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Overview of studies on stemflow chemistry effect on soil: systematic review of the literature

Panorama dos estudos acerca da influência da composição do escoamento pelo tronco sobre o solo: revisão sistemática da literatura

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ABSTRACT

The study systematically analyzes the literature in order to identify the main contributions of the trunk runoff study on the soil nutrient flux in recent years. The review included 47 articles published from 2015 to 2019. The aim of the present study is to correlate the main stemflow research subtopics that have contributed to chemical soil enrichment. Correlation analysis was performed in Iramuteq software with the aid of R software, based on keywords in the selected articles. There has been an overall upward trend in research related to stemflow impact on soil nutrient flux, mainly in Asia, whose publications have significantly increased over the latest years. Based on the keyword co-occurrence map, "stemflow" and "throughfall" were the main used terms because they established strong correlation to other keywords, mainly to "concentration", "composition", "biogeochemical cycle", "nutrient cycling" and "dissolved organic matter". These terms, in their turn, were correlated to and co-occurred with several other keywords, such as "soil", "nitrogen", "water chemistry", "nutrient dynamics" and "cations".

Keywords: nutrient cycling; nutrient concentration and composition; forest hydrology; nutrient enrichment.

RESUMO

Este trabalho analisa sistematicamente a literatura com o intuito de identificar as principais contribuições do estudo de escoamento pelo tronco sobre o fluxo de nutrientes no solo nos últimos anos. A revisão contemplou 47 publicações do período entre 2015 e 2019. Com base nas palavras-chave das publicações encontradas, aplicou-se a análise de similitude no *software* Iramuteq, com o auxílio do *software* R. Observou-se que há uma tendência geral de crescimento das pesquisas nesse tema, principalmente na Ásia, onde houve aumento de publicações nos últimos anos. Por meio do mapa de coocorrência, as palavras "*stemflow*" e "*throughfall*" aparecem como termos principais que criam relações de ocorrência com outras palavras, principalmente "*concentration composition*", "*biogeochemical cycle*", "*nutrient cycling*" e "*dissolved organic matter*". Estas, por sua vez, trazem diversas palavras que se relacionam e coocorrem com elas, como "*soil*", "*nitrogen*", "*water chemistry*", "*nutrient dynamics*" e "*cations*".

Palavras-chave: ciclagem de nutrientes; concentração e composição de nutrientes; hidrologia florestal; enriquecimento de nutrientes.

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Introduction

In forested areas, canopies play an important role in the partitioning of rainfall. During this process there is also a redistribution of particulate matter that is deposited from the atmosphere on vegetative surfaces and transported to soil layers by throughfall and stemflow (Cayuela et al., 2019). Tree canopy chemistry undergoes quantitative and qualitative changes as they intercept the incident rainfall and react with it. These changes are mainly caused by both dry deposition washoff and canopy exchange processes due to leaching and leaf absorption (Liu et al., 2019). Throughfall (TF) and stemflow (SF) are two canopy-derived flow paths of precipitation as it is transferred to the forest floor. Stemflow has historically been considered to be a minor component of forest canopy water budgets compared with throughfall, and it was neglected in early studies of forest water and nutrient balances (Llorens and Domingo, 2007). Tonello et al. (2021) summarized the main contributions of stemflow (SF) studies from recent years through a systematic review of the literature, including 375 scientific articles published between 2006 and 2019. The authors identified that few studies have related the stemflow effects in biogeochemical cycle more broadly. Stemflow is of biogeochemical importance in forested ecosystems because it is a spatially localized point input of water and nutrients at the plant stem (Levia and Herwitz, 2000; Levia and Frost, 2003). The knowledge of the various interactions of the stemflow in biogeochemical cycle leads to more assertive conservation and restoration actions.

