam soils was significantly lower in *Acacia mearnsii* cleared as compared to uninvaded soils around the Wit River system in the Western Cape. On the other hand, Fourie [27] observed no significant difference in total nitrogen in *Acacia mearnsii* invaded, cleared and uninvaded sandy soils in Cape Town.

A study by Oelofse et al. [29] carried out in Matatiele under clay loam soils reported no significant difference in bulk density between *Acacia mearnsii* under cleared and uninvaded sites. Similarly, Gwate et al. [26] reported no significant difference between *Acacia mearnsii* under invaded, cleared, and uninvaded soils with respect to bulk density. A study by Naudé [30] reported significantly higher bulk density in *Acacia mearnsii* under invaded compared to uninvaded soils. In siltstone soil in Limpopo, Acacia mearnsii cleared soils had significantly lower gravimetric water content compared to invaded and uninvaded sites under siltstone [11]. Similarly, results observed by Ndou and Ruwanza [24] under sandy soils in the Eastern Cape Province had a significant difference in gravimetric water content between *Acacia mearnsii* cleared and uninvaded. In contrast, no significant difference was reported in *Acacia dealbata* invaded, cleared and in uninvaded soils in Tsitsa Catchment in the Eastern Cape [18]. The inconsistency in the results could be due to soil and geographical area, the age of the wattle tree, and the number of years after clearing [24,29]. Therefore, investigating the effects of wattle trees of physicochemical properties is vital to understanding changes that occur at a local scale.

Various studies are available on the invasion of the black and silver wattle on their influence on the environment but the information on soil properties during and after wattle invasions is not well organized for the understanding of the invasion effects on soil physicochemical properties. The organization and consolidation of information can be achieved through a systematic review which provides a robust synthesis of available evidence. Systematic reviews have become instrumental in providing solid generalisations using other available studies in academic spaces due to the systematic nature of their methodology. Therefore, this study used the systematic review approach to synthesise the impact of black and silver wattle tree species on soil physicochemical quality in South Africa. We hypothesize that black and silver wattle tree species negatively affects soil physicochemical properties in South Africa.

2. Methods and materials

The methodology followed the systematic review framework [31] to search available articles and theses on the effects of black and silver wattle species invasion on soil physicochemical properties in South Africa. The search was undertaken on the electronic databases Scopus and Web of Sciences. In addition, other articles were searched on Google Scholar and randomly from other 'articles' reference lists. The search terms considered for this review used a combination of the following words; "black wattle" or "Acacia mearnsii" OR "silver wattle" OR "Acacia dealbata") AND "("soil physical properties" OR "bulk density" OR "penetration resistance" OR "moisture content" OR" porosity" OR "infiltration" OR "hydraulic conductivity") AND "("soil chemical properties" OR "nutrients" OR "soil organic carbon" OR "nitrogen" OR "phosphorus" OR "nitrates" OR "ammonium" OR "pH" OR "electrical conductivity") AND "("South Africa").

The article selection framework adhered to the PRISMA flow diagram (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Fig. 1). The following inclusion criteria were used for guidance in our article selection.

I. Studies should consist of at least one of the two Acacias (black and silver wattle) species being looked at in this study and should have been conducted in South Africa. Both experimental (e.g., enclosure or controlled) and observational (e.g., time-series data, geographical comparisons) study types were included.
II. Studies should consist of uninvaded as the control or invaded or cleared as their treatments.
III. Studies should have assessed at least one variable of soil physicochemical properties.
IV. Studies should have been written in English only.

Each of the returned article was screened by three reviewers searching for the above-mentioned keywords in either the title or the abstract. Articles that adequately addressed the impact of wattle invasion on soil physicochemical properties was, or any aspect thereof, the paper was retained for the review sample. The information required, was extracted into an Excel file. In every article, we recorded the types of the species under evaluation, the year of publication province and location of the study, landscape, climate, environment (biomes), and type of soil. In cases where periodical data was collected at the in same sampling point in one article, only the last data collected was considered. If in a single article data was collected from different sites; the sites were considered as independent, therefore data was extracted per site. There are also results which data was collected under several depth of soil, only the first depth was considered more specifically 0–10 cm. The results were computed to see if the soil properties were high or lower under invaded or cleared soils in comparison to the non-invaded (control). Thus, if any soil property was high or low than the control, it was represented by + or – sign respectively.

The initial search on Scopus, Web of Science and Others, yielded 207, 301 and 63 articles respectively (Fig. 1). Following the screening process, only 16 articles met the inclusion criteria of the study and were included in the assessment. Articles excluded were largely review and survey studies, studies which looked on other Acacias besides black and silver wattle, studies outside of South Africa and studies which mainly looked on how these invasive species influence productivity of native plants in the region of study. A map showing the locations of experimental sites of the studies included in the systematic review was created using Google Maps (Fig. 2).

