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Woody encroachment impacts on soil properties

L'impact des ligneux sur les propriétés du sol

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2017-2018

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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 Ingénierie du Projet d'Aménagement, Paysage et Environnement de l'UMR 6173 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

Nous tenons à remercier notre directrice de recherche, madame Séraphine Grellier, pour nous avoir encadré et conseillé durant toute cette période dans le projet de fin d'études et nous avoir permis de concrétiser notre travail. Merci également d'avoir pris le temps de nous corriger et expliquer de la rédaction du rapport.

SOMMAIRE

Introduction

Increases in woody plant abundance, with accompanying changes in the herbaceous cover and the composition of the natural vegetation in grassland and savanna regions, is termed bush or shrub encroachment (Archer etal. 1988, Brown and Archer 1999, O'Connor and Crow 2000, Hoffman and Ashwell 2001). During the process of the encroachment, the surface vegetation changed from herb to shrub, the coverage of herbaceous plants decreased, the bare land increased, and the temporal and spatial heterogeneity of soil moisture and nutrients increased. The structure and function of the original community ecosystem have a significant impact. Encroachment of endemic woody species and gully erosion in grasslands and savannas has increased worldwide over the past 100 years. Research shows that nearly 10% ~ 20% of the arid and semi-arid regions have experienced shrub or bush encroachment. It has been a global phenomenon widely reported in the United States, Africa, Australia, South America and Mediterranean Basin during the past decades (van Auken, 2000; D'Odorico et al., 2011; Eldridge et al., 2011). Controlling mechanisms and the consequences of woody encroachment on ecosystems are at the heart of a scientific debate.

However, a number of factors contributed to the formation of this phenomenon. Including overgrazing, fire, increased greenhouse gases, drought caused by global warming, and changes in rainfall patterns. Through the analysis of the existing literature, we find that the most common influencing factors are overgrazing and grassland burning. As overgrazing and other disturbance will reduce the above-ground biomass of the herb, the cover of the herbaceous vegetation will be reduced. At the same time, the surface homogeneity will be destroyed, the surface bareness will increase, and the soil erosion will be intensified, resulting in the loss and redistribution of soil moisture and nutrients. Shrubs access to more available resources, especially water. Changes in resource balance are conducive to the germination and growth of shrubs, leading shrubs occupy a dominant position in the community in a short time. As for the fire, frequent fires reduce the richness of herbs with good palatability, and promote the development of plant with poor palatability, good fire-resistant, and rich lignin. Meanwhile, studies suggest that climate warming promotes shrub invasion because the majority of invasive shrub growth is limited by low temperatures. Global warming mitigates damage caused by frost damage, reducing the mortality of savannah-sensitive shrubs. There is also a close relationship between climate change and fire. Global warming will affect the frequency and intensity of fire, thus affecting the density of shrubs and herbs. Increasing CO_2 concentration can also promote shrub invasion. As shrubs and herbs have different physiological characteristics, CO_2 can affect vegetation growth by changing water use efficiency, photosynthetic rate and photosynthetic nutrient utilization. Most of the tropical and subtropical herbs are C4 plants, most of which are C3 plants. C4 plants have higher water use efficiency in arid and semi-arid environments, making the herbs more competitive. However, when the concentration of CO_2 in the atmosphere increases, the concentration of CO_2 between the shrubs cells, and in the atmosphere will also increase, thereby enhancing the water use efficiency of the shrubs and making the shrubs more competitive than the herbs. In short, the factors that affect the invasion of shrubs into the grassland are complex with the vegetation interactions.

As for the consequences, this phenomenon has led to complex effects. Woody encroachment is often closely linked to changes of functions and structure in ecosystem. At the community level, shrub invasion affects the biomass of vegetation and species richness of the ecosystem. In 13 North American prairie communities, the species richness decreased with the invasion of woody plants, on average 45%, and the species richness of the communities with higher precipitation decreased more. What's more, it makes the distribution of above-ground vegetation changed, affecting the distribution of root system and the distribution of nutrient elements and water, reducing soil nutrient. Shrub density increases occurred in the North American Chihuahuan Desert and Australia's arid and semi-arid grasslands. Prairie shrubs inhibited the growth of vegetation in the lower canopy, decreased the nutrient pool and changed the elemental distribution, which is considered as the main reason for the decline and accelerated degradation of ecosystem. Many studies suggest that woody encroachment is another way of expressing grassland degradation or desertification, because the increase of surface runoff caused by shrubification and soil erosion, as well as the reduction of soil moisture, are typical examples of desertification. From a conservation perspective, woody encroachment has been threatened the maintenance of grassland and savanna ecosystems and its endemic biodiversity.

In most cases, in arid and semi-arid grasslands, there is a lot of calcareous soil under vegetation. Poor eluviation is the common feature of grassland. Infiltration of water is not easy to dissolve and take away the material in the soil. There are deposits of calcium in the lower part of the soil profile where salt-based substances are abundant, mostly neutral to alkaline. Organic matter mainly enters the soil in the form of roots, and the humus content gradually descends from the surface layer. In desert areas, there are many crusts in the soil, and the surface is highly aggregated. The easily soluble salts accumulate in the depth of the profile, forming calcification and salinization. All in all, the soil properties in the above areas are likely to promote soil eutrophication, salinization, and they are adverse to fighting wind erosion and water erosion. The following content will also analyze the interaction of this type of soil and woody plant invasion. The objectives of our project are to review the consequences of woody encroachment, especially for soil properties. Various data including the geographical extent of woody encroachment, the types of woody plants, its causes, relative climates and soils types are collected. In the first stage, we summarized the articles and various data, and simply understood the impact of various indicators on soil properties. In the second stage, we carefully read the articles according to the topics of each chapter, searched for the corresponding results, analyzed the integration conclusions and asked questions.

In the end, we have summarized and extended the following aspects:

How the soil fauna and flora, **soil carbon cycling**, **ratio of carbon-nitrogen**, **soil nutrients**, **soil physical properties**, **water resources**, **and soil erosion are affected by woody encroachment**?

Because of plentiful factors in the viewing of this paper, although there are a large number of documents, there are still some issues that have not been ascertained or disclosed, and we also put forward our own understanding and assumptions. The phenomenon of wood invasiveness is still spreading all over the world. Although this article only deals with the impact on the soil, we also deeply understand the causes, results, development trends and significance to the natural environment and humans from many aspects. This has enriched our professional knowledge in our study in this field and has also strengthened our research capabilities.

Method

In the first stage, we conducted a preliminary analysis of the impact of woody plant invasion on the soil in the form of database analysis. In order to elucidate the real impact of woody plant invasion on the soil, we carried out an extensive reading of the collected articles and conducted shallow output in the following aspects. According to the existing 182 studies, including the first author's name, year of publication, title, periodical, article type, continent, country, plant genera, legume or non-major theme, cause of invasion, climate, rainfall, type of biomes and the soil type has been built. Through this database, several facts can be found: The name of the first author provides us with information on the people working in this field for the study of soil; There may be a correlation between the publication year and global climate change; The journal also gives us the most research on which environmental journals; In the whole article, it is easy to find three different types of articles. If the article is about some experiments designed by the team or the author, then it can be considered to be a topic-oriented article with a specific field; Another indicator such as the mainland and the country that is a good way to further study the analysis of climate and soil types, and also defines the distribution of encroachment worldwide; Determine whether it is leguminous Plants. Due to their nitrogen fixation, they may have negative or positive effects on soil and other plants; The part of the main research theme shows the concern of various topics on the effects of soil erosion; The reasons for the encroachment mentioned in the clarification article are also very important, which is closer to our research, namely the proportion of reasons related to soil; Climate, rainfall and the type of plant biome, through the analysis of these three factors, we can more easily find the effect of encroachment; The last one is the soil type, which is also important for clarifying the wood erosion and the real reason for the absorption of different elements. After all, different types of soil plant support may be different.

In the second stage, through the screening, we conducted targeted intensive reading of 157 articles. According to different themes, we have summarized and extended the study from soil fauna and flora, soil carbon cycling, ratio of carbon-nitrogen, soil nutrients, soil physical properties, water resources, and soil erosion. For ambiguous information in the database and relevant information in the article that is more complex or not mentioned, we refer to Wikipedia, ArcGIS geographic system information and other related documents in the same field. Due to our lack of understanding of the knowledge in this field, through this step, we have cleared some of the basic knowledge, and it helped us to better understand the article. Also, there are a large number of articles analyzing the impact of soil and other environmental factors on the invasion of woody plants. These conclusions will disturb our thinking. This requires us to discuss the necessary and sufficient optimality conditions between the cause and the conclusion. In addition, for woody plant invasion, all these articles do not have one-by-one control over all the variables to find out their impact on the soil. According to our level and the type of written study, we can only determine what people did in which environment and what kind of experiment did they make. However, in many conclusions, the results are often the opposite or different, so it is difficult to draw a general conclusion to discuss the impact of invasion on the soil. In other words, because each research object, external conditions, and authors' analysis angles are not the same, different assumptions or different conclusions can be drawn for the same issue. This condition requires us to analyze and screen the final impact results, discuss them according to different qualifications, and come up with corresponding assumptions and conclusions.