Stemflow is the rain absorbed by forest canopy and channeled through woody surfaces until it reaches forest ground. The hydrological process of connecting the canopy to the soil has strong impact on the biogeochemical cycle of forest ecosystems. Stemflow (SF) is arguably the longest path a rain drop can travel to reach the soil surface, requiring lengthy interaction between rainfall and canopy surfaces (Van Stan and Gordon, 2018). SF stays much longer on tree surfaces than other rainfall processes; thus, it is an important nutrient cycling step (Levia and Germer, 2015).

The ability of SF to wash off dry deposition and stimulate ion exchange capacity leads to more nutrient-rich water flows than those driven by total rainfall and throughfall (Su et al., 2019). Kumar Gautam et al. (2017) argue that such a process helps replenishing soil nutrient pools, which are a bioavailability zone for plants.

The edaphic properties varied in different below-canopy infiltration areas (Aboal et al., 2015); in this way, the water intercepted by plant stems or trunks can contribute to "fertile islands" growth due to its effect on the area surrounding the trunk base. SF can either leach large nutrient concentrations under certain conditions or not make significant contributions to nutrient flux. Atmospheric components tend to accumulate in canopies and stems during drought periods. Based on total rainfall and throughfall, the first rainfall event makes the accumulated components flow through the trunk and it increases their concentration (Zhang et al., 2016).

Research conducted by Suescún et al. (2019) in Colombia concluded that changes in weather conditions, such as drought and natural forest degradation increase and worsening, can affect the ecohydrological and biogeochemical cycles of tropical forest canopies. Chen, S. et al. (2019) studying stem hydrology and dissolved organic matter flux in perennial forests in an urban area in Japan concluded that the tree size is an important factor influencing the heterogeneity of spatial patterns of chemical solution near the tree trunks.

The aim of the present study was to perform a systematic review of literature comparing the main subtopics on research with stemflow contributions to soil nutrient enrichment.

Materials e Methods

The present study is a systematic literature review based on a thorough analysis of the matching literature and on the selection of the most relevant articles regarding the assessed topic (Guitart et al., 2014). The keywords "stemflow" (flow of intercepted water down the trunk or stem of plants), "nutrients", "nutrient flux" and "nutrient cycling" were entered into ScienceDirect and Scopus databases in order to analyze articles that have associated stemflow with nutrient flux (Chart 1). Scientific articles, review articles, books and book chapters published from 2015 to 2019 were selected. The query was limited to publications in English. The articles found in both databases were identified.

The selected articles were screened, and the ones focused on agricultural plant stemflow were excluded from the research.

The main topic of each research was determined based on Title, Keywords and Abstract sections. The keyword analysis of each selected article was performed in Iramuteq software with the aid of R software

Chart 1 – Parameters of the query carried out at Scopus and ScienceDirect databases.

Scopus:	(TITLE-ABS-KEY (stemflow) AND TITLE-ABS-KEY (nutrients) OR TITLE-ABS-KEY (nutrients AND fluxe) OR TITLE-ABS-KEY (nutrient AND cycling) AND LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "ch") OR LIMIT-TO (DOCTYPE, "re") AND (LIMIT-TO (EXACTKEYWORD, "Nutrient Cycling") OR LIMIT-TO (EXACTKEYWORD, "Leaching") OR LIMIT-TO (EXACTKEYWORD, "Nutrients") OR LIMIT-TO (EXACTKEYWORD, "Atmospheric Deposition") OR LIMIT-TO (EXACTKEYWORD, "Nutrient Dynamics") OR LIMIT-TO (EXACTKEYWORD, "Biogeochemistry") OR LIMIT-TO (EXACTKEYWORD, "Precipitation Chemistry") OR LIMIT-TO (EXACTKEYWORD, "Chemical Composition") OR LIMIT-TO (EXACTKEYWORD, "Nutrient") OR LIMIT-TO (EXACTKEYWORD, "Soil Chemistry") OR LIMIT-TO (EXACTKEYWORD, "Nutrient Fluxes") OR LIMIT-TO (EXACTKEYWORD, "Water Chemistry") OR LIMIT-TO (EXACTKEYWORD, "Positive Ions") OR LIMIT-TO (EXACTKEYWORD, "Interception") OR LIMIT-TO (EXACTKEYWORD, "Nutrient Leaching") OR LIMIT-TO (EXACTKEYWORD, "Ions") OR LIMIT-TO (EXACTKEYWORD, "Stemflow Chemistry") OR LIMIT-TO (EXACTKEYWORD, "Nutrient Enrichment") OR LIMIT-TO (EXACTKEYWORD, "Cations") AND (LIMIT-TO (LANGUAGE, "English")).
ScienceDirect: "stemflow" AND "nutrients" OR "nutrients fluxe" OR "nutrient cycling"	