In as much as this study seeks to cover all provinces in South Africa, studies on the effects of black and silver wattle species on soil physicochemical properties were mainly found in Eastern Cape (90%), Western Cape provinces (9%) and Limpopo province (%1). This partially fulfill our understanding of how these acacia species influence soil physicochemical properties since wattle invasion is mostly widespread in six provinces of the country, which are Gauteng, Mpumalanga, Eastern Cape, Western Cape, KwaZulu Natal, and Free State [33]. However, the unavailability of other studies may not necessarily portray the absence of studies in other provinces, but they may have unsuccessfully met the criteria guiding this study. Thus, further studies are required in other provinces, specifically on soil physicochemical properties as influenced by acacia species.

3. Results and discussion

3.1. The effects of wattle species on soil chemical properties

The results showed that only 16 studies reported the effects of wattle invasion and clearing on soil pH, and 10 of these showed non-significant effects (Table 1). The studies that showed significant effects reported low pH in invaded and cleared soils compared to the non-invaded (Table 1). The lack of significant responses may be caused by the high pH buffering capacity of the soils because the studies reporting no significant effects had high organic carbon and high CEC [24,27]. Soil pH, which indicates acidity plays a role in various soil ecosystem functions, such as the availability and solubility of phosphate ions and cations (NH_4^+, K^+, Ca^{2+}) [30,34] and microbial abundance and activity [35]. The low pH in both invaded and cleared soils could possibly be due to increased rates of nutrient leaching induced by acacia species due to increased water infiltration, which is also accelerated in poor nutrient retention soils such as sandy soils [26]. In addition, litter decomposition and fixed nitrogen nitrification could contribute soil acidification [36]. Also, the increase in H^+ ions further explains the decline in pH since they are negatively correlated [18]. Since the cleared soils still had significantly low pH, it indicates that even after acacia species were cleared, soil pH remained low; thus, soils need to be corrected, which may not be immediately available under natural conditions.

In this study, we identified seven datasets, four on invaded and three on cleared, and in both cases, higher soil electrical conductivity was reported (Table 1). However, only one study reported significant effects of wattle invasion and clearing on EC. This could be explained by the time of soil sampling. Naudé [30] observed higher EC in summer compared to winter most likely caused by high evaporation during summer.

Soil carbon dynamics consists of carbon pools in the soil which play a part in carbon exchange and mineralisation, carbon sequestration, climate change, and energy provision to soil microorganisms [18,27,35]. Overall, acacias alter the carbon pools and

Fig. 2. Map showing the locations of experimental sites of the studies included in the systematic review.

Table 1
Results showing the effects of wattle species on soil chemical properties under invaded and cleared regions in South Africa.