Part I – The soil: as life support for soil fauna and flora impacted by the woody plants

1.1 A micro-climate under trees for herbaceous vegetation

The encroachment of woody plant into grasslands was reported around the world, it is a major land cover change that has consequences for biodiversity and ecosystem function (Scholes and Archer, 1997; Asner et al., 2004; Boutton et al., 2009; Van Auken, 2009). This change in physiognomy have the effect on both the distribution of resources and the magnitude of ecosystem, it could be founded under and around the woody plants, generally resulting in nutrient resource enrichment and higher rates of biological activity in soils beneath their canopies relative to the original grassland (Schlesinger et al., 1990; McCulley et al., 2004; Maestre et al., 2009).

In many studies, the zones of nutrient-rich soil found beneath plant canopies was referred to as "islands of fertility" because it was founded separated and often related to the encroachment in shrubland and grassland to the soil by its function to nutrient, it was more intense and spaced further apart in shrubland than in grassland (Bhark, 2003). This increase in productivity is founded under or near tree crowns and is found most often in the tropics and subtropics and in communities with low tree density, low rainfall, and moderate soil fertility (Knoop and Walker 1985, McClaran and Bartolome 1989, Burrows et al. 1990, Belsky and Amundson 1992, Belsky et al. 1993a). In contrast, trees occurring in communities with high tree density, high rainfall, or extremely nutrient-poor soils display the more effects of reduced understory productivity (Burrows et al. 1988).

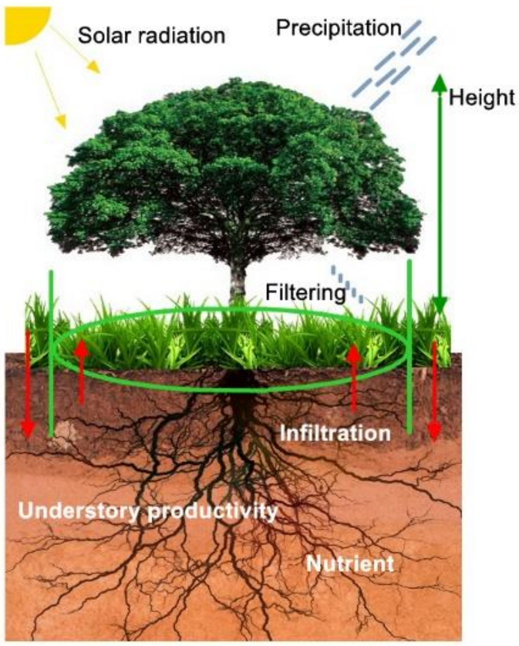

Figure 1: Islands of fertility

In some early research, under some circumstances herbaceous-layer productivity is lower under tree canopies than in nearby open grasslands (Ward & Cleghorn 1964; Grunow, Groeneveld & Du Toit 1980; Dye & Spear 1982; Walker & Noy-Meir 1982).

A number of other studies, however, have reported that isolated trees may also have the effect of improving understory productivity (Holland 1980, Stuart-Hill et al. 1987, Belsky et al. 1989, 1993a, b, Frost and McDougald 1989, Weltzen and Coughenour 1990).
The different factor could have the influence for the effect of woody encroachment to understory productivity of herbaceous-layer under the tree canopies.

1.1.1 Effect of micro-climate and water relations of understory plants

The effect of microclimate was often related with the interaction of tree with canopies and the herbaceous-layer beneath canopies, level of rainfall, season, climate, and biomass could have some effects synthesis to the soil beneath the tree, but these effects were always different and contradictory.

A recent meta-analysis showed that net facilitative or competitive effects of trees on understory grasses were related to annual rainfall, with trees facilitating understory growth where water was limited, but suppressing growth where the water supply was adequate (Dohn et al. 2013). These results, which are consistent with the stress-gradient hypothesis (Bertness & Callaway 1994; Callaway et al. 2002). Blaser (2013) argues that facilitation of understory species is more likely to happen when the benefits accrued from improved water relations outweigh the disadvantage of canopy shading (Holmgren, Scheffer & Huston 1997).

As mentioned above, rainfall could have the effect positive and negative to the productivity of understory plants, however, when the tree was isolated and in the arid climate, it could have effect positive on the soil.

A research of isolated trees in a semi-arid savanna at Kenya on under canopy environments in high- and low-rainfall savannas shows canopy-zone soils were drier than grassland-zone soils due to the tree canopies intercepting a huge amount of rainfall early in the two rainy seasons. In November-March, soil-water contents were higher under canopies because of soil evaporation and plant transpiration was reduced by lower temperatures and also reduced radiant energy (belsky, 1989). But other study found when herbaceous biomass was still low, soils were wetter under trees than in the open due to the lower temperatures and reduced evapotranspiration rates under tree canopies (Maranga 1984). But because herbaceous plants grew faster under tree canopies than in open grassland, canopy-zone plants extracted increasingly greater amounts of water from the soil. As a result, by the latter part of the growing season, more water was lost through transpiration from the canopy zone, and the soils of the two zones were equally dry (belsky, 1993). These differences may be due to different rooting characteristics of the species occupying the two sites. The higher root/shoot ratios at the low-rainfall compared with the high-rainfall site and in grassland compared with canopy zones are consistent with studies showing that plants allocate a greater proportion of their biomass to below-ground organs in xeric environments with the low-rainfall than in mesic environments with the high-rainfall and more in nutrient-poor environments (the grassland zone) than in nutrient-rich environments (the canopy zone) (Fitter 1986).

In addition to rainfall factors, the shade of the canopy will also have a certain degree of influence on solar radiation. This is one of the factors that contribute to the microclimate created by the exchange of water between the herbaceous-layer and the tree. The exact conditions altering productivity under tree canopies relative to the open grassland are unknown.

It is suspected that reductions in understory productivity are due to rainfall interception by overhead canopies, reductions in total solar radiation reaching the ground (Somarriba 1988; Jackson et al. 1990), Increases in understory productivity, on the other hand, are thought to be due to improved soil fertility under tree canopies (Kellman 1979; Joffre & Rambal 1988; Belsky et al. 1989; Young 1989) and to reduced temperatures and evapotranspiration in the shade (Tiedemann & Klemmedson 1977; Maranga 1984; Forst & McDougald 1989). Reductions in solar radiation by tree canopies at the high-rainfall site were similar to those found at the low-rainfall site (Belsky et al. 1989). Hence, trees are most likely to promote understory growth when they improved the supply of multiple resources like water and soil nitrogen without excessively reducing light (Dohn et al. 2013).

1.1.2 The effect of competition between trees and understory plants for soil moisture and nutrients

The reductions in understory productivity are due to competition between trees and herbaceous-layer for water and nutrients (Monk & Gabrielson 1985; Walker et al. 1986, Monk and Gabrielson 1985, Stuart-Hill and Tainton 1989), but this competition is not universal (Belsky 1989, Sala et al. 1989).
This competition was always related to the density of trees. With tree density increasing, savanna trees reduce rather than enhance understory productivity. In areas of high tree density (Belsky and Amundson 1992), trees preempt most of the light and much of the below-ground resources.
Although tree density and soil fertility are not always reported, increased canopy-zone productivity appears to be associated with low-tree-density savannas (Kennard & Walker 1973), deserts (Patten 1978), and high soil fertility; In the other hand, decreased productivity is most often associated with higher-tree-density woodlands (Beale 1973; Sandford et al. 1982) and low soil fertility. The authors of those studies finding increased grassland productivity under tree canopies often suggest that the increases are due to the influence of shade in hot, dry environments and to increased soil fertility found under tree canopies. Those studies founded decreased grassland productivity under tree canopies suggest that the decreases are due to reduced rain-through fall and to competitive interactions between trees and herbs (Ward & Cleghorn 1964; West 1969; Beale 1973; Clary & Jameson 1981; Dye & Spear 1982; Walker et al. 1986).

1.1.3 Effect of fertility and structure of soils below tree crowns

Many previous studies have documented the soils under canopies of trees in semi-arid environments often are more fertile than soils from the surrounding grassland (Ebersohn & Lucas 1965; Charreau & Vidal 1966; Radwanski & Wickens 1967; Singh & Lal 1969; Tiedemann & Klemmedson 1973; Aggarwal et al. 1976; Bernhard-Reversat 1982). Example: Some studies also showed that various soil fertility indices such as organic matter, mineralizable N, extractable P, K, Ca and soil microbial biomass were similarly elevated in the canopy zone of *acacia* and *baobab* trees compared to outside the canopy (Belsky, 1989). In contrast, other studies showing that facilitation under more arid conditions does not apply to all woody plants but only for shrubs and trees with an elevated canopy (Blaser,2013).
The occurrence of increases in understory productivity are thought to be due to improved soil fertility under tree canopies (Kellman 1979; Joffre & Rambal 1988; Belsky et al. 1989; Young 1989) and to reduced temperatures and evapotranspiration in the shade (Tiedemann & Klemmedson 1977; Maranga 1984; Forst & McDougald 1989, Dohn et al. 2013). These effects were always founded in N fixing trees.

Legume trees influence nutrient amount and availability within the root zone of companion species by different processes: (1) Nitrogen biological fixation, (2) Nutrient recovery below the root zone, (3) Reduction in nutrient losses, (4) Increasing soil nutrient availability due to greater soil organic matter (OM) mineralization (Dubeux, 2014).