(R Core Team, 2018). Statistical data were treated to show the correlation among the articles' keywords — this correlation was represented by spatial distance, wherein each word is a point in space. Therefore, keywords separated by shorter distances and connected by thicker lines showed the strongest correlation. The most representative keywords were highlighted in a word cloud presenting smaller words next to them (Iramuteq, 2013).

The main topic frequency of each article was summarized in a word cloud, wherein word size was proportional to how often words were identified as the main topic. The duplicate articles found in both databases were considered only once.

The articles were subsequently clustered and assessed based on their publication year and continent of origin.

Results and Discussion

Current status of stemflow and soil dynamics research

Forty-seven (47) articles were published between 2015 and 2019: 37 articles into Scopus and 10 articles into ScienceDirect databases. Five (5) articles are listed both in Scopus and SicenceDirect databases. Thus, the total number of distinct articles is 42: 32 articles in Scopus and 5 articles in ScienceDirect databases (Table 1).

Table 1 – Articles listed and published (2015-2019) into selected databases.

	Authors	Title	Journal
Scopus			
1	Álvarez-Sánchez et al. (2016)	Inorganic nitrogen and phosphorus in stemflow of the palm Astrocaryum mexicanum Liebm. located in Los Tuxtlas, Mexico	*Tropical Ecology*
2	Bade et al. (2015)	Chemical properties of decaying wood in an old-growth spruce forest and effects on soil chemistry	*Biogeochemistry*
3	Bigelow and Canham (2017)	Neighborhood-Scale Analyses of Non-additive Species Effects on Cation Concentrations in Forest Soils	*Ecosystems*
4	Bittar et al. (2018)	Estimation of throughfall and stemflow bacterial flux in a subtropical oak-cedar forest	*Geophysical Research Letters*
5	Cayuela et al. (2019)	Particulate matter fluxes in a Mediterranean mountain forest: interspecific differences between throughfall and stemflow in oak and pine stands	*Journal of Geophysical Research: Atmospheres*
6	Chen, L.C. et al. (2019)	Mediation of stemflow water and nutrient availabilities by epiphytes growing above other epiphytes in a subtropical forest	*Ecohydrology*
7	Chen, S. et al. (2019)	Stemflow hydrology and DOM flux in relation to tree size and rainfall event characteristics	*Agricultural and Forest Meteorology*
8	Deng et al. (2017)	Effects of canopy interception on epikarst water chemistry and its response to precipitation in Southwest China	*Carbonates Evaporites*
9	Duval (2019)	Rainfall partitioning through a mixed cedar swamp and associated C and N fluxes in Southern Ontario, Canada	*Hydrological Processes*
10	Fukushima et al. (2015)	Influence of strip thinning on nutrient outflow concentrations from plantation forested watersheds	*Hydrological Processes*
11	Levia and Germer (2015)	A Review of Stemflow Generation Dynamics and Stemflow-Environment Interactions in Forests and Shrublands.	*Reviews of Geophysics*
12	Li et al. (2017)	Abiotic processes are insufficient for fertile island development: A 10-year artificial shrub experiment in a desert grassland	*Geophysical Research Letters*
13	Limpert and Siegert (2019)	Interspecific Differences in Canopy-Derived Water, Carbon, and Nitrogen in Upland Oak-Hickory Forest	*Forests*
14	Liu et al. (2019)	Base Cation Fluxes from the Stemflow in Three Mixed Plantations in the Rainy Zone of Western China	*Forests*
15	Lombardo et al. (2018)	Organic carbon fluxes by precipitation, throughfall and stemflow in an olive orchard in Southern Spain	*Plant Biosystems*
16	Lu et al. (2016)	Nutrient characteristics of throughfall and stemflow in the natural forest of Pinus densata in the Tibetan plateau	*Phyton*