Reference	Ecosystem	Soils	Wattle	Invaded	Cleared
Ruwanza, 2017	Thornveld	sandy loam	Black	pH(−)*, P Bray II(−)*, TC(+)*, TN(−)ns, NO3–N(−)ns, NH4–N(+)ns, K(+)ns, Na(+)ns, Ca(+)ns, Mg(+)ns	
Balintulo 2021			Silver	pH(−)*, P Bray II(−)ns, TC(+)ns, TN(+)ns, K(+)ns, Na (−)ns, Ca(−)ns, Mg(−)ns	pH(−)*, P Bray II(+)ns, TC(+)ns, TN(−)ns, K(+)ns, Na(−)ns, Ca(−)ns, Mg(+)ns
De Neergaard et al. 2005		loam clay	Black	Mineral N(−)ns, Olsen P(+)*	Mineral N(−)ns, Olsen P(+)*
De Neergaard et al. 2005		loam clay	Silver	Mineral N(−)ns, Olsen P(+)ns	Mineral N(−)ns, Olsen P(+)*
Gwate et al. 2021	Grassland	sandy	Black	pH(−), P(+), K(−), Ca(−), Mg(+), CEC(+), Zn(−), TN (+)	pH(−), P(+), K(+), Ca(+), Mg(−), CEC(+), Acidity(+), Zn(−), TN(+)
Gwate et al. 2021	Grassland	sandy	Black	pH(−), P(+), K(+), Ca(−), Mg(−), CEC(+), Zn(−), TN (−)	pH(−), P(+), K(+), Ca(−), Mg(−), CEC(+), Acidity(+), Zn(−), TN(−)
Gwate et al. 2021	Grassland	sandy	Black	pH(+), P(+), K(+), Ca(+), Mg(+), CEC(−), Zn(+), TN (+)	pH(+), P(−), K(−), Ca(+), Mg(−), CEC(−), Acidity(−), Zn(+), TN(+)
Gwate et al. 2021	Grassland	sandy	Black	pH(−), P(+), K(−), Ca(+), Mg(−), CEC(+), Zn(+), TN (+)	pH(−), P(+), K(+), Ca(+), Mg(−), CEC(+), Acidity(+), Zn(−), TN(+)
Moyo 2010	Sourveld	sandy	Black	EC(−)ns, pH(−)*, SOC(+)*, TN(+)*	
Ndou and Ruwanza 2016	Bushveld	sandy	Black		pH(−)ns, P Bray II(−)ns, TC(−)ns, TN(−) ns, K(−)ns, Na(−)ns, Ca(−)ns, Mg(−)*
Ndou and Ruwanza 2016	Bushveld	sandy	Black		pH(−)ns, P Bray II(−)*, TC(−)ns, TN(−)*, K(−)*, Na(−)*, Ca(−)*, Mg(−)*
Ndou and Ruwanza 2016	Bushveld	sandy	Black		pH(−)ns, P Bray II(−)*, TC(−)*, TN(−)*, K (+)*, Na(−)*, Ca(−)*, Mg(−)*
Railoun et al. 2021	Fynbos		Black	TN(+)*, P(+)*	
van der Waal 2009	Fynbos	sandy loam	Black	pH(−)*, TN(+)*, P(+)ns, K(+)*, C(+)ns, Cu(+)ns, Zn (−)ns, Mn(+)*, B(+)ns, CEC(+)ns, Na(+)*, Ca(−)ns, Mg(−)ns	
van der Waal 2009	Fynbos	sandy loam	Black		pH(−)*, TN(+)*, P(+)*, K(+)*, C(+)*, Cu(+)ns, Zn (−)ns, Mn(+)*, B(+)ns, CEC(+)ns, Na(+)ns, Ca(+) ns, Mg(−)ns
van der Waal 2009	Fynbos	sandy loam	Black		pH(−)*, TN(+)ns, P(+)ns, K(−)ns, C(+)ns, Cu(−)*, Zn(−)*, Mn(+)*, B(−)ns, CEC(−)*, Na(−)*, Ca(−)*, Mg(−)*
van der Waal 2009	Fynbos	sandy loam	Black		pH(−)ns, TN(+)*, P(+)*, K(+)ns, C(+)ns, Cu(−)ns, Zn(+)*, Mn(+)*, B(+)*, CEC(+)*, Na(+)ns, Ca(+)*, Mg(+)ns
Wiener et al. 2020	Fynbos	sandy loam	Black	TC(+)ns, TN(+)ns, C:N(+)ns, TP(+)ns	TC(+)ns, TN(+)ns, C:N(−)ns, TP(+)*
Wiener et al. 2020	Fynbos	sandy loam	Black	TC(+)ns, TN(+)ns, C:N(−)ns, TP(+)ns	TC(+)*, TN(+)*, C:N(−)ns, TP(+)ns
Yapi et al. 2018	Grassland	clay	Black	pH(−)*, P(+)*, TN(+)*,C(+)*, Na(−)*, CEC(+)ns	pH(−)ns, P(+)*, TN(+)ns,C(+)*, Na(−)*,CEC(+)ns
Fourie 2014	Fynbos	sandy	Black	pH(+), EC(+), Nmin(−), C:N(−), NH4–N(+), NO3–N (+), TN(+), TC(+)	pH(+), EC(+), Nmin(−), C:N(−), NH4–N(+), NO3–N(+), TN(+), TC(+)3
Naudé 2012	Fynbos	sandy	Black	EC(+)*, P Bray II(+)ns, TC(+)ns, TN(+)*, C:N(−)ns	EC(+)*, P Bray II(−)ns, TC(−)ns, TN(−)ns, C:N(−)ns
Jacobs et al. 2013	Fynbos		Black	pH(+)ns, EC(+)ns	pH(+)ns, EC(−)ns
Pietersen 2009	Fynbos		Black	OC(−)	
Pietersen 2010	Fynbos		Black	OC(−)	
Pietersen 2009	Fynbos		Black	OC(+)	
Pietersen 2010	Fynbos		Black	OC(+)	
Oelofse et al. 2016	Grassland	clay loams	black	TC(+)	
Oelofse et al. 2016	Grassland	clay loams	black	TC(+)	
Oelofse et al. 2016	Grassland	clay loams	black	TC(+)	
Oelofse et al. 2016	Grassland	clay loams	black	TC(−)	
Oelofse et al. 2016	Grassland	clay loams	black	TC(+)	
Oelofse et al. 2016	Grassland	clay loams	black	TC(+)	

EC: Electrical Conductivity, N: Nitrogen, C: Carbon, P: Phosphorus, K: Potassium, Na: Sodium, Ca: Calcium, Mg: Magnesium, B: Boron, Mn: Manganese, Cu: Copper, Zn: Zinc, Na: Sodium, CEC: Cation Exchange Capacity, TC: Total Carbon, TN: Total Nitrogen, TP: Total Phosphorus, NO3–N: nitrate-nitrogen, NH4–N: Ammonium-nitrogen, Nmin: Nitrogen Mineralisation. The positive (+) and negative (−) signs depicts if the soil properties increased or decreased respectively from the control. The "*" represents if there was significant difference between the control and the cleared soil on the parameter, while "ns" represents if there was no significant difference between the control and the cleared soil on the parameter from the extracted article.