Some studies were also showed the understory productivity depending on the capacity of the tree to fix nitrogen and the variation in canopy shape (Dohn et al. 2013). Many studies documented the facilitative effect under dry conditions was greatest for N-fixing trees, suggesting that these plants improve both N availability and the soil moisture condition (cf. Eldridge et al. 2011; Sitters, Edwards & Venterink 2013). Non-fixing high Canopy-trees also increased understory growth, but the shift from net facilitation to net competition occurred at a lower rainfall than for N-fixing species (Blaser, 2013).
In general, the transition from grassland to shrubland leads to greater spatial heterogeneity in soil resource levels (Schlesinger et al. 1996). Resulting patterns of water, nutrient, and organic matter availability have great consequences for microbial processes (Schade, 2005), with these effects, it could have direct and indirect effects on the soil. Often increasing rates of the nitrogen mineralization and the nitrification (Kieft et al. 1998), and denitrification (Wainwright et al. 2002), and the production and diversity of understory plant communities (Schade et al. 2003).
As a result, the growth of companion crops under tree crowns may be reduced or favored, depending on factors such as microclimate, the degree of shading, tree competition for soil moisture and plant nutrients, and shade tolerance of shaded species (Burner and Brauer 2003). The effect of the leguminous tree could have the function of supporting the increasing nutrient cycling.

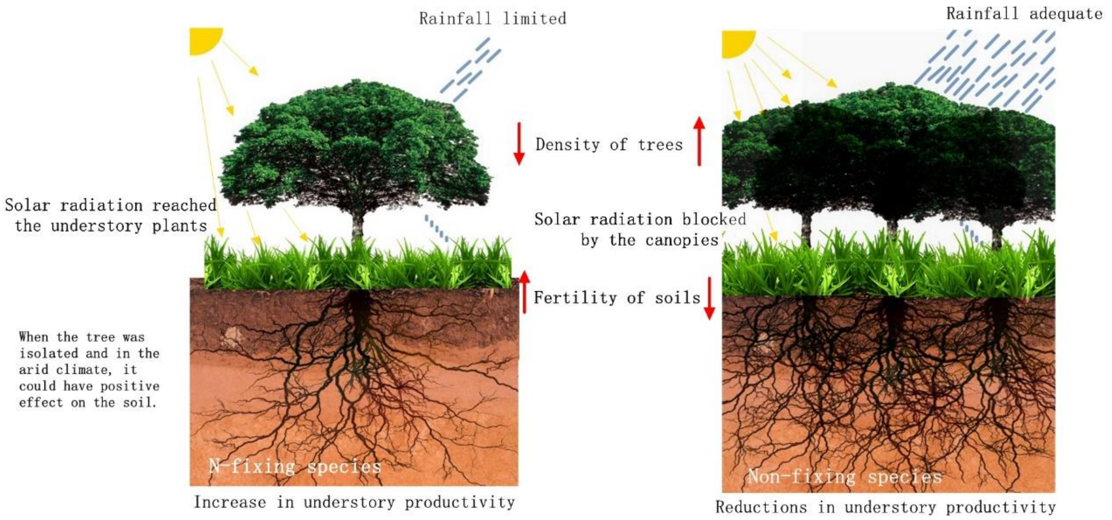

Figure 2: Effects in understory productivity

1.1.4 Short conclusion

The interaction of tree with canopies and the herbaceous-layer beneath canopies has related by the level of rainfall, season, climate, biomass, radiation of the sun, shape of canopy, the density of trees, competition between trees, the height of trees, N-fixing trees or not N-fixing trees, soil fertility, geographical environment has some effects synthesis to the soil.

1.1.5 Towards a deeper understanding of uncovered questions

The microclimate generated under the trees often produces some opposite results. The main reason for this phenomenon is that different studies have different external factors and lead to different results. To further deepen this issue, more relevant experiments will be conducted in the future. To resolve this question, the meta-analyses that covers different climates and environments with a method of variable control could be easier to find out the effect is positive or negative.

1.2 Biodiversity of pedofauna and food web interactions

1.2.1 Main effects

Through the summary and analysis of different articles, many studies reported the woody encroachment have the effect of increasing aboveground and belowground primary productivity (Archer et al., 2001, Lett et al. 2004; Hughes et al. 2006), biomass and density of roots (Watts, 1993; Hibbard et al., 2001; Millard et al., 2008), storage of C and N in soil organic matter (Liao et al., 2006 a, b; Boutton et al., 2009), and soil microbial biomass (McCulley et al., 2004; Liao and Boutton, 2008). These factors have interaction effects with each other and have a very important influence on the distribution of soil microfaunae like protozoa and nematodes in the soil, and affect these important constituents of soil food webs (Bonkowski, 2004). Nematodes are the most numerous soil mesofauna and occupy all consumer trophic levels within the soil food web, biodiversity and trophic structure of soil nematode communities are changed following woody plant invasion of grassland (Biederman, 2009). Some studies documented sites with woody plant invasions have reduced nematode species richness, particularly among root-parasite species (Jackson et al., 2002). In contrast, in the Chihuahuan Desert, nematode density increased with *P. glandulosa* root biomass and soil nitrogen (Freckman and Virginia, 1989). This different result shows the influence of woody encroachment on the nematodes were depends on whether the invasive species is nitrogen fixation or non-nitrogen fixation, plant roots property and total soil microbial biomass (e.g., nutritional quality, biochemical composition, physical attributes, etc.) (Biederman, 2009). After the encroachment of woody plant communities dominated by N-fixing tree legumes in subtropical savanna ecosystem, the large increase in bacterivore nematodes occurred, it corresponded to increases in soil microbial biomass, and may accelerate microbial turnover and the mineralization of N. This may also provide a feedback that provides the persistence of N-rich woody plant communities in this system (Biederman, 2009).

The difference in nematode community structure became more obvious with time following woody encroachment. Although we know that nematodes communities are different between centers of woody plant and the nearby grasslands (Biederman and Boutton, 2009; Freckman and Mankau, 1986), there may have other important horizontal and/or vertical spatial effects in nematode community structure in savanna landscapes, food resources decreased and pore space with soil depth generally correlate with reduced nematode density and diversity in lower soil depths (Sohlenius and Sandor, 1987; Yeates et al., 2008). This decay in diversity with depth may be more pronounced in the grass communities, which have shallower root distributions (Archer et al., 1988). The food web of microfauna was also affected by the encroachment. The differences in gram-positive bacteria, *Actinobacteria*, and fungi communities were founded in soils below and between shrubs, the maximum depth of these organisms increased from 2.1m in grasslands to 4.0m in invaded woody sites, as the composition of the nematode food web was reduced from five trophic groups to two (Jackson et al. 2002). Lower bacterial and fungal species richness were also founded at these sites, primarily due to the loss of root-feeding species (archer, 2010).

In general, woody encroachment into prairie ecosystems changes microbial community structure and likely their activity in soils (Hollister, 2010). Greater plant species richness may increase the abundance of saprophytic or arbuscular mycorrhizal (AM) fungi (Chung et al. 2007) and woody encroachment causes declines in plant species richness (Ratajczak et al. 2011).

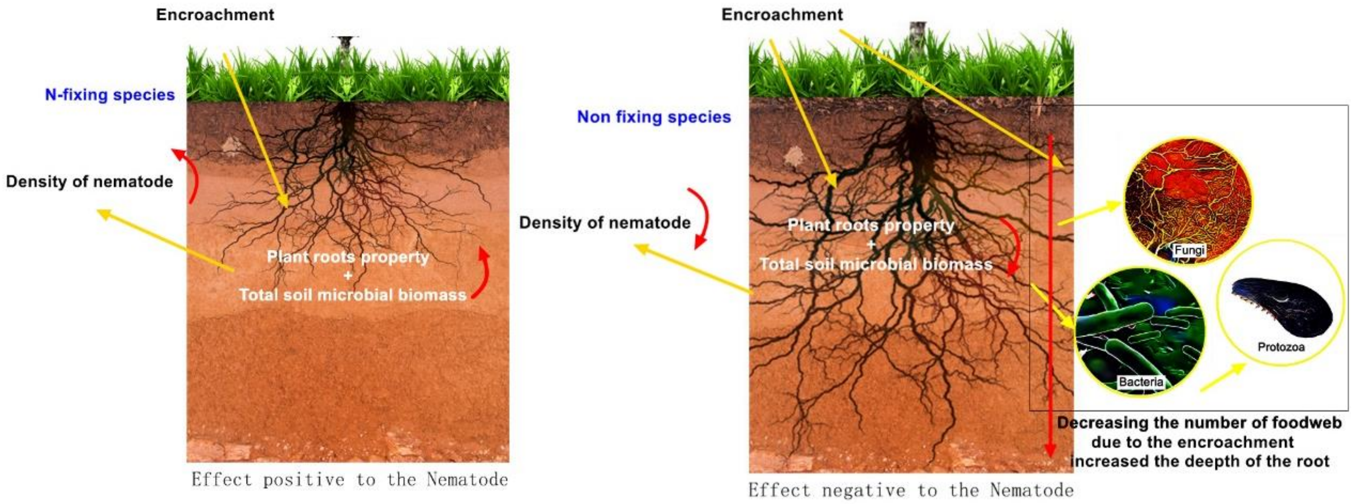

Figure 3: Effects of encroachment to the Nematode

1.2.2 Short conclusion

Woody encroachment could affect the microfauna in soil with belowground primary productivity, storage of C and N in soil organic matter, root biomass and soil nitrogen, soil microbial biomass, soil depths to the bacterial and fungal species richness and the horizontal and/or vertical distribution.