Continues...

Table 1 – Continuation.

	Authors	Title	Journal
17	Lu et al. (2017)	Nutrient Fluxes in Rainfall, Throughfall, and Stemflow in Pinus densata Natural Forest of Tibetan Plateau	*Clean - Soil, Air, Water*
18	Michalzik et al. (2016)	Effects of aphid infestation on the biogeochemistry of the water routed through European beech (Fagus sylvatica L.) saplings	*Biogeochemistry*
19	Rehmus et al. (2017)	Aluminum cycling in a tropical montane forest ecosystem in southern Ecuador	*Geoderma*
20	Rice et al. (2016)	Role of riparian areas in atmospheric pesticide deposition and its potential effect on water quality	*Journal of the American Water Resources Association*
21	Rosier et al. (2016)	Seasonal dynamics of the soil microbial community structure within the proximal area of tree boles: Possible influence of stemflow	*European Journal of Soil Biology*
22	Rossi and Ares (2016)	Overland flow from plant patches: Coupled effects of preferential infiltration, surface roughness and depression storage at the semiarid Patagonian Monte	*Journal of Hydrology*
23	Siegert et al. (2017)	Do storm synoptic patterns affect biogeochemical fluxes from temperate deciduous forest canopies?	*Biogeochemistry*
24	Su et al. (2019)	Hydrochemical Fluxes in Bulk Precipitation, Throughfall, and Stemflow in a Mixed Evergreen and Deciduous Broadleaved Forest	*Forests*
25	Suescún et al. (2019)	ENSO and rainfall seasonality affect nutrient exchange in tropical mountain forests	*Ecohydrology*
26	Sun et al. (2015)	Variation characteristics of nitrogen concentrations through forest hydrologic subcycles in various forests across mainland China	*Environmental Technology*
27	Thieme et al. (2019)	Dissolved organic matter characteristics of deciduous and coniferous forests with variable management: different at the source, aligned in the soil	*Biogeosciences*
28	Türtscher et al. (2019)	Reconstructing Soil Recovery from Acid Rain in Beech (Fagus sylvatica) Stands of the ViennaWoods as Indicated by Removal of Stemflow and Dendrochemistry	*Water, Air and Soil Pollution*
29	Van Stan and Stubbins (2018)	Tree-DOM: Dissolved organic matter in throughfall and stemflow	*Limnology and Oceanography Letters*
30	Vandecar et al. (2015)	Phosphorus input through fog deposition in a dry tropical forest	*Journal of Geophysical Research: Biogeosciences*
31	Yuan et al. (2017)	Comparisons of stemflow and its bio-/abiotic influential factors between two xerophytic shrub species	*Hydrology and Earth System Sciences*
32	Zhang et al. (2016)	Variations of Nutrients in Gross Rainfall, Stemflow, and Throughfall Within Revegetated Desert Ecosystems	*Water, Air, and Soil Pollution*
ScienceDirect			
1	Attarod et al. (2019)	Replacing an oriental beech forest with a spruce plantation impacts nutrient concentrations in throughfall, stemflow, and O layer	*Forest Systems*
2	Rosier et al. (2015)	Forest canopy precipitation partioning: an important plant trait influencing the spatial structure of the symbiotic soil microbial community	*Advances in Botanical Research*
3	Jian et al. (2019)	Retracted: Study on the throughfall, stemflow, and interception of two shrubs in the semiarid Loess region of China	*Agricultural and Forest Meteorology*
4	Wilcke et al. (2019)	Temporal Trends of Phosphorus Cycling in a Tropical Montane Forest in Ecuador During 14 Years	*Journal of Geophysical Research: Biogeosciences*
5	Wang et al. (2019)	Dissolved Organic Matter Characteristics and Important Site Factors in a Subtropical Mountain Forest in Central China	*Forest Science*
Scopus and ScienceDirect			
1	Berger et al. (2016)	A slight recovery of soils from Acid Rain over the last three decades is not reflected in the macro nutrition of beech (Fagus sylvatica) at 97 forest stands of the Vienna Woods	*Environmental Pollution*
2	Schooling et al. (2017)	Stemflow chemistry in relation to tree size: A preliminary investigation of eleven urban park trees in British Columbia, Canada	*Urban Forestry & Urban Greening*
3	Schwendenmann and Michalzik (2019)	Dissolved and particulate carbon and nitrogen fluxes along a Phytophthora agathidicida infection gradient in a kauri (Agathis australis) dominated forest	*Fungal Ecology*
4	Türtscher et al. (2017)	Declining atmospheric deposition of heavy metals over the last three decades is reflected in soil and foliage of 97 beech (Fagus sylvatica) stands in the Vienna Woods	*Environmental Pollution*
5	Van Stan and Pypker (2015)	A review and evaluation of forest canopy epiphyte roles in the partitioning and chemical alteration of precipitation	*Science of the Total Environment*