cycling primarily due to changes in soil organic matter content [35]. We identified 31 datasets on soil organic carbon, 19 on invaded and 12 on cleared, and seven datasets reported significant responses to wattle invasion and clearing (Table 1). Studies with non-significant responses had soils with soil organic carbon exceeding 2%. Results with significant responses from the reviewed articles showed generally higher carbon pools in invaded compared to cleared soil and uninvaded soils. Acacias tend to shed large quantities of leaves, such that when leaves fall from the trees together with the root turnover, they deposit vast quantities of biomass, which causes high decomposition of soil organic matter, thus increasing carbon pools [14,18,29]. After clearing, the low total carbon is expected because of a lack of organic matter inputs or the low input from the recovering vegetation. In cleared sites, especially recently cleared, the soil is left bare, exposing it to direct sun and high temperatures, which stimulates rapid litter decomposition and, thus loss of soil carbon [24,37]. Water and wind erosion may also increase the loss when soil is left bare.

Soil nitrogen pools are critical for soil nutrition due to the significance of nitrogen in plant nutrients, while they are subjected to heavy environmental losses. This study recorded diverse nitrogen pools, total nitrogen ammonium-nitrogen, nitrate-nitrogen, Mineral nitrogen, and nitrogen cycling. Results on soil nitrogen dynamics were heterogeneous. There was a total of 31 dataset reporting on total nitrogen and 20 of these reported non-significant effects while the other 11 showed significant effects. Six of the studies with significant effect were on invaded soils and the total nitrogen was higher in invaded soils compared to uninvaded. The other five studies on cleared soils where three reported increased total nitrogen while the other two showed a decrease (Table 1). Mineral nitrogen was low in both invaded and cleared soils. There is a strong indication that acacias increase nitrogen. The high nitrogen in the soil after acacia invasion is an expectation that is directly a result of acacias as nitrogen-fixing leguminous plants [19,20,38,39]. However, the non-significant responses may be due to various factors such as the acacia type, soil type and initial nitrogen content, climate, and type of ecosystem [25]. For instance, sandy soils with relatively low organic matter may tend to leach more nitrogen than soils with high organic matter, while regions nearer to riverbanks may be exposed to nitrogen erosion than terrestrial upland [27,30]. Also, acacias may have high polyphenols concentration which may reduce nitrogen decomposition from litter debris [40]. The decrease in total nitrogen in cleared soils observed in this study signifies a decline in nitrogen-fixing activities, litter availability, and mineralisation rate, and probably denitrification due to the removal of acacia trees [18]. Usually, nothing grows under acacia trees; therefore, after the clearing of wattle, the soil is left bare, which may result in water logging after heavy rains.

The results showed that available phosphorous was higher in invaded and cleared soils than uninvaded soils [17,19,25]. While

Table 2
Results showing the effects of wattle species on soil physical properties under invaded and cleared regions in S.A.

Ref	Ecosystem	Soils	Wattle	Invaded	Cleared
Ruwanza and Tshililo, 2019	Bushveld	siltstones	black	GWC(+)ns, PR(+)ns, I_C (−)*, K_S (−)ns	GWC (−)*, PR (+)*, I_C (+)ns, K_S (+)ns
Ruwanza, 2017	Thornveld	sandy loam	black	GWC(+)ns, PR(+)*, I_C (−)*, K_S (−)ns, SR (−)ns	
Balintulo 2021			silver	GWC(+)ns, PR(−)ns, I_C (−)*, K_S (+)ns, SR (−)*	GWC(+)ns, PR(+)ns, I_C (+)*, K_S (+)ns, SR (−)*
Gwate et al. 2021	Grassland	sandy	black	BD(−)	BD(−)
Gwate et al. 2021	Grassland	sandy	black	BD(−)	BD(−)
Gwate et al. 2021	Grassland	sandy	black	BD(−)	BD(−)
Gwate et al. 2021	Grassland	sandy	black	BD(+)	BD(−)
Moyo 2011	Sourveld	Sandy	black	S(+)ns	
Ndou and Ruwanza 2016	Bushveld	Sandy	black		GWC(−)ns
Ndou and Ruwanza 2016	Bushveld	Sandy	black		GWC(−)*
Ndou and Ruwanza 2016	Bushveld	Sandy	black		GWC(−)*
Oelofse et al. 2016	Grassland	clay loams	black		BD(−)
Oelofse et al. 2016	Grassland	clay loams	black		BD(−)
Oelofse et al. 2016	Grassland	clay loams	black		BD(−)
Oelofse et al. 2016	Grassland	clay loams	black		BD(−)
Oelofse et al. 2016	Grassland	clay loams	black		BD(−)
Oelofse et al. 2016	Grassland	clay loams	black		BD(−)
van der Waal 2009	Fynbos	sandy loam	black	PR(−), SR(+)	
van der Waal 2009	Fynbos	sandy loam	black		PR(−), SR (+)
van der Waal 2009	Fynbos	sandy loam	black		PR(−), SR (+)
van der Waal 2009	Fynbos	sandy loam	black		PR(−), SR (+)
Yapi et al. 2018	Grassland	Clay	black	I_C (−)*, GWC(−)	I_C (+)*, GWC(+)ns
Fourie 2014	Fynbos	Sandy	black	GWC(−), BD(+)	GWC(−), BD(+)
Kambol 2013	Fynbos	Sandy	black	GWC(−), BD(+)	GWC(−), BD(−)
Naudé 2012	Fynbos	Sandy	black	BD(−)*	BD(+)ns