1.2.3 Towards a deeper understanding of uncovered questions

Whether the invasive species is nitrogen-fixed or non-nitrogen-fixed is full of contradictions. The ecological circulation mechanism caused by the nutrient in the food web is still full of uncertainty. At the same time, many studies have focused on the interaction between nematodes and fungi and bacteria. In addition, detailed and targeted studies have not been conducted on other species such as termites and other microorganisms.

Part II- Encroachment modifies soil biogeochemical cycles

2.1 C below ground stock changes, C/N turnover

2.1.1 C below ground stock changes

Soil C constitute over two-thirds of the global C storage found in terrestrial ecosystems (Scurlock and Hall, 1998, Scurlock and Hall, 1998, Chen et al., 2003), in which semi-arid tropical area stocked wide ranges of biomass C stocks (20-150 Mg/ ha) (Tiessen et al., 1998). Where the total carbon (C) stock of the savanna was 204 ± 53 Mg/ha, with approximately 84% belowground C storage (Birhane, 2017). These changes in ecosystem characteristics following woody plant encroachment into grasslands have strong potential to modify C dynamics and storage and may have strong influence both in regional and global climate through feedback interactions (Schlesinger et al., 1990; Ojima et al., 1999; Asner et al., 2004). A better understanding towards how shrub encroachment effects C dynamics is necessary for quantifying and balancing the global C budget (Lett et al., 2004). Despite the woody plant invasion could have the possibility to influence the C cycle and N cycle in ecosystem at global scales (Kieft et al., 1998; McCarron et al., 2003; McCulley et al., 2004; Wessman et al., 2004; Briggs et al., 2005; Norris et al., 2007; Strand et al., 2008; Throop & Archer, 2008), mechanisms and processes associated with C dynamics and storage in the affected systems are poorly understood (Jackson et al., 2000, 2002; Hudak et al., 2003; Wessman et al., 2004, Woodbury et al., 2007). Thus, there is growing interest in determining how changes from grass to woody plant dominance might influence global biogeochemical cycles and the climate system via impacts on soil carbon storage and dynamics (Houghton et al., 1999; Asner et al., 2004; Archer, 2009).

Different studies from the worldwide sites have found that shrub encroachment in grassland often changes the SOC content, but these studies have many uncertainties and have resulted in contradictory conclusions. Some studies found that shrub encroachment increases SOC (Throop, 2013, Mckinley, 2008, Hagos, 2005, Boutton et al., 2009, Stock et al., 1995; San Jose et al., 1998; Geesing et al., 2000; Burrows et al., 2002; Reyes-Reyes et al., 2002; Zavaleta and Kettley, 2006). In contrast, shrub encroachment resulted in SOC decreases in some areas (Jackson, 2002, Coetsee, 2012) or caused negligible changes in other studies (Lett, 2004). These contradictory results revealed a large regional, climate, and many other variation in the impact of shrub encroachment on SOC.
It is necessary to clarify how the different factor of woody encroachment influenced on soil C storage.

2.1.2 Effect of net primary productivity

Increased storage of soil organic carbon (SOC) is likely to occur if the rate of net primary productivity (NPP) increases relative to the rate of organic matter decomposition following woody plant encroachment into grassland (boutton, 2009).Increased annual net primary productivity (ANPP) and associated increases in litter fall often accompany transitions from grassland to shrub land, potentially increasing ecosystem C sequestration and soil organic carbon (SOC) storage (Kieft et al., 1998; Norris et al., 2001a, b; McCulley et al., 2004; Brantley & Young, 2008; Knapp et al., 2008; Strand et al., 2008; Throop & Archer, 2008).

2.1.3 Modeling methods

Using modeling methods, woody proliferation in southern Texas would lead to *Prosopis* woodlands with aboveground C stocks 15-24 times greater than those of grasslands they replaced (Hibbard et al.2003). Asner et al. (2003) used remote sensing techniques to estimate a 30% net increase in woody plant cover across 400 km^2 of northern Texas during a 63-year period that resulted in a 32% increase in aboveground woody plant C pools.

2.1.4 In contrast effect of encroachment

In many of the studies where huge increases in SOC were observed, encroaching woody plant species were often N-fixing tree legumes (Virginia and Jarrell, 1983; Bush and Van Auken, 1986; Stock et al., 1995; Pugnaire et al., 1996). Greater inputs of fixed N to N-limited ecosystems reduce N limitation of plants and microbes and results in higher plant productivity (Wardle, 1992). The presence of N-fixing species may be an important driving factor in the observed increases in SOC in many arid land ecosystems because of the limiting effects of N in most ecosystems, (montane, 2007).
Higher microbial biomass C was also found in *P. juliflora* (leguminous) stands (Reyes-Reyes et al., 2002), which shows how strongly *P. juliflora* invasion can influence the overall C pool. In the study by Birhane (2017) found the highest C stock is recorded in the highly invaded areas by *Prosopis juliflora* with 86 Mg/ha, with more C being stored in the soil compared to above-ground carbon pools (Birhane, 2017).

In contrast, a few recent studies have shown no changes in SOC (McCarron et al., 2003; Smith and Johnson, 2003; Dai et al., 2006; Hughes et al., 2006) or actual decreases in SOC with woody plant encroachment (Jackson et al., 2002).
Despite substantial increases in aboveground C and N pools with woody encroachment, we did not see significant changes in C and N pools in the upper 10 cm of the soil (hughes, 2006). This is consistent with observations for *Juniperus* encroachment in Kansas prairie (Smith & Johnson, 2004), but contrasts with other observations for *Prosopis* in northern Texas where SOC pools decreased 10–11% (Jackson et al., 2002) and observations in southern Texas (Boutton et al., 1998; Geesing et al., 2000; Hibbard et al., 2001; McCulley et al., 2004) and Arizona (Tiedemann & Klemmedson, 2004) where encroachment by *Prosopis* increased near-surface soil C and N pools.

2.1.5 Tree age effect

In savannas (Archer et al., 2001), reported that in southern Texas bush encroachment by mainly the leguminous tree *Prosopis glandulosa* resulted in higher root biomass, and increased SOC with increasing tree age. The reduction in C accumulation rates in older thickets may simply result from the reduction in litter fall as thickets age rather than SOC saturation of older soils. While thicket age greatly affected litter fall, standing litter mass and associated C and N pools did not vary with thicket age (Sinsabaugh et al., 2008). The study which has different result suggests that higher litter fall rates in younger thickets are coupled with higher decomposition rates, but decomposition rates in these communities have not yet been evaluated. Changes in soil pH across the chrono sequence, from neutral in the youngest soils to acidic in older soils (Ehrenfeld, 1990; Dilustro & Day, 1997), could contribute to differential rates of decomposition among thickets. The effect of tree age to soil C storage wasn't sure, which needs a further research.

2.1.6 The effect of rainfall

The process of shrub encroachment could have influenced the effect on SOC content induced by directly or indirectly by climate, soil conditions and local shrub types (Liao, c, 2008). The rate or direction of SOC changes occurring after woody plant establishment is not consistent in the scientific literature. Jackson identified a negative relationship between precipitation and changes in SOC and nitrogen content (STN) when grasslands were invaded by woody vegetation. When drier sites gaining and meanwhile wetter sites losing SOC (Jackson et al.2002). With the SOC levels decreasing in areas of high precipitation (>1200 mm), and increasing in areas with low precipitation (Guo, Gifford, 2002). A meta-analysis found that the relationship between precipitation and SOC increment in response to shrub encroachment was generally negative (Barge et al.2011).

In the Lope National park at Gabon, with an average annual precipitation of about 1500 mm, woody encroachment should cause a decline in SOC levels. Nevertheless, in the topsoil of all the stages, SOC levels were stable (Chiti, 2017).

2.1.7 Tree-shrub litter production

Differences in plant productivity and input quality between shrubs and grasses may affect the accumulation and decomposition patterns of soil organic matter pools (Montane, 2007). If shrubs have lower productivity, shrub encroachment is likely to result in net losses of C and N, especially below ground. However, the generally lower quality of shrub litter and roots (higher C to N ratio; lignified tissues, secondary compounds) may hinder soil organic matter decomposition and favor C accumulation (Paustian et al., 1997; Murphy et al., 1998; Moorhead et al., 1999).

2.1.8 C/N turnover

Nitrogen cycling in semi-arid and arid grassland ecosystems is been changed following encroachment of woody leguminous trees. As nutrients become rapidly concentrated developing and caused a number chemical feedbacks within the system that accumulate or reduce soil organic matter stocks (Schlesinger et al. 1996; Schlesinger and Pilmanis 1998; Liu et al. 2010). In fact, according to Rastetter et al. (1992), in N-limited ecosystem the changes of C storage are mainly governed by three biogeochemical cycles: (1) total N stocks, (2) C/N ratios in key pools and (3) redistribution of N among pools with different C/N ratio.

2.1.9 C/N rate decreased with the increase of rainfall

Some modelling studies reported that C losses may occur only if there is a substantial decrease in soil N stock and that the annual rainfall would have effects for both changes in C and N stocks rate (Halliday et al. 2003; Kirschbaum et al. 2008). The research of Alberti in 2011 shows some effects of the decrease of N rate was related to the changes of C with increasing levels of rainfall. Changes in N seems to drive changes in soil organic C. Under low rainfall, system retained C because losses of N were compensated by a slight increase in soil C/N ratio; but as the rainfall increased, soil C was lost due to a loss of system nitrogen stocks which were not sufficiently compensated by an increase in C/N ratio. The same conclusion was founded in the previous studies mainly due to the drainage from the system (Parfitt et al. 1997, 2003; Scott et al. 1999; Randall and Ila 2001).

