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Woody encroachment impacts on soil properties

Impact de l'invasion ligneuse sur les propriétés du sol

Sous la direction de
Séraphine GRELLIER

Mélina CLOT

Woody encroachment impacts on soil properties – a review

Bibliometric analysis and focus on impacts of woody encroachment on soil carbon cycle

Directrice de recherche
Séraphine GRELLIER

Mélina CLOT

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La formation au génie de l'aménagement et de l'environnement, assurée par le département aménagement et environnement de l'Ecole Polytechnique de l'Université de Tours, associe dans le champ de l'urbanisme, de l'aménagement des espaces fortement à faiblement anthropisés, l'acquisition de connaissances fondamentales, l'acquisition de techniques et de savoir-faire, la formation à la pratique professionnelle et la formation par la recherche. Cette dernière ne vise pas à former les seuls futurs élèves désireux de prolonger leur formation par les études doctorales, mais tout en ouvrant à cette voie, elle vise tout d'abord à favoriser la capacité des futurs ingénieurs à :

- Accroître leurs compétences en matière de pratique professionnelle par la mobilisation de connaissances et de techniques, dont les fondements et contenus ont été explorés le plus finement possible afin d'en assurer une bonne maîtrise intellectuelle et pratique,
- Accroître la capacité des ingénieurs en génie de l'aménagement et de l'environnement à innover tant en matière de méthodes que d'outils, mobilisables pour affronter et résoudre les problèmes complexes posés par l'organisation et la gestion des espaces.

La formation par la recherche inclut un exercice individuel de recherche, le projet de fin d'études (P.F.E.), situé en dernière année de formation des élèves ingénieurs. Cet exercice correspond à un stage d'une durée minimum de trois mois, en laboratoire de recherche, principalement au sein de l'équipe Dynamiques et Actions Territoriales et Environnementales de l'UMR 7324 CITERES à laquelle appartiennent les enseignants-chercheurs du département aménagement.

Le travail de recherche, dont l'objectif de base est d'acquérir une compétence méthodologique en matière de recherche, doit répondre à l'un des deux grands objectifs :

- Développer toute ou partie d'une méthode ou d'un outil nouveau permettant le traitement innovant d'un problème d'aménagement
- Approfondir les connaissances de base pour mieux affronter une question complexe en matière d'aménagement.

Afin de valoriser ce travail de recherche nous avons décidé de mettre en ligne sur la base du Système Universitaire de Documentation (SUDOC), les mémoires à partir de la mention bien.

REMERCIEMENTS

Je tenais à remercier ma directrice de recherche, Madame Séraphine Grellier, pour son encadrement et ses conseils tout au long de ce projet de fin d'études, mais également Monsieur Pascal Podwojewski pour ces temps d'échanges et ses compléments apportés sur le sujet, qui ont permis d'enrichir cette review et de faciliter son écriture.

CONTENT

ABSTRACT

Woody plant encroachment has been largely observed around the word, especially in the last 160 years. If it is a natural phenomenon, it seems to be accelerating in recent years, and touched varied ecosystems worldwide. Its causes and consequences have been largely studied and seems to be plurals and site specific. Encroachment appears to be governed by an interaction between global changes, resources availability and anthropological or natural disruptions. Sometime describe as a sign of degradation or desertification, larger analysis shown ecosystem structure and functioning is not always negatively altered by woody plants. Soils, as support of this invasion, are affected in many ways by encroachment. However, no scientific consensus exists on soil encroachment consequences. Moreover, abundant literature with very few syntheses renders difficult a global comprehension.

To clarify these impacts on soil properties, we conducted a bibliometric analysis based on 198 articles, which aimed to characterized how soil is considered in woody plant encroachment studies. It turns out that most of studies have been conducted in USA, South-Africa and more recently China. If all climates are concerned by encroachment, research has focus there so far mainly in arid, semi-arid and subtropical climate. Carbon and nitrogen changes are main fields of study.

The second part of this review focus on the impacts of encroachment on soil carbon cycle. It showed encroachment affects above and belowground biomass, soil organic carbon, and changes also soil respiration. Moreover, it can influence water runoff and lead to erosion, a pathway of potential losses of carbon. Changes in carbon cycle are therefore plural, and depend on climate, soil properties, encroaching species, level of encroachment, historical land use, and an interaction of all these factors. In a carbon sequestration perspective, it seems that encroached areas are potential sink of carbon in most of cases, even if a robust generalization of woody encroachment impact on ecosystem carbon balance is elusive due to the variety of the phenomenon. However, stability of these increases remains unclear and need to be further investigate. Uncovered questions are submitted in order to sketch potential lines of inquiry.

Key words: encroachment, soil properties, bibliometric analysis, soil carbon cycle

INTRODUCTION

Woody plant encroachment, also referred as scrub thickening, shrub encroachment, woody plant expansion, woody thickening or xerification (Acharya et al., 2018) has been largely observed around the word, especially in the last 160 years (Van Auken, 2009). If it is a natural phenomenon, it seems to be accelerating in recent years (Bond & Midgley, 2012; Van Auken, 2009). It is defined as the increase in density, cover, and biomass of woody or shrubby plants in various grasslands (Van Auken, 2009) (Figure 1). The phenomenon occurs mainly in grasslands, defined as large open areas of country covered with grass, and savannas, composed of both grasses and trees layers, where tree or shrub density is influenced by several factors, including precipitation, soil type, fire, grazing and land management (Sitter et al, 2012). Encroaching species are indigenous plants (Grellier, 2011) and vary according to the site of study. In North America, mesquite vegetation, such as *Prosopis glandulosa* (Barger et al., 2011) or *Prosopis velutina* (Throop & Archer, 2008) are some examples; in South Africa, *Accacia mellifera* (Hudak et al., 2003) or *Vachellia karoo* (Mureva et al., 2018) were studied; in China, *Caragana microphylla* encroached large areas of Inner Mongolian grasslands (Zhu et al., 2021; Zhang et al., 2019). Quite often, encroaching species are Fabaceae species, able to fix atmospheric nitrogen.

Figure 1 : Woody thickening over the last century near Queenstown, South Africa. (Source from left to right: Pole Evans (South African National Botanical Institute), 1925; Timm Hoffman and James Puttick (Plant Conservation Unit, University of Cape Town), 1993 and 2011) (from Bond & Midgley, 2012).

Woody plant encroachment causes have been largely studied across the world and seems to be plurals and site specific. Invasion appears to be governed by an interaction between global changes, resources availability and anthropological or natural disruptions. Therefore, herbivory (Roques et al., 2001; Van Auken, 2009), fire frequency (Roques et al., 2001), precipitations (Sankaran et al., 2005), and atmospheric carbon dioxide (Bond & Midgley, 2012; Harte et al., 2015) are some examples of main drivers of woody plant proliferation worldwide. Effects of woody encroachment on ecosystems are also a main studied subject, with no scientific consensus (Eldridge et al., 2011). In any case, woody plant encroachment makes soil properties more heterogenous than before (Liu et al., 2011; O'Donnell & Caylor, 2012). Sometime describe as a sign of degradation or desertification (Ravi et al.,2010), especially because its potential to threaten the social and ecological viability of pastoral enterprises (Eldridge & Ding, 2020), larger analysis shown ecosystem structure and functioning are not always negatively altered by woody plant encroachment (Eldridge et al., 2011; Eldridge & Soliveres, 2014). If woody plant encroachment in not always synonymous of land degradation, it has however important fauna and flora (Scholes & Archer, 1997; Ladwig et al., 2021), hydrologic (Acharya et al., 2018), and biochemical cycles (Barger et al., 2011) implications. The expansion of shrubs and trees on previously herbaceous dominated lands has a strong potential to modify carbon dynamics and storage.

Soils have indeed a great ability to sequester and store carbon (Gross & Harrison et al., 2018). This ability varies from type of soil (Lal et al., 1997) (Table 1). Carbon in soils can be divided in two types of pool, the soil organic carbon (SOC) and the soil inorganic carbon (SIC), which refers to the parent rock soil carbonate formed in the weathering process of silicate carbon (Bai et al., 2017). If SIC and its dynamics are poorly known (Lal et al., 1997; Liu et al., 2020), soil scientists are beginning to understand the dynamics of SOC and factors affecting it (Lal, 1997). In terms of soil quality, productivity and health, this fraction of soil C is less important than SOC but the sequestration of carbon inorganic in soil plays a considerable role to mitigate global warming. (Deb et al., 2015). The current SOC pool in the world soil could contain about two to three times the amount of carbon stored in the atmosphere and vegetation combined (Lefèvre et al., 2017).

Table 1: Estimates of soil organic and inorganic carbon pools in world soils (Lal et al., 1997)

Soil	**Carbon pool to 1m depth (Pg)**	
	Organic	**Inorganic**
Ultisols	101	0
Andisols	69	1
Aridisols	110	1044
Oxisols	150	0
Inceptisols	267	258
Alfisols	136	127
Mollisols	72	139
Vertisols	38	25
Spodosols	98	0
Entisols	106	117
Histosols	390	0
Miscellaneous	18	0
Total	1555	1738

SOC is a dynamic storage, controlled by SOC enhancing and SOC degrading processes (Lal, 1997). SOC inputs are several: plant death, root exudation, animal death and excretion (Gougoulias et al., 2014; Gross & Harrison, 2018). Approximately, soil organic matter contains 58% of soil organic carbon, a percentage which may vary depending on soil depth and soil type (Trivedi et al., 2018). The decomposition of this organic material is permitted by the microorganisms, composed of bacteria, fungi, algae, actinomycetes, protozoa and some nematodes. (Deg et al., 2015), who also needed nitrogen (N) and other nutrients such as phosphorus (P) to growth. Nitrogen cycle is therefore closely related to carbon cycle in soil. If the nitrogen available to the decomposers during the degradation of a substrate is not sufficient to cover their needs, the degradation rates can be changed (Recous et al., 2017).

Carbon is incorporated into the bulk SOC though the transport of dissolved organic carbon (DOC) from the litter layer as well through the mixing of particulates organic matter (POM) into superficial soil layer via bioturbation (Gross & Harrison, 2018). Eventually, COS can be lost via heterotrophic respiration of soil microbes (Dynarski et al., 2020), which emitted carbon dioxide or methane, or through water erosion of soils, which carries away DOC (Lefèvre et al., 2017). Various components of the soil environment interact to protect SOC from loss (Gross & Harrison et al., 2018). SOC protection occurs through abiotic mechanisms such as physical protection and mineral sorption. Microaggregates in soil, held together by exudates, roots and fungal hyphae (Button et al., 2009), enable physical protection of SOC by creating anoxic conditions or spatial separation from microbial decomposers (Gross & Harrison, 2018). Physico-chemical associations with silt and clay surfaces, called mineral sorption, are the second major way to protect SOC (Button et al., 2009; Gross & Harrison, 2018). Biochemical recalcitrance inherited from original plant chemistry or acquired though post-depositional modification can also influence the degree to which new organic matter inputs are stabilized and protected from decomposition (Button et al., 2009). However, the presumed chemical recalcitrance of complex molecules that accumulate SOC, such as lignin or lipids, does not substantially contribute to the persistence of SOM in soil (Lefèvre et al., 2017; Hartley & Singh, 2018). SOC is therefore a continuum of structures derived from the progressive decomposition of litter and exudates and includes the microbial biomass carbon too (Gougoulias et al., 2014) (Figure 2). The several SOC means of protection create varying degrees of C sequestration potential and soil residence time (Sharenbroch et al., 2010), ranging from a few days to centuries.