GWC: Gravimetric Water Content, PR: Penetration Resistance, I_C: Cumulative Infiltration, K_S: Saturated Hydraulic Conductivity, IS: Aggregate Stability, BD: Bulk Density, SR: Soil Repellency. The positive (+) and negative (−) signs depict if the soil properties increased or decreased respectively from the control. The "*" represents if there was a significant difference between the control and the cleared soil on the parameter, while "ns" represents that there was no significant difference between the control and the cleared soil on the parameter from the extracted article.

studies by Balintulo [18] and Ruwanza [14] had low available phosphorous in invaded soil as compared to uninvaded soils. Total phosphorous was higher in invaded and cleared soils than uninvaded soils [26]. Similarly, nitrogen and phosphorous increase can be explained by the large leaf litter generation in acacia trees, which decomposes and releases soil phosphorous [37]. Acacias, in the long run, can develop ways where they form root clusters to help them with phosphorus acquisition even in regions where they are insignificantly available, for instance highly weathered soils, making them competent like plants that have mycorrhizal symbioses [25]. In addition, considering that wattles have an extensive root system, their lateral roots can penetrate deeper soil layers to acquire more phosphorus [41]. However, the influence of pH on soil phosphorus is well known [42–44], in which low pH decreases phosphorous availability in the soil. Though in this study, we observed that acacias reduce soil pH, which is supposed to reduce soil phosphorous, was not the case [14,18] and may indicate that in acacia invasion soil pH may not be the primary factor influencing soil phosphorous.

Soil K was generally higher on both invaded and cleared soils than uninvaded soil [18,26]. This was similar to cation exchange capacity, whereas Calcium and Magnesium were high on invaded soils and generally low on cleared soils. The increase in these soil nutrients on invaded soils indicates a general litter mineralisation activity while the acacia species are still available [18]. The low Calcium and Magnesium on cleared soils signifies the reduced mineralisation activity due to vegetation cover as well as limited mineralisation and microbial activities [24]. Since increased decomposition activity raises soil organic matter content, the soil will have a strong ability to attract positive cations, increasing soil cation exchange capacity. This may also differ with soil type; for instance, cation exchange capacity tends to be higher in clay than in sandy soils [26]. The results were heterogeneous, possibly due to few data points available, making it difficult to give a concrete decision; therefore, studies need, studies need to focus more on micronutrients. Zinc was generally low on both invaded and cleared soils, whereas sodium had equally high and low values on invaded soils. Boron, Mangense, and Copper concentrations were high under invaded soils [37]. Studies also reported high Magnanese in cleared soils but with low Boron and Copper. Similar, to the explanations of other nutrients above, micronutrients increased in invaded soils due to the increasing mineralisation activity of acacia leaf litter, and when the acacias are cleared the activity is reduced and thus decrease in micronutrients [26].

3.2. *The effects of wattle species on soil physical properties*

The gravimetric water content, cumulative infiltration and saturated hydraulic conductivity are critical hydraulic soil parameters crucial is determining moisture availability and movement in the soil and affects nutrient fluxes [30]. The gravimetric water content was generally higher on invaded and low on cleared soils relative to the uninvaded, while both cumulative infiltration and saturated hydraulic conductivity were low on invaded and higher in cleared soils compared to the control (Table 2). The increase in moisture content on invaded soils is due to the availability of acacia trees that avoid direct sun heating, hence less evaporation [11]. The moisture content in cleared areas is expected to decrease as the soil is bare. The decrease in cumulative infiltration might arise from the 'acacia's leaves with hydrophobic substances which induces hydrophobicity and favours soil compaction, leading to a decrease in water infiltration and hydraulic conductivity [14].