2.1.10 C/N rate not changed by N-fixing shrub

However, there were some other research shows the rate of C/N wasn't changed with the encroachment by the N-fixing shrub. Increased SOC and N without changes in soil C:N ratios have also been observed with encroachment of *Prosopis glandulosa*, a N-fixing shrub, in arid grasslands (Hughes and other 2006; Wheeler and others 2007) and uplands invaded by *Prosopis* in the temperate (Hughes et al. 2006) and subtropical (McCulley et al. 2004) southern Great Plains grasslands. *Juniperus occidentalis*, endemic to the northwestern U.S., has also promoted large accumulations of C after encroaching into grasslands (McKinley, 2008). Biomass data suggest inputs via tree/shrub roots were more important than foliar litter inputs in driving the observed C and N accumulation (hibbard, 2001).

2.1.11 Short conclusion

Changes in soil carbon storage in woody plants are mainly concentrated in primary productivity, tree age, geographical environment, vegetation type, rainfall, and litter and other factors. At the same time as a very important indicator, the soil carbon and nitrogen ratio is also affected by rainfall and the effects of nitrogen-fixing plants.

2.1.12 Towards a deeper understanding of uncovered questions

Due to all the previous discussion of effect of woody encroachments on soil C storage, it is not yet clear why responses to woody encroachment are variable and range from net losses to net gains in soil C. Documented variable effects of woody plant impacts on SOC may be due to several factors such as species-dependent changes in microclimate, litter production, litter quality, and rooting depth and biomass (Bush and Van Auken, 1986; Lugo and Brown, 1993; Pugnaire et al., 1996; Jackson et al., 2000), and their interactions with edaphic properties such as soil depth and texture.

As the different results were founded in the changes of soil C/N rate, more information on the nutrient concentration, productivity, turnover, and decomposition of shallow woody plant roots is needed to be discussed to quantify C and N cycling and C/N rate to understand the encroachment of shrubs in savanna and woodland system.

2.2 Nutrient

People widely believe that woody plant encroachment is a symbol of declines in ecosystem functions, and it is usually associated with the degradation of landscape or desertification (Eldridge, 2014). In fact, there is enrichment of nutrients being accompanied by the occurrence of this phenomenon. Through above parts of analysis, soil organic carbon will be enriched by the "fertile islands" effect, and the concentration of nitrogen can also rise a lot (Archer, 2000; Su et al, 2002). However, woody plant encroachment can have more complex effects on soil nutrient production. The "fertile islands" effect does not simply affect soil organics. At the same time, the "salt island" effect and rhizosphere effect will also exist. The water-soluble nutrients and mineral nutrients (difficult to dissolve), in the form of ions, change distinctly due to the presence of trees. This concentrations of various nutrients depend also on complicated factors such as species of tree, wind, water, animals (Belsky et al., 1989; Weltz et al., 1998; Okin & Gillette, 2001), soil moisture, temperature, pH or soil cation exchange (Marschmer, 1995; Rolo,2012).

2.2.1 Fertile island effect

Shrub fertile island is a common feature in arid ecosystems, which is the interaction between plant and soil physical as well as biological processes. A large number of experiments have shown that it has a significant protective effect on the surrounding soil nutrients. In other words, soil nutrient status under the canopy is higher than that of the open grassland (Schlesinger 1996; Abule et al., 2005; Archer, 2000; Hibbart et al., 2001; Blaser et al., 2014; Dubeux Jr 2014; Belsky et al., 1993, Ludwig et al., 2004, Treydte et al., 2007, Jessica 2009; Throop et al., 2008). We mainly describe changes in the concentration of elements such as nitrogen (N), phosphor (P) and potassium (K).

· *Nitrogen stocks changes*

By studying data on two major woody species (*Acacia tortilis* and *Balanites aegyptica*), there is more nitrogen being mineralized in canopy-zone soils. Initial inorganic N levels in soils from under tree canopies are higher than those from grasslands. (Abule, 2005)
Similarly, some other studies (Anthony et al. 2014; Duncan C 2008; Karen 2004) also showed that woody encroachments stimulate more N- mineralization, nitrification rate and a better soil respiration (Raich and Schlesinger, 1992). Specifically, there is 51% increase in N compared to grasslands according to the data based *Caragada microphylla*, *Artemisia halodendron*, *Artemisia frigida*, *Salix gordejvii* (Su, Zhang, Zhao, 2002). However, due to differences in environment and species, there are also some opposite results. Such as the example of nitrogen stocks changes of semi-humid environment in Africa (Grellier et al., 2013; Podwojewski et al., 2014).

· *Phosphor and potassium changes*

Through the case of *reaumuria soongorica*, the content of total P and total K in soil under shrubs increased, but the difference did not reach a significant level, compared to nitrogen (He, Liu, Xie, 2015). This may be due to the fact that the enrichment of nutrients around trees is not only related to the selective uptake of nutrients by plants, but also related to deficiency of nitrogen, but surplus of phosphorus and potassium in the soil in the study area. What's more, Dubeux Jr also found that phosphorus, and organic matter from soil collected under tree canopies were inversely proportional to distance from the tree trunk. And he gave a view that tree shade stimulated soil microbial activity. Microbe promotes the decomposition of organic matter, and there will be more degradation of soil organic matter under the canopy, which is related to the concentration of soil phosphorus. For the plant pearl millet whose production is positively affected by soil phosphorus, the data show that its production remains at a relatively high level in areas where the original phosphorus concentration is not high, which support that its growth promotes the content of phosphorus in soil (Dubeux Jr, 2014).

Meanwhile, changes in the above content are also affected by external conditions (Jackson et al., 2002; Zhang et al., 2016). For example, the effect of climate, several soil nutrient indices were found to be higher under tree canopies than in open grasslands at the high-rainfall site, although the differences were not as great as at the low-rainfall site (Belsky et al. 1989). We can understand that the water flows also promote the decomposition of organic matter. But, trees are better able to promote nitrogen mineralization in arid regions (Blaser et al., 2014; Eldridge et al., 2011). Moreover, different nutrients have different conditions at different soil layer. Phosphorus and potassium contents in soils under shrubs were significantly higher in the 0-10 cm and 10-20 cm soil layers than in the soil outside the shrubs, whereas nitrogen content in and outside the shrubs reached a significant level only between 0-10 cm. At the same time, the soil nutrients in the same location showed that the shallow soil was higher than the deep soil (He, Liu, Xie, 2015). For different plant species, the difference is more obvious. Such as tree size, there is higher nitrogen under bigger trees than smaller trees (Ludwig et al, 2004; Treydte et al, 2007). Besides, tree canopy had a positive effect on soil fertility and leguminous tree canopies tended to improve soil properties more than non-legumes (Dubeux Jr, 2014; Wiegand et al. 2005; Treydte et al. 2007). Because of their ability to fix nitrogen, it's more easy to achieve rapid decomposition of dead leaves and other trash so that woody shrubs provide N to the ecosystem (Carlsson and Huss-Danell, 2003; Hibbard et al., 2001). But, there are no statistically significant differences in data between different legumes (Abule, 2005). Therefore, the "fertile island" effect caused by woody encroachment can enrich soil nutrients under the canopy. N, P, K and other elements can also promote the growth of trees and other plants, and it is possible that the cycle will cause continuous growth of shrubs and affects competition among species.

2.2.2 Salt island effect

In fact, it is also a kind of fertile island effect, but it is mainly reflected in the change of soil ions, with the significant differences in soil salinity both inside and outside the shrub (Belsky et al., 1993; Schlesinger et al. 1996; Cable et al. 2009; Hibbart et al., 2001; Trinogga, 2010; Grellier, 2011; Rolo 2012). Experimental results of *reaumuria soongorica* show that the main salt ions, including HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+, Na^+, in the shallow soil layers under the shrubs were significantly higher than those outside the shrubs. Even the content of these three ions, Cl^-, SO_4^{2-}, Na^+, is more than 20 times that of the soil outside the shrubs (He, Liu, Xie, 2015). The same results were obtained in other shrub experiments, such as under *acacias* and *caragada*. Similar to the case of nitrogen, some ion concentrations decrease as the soil thickness increases. The so-called enrichment of salt and nutrients around shrubs has obvious surface aggregation. This situation is thought to be due to the shift of salinity with the movement of soil moisture, and the strong evaporation of the arid area produces significant salt deposition on the soil surface (Yao, Yang, 2007; Yan, Wang, Gao, 2010). Accurate to different ions, different species under the canopy also have different conditions. The salt island effect is also inseparable from the decomposition of tree litter and shrub's interception of fine particulate matter (Zhu, Zhao, Li, 2007; Zhao, Su, Zhang, 2007; Vejre and Hoppe, 1998; Vanlauwe et al., 2005). For *reaumuria soongorica*, the accumulation of Na^+ under shrubs is significantly higher than that of K^+ and Mg^{2+}, and the exchange amount of Mg^{2+} is also significantly less for acacias (Belsky, 1993; He, Liu, Xie, 2015). The enrichment of ions may be related to the characteristics of the trees and the plant morphology. It is believed that the more important the soil elements are for the growth of the species, the more significant the accumulation of soil elements in the soil (Zhang, Fan, 1998). As for pH level, this is actually a category of soil chemistry, but it is closely related to the concentration of ions in the soil. Some studies indicate that pH in canopy-zone soils in was lower than in open grasslands, which means soil under woody plants is more acidic. It can be explained by the higher oxidation of anion because of an important input of organic matter (Whitford, 1992; Mlambo, D.et al. 2005; Eldridge et al., 2011). Some shrubs can absorb more cations, and roots secrete organic acids (Yang, Yu, Qiu, 1999). However, changes of pH also have different results in different studies, and some studies suggest that pH under the shrub will increase. The reason may be due to the fact that the soil pH is related to various factors such as the selective absorption of ions by plants, root exudates, and microorganisms (Garner, Steinberger, 1998; Schlesigner, 1996; Wezel, Rajot, Herbrig, 2000; Whitford, Anderson, Rice, 1997).