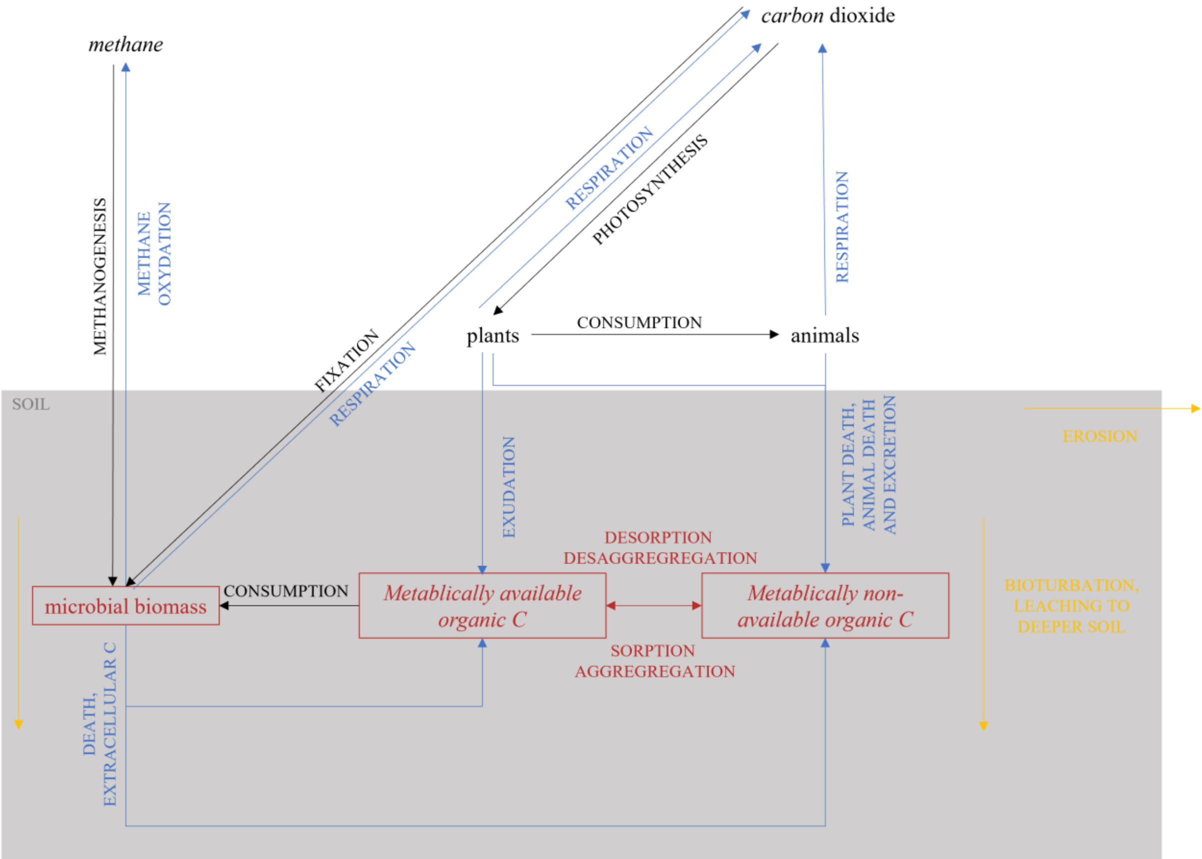

Figure 2: Carbon enters in soil mainly via plants and animals' inputs, and it is lost via respiration. Plants and animals derived organic carbon is processed by soil micro-organisms to CO2, microbial biomass, and extracellular substances (enzymes, metabolites, aggregation agents). Enzyme may catalyze the depolymerization of soil macromolecular constituents, while other substances may promote aggregation and therefore physical protection of SOC. SOC can be transported in deeper soils as particulate matter via bioturbation or via leaching of mineral associated organic matter (Clot, 2022 adapted from Gougoulias et al, 2014; Dynarski et al., 2020; Gross et al, 2018).

As woody plant encroachment influences soil microbial richness (Collins et al., 2020), aboveground and belowground ecosystem biomass (Hughes et al., 2006), SOC stocks (Dlamini et al., 2019), SIC (Liu et al., 2020), Co_2 flux (Thomas et al., 2018), or even erosion (Parizek et al., 2002; Puttock et al., 2014), it could therefore influence carbon biochemical cycle at a local, regional, and global scale. Moreover, woody plant encroachment mainly occurs in grasslands and arid or semi-arid areas, that appears as strategic carbon storage locations. Indeed, grasslands, including rangeland, shrubbery areas, pastures, and crops, occupy 40% of the Earth's surface, when arid and semi-arid areas represent 40% of emerged lands (Lefèvre et al., 2017). Even small changes in ecosystem C storage accompanying the proliferation of trees and shrubs could therefore constitute a potential sink or source of carbon (Barger et al, 2011), with influence on regional and global climates through feedback interactions (Barger et al., 2011; Liu et al., 2016; Hudak et al., 2003; Gross & Harrison, 2018).

This review aims to enhance the understanding of the impact of woody plant encroachment on soil properties. To this aim, a bibliometric analysis has been conducted to better understand how soils are considered in woody plant encroachment studies around the world and underlined uncovered questions.

This bibliometric analysis is presented in the first part of the review. A focus on carbon biochemical cycle and shifts associated with woody plant encroachment has been made is the second part of the review. It will question the impacts of woody plants invasion on the carbon biochemical cycle in encroached ecosystems and will deeper investigated shifts in soil organic carbon.

MATERIALS AND METHODS

This review is based on a literature analysis of 198 articles having been published between 1975 and 2021. These articles have been retrieved through a literature database search in Web of Science through the website bibcnrs (https://bib.cnrs.fr) and Google Scholar using keys word "woody plant", "woody plant encroachment", "shrub encroachment", "woody plant invasion" in combination with "soil" or "soil properties". A database including name of the first author, date of publication, title, journal, thematic of journal, type of article, continent, country, climate, climate class, rainfall, rainfall class, biome, biome class, type of encroaching plant (N_2-fixing plant or non N_2-fixing plant), soil type and soil texture had been built since 2017. Articles' main subjects had been also indicated among carbon, nitrogen, nutrient, other chemical soil properties, soil moisture, infiltration, erosion, microbiology, soil fauna, other physical soil properties, for further treatments. The more recent articles have been added to the database, especially those published between 2019 and 2021.

The second part of this review focus on the carbon biochemical cycle and changes due to woody plant encroachment. To this end, 55 articles in the database were selected according to their title and their abstract contents. Those articles have been analyzed to spotlight the shifts observed, the main drivers of these changes and their implications.

BIBLIOMETRIC ANALYSIS

1. A recent research subject

1.1. Major contributions in recent years

If woody plant encroachment is not a new phenomenon worldwide, its links with changes in soil properties seems yet a recent research subject, mainly developed after 2000. Major contributions to the research date from the last years, with a pick in 2013 and 2019 (Figure 3).

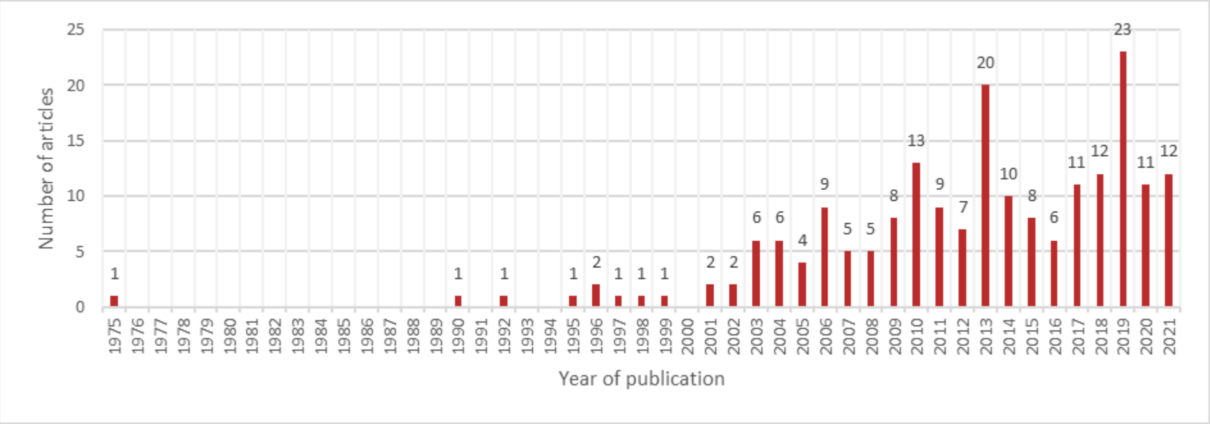

Figure 3: Number of published articles since 1975 relative to woody encroachment and soil properties

Woody encroachment is therefore gaining attention among the scientific community. Journal with soil or ecology thematics are the main contributors to the database (Figure 4). This is not surprising considering the dealing subject of this review, namely woody plant encroachment and impacts on soil properties.

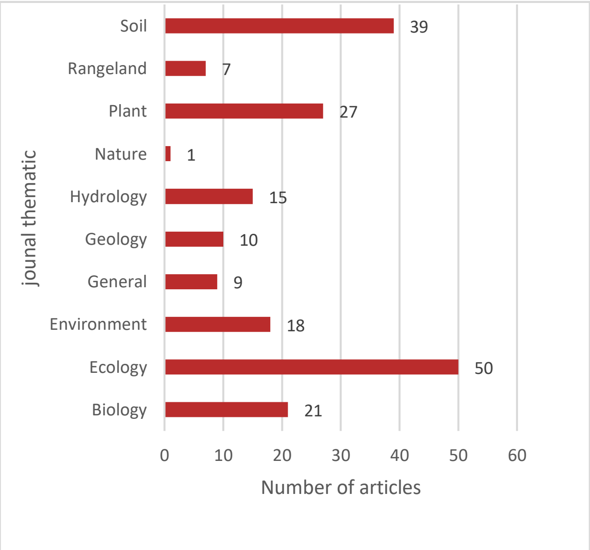

Figure 4: Number of published articles about woody encroachment per journal thematic

1.2. North America, South Africa and China, favorite fields of study

Woody plant encroachment occurs all around the world. 5 continents and 24 different countries are cited in the used database (Figure 5 and 6), illustrating the variety of ecosystem touched.

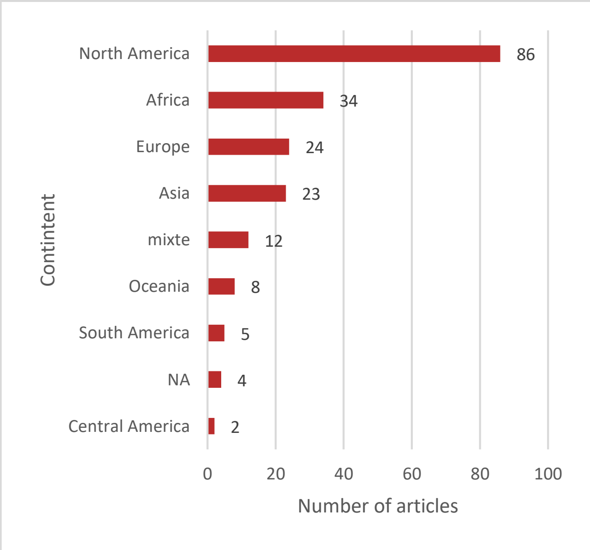

Figure 5: Number of articles per studied continent

However, studies have focus so far mainly on North America and Africa (Figure 5), especially in the United States of America and South Africa (Figure 6). The large surfaces touched by shrub encroachment in North America (Barger et al., 2011) could explain the great interest of the scientific community for this region. In Africa, land encroached has a important significance to human economy, usually supporting rangeland, livestock, and wild herbivore biomass (Sankaran et al., 2005; Luvuno et al., 2018). Consequences of woody plant encroachment on human livelihoods could explain the concentration of studies on these sites. More recent studies seem to focus on Europe (Maestre et al., 2009; Hunziker et al., 2017; Pellis et al., 2019; Nadal-Romero et al., 2018) and Asia, especially in China (Figure 6) (Zhou et al., 2018; Li et al., 2019; Hu et al., 2018). Indeed, all articles dealing with China in the database have been published after 2013.

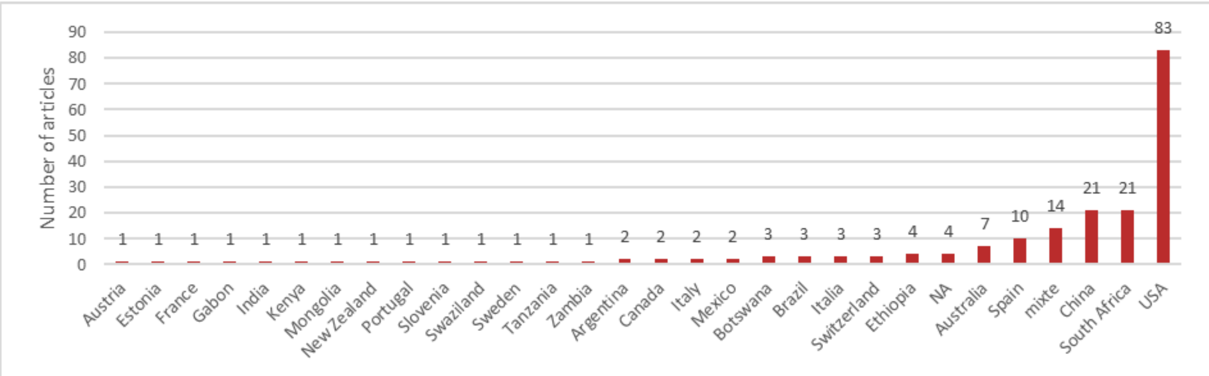

Figure 6: Number of articles per country of study

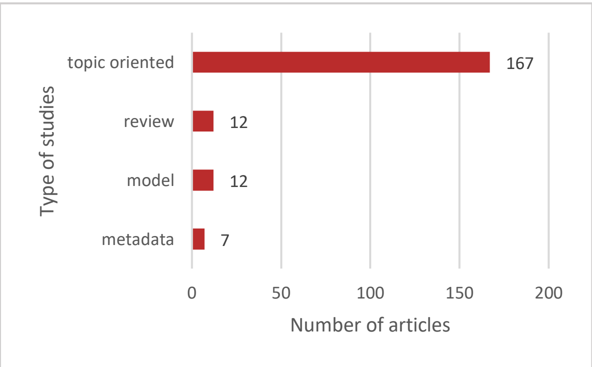

Figure 7: Number of published articles per type of studies

Few studies are conducted on several countries, which underlines the lack of global synthesis on this subject and the need for generalization. Moreover, almost all articles are topic oriented, only 12 were considered as review, underlying this lack (Figure 7).