The bulk density and penetration resistance are soil parameters associated with soil compaction and their increase is unfavourable to agriculture, while aggregate stability is associated with improving soil strength. The results showed that bulk density was generally lower on invaded and cleared soils than uninvaded soils [26]. Penetrative resistance lower [18] while aggregate stability was higher in invaded soils compared to uninvaded soils [12]. The lower bulk density on invaded and cleared soils can be attributed to the high volume of leaf litter from the trees, which generates organic matter due to mineralisation and loosens the soil, thus reducing soil compaction [12]. This may similarly relate to the decrease in penetration resistance on invaded soils, but on cleared soils, the penetration resistance decreases, which may be due to an increase in compaction with machinery during the clearance. Also, the organic matter from leaf mineralisation and roots may enhance soil binding, improving aggregate stability.

4. Conclusion

The current study aimed to systematically review the available literature on the acacia species (black and silver) affects soil chemical and physical properties in South Africa. Results on soil chemical properties showed that acacia invasion increased the concentration of electrical conductivity, soil organic carbon, total nitrogen, ammonium-nitrate, nitrate nitrogen, phosphorous, potassium, cation exchange capacity, Calcium, Magnesium, Boron, Manganese, and Copper become high, while pH, min nitrogen, and Zinc was reduced. High concentrations of electrical conductivity, total nitrogen, ammonium-nitrate, nitrate-nitrogen, phosphorous, potassium, cation exchange capacity, and Boron are also found in cleared compared to uninvaded soils. Gravimetric water content and aggregate stability are high under acacia invasion, while cumulative infiltration, saturated hydraulic conductivity, bulk density, and penetration resistance are low. When acacias are cleared, cumulative infiltration, saturated hydraulic conductivity, penetration resistance, and aggregate stability remain high, whereas gravimetric water content and bulk density remain low. Generally, these results revealed that acacias improve soil properties. Still, improving these properties is particularly beneficial to the sustenance of these acacias, which becomes a problem for their control because the environment will continuously favour their productivity. This study is based on the Eastern Cape, Western Cape, and Limpopo Province. Though the results of this study may explain the associated dynamics on how acacias affect soil physical and chemical properties, there was a lack of studies from other provinces which could have further given insights per a particular region. This requires more research to be done in these provinces. This systematic review identified a lack of studies on how acacias influence soil chemical and physical properties in other Provinces.

CRediT authorship contribution statement

Zenande Lusizi: Writing – original draft, Methodology, Data curation, Conceptualization. **Hamond Motsi:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Patrick Nyambo:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Dimpho Elvis Elephant:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization.