2.2.3 Rhizosphere effect

Woody plants have well-developed root systems. Some photosynthetic products are input into the soil through rhizosphere sedimentation, which results in significant interception and preservation of soil nutrients (Lee, Wani, Sahrawat, 1997; Martinez-Meza, Whitford, 1996; Schottelndreier, Falkengren, 1999). Another study found that woody plants in savannah “have a lower bulk density, contain more root biomass, have higher concentrations of SOC and total N and have a greater rate of respiration and N-mineralization and nitric oxide emission” in a subtropical climate (Archer, 2000, p8). Experiments showed that the total N of several shrub rhizosphere soils was as high as 54% compared with the whole soil, indicating that a large amount of root exudates and root tissue shedding matter were deposited in the rhizosphere micro-environment (Su, Zhao, Zhang, 2002). Shrubs in sandy land exhibit more pronounced rhizosphere effects, probably because shrubs growing in the desert often need more nutrients for root growth to resist long-term environmental stress and thus have more rhizosphere deposition. The deposition of nutrients in the rhizosphere of shrubs not only provides a rich source of decomposition for soil microorganisms, but also can change the physical and chemical environment of root soils, thereby exerting an important influence on the nutrient content in the rhizosphere soil. The amount of nutrients deposited in the rhizosphere is also related to plant species, and is also induced and regulated by the soil environment and plant nutrient status. For example, the p in the rhizosphere soils of different shrubs is significantly different. The rhizosphere soils of *artemisia halodendron* and *artemisia frigida* are enriched in P, indicating that their root system has strong adsorption capacity of P, whereas *populous simonii* and *caragada mircrophylla* are opposite. This also proves that the physiological characteristics of different species, the demand for nutrients and the morphology and structure of the roots will affect the enrichment of nutrients (Lynch, Whipps, 1990).

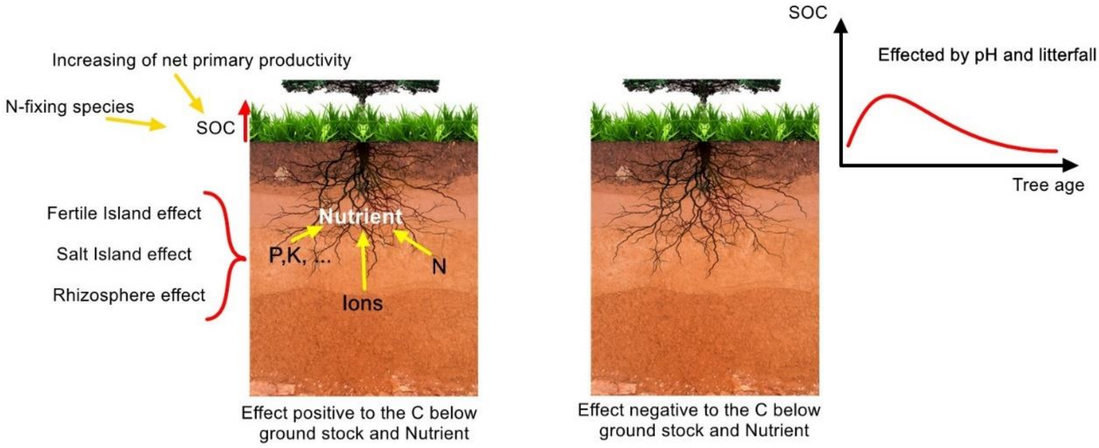

Figure 4: Effects to the C below ground stock and Nutrient

2.2.4 Short conclusion

In semi-drought areas, woody plants intercept, deposit, and decompose wind erosions and plant litter, roots absorb nutrients, plant secretions and soil microbial activity products, and other materials through shrub runoff, factors such as rainfall and input of soil will promote the formation and development of fat islands, thereby changing the soil nutrients, and at the same time there are salt islands and root effects. More experimental results prove that the invasion of woody plants increases soil nutrients, including total nitrogen, total phosphorus, and other metal ions and acid ion concentrations. This series of changes will show various degrees of changes due to various factors such as species, soil and environment. At the same time, in many experiments, there are cases with opposite conclusions, which require more research and more in-depth analysis to confirm.

2.2.5 Towards a deeper understanding of uncovered questions

Since different plants selectively absorb different ions, they will lead to different nutrient enrichment. This also requires further analysis based on the genetic material and physiological habits of the plant. The different nature of the soil resource itself will also affect the impact of enrichment. For example, the alkaline sierozem will cause a large difference in soil total nitrogen, total phosphorus and carbon content. Most studies do not specifically analyze the impact of this aspect. In addition, most data reflect changes in the shallow and shallow-to-medium layers of the soil. However, the roots of woody plants can penetrate deep into the soil. Specific changes in this part are also worth exploring in detail.

Part III- Encroachment and hydrology

3.1 Physical properties

Soil physical properties not only determine the water, gas, heat and biological conditions in the soil, but also have an important impact on soil water storage capacity, utilization and absorption of soil nutrients, and are the result of a combination of natural conditions such as climate, vegetation, topography, and geology. Through a certain amount of research, it can be concluded that woody encroachment has affected temperature, bulk density, pores, moisture, and conductivity to some extent.

3.1.1 Temperature

Due to the shadows provided by trees and complex roots, woody plants have a certain degree of regulation of soil temperature, often accompanied by a decrease in temperature (Van, 2009, Price & Morgan, 2008; Belay et al., 2013). For *acacia tortilis* and *adansonia digitata*, similar to the more xeric site, solar radiation was reduced by 45-65% and soil temperatures were reduced by 5-12°C under both tree species (Belsky, 1993). What's more, studies have shown that there is a certain degree of mutual adjustment between the shrub and soil temperature. For *C. microphylla*, in Inner Mongolia grassland, both diurnal soil temperature and daily soil temperature for shrub was significantly higher than those in grassland in winter, but the trend was reversed in summer. The summer soil cooling and winter soil warming effects would favor shrub to resist drought and freeze damage ensuring continuing shrub growth and survival under arid and clod conditions. These evidences suggest that feedbacks between *C. microphylla* and soil moisture and temperature were overall positive (Li, Zhang, Peng, Hu, Ma, 2013). And some studies have found that such changes are more prominent in the growing season, explaining most of the low soil respiration in woodlands (Smith, D, 2004).

3.1.2 Bulk density and permeability

Soil bulk density reflects the soil texture, tightness and resistance to plant root growth, while the permeability reflects soil porosity, aeration, and affect the water content. Generally, soil bulk density is significantly lower under tree canopies than in the open site (Belsky, 1993). The soil bulk density under the condition of non-vegetation was the largest, and the soil bulk density under the shrubs increased with the increase of soil depth, but the change of soil bulk density without vegetation was the opposite (Yang, Mo, Li, Yu, Dai, 2015), which may be due to the action of plant root activity. As a result, the more developed the root system, the smaller the soil bulk density and the greater the porosity, giving more room for gas and water. In particular, the roots of shrubs can penetrate deeper into the soil. In addition, the pores are large and the space for containing water is large. Water-infiltration into soils was deeper and infiltration rates were higher under tree canopies than in open grasslands (Belsky, 1993; Liu, Zhang, Li, 2004). The data of experiment of *Caragana microphylla* shows that the soil bulk density of the shrubs is 0.97 times that of the grass flooring, and the soil moisture infiltration rate is 5.16 times that of the grass patch. At the same time, there is different sensitivity to precipitation pulse between the shallow soil moisture under shrub canopy and in the inter-space grass, in different soil layers. The 0-10cm soil layer of grass patches was more sensitive to the response of water, while the soil layers below 25 cm of shrub patches were more sensitive. (Li, Zhang, Peng, Hu, Ma, 2013). The process of woody encroachment enhances the spatial heterogeneity of the soil. Shrub patches can quickly transport soil moisture and store it in deep soil (Peng, Tong, Li, 2017).