1.3. Carbon and Nitrogen shifts with woody encroachment, favorite subject of study

For each article in the database, main subjects were indicated. Due to the multiple causes and consequences of encroachment (Roques et al., 2001; Van Auken, 2009), there are numerous (Figure 8). Moreover, a lot of articles have several main subjects, between two and three for the majority (Figure 9).

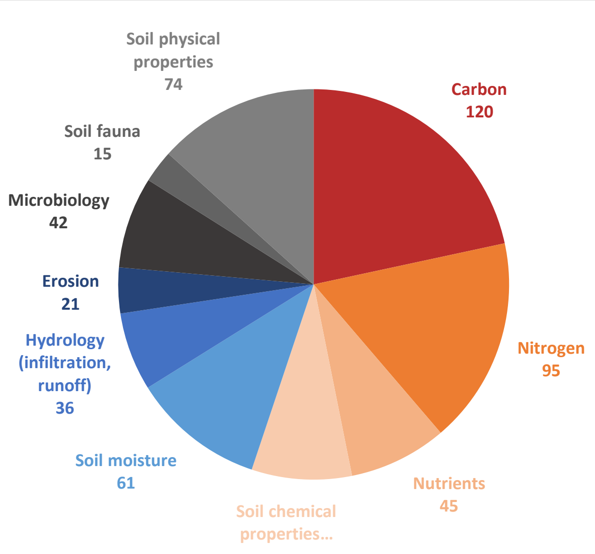

Figure 8: Number of articles per main subjects

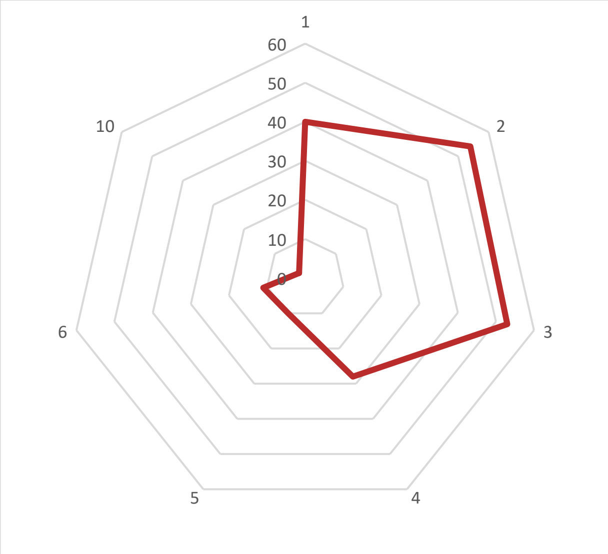

Figure 9: Number of articles per number of main subjects

The most common subject combination is carbon/nitrogen, which appears 13 times, and carbon/nitrogen/microbiology, which appears 10 times. The prevalence of these subject associations might be explained by the interdependence of the carbon and nitrogen cycle in soils, and the influence of these two parameters on the microbial activity (McKinley et al., 2008). In addition, with these main combinations, it seems carbon and nitrogen are the main studied subjects (Figure 8). With a large part of proliferating woody plant species being N_2-fixing plants, shifts on ecosystem nitrogen pools are expected (Hudak et al., 2003; Blaser et al., 2014), and are therefore an important subject of research. Moreover, woody encroachment resulted in a significant redistribution of carbon between its major reservoirs (Barger et al., 2011), and have been largely studied in several specific ecosystem (Throop et al., 2013; Wheeler et al., 2007; Mureva et al., 2018). Conversely, biology (soil fauna and microbiology) is the least studied subject, only 57 articles mentioned it.

2. Main encroached fields characteristics

2.1. Arid/semi-arid and subtropical grassland, first ecosystems concerned

Analyzing article's distribution per climate and rainfall classes enables to reach some conclusions. Woody plant invasion occurs in numerous climate classes around the word. Once more, the phenomenon is characterized by the variety of ecosystem concerned. Consistent with the favorite field of study underlined above, the data base spotlights the arid/ semi-arid, and subtropical climate (Figure 10), which seem more impacted by shrubbery. Arid and semi-arid climate are characterized by low precipitations (0-500 mm) whereas greater rainfalls (700-1000 mm) are observed in subtropical climate. These results coincide with the article's distribution per rainfall obtained (Figure 11), where all classes under 1000 mm are several times studied.

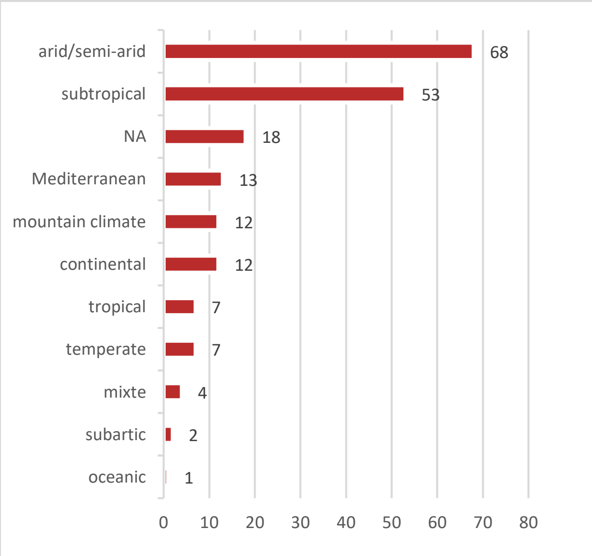

Figure 10: Article's distribution per climate class

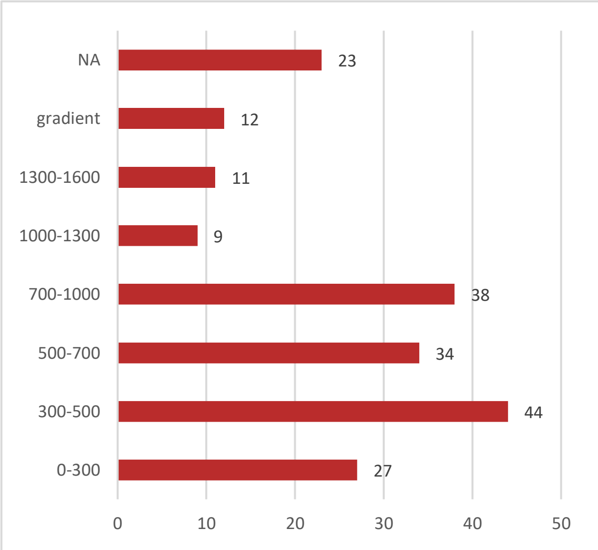

Figure 11: Article's distribution per rainfall class

2.2. Among proliferating woody plants, a N_2-fixing specie predominance

Proliferating woody plants appeared to be site specific and highly variable. However, it can be underlined the large proportion of N_2-fixing species. Indeed, a third part of the database studied the encroachment of N_2-fixing species, when 31% of articles focus on a mix of N2-fixing species and non N_2-fixing species (Figure 12). Woody plant encroachment seems therefore to be largely caused by Fabaceae species. Leguminous shrubs, with their ability to fix atmospheric nitrogen, could profoundly alter the species composition of the native grassland.

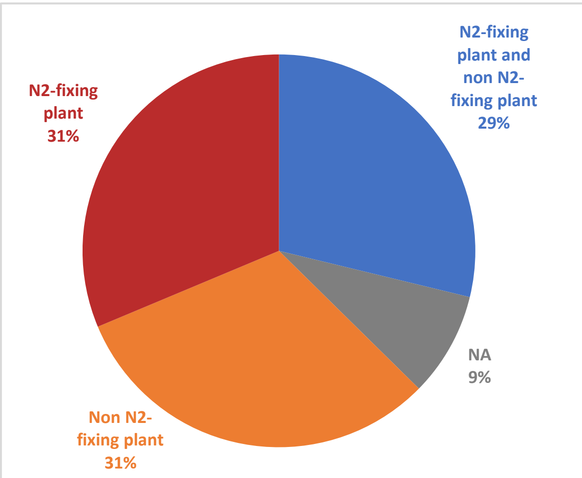

Figure 12: Article's distribution by plant characteristics

2.3. A diversity of soil type, soil texture and biomes encroached

Analyzing the soil type statement for each article put forward that it is quite often a non-indicated parameter. Indeed, 90 articles of the database don't indicate the soil type of studied area, underlying the lack of data about this parameter. When the information is available, soil type variety of encroached areas can be underline. More than 40 different soil type are cited, which reinforces the complexity of woody plant encroachment phenomenon. However, among all soil type encroached, the prevalence of Mollisol, which appears 25 times can be underline, as Aridisol, which appears 11 times. Mollisol is a soil which as deep, high organic matter and a nutrient-enriched surface soil, between 60 and 80 cm in depth. They are formed under grassland vegetation, where the annual proliferation of fine roots contributes to a relatively high organic carbon content (Buol et al., 2011). As encroached areas are grass dominated spaces, prevalence of Mollisol in soil type is therefore no supprising. Aridisols occur in both cool and temperate deserts and warm deserts at lower latitude. This type of soil is typic form dry regions (Buol et al., 2011). These two major soil types coincide with the predominance of arid semi-arid climates underline above.

Analyzing soil texture and biome encroached spotlight a diversity of this both factors in studied articles. No predominant texture or biome can be put forward, showing once more woody plant encroachment is a diverse phenomenon.

Woody plant encroachment appears therefore as a recent subject of study, mainly conducted in United States of America, South Africa and China. Encroachment happens above all in arid/ semi-arid climate, as well in subtropical climate and often brings into play Fabaceae species. This phenomenon is characterized by its diversity of encroaching species, biomes encroached, encroachment drivers and its consequences. In the second part of the review, impacts of woody plant encroachment on carbon biochemical cycle will be studied.

ENCROACHMENT MODIFIES SOIL CARBON CYCLE

Woody plant encroachment is generally thought to increase carbon stored in the ecosystem encroached, even though there are evidence for a decrease in some situations. However, this increase in characterized by a high degree of uncertainty (Liu et al., 2011; Dlamini et al., 2019; Asner et al., 2004). Indeed, mechanisms underpinning the direction and magnitude of soil C gain or loss are poorly understood (Dlamini et al., 2019; Barger et al., 2011; O'Donnell & Caylor, 2012). A poor comprehension of interactions and feedbacks between climate, vegetation and soils can explain these uncertainties. The changes observed are explained as an effect of varying plant production and decomposition rates which ultimately determine SOC storage (Coestee et al.,2012), and stimulation of CO_2 flux (Brantley et al, 2010) or erosion (Parizek et al., 2002; Puttock et al., 2014). This second part of the review aims to better understand the changes observed in carbon biochemical cycle following woody plant encroachment, from shifts in above and belowground biomass, to erosion mechanisms, including SOC storage and factors influencing soil carbon persistence.

1. Above and belowground carbon pools change following woody plant encroachment

1.1. Above and belowground biomasses, a potential input of carbon in soil

As grass species are replaced following woody and shrubby species with encroachment, several changes in above and belowground biomass occur. Aboveground biomass contains leaves and stems, and bole of the plant, i.e. the aerial part, but also litter accumulated under trees, when belowground biomass refers to roots. Indeed, herbaceous and shrub or trees species don't have the same structure, and encroachment represents a change in net primary production. This biomass may conduce to a change in above and belowground carbon storage because, as recalled in the introduction, biomass contains a large part of carbon. In their review, Barger et al. (2011) considered for instance 50% of total biomass is carbon.