Main topic analysis based on publication year and continent of origin

Although there was upward trend in Scopus articles from 2015 to 2017, it dropped sharply in 2018. Yet, the number of published articles increased in 2019. The number of ScienceDirect articles remained stable from 2015 to 2017; it was followed by a decrease in 2018 and an increase in the last analyzed year (2019) (Figure 1).

Moreover, both Scopus and ScienceDirect databases showed that Asia was the continent accounting for the largest number of publications on the topic addressed herein over the last 5 years; it was followed by North America (Figure 2). Conversely, Oceania and South America recorded the lowest number of published articles.

Keyword analysis

The Graph Theory-based keyword analysis allows identifying the frequency of a given word and the signs of connection among words, which helps identifying the text corpus content structure (Figure 3). "Stemflow" and "throughfall" were the two words that have stood out the most among the selected articles and they are highlighted in the middle of this structure. They branch off in the structure for being highly correlated to other terms, such as "forest" and nutrient".

Overall, it can be inferred that the literature discussed herein, in addition to presenting references inherent to the stemflow and throughfall process, also acknowledged stemflow as an important channel for nutrient input into forest soil. Yet, there are other essential aspects for the broad understanding of the topic addressed herein. The "stemflow" cluster was correlated to terms such as "concentration", "chemistry", "biogeochemical cycle" and "nutrient dynamics", whereas the "throughfall" cluster encompassed words such as "ecohydrology" and "interception".

Thus, both stemflow and throughfall take part in nutrient dynamics, since they alter the chemistry of rainwater that flows down tree canopies and contribute to biogeochemical cycling by carrying nutrients into the soil. Zhang et al. (2016) and Schooling et al. (2017) have shown that throughfall and stemflow water cycles are key drivers of ecosystem processes, mainly of nutrient cycling. Su et al. (2019) argue that rainfall is one of the main chemical input sources in forest ecosystems; therefore, understanding nutrient cycling and hydrochemical fluxes of forest ecosystems is essential to manage their dynamics. Attarod et al. (2019), demonstrated that changing from a natural beech forest to a spruce plantation significantly alters nutrient fluxes leached from the canopy and that provides essential information on how planting exotic species affect nutrient cycles.