3.1.3 Moisture and water holding capacity

Depending on vegetation cover density and climatic conditions, the presence of vegetation can lead to higher or lower soil moisture conditions because roots and canopies affect water balance through various mechanisms (O'Donnell, 2012). Also because of shade and temperature's drop, better conditions for the activity of microorganisms retain more moisture in the soil and keep it moist and fertile, generally expressed as total soil moisture in shrub land is greater than that in gap grass (Li, Zhang, Peng, Hu, Ma, 2013; Zavaleta,2006, Price & Morgan, 2008; Belay et al., 2013). Of course, there is a close relationship with rainfall. Rainfall affects the soil moisture more directly, and changes in soil bulk density, voids, and infiltration caused by the presence of trees and the development of root systems ultimately increase the water holding capacity of the soil. However, due to the difference in growth period and shrub species, there will be different situations. Belsky found that, except for early in the growing season, soil-moisture values are similar under tree canopies and in open grasslands (Belsky, 1993). Among different trees, for *Juniperus*, soil temperatures were lower below the canopies while soil moisture remained unchanged (Van, 2009), and *Cistus*, a shallow rooted shrub, reduced top-soil water content, while *Retama*, a deep-rooted, increased top-soil water content (Rolo,2012).

3.1.4 Conductivity

There is a certain relationship between tree density and land conductivity. Through the analysis of the electrical characteristics data of the surface soil and the bottom soil, it can be known that the soil with high electrical conductivity is free of trees (Griller, 2013; He, Liu, Xie, 2015). This is mainly because there is a significant difference in the content of salt ions of soil nutrients between the shrub-land and grassland. Due to the "fertile island" effect, the soil under the shrubs is rich in nutrients, the microbial activity under the shade is high, and the microorganisms break down more organic matter more quickly. The growth of the shrubs selectively absorbs various ions, and then the litter of the leaves and branches recycles the nutrients back to the land. The ion concentration generally increases, resulting in an increase in the conductivity.

3.1.5 Short conclusion

In general, woody encroachment will result in a decrease in soil temperature, a decrease in soil bulk density under the plant, an increase in soil pores and in infiltration, an increase in water content and in humidity, and an increase in electrical conductivity. Also due to the different types of woody plants, the environment, the soil and other factors, there will be opposite cases that need to be studied. These changes are mutually promoted and regulated, and are accompanied by the effects of plant root systems. Because of the changes in the physical properties of the soil, other effects have also been triggered, resulting in changes in water flow and soil erosion.

3.1.6 Towards a deeper understanding of uncovered questions

The impact of woody encroachment on soil, in general, increases the spatial heterogeneity of the soil. The content of spatial heterogeneity is complex and involves a variety of properties. Soil topography and other natural conditions are also important factors in the formation of soil heterogeneity. On the slope scale, the patch soil organic matter, soil bulk density, soil calcium layer depth, etc., tend to increase from the top of the slope to the downward slope. In addition, the soil viscosity, the number of agglomerates, and the mechanical stability affect the properties of fertility and corrosion resistance and are also affected. There are individual data indicating clay concentration increased with distance from tree trunk to full sunlight (Dubeux Jr, 2014). The secretions of physiological activities of microorganisms in the roots and soil of plants will have a cementation effect on the soil, generate and amplify agglomerates, improve water stability and mechanical stability.

3.2 Water flows and resources

According to the degree of drought, seasonality, and availability of groundwater, the water flow and evaporation process are affected differently by the invasion of woody plants. Differences in natural landscapes, climate, and runoff mechanisms affect the impact of woody plants on hydrological processes (HUXMAN, WILCOX, BRESHEARS, SCOTT, 2005). Due to differences in the characteristics of plant canopy and rooting structures, climate, soil types, and landforms, the available data are insufficient to support the relationship between water flows and plant cover rates for all hydrological systems (Archer, 2010).

3.2.1 Reduction of runoff

In areas with more humid and more abundant rainfall, the formation of runoff mainly depends on rainfall and infiltration of rhizomes of plants. Because of plant canopy, it will intercept some of the rainfall and reduce the source of moisture in the soil. As a result, surface and groundwater flows are reduced, but the degree of reduction depends on annual precipitation (Qiao, 2017; Honda, Durigan, 2017). Moreover, due to the well-developed root system of woody plants, it has a strong ability to absorb water and enhance water transpiration. The rise of transpiration induces a high evapotranspiration. (Huxman et al., 2005). Meanwhile, given that water returning to the atmosphere as vapor generally does not become rain in the same location where it evaporates. Compared to the reduction by rainfall interception and transpiration, plant stem flow and soil infiltration contribute too little to increasing water flow. Therefore, there is the decrease in water productivity (Li, 2001). With the increase of tree biomass, the reduction of water production is the direct consequence of the increase of rain interception and transpiration. (Honda, Durigan, 2017; Jarvis and McNaughton, 1986; Crockford and Richardson 2000; Huxman, 2005). Under these circumstances, woody plant encroachment into tallgrass prairie has the potential to reduce groundwater recharge (Acharya, Hao, Ochsner, Zou, 2017).

3.2.2 The opposite result under different conditions

However, under different climate and geological conditions, some experiments have shown that there are more runoffs in bush areas. The results from the transitional land show that the dynamic changes in runoff from grassland degradation to shrubs are more complex. The rainfall from the grassland to the shrub-land increased, and the surface runoff changed nonlinearly (Turnbull, 2009). Similarly, Parsons conducted rainfall simulation experiments in southern Arizona. Relative experiments show that, on the shrub-land the runoff coefficient is higher, equilibrium runoff occurs more frequently, overland flow attains higher velocity, and erosion rates are higher than on the grassland (Parsons, 1996). In fact, both of the above studies have occurred in the desert. According to the analysis, in the dry desert environment, there is no time for high-intensity rainfall, which is not enough to be the first factor influencing the runoff. The growth of woody plants needs to resist harsh environments. Combined with their own growth characteristics, they can increase ground growth and inhibit competitive grassland growth (Kulmatiski, 2013). According to the underground activities of the trees, infiltration can be increased through rooting and stem flow (Dunkerley, 2002; Levia and Frost, 2003; Liang et al., 2009), and to modify groundwater flows (Huxman et al., 2005; Liang et Al., 2009). Stem flow infiltrates the soil and can reach a great depth by preferentially following the roots (Johnson and Lehmann, 2006; Martinez-Meza and Whitford, (1996). As stem flow increases with canopy size (Martinez-Meza and Whitford, 1996), adequate canopy area may be favorable for water infiltration at the basin scale, and thereby to higher groundwater recharge, which is the source of the base flow in these rivers (Wilcox, 2010). The interaction and feedback between vegetation and hydrological processes determine groundwater recharge in water-limited ecosystem (Acharya, Hao, Ochsner, Zou, 2017).

3.2.3 Relationship with soil erosion

Compared with bare soil, more infiltrations occur under the trees (Dye and Walker, 1980, Eldridge et al., 2011). Due to changes in the physical properties of the soil, the soil under the canopy will have more porosity (Belsky, 1993; Liu, Zhang, Li, 2004; Dye and Walker, 1980). Increased infiltration further increases soil pressure, swells the soil and destroys structural stability, and leads to erosion. (Sonneveld, 2005; Grellier, 2011).

3.2.4 Short conclusion

Under different environmental conditions, different factors will dominate the impact of shrub invasion on water flow and water resources. Therefore, due to various limitations, there is no absolute positive or negative correlation between wood intrusion and the hydrological environment. We can only conclude that the presence of woody plants will intercept rainwater to a certain extent, increase transpiration, and reduce runoff in humid environments with large rainfall. In a relatively arid environment, the developed root system of woody plants promotes the infiltration of soil moisture and plays a positive role in underground water storage. At the same time, this positive effect will increase the possibility of soil erosion.

3.2.5 Towards a deeper understanding of uncovered questions

In fact, soil water resources and runoff are more dominated by rainfall. The existence of shrubs will show different trends due to differences in climate and precipitation. This point, in many experiments, the results of simulated rainfall were too absolute and one-sided. Because the current climate change is changing rapidly, it is necessary to constantly track and analyze the phenomena caused by climate and rainfall changes to determine the effect of specific shrubs on the soil.

3.3 Soil erosion

The increase in soil erosion is closely related to the increase in the shrub coverage of the land (Parizek, 2002). In arid areas, shrub lands instead of grasslands have greatly increased soil wind erosion, water erosion, and dust transport (Gillette & Pitchford, 2004; Wainwright et al. 2000; Breshears et al. 2009), and have caused a certain vicious circle (D'odorico, P, 2012). Erosion has been shown to increase the transport of sediments and change the flow of rivers (Jepsen et al. 2003), affecting water quality, riparian vegetation and aquatic animals (Cowley 2006), soil fertility and ecosystem processes (Valentin et al. 2005; Okin et al. 2006). Therefore, the soil erosion caused by the replacement of grassland with arid shrubbery land has complex and far-reaching effects.