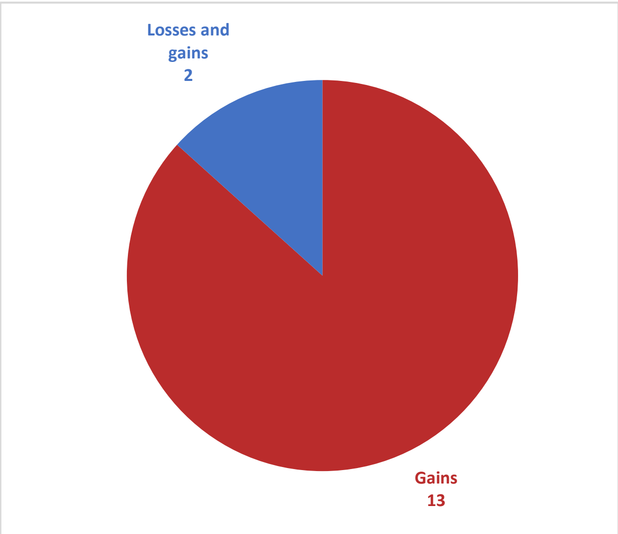

Figure 12 : Above and below-ground directions of changes following woody plant encroachment (Only studies comparing encroached areas with non-encroached areas, or studying a gradient of encroachment are considered)

With woody plant encroachment, above and belowground biomasses trend to increase (Hughes et al., 2006; Lett et al., 2004; McKinley & Blair, 2008) (Figure 12). Button et al. (2009) underlined for instance a significantly greater carbon stock in roots and litter in wooded landscapes compared with remnant grassland. In the same way, Coestee et al. (2012) showed thickets contained significantly more above-ground carbon than adjacent savannas, and Hu et al (2015) attributed the larger number of macropore observed in encroached areas to greater root development.

These aboveground and belowground storage could influence SOC, by being a net input of carbon in soil (Li et al., 2019; Montané et al., 2010). Litter of aboveground biomass woody plant is indeed presenting a higher recalcitrance that could explain the increase of SOC following encroachment (Montané et al., 2010; Chiti et al., 2016). However, beside an increase in aboveground carbon, no significant difference was observed in soil carbon (Coestee et al., 2012), underlying above and below-ground carbon doesn't appear always coupled with an increase of SOC. At a larger scale, Barger et al. (2011) also put forward the absence of correlation between increase of biomass and increase of SOC, as did other (Hughes et al., 2006; Lett et al., 2004; Scharenbroch et al., 2010).

1.2. Influence of climate and soils characteristics on above and belowground biomasses

Increase of above and below ground biomass in ecosystem encroached seems to depend on several factors favoring more or less the increase. Therefore, direction and magnitude of changes in above and belowground biomass vary according to studies, through precipitation and texture.

1.2.1. Precipitations influence above and belowground biomasses

Precipitations play a part in above and belowground biomass growth, as a limiting driver. For instance, Barger et al. (2011) describe in North America, both positive and negative changes according to Mean Annual Precipitation (MAP). Relative to historic vegetation, aboveground carbon stocks increased with woody plant encroachment in semiarid and subhumid region (MAP >336 mm) but decreased in arid region (MAP < 336 mm) (Barger et al., 2011). A relationship also underlined by Eldridge et al. (2011), who reported decreases in annual primary production in xeric sites and increases at higher precipitation sites. It seems to exist a threshold value under which shrub and tree growth is limited by water availability. A threshold which varies across studies, being for instance of 650 mm in Africa (Sankaran et al., 2005) or 336 mm in North America (Barger et al., 2011).

1.2.2. Soil texture influences above and below ground biomasses

Some specific textures have been demonstrated to more enhance woody plant cover, such as coarse texture soil versus fine texture soil (Barger et al., 2011; Li et al., 2016). However, in wet sites, this relationship can be reversed (Barger et al., 2011).

1.3. Stability of aboveground and belowground carbon storage

1.3.1. Evolution of above and belowground biomasses through time

Increases and decreases of above and below ground biomasses have been therefore observed following encroachment. However, these directions of change can vary trough time. In an American temperate savanna for instance, Hughes et al. (2006) showed for instance aboveground carbon mass increase linearly with woody stand age. In Ethiopia, Birhane et al. (2017) demonstrated in the same way an increase of above and belowground biomass with encroachment, the rate of increase being higher when rangelands were densely invaded. However, increase of biomasses through time is not always observed for each component of above and below ground biomass. Brantley et al. (2010) underlined accumulation rate of litter C was higher in the youngest thickets than oldest thickets, showing a permanent increase of above and below ground biomass is not certain.

1.3.2. Above and belowground biomasses, a vulnerable carbon stock

With woody plant encroachment, vegetal cover and vegetal biomass change. Most studies underlined an increase of aboveground biomass, which therefore enhance carbon ecosystem storage. However, authors also alert about the stability of this storage. Jackson et al. (2002), for instance, spotlighted the vulnerability of these C stocks, that can be lost through perturbation as fire, biomass harvesting or other disturbances. Fino et al. (2020) argued in the same way.

Woody plant encroachment modifies above and belowground biomass, and therefore impact carbon soil input. Generally, an increase in biomass in observed, especially when there is no nutrients or water limitation. This accrual of above and below ground biomass could represent a net input of carbon in soil and is also a temporary carbon stock.

2. Soil organic carbon pool changes following woody plant encroachment

2.1. Diverse directions of changes

Soil organic carbon response to woody plant encroachment seems to be several and site specific. By comparing encroached and non-encroached areas, or gradients of encroachment, increases, decreases or no net changes have been observed worldwide (Figure 12).

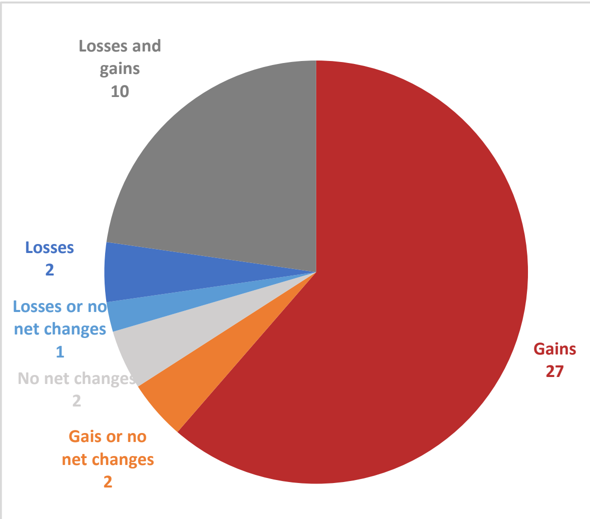

Figure 12: SOC directions of change following woody plant encroachment (Only studies comparing encroached areas with non-encroached areas, or studying a gradient of encroachment are considered)

However, most studies agreed encroachment enhances SOC (Chiti et al., 2016 ; Ding et al, 2019 ; Dlamini et al., 2019 ; Gomze-Rey et al., 2013 ; Li et al., 2019 ; Liao et al., 2006 ; Liu et al., 2011 ; McKinley & Blair, 2008 ; Pellis et al., 2019) (Figure 12). In a large study across North America drylands, Barger et al. (2011) show, in average, an increase of SOC in the ecosystem following invasion. In the same way, Li et al. (2016) demonstrated in a meta-analysis of 142 studies that SOC content tended to increase as shrubs or trees encroached grasslands. These increases take place in at different soil depth, with contradictions among studies. In the Rio Grande Plain in the United States of America, Button et al. (2009) demonstrate woody plant encroachment increases significantly SOC in upper 30 cm of profile.

Conversely, Chiti et al. (2016) show changes in SOC occur below 30 cm depth and appoint subsoil as the principal compartment contributing to SOC sequestration. Several authors underlined indeed the role of deep soil in carbon sequestration, as Li et al. (2019), who demonstrated 44% to 54% of SOC was stored in soil layers of 100 cm to 500 cm.

However, other studies underline the negative effect, i.e., loss of SOC, occurring with woody plant encroachment on SOC. Fino et al. (2020) observed SOC stocks in the 30-60 cm compartment decreased significantly in the final stage of succession. This decrease extended from -30% to -60% in comparison from managed grasslands (Fino et al., 2020). Li et al. (2019), also underline a loss of SOC with encroachment, as did Li et al. (2020), Mureva et al. (2018), Jackson et al. (2002), in certain climatic conditions.

In some studies, no SOC changes were observed (Montané et al., 2007; Scharenbroch et al., 2010).

The increase of SOC following woody plant encroachment seems therefore depending on several factors explaining directions and magnitude of these changes. Edaphic and climatic drivers are indeed underlined by several authors. The following part will therefore focus on these factors and drivers of changes.

2.2. Directions influenced by climate, soil properties and encroaching species

Several factors can influence carbon cycle in soil. Among them, climate and soil properties appeared to be the most important, an importance that can switch with depth (Jobbagy & Jackson, 2000).

2.2.1. Climate influences SOC

Climate has a strong influence on carbon storage. Indeed, temperature and water soil content, mainly determined by climate condition, influence vegetation productivity and decomposition rates through controlling the soil microbes, enzyme activity and soil respiration (Levèfre et al., 2017; Zhao et al., 2021). For instance, high soil water content (SWT) may stimulate the carbon uptake, i.e., ecosystem productivity, or release it though a maximization of soil respiration (Zhao et al., 2021). Thus, several authors studied climate influences on SOC.

Table 2 : SOC directions of change according to climate class used in the database (Only studies comparing encroached areas with non-encroached areas or studying a gradient of encroachment are considered. Studies conducted through a several climates have not been counted in this table)

	arid/semi-arid	**continental**	**mediterranean**	**mountain**	**subtropical**	**temperate**	**tropical**
Losses	0	0	0	2	0	0	0
Losses and gains	3	1	2	2	0	0	0
Gains	7	2	2	0	13	0	2
Gains or no net changes	0	0	1	0	1	0	0
No net changes	1	1	0	0	0	0	0
Losses or no net changes	0	0	0	1	0	0	0
total	**11**	**4**	**5**	**5**	**14**	**0**	**2**

If contradictions appear among studies, most articles showed an increase of SOC with encroachment, except in mediterranean and temperate, where the table doesn't allow to conclude, and mountain climate where losses seem preponderant (Table 2). However, climate classes are not always homogeneous through studies, and comparison based only on the database classification is limited. Analyzing more deeply the articles enable to reach further conclusions.

Li et al. (2016) meta-analysis demonstrated a significantly increase of SOC in semi-arid and humid areas, where no net changes were observed in arid zones and dry sub-humid areas. A result also confirmed by Mureva et al. (2018) who found soil organic carbon increases in semi-arid region, and by Li et al. (2019) who observed an increase of SOC in comparison with adjacent grassland in humid areas.

Precipitations

Li et al. (2016) generalized this statement by underlying a positive relationship between the average percentage of SOC changes and the mean annual precipitation (MAP), with wetter sites gaining SOC and drier sites losing SOC. This result differs from those of Jackson et al. (2002), who found a negative relationship between precipitation and changes in soil carbon, as did Alberti et al. (2011) and Mureva et al. (2018) (Table 3). These authors underlined in dry sites, shrub and trees have a greater develop extensive root systems that extract nutrients from the horizontal and vertical planes, leading to local nutrient recycling and greater biomass production associated with organic matter accumulation than in previous grasslands. This advantage is also called "island of fertility" (Van Auken, 2009). Conversely, in high-precipitation areas, grasslands are highly productive and allocate a large proportion of SOC belowground with greater root turnover rates (Mureva et al., 2018). Threshold values separating gaining sites from losing sites are different among studies (Mureva et al., 2018; Jackson et al., 2002; Alberti et al., 2011), showing that precipitation is not the only factor to consider. In addition to positive and negative relationships, other authors highlighted these two parameters to be independent. Indeed, Barger et al. (2011) demonstrated a non-correlation between SOC changes and precipitations.

Temperature

Changes along a temperature gradient are also heterogeneous (Table 3). Li et al. (2019) demonstrated a negative correlation between SOC and temperature, in contradiction with the metanalysis realized in three years before (Li et al., 2016). This might be because the 2019 study took place in a continental climate, where precipitation are low (ranges from 200 to 350 mm), and therefore water availability is constrained. Low temperature in this situation can reduced water stress and caused less severe depletions of carbon input, and decreased biological process, that means, a low decomposition and an increased SOC (Li et al., 2019). The positive correlation with temperature is also suggested by Alberti et al. (2011), as thermo-Mediterranean sites presented more carbon accumulation than meso-Mediterranean sites.