Declaration of competing interest

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References

[1] R.T. Shackleton, C.M. Shackleton, C.A. Kull, The role of invasive alien species in shaping local livelihoods and human well-being: a review, J. Environ. Manag. 229 (2019) 145–157.
[2] R. Gulzar, S.A. Wani, T. Hassan, C.S. Reddy, B.B. Shrestha, S.A. Mukul, A. Shabbir, I.M. Iqbal, S.M.W. Ranwala, Dorjee, P. Sujanapal, I. Rashid, A.A. Khuroo, Looking beyond the political boundaries: an integrated inventory of invasive alien flora of South Asia, Biol. Invasions (2023) 1–22.
[3] W. Stafford, C. Birch, H. Etter, R. Blanchard, S. Mudavanhu, P. Angelstam, J. Blignaut, L. Ferreira, C. Marais, The economics of landscape restoration: benefits of controlling bush encroachment and invasive plant species in South Africa and Namibia, Ecosyst. Serv. (2017) 1–10.
[4] E.J. Hudgins, R.N. Cuthbert, P.J. Haubrock, N.G. Taylor, M. Kourantidou, D. Nguyen, A. Bang, A.J. Turbelin, D. Moodley, E. Briski, S.G. Kotronaki, F. Courchamp, Unevenly distributed biological invasion costs among origin and recipient regions, Nat. Sustain. (2023) 1–12.
[5] D. Hiatt, K. Serbesoff-King, D. Lieurance, D.R. Gordon, S.L. Flory, Allocation of invasive plant management expenditures for conservation: lessons from Florida, USA, Conserv. Sci. Pract. 1 (2019) 1–10.
[6] R.N. Cuthbert, A.C. Bartlett, A.J. Turbelin, P.J. Haubrock, C. Diagne, Z. Pattison, F. Courchamp, J.A. Catford, Economic costs of biological invasions in the United Kingdom, NeoBiota 67 (2021) 299–328.
[7] D. Renault, E. Manfrini, B. Leroy, C. Diagne, L. Ballesteros-mejia, E. Angulo, F. Courchamp, Biological invasions in France : alarming costs and even more alarming knowledge gaps, NeoBiota 67 (224) (2021) 191–224.
[8] C. Diagne, A.J. Turbelin, D. Moodley, A. Novoa, B. Leroy, E. Angulo, T. Adamjy, C.A.K.M. Dia, A. Taheri, J. Tambo, G. Dobigny, F. Courchamp, The economic costs of biological invasions in Africa : a growing but neglected threat? NeoBiota 67 (2021) 11–51.
[9] K. Brewer, R. Lottering, K. Peerbhay, Remote sensing of invasive alien wattle using image texture ratios in the low-lying Midlands of KwaZulu-Natal, South Africa, Remote Sens. Appl.: Soc. Environ. 26 (2022) 100769.
[10] J. Chamier, K. Schachtschneider, D.C. le Maitre, P.J. Ashton, B.W. van Wilgen, Impacts of invasive alien plants on water quality, with particular emphasis on South Africa, WaterSA 38 (2012) 345–356.
[11] S. Ruwanza, K. Tshililo, Short term soil and vegetation recovery after Acacia Mearnsii removal in vhembe biosphere reserve, South Africa, Appl. Ecol. Environ. Res. 17 (2019) 1705–1716.
[12] H.P.M. Moyo, Effects of Removing Acacia Mearnsii on the Water Table, Soil and Vegetation Properties in the Tsomo Valley of the Eastern Cape Province, South Africa, University of Fort Hare, 2010. Available from: https://go.exlibris.link/PpYMJlw3.
[13] L. Lazzaro, C. Giuliani, A. Fabiani, A.E. Agnelli, R. Pastorelli, A. Lagomarsino, R. Benesperi, R. Calamassi, B. Foggi, Soil and plant changing after invasion: the case of Acacia dealbata in a Mediterranean ecosystem, Sci. Total Environ. 497–498 (2014) 491–498.
[14] S. Ruwanza, Invasion of abandoned agricultural fields by Acacia mearnsii affect soil properties in eastern Cape , South Africa, Appl. Ecol. Environ. Res. 15 (2017) 127–139.
[15] O. Gwate, S.K. Mantel, A. Finca, L.A. Gibson, Z. Munch, A.R. Palmer, Exploring the invasion of rangelands by Acacia mearnsii (black wattle): biophysical characteristics and management implications, Afr. J. Range Forage Sci. 33 (2016) 265–273.
[16] S. Vicente, C. Máguas, D.M. Richardson, H. Trindade, J.R.U. Wilson, J.J. Le Roux, Highly diverse and highly successful: invasive Australian acacias have not experienced genetic bottlenecks globally, Ann. Bot. 128 (2021) 149–157.
[17] T.S. Yapi, An Assessment of the Impacts of Invasive Australian Wattle Species on Grazing Provision and Livestock Production in South Africa, Stellenbosch: Stellenbosch University, 2013. Available from, https://scholar.sun.ac.za/handle/10019.1/95455.
[18] P. Balintulo, Soil and Vegetation Recovery Following Acacia Dealbata Clearing in the Tsitsa Catchment, Eastern Cape Province of South Africa : Implications for Ecological Restoration, Rhodes University, Grahamstown, South Africa, 2021. Available from: https://commons.ru.ac.za/vital/access/services/Download/vital:56783/SOURCE1.
[19] A. De Neergaard, C. Saarnak, T. Hill, M. Khanyile, A.M. Berzosa, T. Birch-Thomsen, Australian wattle species in the Drakensberg region of South Africa - an invasive alien or a natural resource? Agric. Syst. 85 (2005) 216–233.
[20] T.G. O'Connor, B.W. van Wilgen, The impact of invasive alien plants on rangelands in South Africa, in: J Richardson vanWilgen BW Measey, J.R. DM Wilson, T. A. Zengeya (Eds.), Biol. Invasions South Africa, vol. 14, Springer International Publishing, Cham, 2020, pp. 459–487.
[21] E. Marchante, A. Kjøller, S. Struwe, H. Freitas, Soil recovery after removal of the N2-fixing invasive Acacia longifolia: consequences for ecosystem restoration, Biol. Invasions 11 (2009) 813–823.
[22] H. Hirsch, M.L. Castillo, F.A.C. Impson, C. Kleinjan, D.M. Richardson, J.J. Le Roux, Ghosts from the past: even comprehensive sampling of the native range may not be enough to unravel the introduction history of invasive species—the case of Acacia dealbata invasions in South Africa, Am. J. Bot. 106 (2019) 352–362.

[23] M.A. Maoela, K.J. Esler, S.M. Jacobs, F. Roets, Invasive plant removal increases insect herbivory pressure on a native tree due to an increase in resource quality, Plant Ecol. 220 (2019) 649–661.

[24] E. Ndou, S. Ruwanza, Soil and vegetation recovery following alien tree clearing in the Eastern Cape Province of South Africa, Afr. J. Ecol. 54 (2016) 460–470.

[25] M.Z. Railoun, J.P. Simaika, S.M. Jacobs, Leaf litter production and litter nutrient dynamics of invasive Acacia mearnsii and native tree species in riparian forests of the Fynbos biome, South Africa, For. Ecol. Manag. 498 (2021) 10.

[26] O. Gwate, S.K. Mantel, L.A. Gibson, Z. Munch, B. Gusha, A.R. Palmer, The effects of Acacia mearnsii (black wattle) on soil chemistry and grass biomass production in a South African semi-arid rangeland: implications for rangeland rehabilitation, Afr. J. Range Forage Sci. 38 (2021) 270–280.