3.3.1 Different factors leading to increased erosion

· *Runoff and Bare soil*

As mentioned above, under certain conditions, woody plant invasion increases runoff for the same amount of rainfall (Parizek et al, 2002; Huxman et al, 2005; Petersen and Stringham， 2008), and the runoff is faster on the shrubland than the grassland (Abrahams, 1995). Increased runoff and flow rates effectively accelerate soil erosion rates. The invasion of woody plants has different processes and will result in different landscapes. Experiments have shown that a positive correlation between the gully withdrawal rate and the area of the acacia crown was measured when trees were invaded between 2001 and 2009. However, this species only became significant when trees covered a sufficient area (Grellier, 2012). The decrease in grass quantity is often replaced by scattered shrubs, which eventually leads to a large increase in the bare part of the soil (Schlesinger et al., 1990; Huenneke et al., 2002; Baez et al., 2006). The degraded soil gaps are interconnected where the plant barely grows. The gap area has little protection from raindrops, enhancing soil separation and sediment transport as well as allowing runoff to leave the patch and eventually reach the site. (Abrahams, 1995; Parizek, 2002; Turnbull, 2010). Besides promoting runoff erosion by bare soil, under conditions of relatively dry and sparse vegetation, when the wind force is greater than the soil's resistance to erosion, the soil particles are suspended in the airstream and lost, which is the wind erosion. What’s more, the fertility islands generated by the microclimate under the canopy of woody plants will cause the shrubs to have a higher topography. The difference in height between the bare soil and the shrub also encourages the flow of water away from sediment (Parizek et al, 2002). Shrubs can regenerate in these small islands, but any plant on the land between shrubs is difficult to regenerate, which in turn exacerbates erosion and creates a vicious cycle (Goldberg 和 Turner， 1986; McAuliffe， 1988; D'odorico, P, 2012). The physical crust of bare soil is also a factor that accelerates erosion. In semiarid grasslands, a sediment layer takes shape under canopy, with the effect of raindrop or trampling impacts, causing the soil physical crusts. It is often hardened relative to uncrusted soil due to the accumulation of salts and other nutrients. Physical soil crusts often reduce water infiltration and increase runoff, can inhibit plant establishment, and when disrupted can be eroded rapidly (Petersen and Stringham, 2008 in Grellier, 2011; Buresi, 2014).

· *Freeze-thaw erosion*

Woody encroachment increased the soil moisture below the canopy and caused the soil to become loose, which promotes freeze-thaw erosion in some areas (Parsons et al. 1995). In cold regions, on the slopes formed by some loose deposits, the soil moisture content is high, or groundwater seeps out. The winter freezes, the surface layer of the spring melts first, and the lower part still freezes, forming a water-repellent layer, and the upper part is infiltrated by water. The soil is in the flow-plastic state and flows down the slope to form a mud flow slope or mud flow ditch. Therefore, this form mainly occurs in some areas with high soil moisture, especially shady slopes. Climate and topography also play a decisive role in this situation. In the experimental analysis of Abrahams, he mentioned that it was observed that the soil surface was more "loose" on the bushes than on the grass and there was a significant frost effect. This difference is reflected in the erosion rate vs. time plot, indicating that the erosion rate on the bushes is faster (Abrahams, 1995).

3.3.2 Protective effects

More literature points out the support for soil erosion by woody plant invasion, but the result is not always the same. Because trees can also reduce runoff through litter input, thereby protecting the soil from spatter (Descroix et al., 2001; Wainwright et al.,1999; Dunjó et al., 2004) or consolidating soil structures by increasing the canopy vegetation and extending the root (Pierson et al., 2010), and reduce the supply of material to be eroded. Even a specific survey by Grellier et al. on vegetation coverage showed similar herb biomass under the canopy and open grassland. Therefore, a hypothesis was put forward that the runoff between shrubs and shrubs may not be significantly different, and surface water processes may not be affected by grass trees (Grellier, 2012; Cerdà, 1999). Therefore, under different regional and environmental conditions, surface runoff may not be the main erosion process. After all, this is a result of many factors.

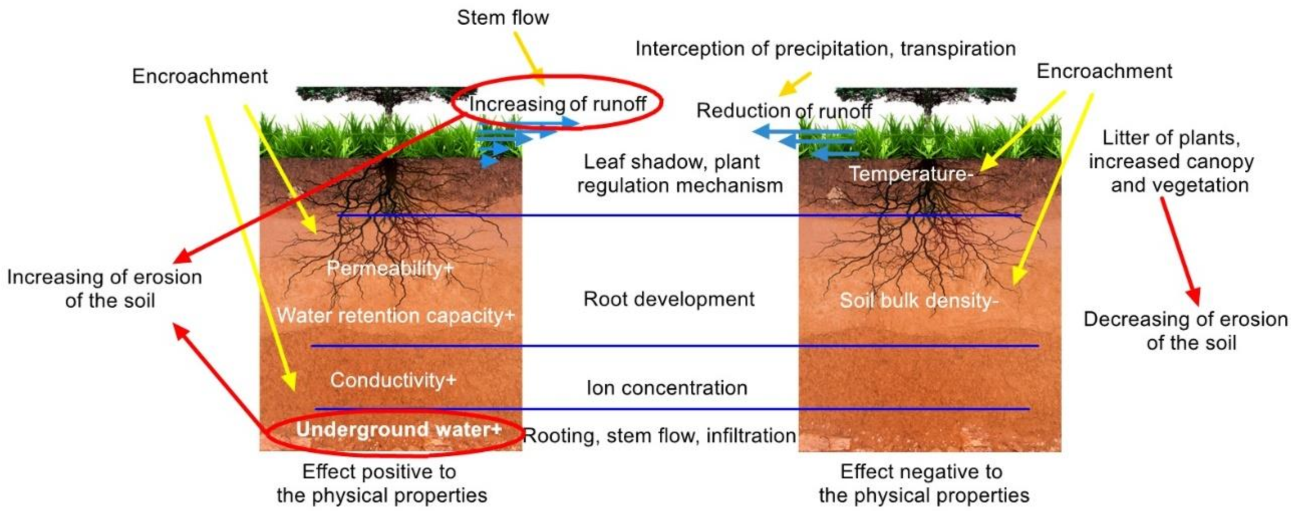

Figure 5: Effects to the different properties influenced by the encroachment

3.3.3 Short conclusion

Soil erosion is influenced by many factors such as climate, topography, soil, and vegetation. Invasion of woody plants will promote or protect the phenomenon to a certain extent. When the transition from grassland to shrub forest, the changes of soil moisture, runoff and erosion are significant, but these changes are not simple and not linear (Turnbull, Wainwright, Brazier, 2010). Because it is not the difference between grassland and shrub in two absolute terminal states, which shows the importance of vegetation in the observation of changes in the transition process. Meanwhile, erosion processes and mechanisms depend on the spatial and temporal scale of the study (Grellier, 2012). Under different scales of research, the dominant factors affecting soil erosion will change, and the impact of woody invasion will also show different effects at different scales.

3.3.4 Towards a deeper understanding of uncovered questions

By summarizing the existing research results, we can see that the erosion of woody plants does, to some extent, promote soil erosion under certain conditions. After all, the phenomenon of soil erosion has deteriorated globally. This has also led to more research to obtain the above results. However, through the analysis of various cases, the results are incomplete. There are still many researchers who provide strong evidence to support the enthusiasm of woody plants for soil and water conservation. More studies use the hypothetical way to express the results of the research. However, the facts still need more experiments and analysis to prove. For example, how different tree species and soil types intervene, how the deep drainage of soil affects erosion, how other soil changes caused by wood intrusions aggravate or protect soil erosion, and so on.

Conclusion

The purpose of this review is to improve the understanding of the effects of woody encroachment soils to the soils and to summarize the main consequences of these encroachments. In fact, woody plants influence the characteristics of organisms by vegetation cover, physical effects including soil erosion and chemical effects like C and N storage, root biomass and soil nitrogen, other nutrient pools, pH to the soil properties such as soil pores and infiltration, depth, humidity, and conductivity. The invasion of woody plants increases soil nutrients, including total nitrogen, total phosphorus, and other metal ions and acid ion concentrations.

At present, through the different results of the soil properties caused by the invasion of woody plants, it is difficult to find a unified conclusion to prove whether its role is positive or negative or not. The reason for this phenomenon is the method of controlling variables to determine the definite effect of a certain factor on the soil has caused the complexity of related research and the opposite view of different problems.

We should conduct further research on the uncertainties and contradictory conclusions we have made. Whether the invasion of woody plants has beneficial or harmful effects on the global vegetation and environment is still not completely determined, but we can be sure that human activities will intensify this effect. This phenomenon should be suppressed in the specific natural environment before the mechanism of this phenomenon is fully understood.

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Woody encroachment impacts on soil properties
L'impact des ligneux sur les propriétés du sol

Résumé :

Au cours des 100 dernières décennies, l'envahit des ligneux dans les pâturages et savanes ont augmenté dans le monde entier. Comprendre l'ensemble de ces impacts positifs et négatifs sur le sol (propriétés biologique, physique et chimique) et trouver une manière de contrôle des ligneux est une nécessité.

Avec l'augmentation des populations humaines, la dégradation mondiale des pâturages s'intensifie, la fréquence des incendies est également intensifiée. Parallèlement, sur la base d'études approfondies, plusieurs facteurs tels que le changement climatique, notamment le taux de CO2 dans l'atmosphère, la proportion de précipitations, les conditions édaphiques ont également affecté ce phénomène. La plupart des études se concentrent davantage sur les effets sur les propriétés. Cette étude est en train de révéler que les conséquences sur les propriétés du sol dépendent de nombreux facteurs comme l'espèce du ligneux (espèce légumineuse ou non légumineuse), des conditions environnementales (climat dont la température et les précipitations, site de l'étude), le degré d'invasion, la compétition pour les ressources du sol et la densité du sol.

Les objectifs de notre projet sont d'examiner les conséquences pour la fonction de l'écosystème, en particulier pour les propriétés du sol. Les conditions géographiques de l'envahit ligneux, les types de plantes ligneuses, leurs causes de l'envahit, les climats relatifs et les types de sols sont recueillies et sont prises en compte. Le travail plus important est l'analyse et l'évaluation de la base de données parmi les nombreuses études.

Mots Clés : invasion, ligneux, prairies, savanes, propriétés du sol, arbustes.