Table 3: Correlations observed between precipitation and temperature factors and increase of SOC

	Correlation with SOC		
	Positive	**Negative**	**No correlation**
Precipitation	Li et al. (2016) Li et al. (2019) in humid areas	Jackson et al. (2002) Alberti et al. (2011) Mureva et al. (2018)	Barger et al. (2011)
Temperature	Li et al. (2016) Alberti et al. (2011)	Li et al. (2019) in continental climate	

Li et al. (2016) suggest these differences of correlation between precipitation or temperature and SOC come from a lack of studied conducted along a climate gradient. Indeed, only six studies in the database have been conducted through a rainfall gradient, and only two through several climates. Table 2 also underlined a need of further research in temperate and tropical climate, were very few studies have been conducted. Moreover, these contrary results also claimed climate alone can't explain the variation in SOC changes following woody plant encroachment. Soils properties also greatly influence soil carbon storage, as it will be shown in the next part of the review.

2.2.2. Soil properties influences SOC

As climate, soil properties have a strong influence on SOC accumulation and stabilization. Several authors studied this relative influence and sketched main soil characteristics susceptible to promote carbon accumulation. This part will therefore focus on texture, bulk density, C:N ratio, and cation exchange capacity (CEC), factors that have been spotlighted though the articles analyzed to significantly influence the magnitude and direction of SOC.

Texture

Soil texture also influence SOC. As seen above, texture influence development of aboveground and belowground biomass, coarse texture favoriting woody plant settlement. However, in soil, fine particles form stable organo-mineral complexes (clay + silt) with physical protection, which prevent SOC from decomposition (Deg et al., 2015; Li et al., 2016). As clay fraction is the finest particles in soil, from 0 to 2 µm on average, soil with an important clay content will be expected to promote SOC. Indeed, Hudak et al. (2003) observed SOC was a function of clay soil fraction, as did Barger et al. (2011). In the same way, Wheeler et al. (2007) observed a positive relationship between clay content and soil carbon pools, when elevation, MAP and mean annual temperature (MAT) were constant. However, in their meta-analysis, Li et al. (2016) showed SOC content increased significantly with shrub encroachment in sandy clay loam, sand, and sandy loam, when it decreased in silty clay soil. Shrub encroachment SOC was not significantly affected in other textures (Li et al., 2016) (Figure 13).

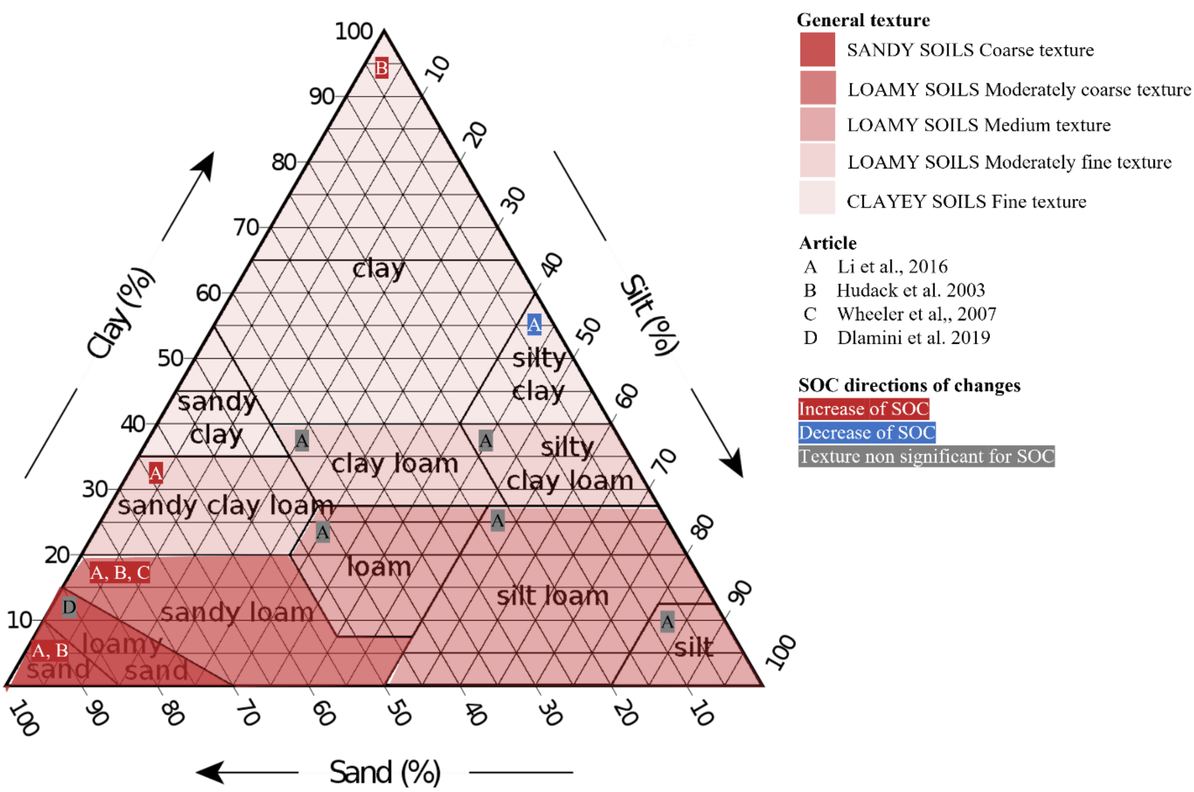

Figure 13: USDA Soil texture, general texture associated, and impact on SOC directions according to different articles (Source Wikimedia Commons, adapted)

These results showed clay fraction is not the only parameter favorizing SOC accrual. Moreover, positive correlation with clay fraction is not always observed. Dlamini et al. (2019) found for instance no significant correlation between SOC and clay content. Texture influence on SOC is therefore several, as coarse texture favorizing shrub settlement and therefore biomass increase can potentially increase SOC stocks, where fine texture, with high clay content, stabilizing SOC in soil. In a system where low protection of organic matter are expected due to low silt and clay content, accumulation of organic matter results firstly from an increase in primary production relative to decomposition, and/or inputs of residues with high chemical resistance to decay (Liao et al., 2006).

Bulk density

Bulk density is linked with texture evocated above. Indeed, a high bulk density can indicate a compacted soil, but also a great proportion of sand, as a low bulk density indicated fine texture soil. As see just before, shrub preferentially settle in coarse texture, where bulk density is therefore high. In this way, Li et al. (2016) found a clear positive relationship between the average percentage change in SOC content and soil bulk density. However, as high bulk density means low clay fraction, several authors found in another hand a negative correlation with soil bulk density (Dlamini et al., 2019; Barger et al., 2011). Barger et al. (2011) also underlined a threshold of 1.6 $g.m^3$ above with COS losses were confirmed.

N : C ratio and nitrogen availability

In soil, nitrogen and carbon cycle are closely related. As they did for carbon, most of studies observed an increase of nitrogen in soil following woody plant encroachment (Li et al., 2019; Blaser et al. 2014; Brantley et al., 2010). This increase of N in soil could result from several mechanisms. First, the ability of trees and shrub to accumulate nutrients from depth, as called the "fertile island" effect, and secondly, influence of Fabaceae species, able to fix the atmospheric nitrogen, which are often encroaching species. Indeed, N_2-fiwing plants can cause imbalance between the biochemicals cycles and changes the nutrients availability of the ecosystem.

The consequences of this nitrogen accumulation in soil are controversial. Accumulation of nitrogen in soil result in a low C:N ratio (Hudak et al., 2003; Montané et al., 2006), which permits a higher decomposition speed and therefore an increase of SOC losses (Montané et al., 2006). In this way, several authors underlined a negative correlation of SOC stocks with soil nitrogen (Li et al., 2016; Montané et al., 2006; Dlamini et al., 2019). However, increase of nitrogen availability also permits a greater aboveground and belowground growth (Hunziker et al., 2017; Scharenbroch et al., 2010), nitrogen being an indispensable nutrient for the plant world. Therefore, a low nutrient availability, particularly N, might limit soil C storage through mechanisms still not complete understood (Alberti et al., 2015). It might be because of the presence of nitrogen compounds stimulates microbial activity and results in an accumulation of microbial residues persist in soil (Derrien et al., 2016). Alberti et al. (2011) observed in this way SOC losses between encroached and non-encroached areas were observed when a substantial decrease in soil nitrogen stock.

Cation exchange capacity

In a studied conducted by Dlamini et al. (2019), soil C content and stocks were positively correlated with effective cation exchange capacity (CEC). The authors suggest that way carbon soil is chemically stabilized via complexation interactions with polyvalent cations (Dlamini et al., 2019).

Soil properties can therefore greatly influence SOC storage, in a positive or negative way, with contradiction among studies (Table 4). Thus, climate and soil properties are needed to be considered to better understand changes in soil organic carbon content.

Table 4: Correlations observed between soil properties and increase of SOC following woody plant encroachment

	Soil properties and their correlation with SOC		
	Positive	**Negative**	**No correlation**
Clay content	Hudak et al. (2003) Barger et al. (2011) Wheeler et al. (2007)		Dlamini et al. (2019)
Coarse texture	Li et al. (2016)	Li et al. (2019) in continental climate	
Bulk density	Li et al. (2016)	Dlamini et al. (2019) Barger et al. (2011)	
N : C ratio	Hunziker et al. (2017) Scharenbroch et al. (2010) Alberti et al. (2011)	Montané et al. (2006) Li et al. (2016) Dlamini et al. (2019)	
CEC	Dlamini et al. (2019)		

2.2.3. Woody plant encroaching specie characteristics influence SOC

As encroachment is a diverse phenomenon occurring in diverse latitudes and longitudes, encroaching species are several. *Acacia* (Grellier, 2011; Siters et al., 2013), *Juniperus* (McKinley & Blair, 2008) or *Prosopis* (Throop & Archer, 2008; Barger et al., 2011) are few genus examples. Diverse species are expected to have diverse consequences on soil organic carbon. Most of articles studied showed to enhance SOC, with no apparent link with the characteristics of specie (Table 5).

Table 5: SOC directions of changes following woody plant encroachment according to the specie's characteristics

	Mixte	**Non N2-fixing specie**	**N2-fixing specie**
Losses	0	2	0
Losses and gains	4	2	2
Gains	6	11	12
Gains or no net changes	1	1	0
No net changes	1	0	0
Losses or no net changes	0	0	0
total	**12**	**16**	**12**

However, Fabaceae species, with their ability to fix atmospheric nitrogen, can induce changes in nitrogen soil content, and therefore impact differently SOC storage. In this way, several authors underlined SOC sequestration depending on shrub or wood specie (Gomez-Ray et al., 2013; Li et al., 2016). For instance, Li et al. (2016) demonstrated SOC content to show a greater rate of increase in grassland encroached by leguminous shrubs than non-leguminous, as did Montané et al. (2006). It might be due to a higher quality input derived from leguminous species (Montané et al., 2006). Pellis et al. (2019) also observed a difference or SOC between conifer species and broadleaves species. The higher C : N ratio of the conifer litter might reduce it decomposability rate and therefore promote SOC.

SOC directions of changes seem therefore to depend on several and interactive factors, such as climate, type of vegetation, and soil properties. The relative influence of these drivers can vary according to studies, even if soil properties, and especially texture, is often underlined (Li et al., 2019; Li et al., 2019; Jobbagy & Jackson, 2000). In surface layer, between 0 and 100 cm, climatic and vegetation factors have a high explanatory power for SOC, whereas this influence decrease with depth. Below 100 cm, soil properties factor appeared to better determine SOC directions of changes (Jobbagy & Jackson, 2000).

2.3. Stability of SOC following encroachment, a potential sustainable storage?

Globally, soil carbon seems to increase following woody plant encroachment. As explain in introduction, SOC is however a dynamic reservoir, with a residence time varying from days to centuries. Several authors interested therefore in the evolution of SOC following woody plant encroachment. Some of them found a clear increase of SOC in the long term, where other explained the opposite.

Hudak et al. (2003), suggested the loss of grass roots as a possible mechanism of declining soil C concentration at sites where a closed canopy prohibited the growth of grass. In the same way, Brantley et al. (2010) demonstrated that rate of soil carbon was higher in the youngest thicket and declined with increasing thicket age. However, Coestee et al. (2012) showed that SOC was not affected by the percent of C4 roots, that is, grass roots didn't influence SOC concentration. Moreover, significant gains were observed in mature forests (Coestee et al., 2012), showing the loss of grass cover is compensate by trees growth. In the same way, Archer et al. (2004) found that SOC pool on invaded sites become enriched relative to remnant grasslands communities, the extent being a linear function of woody patch age. This suggests that SOC accumulation occurs with woody plant encroachment, but may take place very slowly (Coestee et al., 2012; Gomez-Rey et al., 2013), accumulation increasing as the trees grow (Archer et al., 2004). Some authors also describe a decrease of SOC in the first stage, but an increase in a long term (Hunziker et al., 2017) or no changes in long term between grassland and invaded sites (Nadal-Romero et al., 2018) (Figure 14).