[27] M. Fourie, Investigating soil nitrogen dynamics in natural , invaded and cleared fynbos riparian ecotones and implications for riparian functioning, Available from, https://scholar.sun.ac.za/server/api/core/bitstreams/4e7c0830-7cc1-4e05-ba68-b5646ce8152b/content, 2014.

[28] K. Wiener, J. Simaika, S.E. Grenfell, S. Jacobs, Effects of invasive N2- fixing Acacia mearnsii on sediment nutrient concentrations in mountain streams: implications of sediment geochemistry for ecosystem recovery, Catena 195 (2020) 104786. Contents.

[29] M. Oelofse, T. Birch-Thomsen, J. Magid, A. de Neergaard, R. van Deventer, S. Bruun, T. Hill, The impact of black wattle encroachment of indigenous grasslands on soil carbon, Eastern Cape, South Africa, Biol. Invasions 18 (2016) 445–456.

[30] M. Naudé, Fynbos Riparian Biogeochemistry and Invasive by Australian Acacias, Stellenbosch University, 2012. Avaiable from, https://scholar.sun.ac.za/items/64700da7-8d18-4510-bcff-f74a11682c9d.

[31] H. Cooper, Research Synthesis and Meta-Analysis, second ed., Sage, Thousand Oaks, CA, 2010.

[32] D. Moher, A. Liberati, J. Tetzlaff, D.G. Altman, Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement, J. Clin. Epidemiol. 62 (2009) 1006–1012.

[33] Southern African Plant Invaders Atlas, Sapia News, 2012. Available at: http://www.arc.agric.za/arc-ppri/Pages/Newsletters.aspx.

[34] M.G. Hagos, G.N. Smit, Soil enrichment by Acacia mellifera subsp. detinens on nutrient poor sandy soil in a semi-arid southern African savanna, J. Arid Environ. 61 (2005) 47–59.

[35] O.K. Kambol, In Situ and Ex Situ Soil Respiration in Natural , Acacia -invaded and Cleared Riparian Ecotones in the Fynbos Biome, University of Stellenbosch, 2013. Available from: https://scholar.sun.ac.za/handle/10019.1/79854?show=full.

[36] L.S. Koutika, D. Epron, J.P. Bouillet, L. Mareschal, Changes in N and C concentrations, soil acidity and P availability in tropical mixed acacia and eucalypt plantations on a nutrient-poor sandy soil, Plant Soil 379 (2014) 205–216.

[37] B.W. van der Waal, The Influence of Acacia Mearnsii Invasion on Soil Properties in the Kouga Mountains, Eastern Cape, South Africa, Rhodes University, Grahamstown, South Africa, 2009. Avaiable from, https://commons.ru.ac.za/vital/access/manager/Repository?exact=sm_creator:%22Van+der+Waal%2C+Benjamin+Wentsel%22&sort=sort_ss_title%2F.

[38] D.C. Le Maitre, B.W. Van Wilgen, C.M. Gelderblom, C. Bailey, R.A. Chapman, J.A. Nel, Invasive alien trees and water resources in South Africa: case studies of the costs and benefits of management, For. Ecol. Manag. 160 (2002) 143–159.

[39] C.J. Crous, S.M. Jacobs, K.J. Esler, Wood anatomical traits as a measure of plant responses to water availability: invasive Acacia mearnsii De Wild. compared with native tree species in fynbos riparian ecotones, South Africa, Trees Struct. Funct. 26 (2012) 1527–1536.

[40] S. Jacobs, M. Naude, E. Slabbert, O. Kambaj, M. Fourie, K. Esler, K. Jacobs, B. Mantlana, A. Rozanov, D. Cowan, Identifying Relationships between Soil Processes and Biodiversity to Improve Restoration of Riparian Ecotones Invaded by Exotic Acacias, 2013.

[41] J. Sitters, P.J. Edwards, H.O. Venterink, Increases of soil C , N , and P pools along an Acacia tree density gradient and their effects on trees and grasses increases of soil C , N, and P pools along an Acacia tree density gradient and their effects on trees and grasses, Ecosystems 16 (2013) 1–12.

[42] J.B. Jones, Plant nutrition and soil fertility, Available from, https://www.taylorfrancis.com/books/mono/10.1201/b11577/plant-nutrition-soil-fertility-manual-benton-jones-jr, 2011.

[43] R.O. Barnard, C.C. Preez, Soil fertility in South Africa : the last twenty five years Soil fertility in South Africa : the last twenty five years, S. Afr. J. Plant Soil 1862 (2013) 301–315.

[44] M.K. Bhandari, N.R. Regmi, H. Sahani, P. Sherpa, B. Panthi, Integrated nutrient management in maize production – a review, Rev. Food Agric. 2 (2021) 30–33.