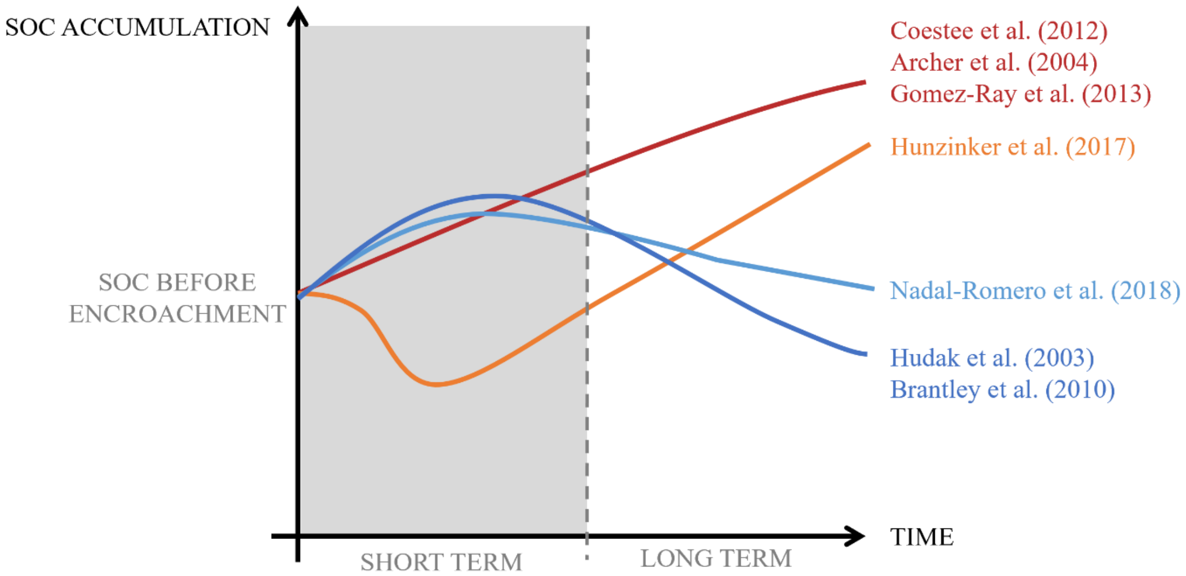

Figure 14 : Possible evolutions of SOC stocks following woody plant encroachment

These different evolutions over time question the stability of soil carbon in encroached ecosystems, a stability that depend on several parameters as climate, microbial activity, soil properties, land management practices (Asner et al., 2003; Blaser et al., 2011).

Button et al. (2009) underlined in this way that the proportion of protected carbon declined of 58 to 65% with woody plant encroachment. Indeed, the percentage of carbon stored in macroaggregates doubled while the importance of microaggregates and free silt and clay as protection declined (Button et al., 2009). If the authors underlined that the non-protected newly accrued SOC is likely to persist in soil as a result of its biochemical resistance to decay (lignin) (Button et al., 2009), more recent studies qualify this resistance, showing that it does not substantially contribute to the persistence of SOC in soil (Lefèvre et al., 2017; Hartley & Singh, 2018, Creamer et al., 2011). The increase of unprotected soil carbon was also underline by Hunziker et al. (2017) in Switzerland, especially during the first stage of encroachment. This unprotected carbon is likely to be leach and mixt with the soil solution, becoming therefore dissolved organic soil (DOC). The study observed in this way a significant increase of DOC (Hunziker et al., 2017), which represents a potential loss of carbon for the ecosystem through leaching. In addition to a decrease of carbon protection, Gomez-Ray et al. (2013) also showed encroachment accelerated carbon mineralization, which could limit SOC accumulation. Conversely, O'Donnell & Caylor (2012) showed that woody plant encroachment increases heterogeneity in soil carbon decomposition rates and has the net effect of increasing soil carbon residence time by 3.6-4.9 years. McKinley et al. (2008) also observed a significant decrease of potential carbon mineralization in encroached soil, which make case for a sustainable carbon accrual in soils. There is therefore a need to better evaluated stability of carbon storage in soil to fully understand change in c cycle.

Following encroachment, changes in soil organic carbon are observed. These changes present several directions and magnitudes, and seem regulated by an interaction of factors, such as climate, soil properties, and vegetation type. Moreover, these changes are time-depending, and there is a need of long-term observations to evaluated changes in C cycle. The final part of this review will focus on the possible emissions of carbon after encroachment.

3. Outputs of carbon following woody plant encroachment: CO_2 flux stimulation, risk of erosion, and soil inorganic carbon

This ultimate part aims to focus on soil carbon losses through different pathways. After changes in carbon soil input and soil accumulation, woody plant encroachment also impacts the different output of carbon, i.e., emission of carbon dioxide through heterotrophic respiration of soil microbes and roots, but also leaching of dissolved organic carbon through water erosion of soil. These losses of carbon could mitigate increases in above and belowground biomass underlined in the first part of the review.

3.1. CO2 flux changes following woody plant encroachment

Dioxide carbon flux is indeed an integral component of the carbon cycle. Soil respiration encompasses CO_2 flux respirated by soil fauna or plant roots. It varies seasonally, and it's controlled by environmental factors such as temperature, humidity, soil nutrient content and oxygen concentration (Lefèvre et al., 2017). As many of these factors being influenced by woody plant encroachment, changes in CO_2 flux are expected following invasion. Among articles, both increase and decrease of soil CO_2 flux was observed (Figure 15).

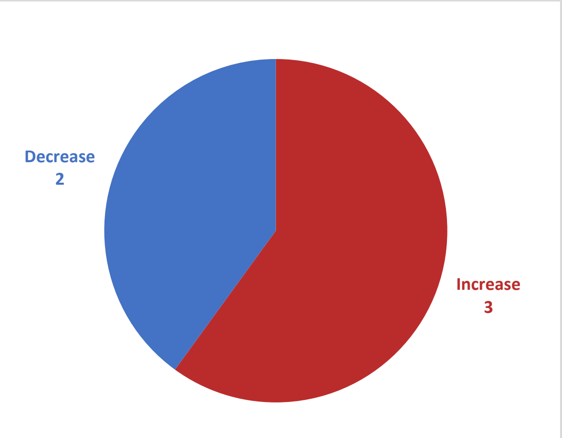

Figure 15: CO2 flux directions following woody plant encroachment (Only studies comparing encroached areas with non-encroached areas, or studying a gradient of encroachment are considered)

Soil CO2 flux was for instance significantly reduced in shrub islands relative to open grassland (Lett et al., 2004; McCarron et al., 2003). On the same way, McCarron et al. (2003) showed that the shift in plant community composition from grassland to shrubland resulted in a 16% decrease in annual soil CO_2 flux. Conversely, Brantley et al (2010) demonstrated a stimulation of emission by shrub encroachment, especially at the first stage of encroachment. Thomas et al. (2018) also underlined an increase of CO_2 under shrubs and trees compared with grasses. This stimulation can result from increased litterfall and soil moisture that often accompany woody plant encroachment. However, increases in CO2 flux in woody thickets did not offset contribution of increased litterfall to SOC (Brantley et al., 2010). As most of studies observed an increase in SOC following encroachment, it seems that CO_2 fluxes, even stimulated with shrubs and trees, do not mitigated carbon inputs in soil. However, few articles are here considered, and deeper research are needed to conclude.

3.2. A risk of leaching and erosion

Besides the decomposition of organic carbon, the leaching of dissolved organic carbon (DOC) can lower the SOC pool. There is consequently a pathway for carbon from the terrestrial to the aquatic system. To fully understand how woody plant encroachment impact soil carbon cycle, there is a need to focus on leaching and erosion processes. Indeed, woody plant impact largely water runoff, by fostering water surface runoff (Parizek et al., 2002). The increase of water runoff could induce erosion processes. In this way, several authors underlined the risk of leaching DOC with woody plant encroachment. Puttock at al. (2014) put forward that woody plant encroachment sites exhibited an accentuated hydrological response to rainfall leading to greater event organic carbon losses. Reduction of grass cover following invasion decreased vegetation protection of soil and therefore increases connectivity and water erosion fluxes, a pathway where soil carbon can be lost. Moreover, carbon lost via erosion partly came from previous stable under grass cover carbon (Puttock et al., 2014). These different losses of carbon via erosion are needed to be considered to better understand carbon cycle change with woody plant encroachment.

3.3. Soil inorganic carbon, a non-negligible pool needed to be deeply considered

Soil inorganic carbon dynamics in non-negligible in terrestrial C biochemical cycle. However, very few studies consider this component in a woody plant encroachment context. This might be due to the traditional widespread idea that these stocks, as mainly in deep soil, are stable, and therefore have a very minor effect on the short-term carbon budget of terrestrial ecosystems (Liu et al., 2015; Ding et al., 2020). However, Liu et al. (2019) showed shrub encroachment significantly reduced SIC in the upper 100 cm, especially in the subsurface soil (20-50 cm). The magnitude of this changes was related with changes in pH, shrub patch size and initial SIC density. It seems that the reduction in SICD can be attributed to the shrub encroachment-related soil acidification. The loss of SIC was mainly released in the atmosphere (Liu et al., 2019). Conversely, Ding et al. (2020) founded an increase of SIC stock following encroachment. Other studies are needed to fully understand effects of woody encroachment on soil inorganic carbon.

Soils, and more generally ecosystems, can therefore loss carbon through different pathway, such as CO_2 emission due to microbial and root respiration, leaching and even erosion. These losses might offset the increase of plant biomass constated above, and therefore threaten carbon storage in soil. Moreover, other misunderstood or poorly studied question, as changes in SIC pool, could also represent an output of carbon following invasion.

CONCLUSION

This review aimed to enhance the understanding of the impact of woody plant encroachment on soil properties, and especially determined the effects of invasion on carbon biochemical cycle. The bibliometric analysis showed woody plant encroachment to be a recent subject of research, mainly conducted in the United-States of America, South Africa, and China, even if there are proofs of encroachment all around the word. It put forward preferential climate areas encroached, and most common encroaching species characteristics.

Impacts of invasion on carbon biochemical cycle are several. Encroachment affects above and belowground biomass, soil organic carbon, and changes also soil respiration. Moreover, it can influence water runoff and lead to erosion, a pathway of potential losses of carbon. Changes in carbon cycle are therefore plural, and depend on climate, soil properties, encroaching species, level of encroachment, historical land use, and an interaction of all these factors. In a carbon sequestration perspective, it seems that encroached areas are potential sink of carbon in most of cases (Li et al., 2016; Eldridge et al., 2011), even if a robust generalization of woody encroachment impact on ecosystem carbon balance is elusive due to the variety of the phenomenon. However, stability of these increases remains unclear due to several bias. First, changes are mainly studied in the first layers of soil, whereas subsoil play an important role in carbon sequestration. Several authors underlined in that way the need to considerate the whole soil profile to estimate soil carbon changes (Fino et al., 2020; Chiti et al., 2016), especially to quantify them robustly and determine magnitude of the changes. Moreover, few studies studied changes in root size, shape and spread whereas woody root system is important to predict changes of carbon inputs in soil. Secondly, according to the bibliometric analysis, few studies focus on the micro-organism's communities' changes, which are key actor in carbon cycling. Gomez-Ray et al. (2013) put also forward the need to consider seasonal microbial activity and its restriction by environmental factors such as temperature and humidity, to fully understand the degrading process of carbon. These uncovered questions are potential lines of inquiry for future research.

BIBLIOGRAPHY

Acharya, B., Kharel, G., Zou, C., Wilcox, B., & Halihan, T. (2018). Woody Plant Encroachment Impacts on Groundwater Recharge : A Review. *Water*, *10*(10), 1466. https://doi.org/10.3390/w10101466

Alberti, G., Leronni, V., Piazzi, M., Petrella, F., Mairota, P., Peressotti, A., Piussi, P., Valentini, R., Gristina, L., La Mantia, T., Novara, A., & Rühl, J. (2011). Impact of woody encroachment on soil organic carbon and nitrogen in abandoned agricultural lands along a rainfall gradient in Italy. *Regional Environmental Change*, *11*(4), 917-924. https://doi.org/10.1007/s10113-011-0229-6

Alberti, G., Vicca, S., Inglima, I., Belelli-Marchesini, L., Genesio, L., Miglietta, F., Marjanovic, H., Martinez, C., Matteucci, G., D'Andrea, E., Peressotti, A., Petrella, F., Rodeghiero, M., & Cotrufo, M. (2015). Soil C : N stoichiometry controls carbon sink partitioning between above-ground tree biomass and soil organic matter in high fertility forests. *iForest - Biogeosciences and Forestry*, *8*(2), 195-206. https://doi.org/10.3832/ifor1196-008

Archer, S.R., Boutton, T.W., & McMurtry, C.R. (2004). Carbon and Nitrogen Accumulation in a Savanna Landscape : Field and Modeling Perspectives.

Bai, S. G., Jiao, Y., Yang, W. Z., Gu, P., Yang, J., & Liu, L. J. (2017). Review of progress in soil inorganic carbon research. *IOP Conference Series : Earth and Environmental Science*, *100*, 012129. https://doi.org/10.1088/1755-1315/100/1/012129

Barger, N. N., Archer, S. R., Campbell, J. L., Huang, C. Y., Morton, J. A., & Knapp, A. K. (2011). Woody plant proliferation in North American drylands : A synthesis of impacts on ecosystem carbon balance. *Journal of Geophysical Research*, *116*. https://doi.org/10.1029/2010jg001506

Birhane, E., Treydte, A. C., Eshete, A., Solomon, N., & Hailemariam, M. (2017). Can rangelands gain from bush encroachment ? Carbon stocks of communal grazing lands invaded by Prosopis juliflora. *Journal of Arid Environments*, *141*, 60-67. https://doi.org/10.1016/j.jaridenv.2017.01.003

Blaser, W. J., Shanungu, G. K., Edwards, P. J., & Olde Venterink, H. (2014). Woody encroachment reduces nutrient limitation and promotes soil carbon sequestration. *Ecology and Evolution*, *4*(8), 1423-1438. https://doi.org/10.1002/ece3.1024

Bond, W. J., & Midgley, G. F. (2012). Carbon dioxide and the uneasy interactions of trees and savannah grasses. *Philosophical Transactions of the Royal Society B : Biological Sciences*, *367*(1588), 601-612. https://doi.org/10.1098/rstb.2011.0182

Boutton, T., Liao, J., Filley, T., & Archer, S. (2009). Belowground Carbon Storage and Dynamics Accompanying Woody Plant Encroachment in a Subtropical Savanna. *SSSA Special Publications*, 181-205. https://doi.org/10.2136/sssaspecpub57.2ed.c12

Brantley, S. T., & Young, D. R. (2010). Shrub expansion stimulates soil C and N storage along a coastal soil chronosequence. *Global Change Biology*, *16*(7), 2052-2061. https://doi.org/10.1111/j.1365-2486.2009.02129.x

Buol, S. W., Southard, R. J., Graham, R. C., & McDaniel, P. A. (2011). *Soil Genesis and Classification* (6e éd.). Wiley-Blackwell.

Chiti, T., Mihindou, V., Jeffery, K. J., Malhi, Y., de Oliveira, F. L., White, L. J. T., & Valentini, R. (2016). Impact of woody encroachment on soil organic carbon storage in the Lopé National Park, Gabon. *Biotropica*, *49*(1), 9-12. https://doi.org/10.1111/btp.12369

Coetsee, C., Gray, E. F., Wakeling, J., Wigley, B. J., & Bond, W. J. (2012). Low gains in ecosystem carbon with woody plant encroachment in a South African savanna. *Journal of Tropical Ecology*, *29*(1), 49-60. https://doi.org/10.1017/s0266467412000697

Creamer, C., Filley, T., Boutton, T., Oleynik, S., & Kantola, I. (2011). Controls on soil carbon accumulation during woody plant encroachment : Evidence from physical fractionation, soil respiration, and δ13C of respired CO2. *Soil Biology and Biochemistry*, *43*(8), 1678-1687. https://doi.org/10.1016/j.soilbio.2011.04.013

Derrien D., Dignac M.F., Basile-Doelsch I., **Barot Sébastien**, Cécillon L., Chenu C., **Chevallier Tiphaine**, Freschet G.T., Garnier P., Guenet B., Hedde M., Klumpp K., Lashermes G., Maron P.A., Nunan N., Roumet C., Baré P. (2016). Stocker du C dans les sols : quels mécanismes, quelles pratiques agricoles, quels indicateurs ?. *Etude et Gestion des Sols*, 23 (1), p. 193-223. ISSN 1252-6851.

Ding, L., Wang, P., Zhang, W., Zhang, Y., Li, S., Wei, X., Chen, X., Zhang, Y., & Yang, F. (2019). Shrub Encroachment Shapes Soil Nutrient Concentration, Stoichiometry and Carbon Storage in an Abandoned Subalpine Grassland. *Sustainability*, *11*(6), 1732. https://doi.org/10.3390/su11061732

Ding, L., Wang, P., Zhang, W., Zhang, Y., Li, S., Wei, X., Chen, X., Zhang, Y., & Yang, F. (2020). Soil stoichiometry modulates effects of shrub encroachment on soil carbon concentration and stock in a subalpine grassland. *iForest - Biogeosciences and Forestry*, *13*(1), 65-72. https://doi.org/10.3832/ifor3091-012

Dlamini, P., Mbanjwa, V., Gxasheka, M., Tyasi, L., & Sekhohola-Dlamini, L. (2019). Chemical stabilisation of carbon stocks by polyvalent cations in plinthic soil of a shrub-encroached savanna grassland, South Africa. *CATENA*, *181*, 104088. https://doi.org/10.1016/j.catena.2019.104088

Dynarski, K. A., Bossio, D. A., & Scow, K. M. (2020). Dynamic Stability of Soil Carbon : Reassessing the "Permanence" of Soil Carbon Sequestration. *Frontiers in Environmental Science*, *8*. https://doi.org/10.3389/fenvs.2020.514701

Fino, E., Blasi, E., Perugini, L., Pellis, G., Valentini, R., & Chiti, T. (2020). Is Soil Contributing to Climate Change Mitigation during Woody Encroachment ? A Case Study on the Italian Alps. *Forests*, *11*(8), 887. https://doi.org/10.3390/f11080887

Eldridge, D. J., Bowker, M. A., Maestre, F. T., Roger, E., Reynolds, J. F., & Whitford, W. G. (2011). Impacts of shrub encroachment on ecosystem structure and functioning : towards a global synthesis. *Ecology Letters*, *14*(7), 709-722. https://doi.org/10.1111/j.1461-0248.2011.01630.x

Eldridge, D. J., & Soliveres, S. (2014). Are shrubs really a sign of declining ecosystem function ? Disentangling the myths and truths of woody encroachment in Australia. *Australian Journal of Botany*, *62*(7), 594. https://doi.org/10.1071/bt14137

Eldridge, D. J., & Ding, J. (2020). Remove or retain : ecosystem effects of woody encroachment and removal are linked to plant structural and functional traits. *New Phytologist*, *229*(5), 2637-2646. https://doi.org/10.1111/nph.17045

Gómez-Rey, M. X., Madeira, M., Gonzalez-Prieto, S. J., & Coutinho, J. (2013). Soil C and N dynamics in a Mediterranean oak woodland with shrub encroachment. *Plant and Soil*, *371*(1-2), 339-354. https://doi.org/10.1007/s11104-013-1695-z

Grellier, S. (2011). *Invasion ligneuse par l'Acacia sieberiana dans un pâturage raviné du KwaZulu-Natal (Afrique du Sud)*. https://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers11-10/010052254.pdf

Gougoulias, C., Clark, J. M., & Shaw, L. J. (2014). The role of soil microbes in the global carbon cycle : tracking the below-ground microbial processing of plant-derived carbon for manipulating carbon dynamics in agricultural systems. *Journal of the Science of Food and Agriculture*, *94*(12), 2362-2371. https://doi.org/10.1002/jsfa.6577

Gross, C. D., & Harrison, R. B. (2019). The Case for Digging Deeper : Soil Organic Carbon Storage, Dynamics, and Controls in Our Changing World. *Soil Systems*, *3*(2), 28. https://doi.org/10.3390/soilsystems3020028

Harte, J., Saleska, S. R., & Levy, C. (2015). Convergent ecosystem responses to 23-year ambient and manipulated warming link advancing snowmelt and shrub encroachment to transient and long-term climate-soil carbon feedback. *Global Change Biology*, *21*(6), 2349-2356. https://doi.org/10.1111/gcb.12831

Hartley, I. P., & Singh, B. K. (2018). Impact of Global Changes on Soil C Storage—Possible Mechanisms and Modeling Approaches. *Soil Carbon Storage*, 245-279. https://doi.org/10.1016/b978-0-12-812766-7.00008-1

Hu, X., Li, X. Y., Guo, L. L., Liu, Y., Wang, P., Zhao, Y. D., Cheng, Y. Q., Lyu, Y. L., & Liu, L. Y. (2018). Influence of shrub roots on soil macropores using X-ray computed tomography in a shrub-encroached grassland in Northern China. *Journal of Soils and Sediments*, *19*(4), 1970-1980. https://doi.org/10.1007/s11368-018-2218-6

Hudak, A. T., Wessman, C. A., & Seastedt, T. R. (2003). Woody overstorey effects on soil carbon and nitrogen pools in South African savanna. *Austral Ecology*, *28*(2), 173-181. https://doi.org/10.1046/j.1442-9993.2003.01265.x

Hunziker, M., Caviezel, C., & Kuhn, N. J. (2017). Shrub encroachment by green alder on subalpine pastures : Changes in mineral soil organic carbon characteristics. *CATENA*, *157*, 35-46. https://doi.org/10.1016/j.catena.2017.05.005

Hughes, R. F., Archer, S. R., Asner, G. P., Wessman, C. A., McMurtry, C., Nelson, J., & Ansley, R. J. (2006). Changes in aboveground primary production and carbon and nitrogen pools accompanying woody plant encroachment in a temperate savanna. *Global Change Biology*, *12*(9), 1733-1747. https://doi.org/10.1111/j.1365-2486.2006.01210.x

Jackson, R. B., Banner, J. L., Jobbágy, E. G., Pockman, W. T., & Wall, D. H. (2002). Ecosystem carbon loss with woody plant invasion of grasslands. *Nature*, *418*(6898), 623-626. https://doi.org/10.1038/nature00910

Jobbágy, E. G., & Jackson, R. B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications*, *10*(2), 423-436. https://doi.org/10.2307/2641104

Ladwig, L. M., Bell-Dereske, L. P., Bell, K. C., Collins, S. L., Natvig, D. O., & Taylor, D. L. (2021). Soil fungal composition changes with shrub encroachment in the northern Chihuahuan Desert. *Fungal Ecology*, *53*, 101096. https://doi.org/10.1016/j.funeco.2021.101096

Lal, R., Kimble, J. M., Follett, R. F., & Stewart, B. A. (Éds.). (1997). Soil Processes and the Carbon Cycle. *CRC*, 1-9. https://doi.org/10.1201/9780203739273

Lefèvre, C., Rekik, F., Alcantara, V., & Wiese, L. (2017). *Carbone organique du sol, une richesse invisible*. FAO, Organisation des Nations Unies pour l'alimentation et l'agriculture. http://www.fao.org/3/i6937f/i6937f.pdf

Lett, M. S., Knapp, A. K., Briggs, J. M., & Blair, J. M. (2004). Influence of shrub encroachment on aboveground net primary productivity and carbon and nitrogen pools in a mesic grassland. *Canadian Journal of Botany*, *82*(9), 1363-1370. https://doi.org/10.1139/b04-088

Li, H., Shen, H., Chen, L., Liu, T., Hu, H., Zhao, X., Zhou, L., Zhang, P., & Fang, J. (2016). Effects of shrub encroachment on soil organic carbon in global grasslands. *Scientific Reports*, *6*(1). https://doi.org/10.1038/srep28974

Liu, F., Wu, X. B., Bai, E., Boutton, T. W., & Archer, S. R. (2011). Quantifying soil organic carbon in complex landscapes : an example of grassland undergoing encroachment of woody plants. *Global Change Biology*, *17*(2), 1119-1129. https://doi.org/10.1111/j.1365-2486.2010.02251.x

Li, H., Shen, H., Zhou, L., Zhu, Y., Chen, L., Hu, H., Zhang, P., & Fang, J. (2019). Shrub encroachment increases soil carbon and nitrogen stocks in temperate grasslands in China. *Land Degradation & Development*, *30*(7), 756-767. https://doi.org/10.1002/ldr.3259

Li, Z., Li, X., Chen, L., Li, R., Deng, F., Zhang, M., & Wen, L. (2020). Carbon flux and soil organic carbon content and density of different community types in a typical steppe ecoregion of Xilin Gol in inner Mongolia, China. *Journal of Arid Environments*, *178*, 104155. https://doi.org/10.1016/j.jaridenv.2020.104155

Liao, J., Boutton, T., & Jastrow, J. (2006). Storage and dynamics of carbon and nitrogen in soil physical fractions following woody plant invasion of grassland. *Soil Biology and Biochemistry*, *38*(11), 3184-3196. https://doi.org/10.1016/j.soilbio.2006.04.003

Liu, S., Zhou, L., Li, H., Zhao, X., Yang, Y., Zhu, Y., Hu, H., Chen, L., Zhang, P., Shen, H., & Fang, J. (2019). Shrub encroachment decreases soil inorganic carbon stocks in Mongolian grasslands. *Journal of Ecology*, *108*(2), 678-686. https://doi.org/10.1111/1365-2745.13298

Luvuno, L., Biggs, R., Stevens, N., & Esler, K. (2018). Woody Encroachment as a Social-Ecological Regime Shift. *Sustainability*, *10*(7), 2221. https://doi.org/10.3390/su10072221

Maestre, F. T., Bowker, M. A., Puche, M. D., Belén Hinojosa, M., Martínez, I., García-Palacios, P., Castillo, A. P., Soliveres, S., Luzuriaga, A. L., Sánchez, A. M., Carreira, J. A., Gallardo, A., & Escudero, A. (2009). Shrub encroachment can reverse desertification in semi-arid Mediterranean grasslands. *Ecology Letters*, *12*(9), 930-941. https://doi.org/10.1111/j.1461-0248.2009.01352.x

McCarron, J. K., Knapp, A. K., & Blair, J. M. (2003). Soil C and N responses to woody plant expansion in a mesic grassland. *Plant and Soil*, *257*(1), 183-192. https://doi.org/10.1023/a:1026255214393

McKinley, D. C., & Blair, J. M. (2008). Woody Plant Encroachment by Juniperus virginiana in a Mesic Native Grassland Promotes Rapid Carbon and Nitrogen Accrual. *Ecosystems*, *11*(3), 454-468. https://doi.org/10.1007/s10021-008-9133-4

Montané, F., Romanyà, J., Rovira, P., & Casals, P. (2010). Aboveground litter quality changes may drive soil organic carbon increase after shrub encroachment into mountain grasslands. *Plant and Soil*, *337*(1-2), 151-165. https://doi.org/10.1007/s11104-010-0512-1

Montané, F., Rovira, P., & Casals, P. (2007). Shrub encroachment into mesic mountain grasslands in the Iberian peninsula : Effects of plant quality and temperature on soil C and N stocks. *Global Biogeochemical Cycles*, *21*(4), n/a. https://doi.org/10.1029/2006gb002853

Mureva, A., Ward, D., Pillay, T., Chivenge, P., & Cramer, M. (2018). Soil organic carbon increases in semi-arid regions while it decreases in humid regions due to woody-plant encroachment of grasslands in South Africa. *Scientific Reports*, *8*(1). https://doi.org/10.1038/s41598-018-33701-7

Nadal-Romero, E., Otal-Laín, I., Lasanta, T., Sánchez-Navarrete, P., Errea, P., & Cammeraat, E. (2018). Woody encroachment and soil carbon stocks in subalpine areas in the Central Spanish Pyrenees. *Science of The Total Environment*, *636*, 727-736. https://doi.org/10.1016/j.scitotenv.2018.04.324

O'Donnell, F. C., & Caylor, K. K. (2012). A model-based evaluation of woody plant encroachment effects on coupled carbon and water cycles. *Journal of Geophysical Research : Biogeosciences*, *117*(G2), n/a. https://doi.org/10.1029/2011jg001899

Parizek, B., Rostagno, C. M., & Sottini, R. (2002). Soil Erosion as Affected by Shrub Encroachment in Northeastern Patagonia. *Journal of Range Management*, *55*(1), 43. https://doi.org/10.2307/4003261

Pellegrini, E., Boscutti, F., Alberti, G., Casolo, V., Contin, M., & de Nobili, M. (2021). Stand age, degree of encroachment and soil characteristics modulate changes of C and N cycles in dry grassland soils invaded by the N2-fixing shrub Amorpha fruticosa. *Science of The Total Environment*, *792*, 148295. https://doi.org/10.1016/j.scitotenv.2021.148295

Pellis, G., Chiti, T., Rey, A., Curiel Yuste, J., Trotta, C., & Papale, D. (2019). The ecosystem carbon sink implications of mountain forest expansion into abandoned grazing land : The role of subsoil and climatic factors. *Science of The Total Environment*, *672*, 106-120. https://doi.org/10.1016/j.scitotenv.2019.03.329

Puttock, A., Dungait, J. A. J., Macleod, C. J. A., Bol, R., & Brazier, R. E. (2014). Woody plant encroachment into grasslands leads to accelerated erosion of previously stable organic carbon from dryland soils. *Journal of Geophysical Research : Biogeosciences*, *119*(12), 2345-2357. https://doi.org/10.1002/2014jg002635

Ravi, S., Breshears, D. D., Huxman, T. E., & D'Odorico, P. (2010). Land degradation in drylands : Interactions among hydrologic–aeolian erosion and vegetation dynamics. *Geomorphology*, *116*(3-4), 236-245. https://doi.org/10.1016/j.geomorph.2009.11.023

Recous, S., Lashermes, G., & Bertrand, I. (2017). Couplages et contrôle des cycles du carbone et de l'azote par les communautés microbiennes dans les sols cultivés. *Les sols et la vie souterraine : Des enjeux majeurs en agroécologie*. https://hal.archives-ouvertes.fr/hal-01543489

Roques, K., O'Connor, T., & Watkinson, A. (2001). Dynamics of shrub encroachment in an African savanna : relative influences of fire, herbivory, rainfall and density dependence. *Journal of Applied Ecology*, *38*(2), 268-280. https://doi.org/10.1046/j.1365-2664.2001.00567.x

Sankaran, M., Hanan, N. P., Scholes, R. J., Ratnam, J., Augustine, D. J., Cade, B. S., Gignoux, J., Higgins, S. I., le Roux, X., Ludwig, F., Ardo, J., Banyikwa, F., Bronn, A., Bucini, G., Caylor, K. K., Coughenour, M. B., Diouf, A., Ekaya, W., Feral, C. J.,. . . Zambatis, N. (2005). Determinants of woody cover in African savannas. *Nature*, *438*(7069), 846-849. https://doi.org/10.1038/nature04070

Scharenbroch, B. C., Flores-Mangual, M. L., Lepore, B., Bockheim, J. G., & Lowery, B. (2010). Tree Encroachment Impacts Carbon Dynamics in a Sand Prairie in Wisconsin. *Soil Science Society of America Journal*, *74*(3), 956-968. https://doi.org/10.2136/sssaj2009.0223

Scholes, R. J., & Archer, S. R. (1997). Tree-Grass Interactions in Savannas. *Annual Review of Ecology and Systematics*, *28*(1), 517-544. https://doi.org/10.1146/annurev.ecolsys.28.1.517

Sitters, J., Edwards, P. J., & Olde Venterink, H. (2012). Increases of Soil C, N, and P Pools Along an Acacia Tree Density Gradient and Their Effects on Trees and Grasses. *Ecosystems*, *16*(2), 347-357. https://doi.org/10.1007/s10021-012-9621-4

Thomas, A. D., Elliott, D. R., Dougill, A. J., Stringer, L. C., Hoon, S. R., & Sen, R. (2018). The influence of trees, shrubs, and grasses on microclimate, soil carbon, nitrogen, and CO2 efflux : Potential implications of shrub encroachment for Kalahari rangelands. *Land Degradation & Development*, *29*(5), 1306-1316. https://doi.org/10.1002/ldr.2918

Throop, H. L., & Archer, S. R. (2008). Shrub (Prosopis velutina) encroachment in a semidesert grassland : spatial-temporal changes in soil organic carbon and nitrogen pools. *Global Change Biology*, *14*(10), 2420-2431. https://doi.org/10.1111/j.1365-2486.2008.01650.x

Throop, H. L., Lajtha, K., & Kramer, M. (2012). Density fractionation and 13C reveal changes in soil carbon following woody encroachment in a desert ecosystem. *Biogeochemistry*, *112*(1-3), 409-422. https://doi.org/10.1007/s10533-012-9735-y

Trivedi, P., Singh, B. P., & Singh, B. K. (2018). Soil Carbon : Introduction, Importance, Status, Threat, and Mitigation. *Soil Carbon Storage*, 1-28. https://doi.org/10.1016/b978-0-12-812766-7.00001-9

Van Auken, O. (2009). Causes and consequences of woody plant encroachment into western North American grasslands. *Journal of Environmental Management*, *90*(10), 2931-2942. https://doi.org/10.1016/j.jenvman.2009.04.023

Wheeler, C. W., Archer, S. R., Asner, G. P., & McMurtry, C. R. (2007). Climatic/edaphic controls on soil carbon/nitrogen response to shrub encroachment in desert grassland. *Ecological Applications*, *17*(7), 1911-1928. https://doi.org/10.1890/06-1580.1

Zhang, Z. H., Li, X. Y., Yang, X., Shi, Y., Zhang, S. Y., & Jiang, Z. Y. (2019). Changes in soil properties following shrub encroachment in the semiarid Inner Mongolian grasslands of China. *Soil Science and Plant Nutrition*, *66*(2), 369-378. https://doi.org/10.1080/00380768.2019.1706430

Zhao, F., Wu, Y., Hui, J., Sivakumar, B., Meng, X., & Liu, S. (2021). Projected soil organic carbon loss in response to climate warming and soil water content in a loess watershed. *Carbon Balance and Management*, *16*(1). https://doi.org/10.1186/s13021-021-00187-2

Zhou, L., Li, H., Shen, H., Xu, Y., Wang, Y., Xing, A., Zhu, Y., Zhou, S., & Fang, J. (2018). Effects of shrub encroachment on vertical changes in soil organic carbon in Mongolian grasslands : using a multi-biomarker approach. *Plant and Soil*, *431*(1-2), 217-230. https://doi.org/10.1007/s11104-018-3761-z

Zhu, Y., Shen, H., Feng, Y., Li, H., Akinyemi, D. S., Hu, H., & Fang, J. (2021). Effects of shrub encroachment on soil aggregates and organic carbon vary in different grasslands in Inner Mongolia, China. *Ecosphere*, *12*(2). https://doi.org/10.1002/ecs2.3363

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CLOT Mélina – PFE DAE5 – IUT ADAGE – 2021.2022

Woody encroachment and impact on soils properties – a review

Bibliometric analysis and focus on impacts of woody encroachment on soil carbon cycle

Résumé : L'empiètement des plantes ligneuses a été largement observé dans le monde, et ce sous de nombreuses latitudes et longitudes. S'il s'agit d'un phénomène naturel, il semble s'accélérer ces dernières années, notamment depuis 160 ans. Ses causes et ses conséquences ont été largement étudiées et s'avèrent être plurielles et spécifiques au site d'étude. Les changements globaux, la disponibilité des ressources et les perturbations anthropologiques ou naturelles sont des moteurs de l'invasion ligneuse, qui de plus interagissent entre eux. Les sols, supports de cette invasion, sont affectés de multiples façons par l'empiétement. Cependant, peu de consensus scientifique existe sur les conséquences de l'empiétement sur les propriétés du sol. De plus, une littérature abondante, peu synthétisée, rend difficile une compréhension globale. Pour clarifier les impacts de l'invasion ligneuse sur les propriétés des sols, une analyse bibliométrique a été mené. Elle vise à caractériser la manière dont le sol est considéré dans 198 études répertoriées, et déduire d'autres champs de recherche possible. La deuxième partie de cette review se concentre sur les impacts de l'empiétement sur le cycle du carbone. Elle démontre que l'empiétement affecte la biomasse aérienne et souterraine, le carbone organique du sol, et modifie également la respiration du sol. De plus, l'invasion peut influencer le ruissellement des eaux et conduire à une accélération des processus d'érosion, une voie potentielle de perte de carbone. Les changements du cycle du carbone sont donc pluriels et dépendent du climat, des propriétés du sol, des espèces envahissantes, du niveau d'empiètement, de l'utilisation historique des terres et d'une interaction de tous ces facteurs. Dans une perspective de séquestration du carbone, il semble que, dans la plupart des cas, les zones empiétées soient des puits de carbone potentiel, même si une généralisation robuste de l'impact de l'empiètement ligneux à travers le monde est illusoire, en raison de la variété du phénomène et des spécificités relatives à chaque région envahie. Cependant, la stabilité de ces augmentations reste incertaine et doit être plus spécifiquement étudiée. Plusieurs pistes de recherches sont proposées pour mieux cerner les impacts de l'invasion ligneuses sur les sols, et orienter vers des champs d'études peu traité actuellement.

Mots clés : invasion ligneuse, propriété du sol, séquestration carbone, cycle du carbone, bibliométrie