The "stemflow" cluster was also made up of words such as "leach", "ion" and "water chemistry", since stemflow is rich in leachate solutions from leaves, branches and stems (Aboal et al., 2015). Moreover, its water residence time in tree surfaces lasts much longer than that of other interception processes. Therefore, stemflow is a key process in nutrient cycling (Levia and Germer, 2015).

Several factors can affect the concentration and flow of nutrients from tree canopies and stems to the soil, such as the following: rainfall volume and intensity; dry seasons preceding rainfall; seasonality. These factors are important because they can change the dilution and leaching processes of the minerals accumulated in tree canopies and stems (Siegert et al., 2017). Yet, soil chemistry can also affect the cycling of nutrients by trees and, consequently, affect the leaching rates of the same nutrients in plant tissue (Aboal et al., 2015). Chen, L.C. et al. (2019) suggest that the tree size is also an important factor affecting the heterogeneity of the spatial patterns of the soil solution chemistry near tree trunks.

The "stemflow" cluster comprises the "soil" subcluster, which is made up of words that validate the importance of stemflow to nutrient input into the soil, such as "chemistry", "soil chemistry", among others. Deng et al. (2017) demonstrate that precipitation shows an acid and nutrient enrichment phenomenon after interception by canopy. Levia and Germer (2015) state that SF has been increasingly acknowledged as an important process for providing water and nutrients to spatial areas of forest ground. SF particles stay on tree surfaces for much longer than particles carried by other rainfall interception processes; therefore, it is a key pathway in the nutrient cycling.

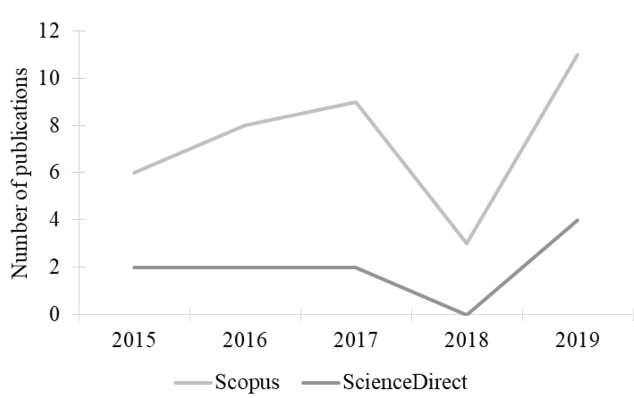

Figure 1 – Distribution of number of publications per year.

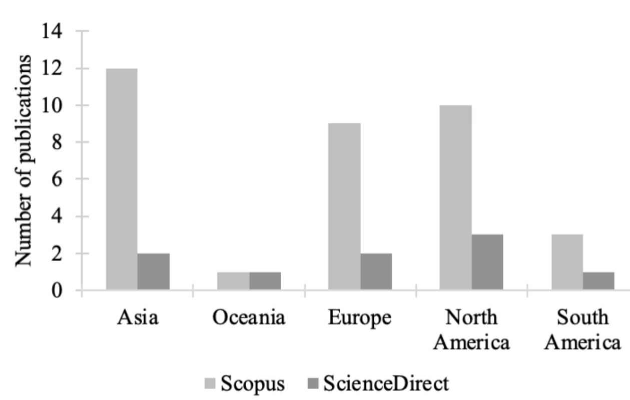

Figure 2 – Distribution of the number of publications by continent.

The term "*fagus sylvatica*" also stands out from the interconnected words belonging to the "stemflow" cluster. *Fagus sylvatica*, *Fagus grandifolia*, *Prunus virginiana*, *Caragana korshinskii* and *Acer rubrum* (Figure 4) were the five most assessed species associated with nutrient cycling; however, the selected articles were mostly focused on species *Fagus sylvatica* (Berger et al., 2016; Michalzik et al., 2016; Thieme et al., 2019; Türtscher et al., 2019). *Fagus sylvatica*, also known as European beech, is one of the most common tree species in Europe; it is distributed in Central and Western Europe.

There was no study providing an overview of the stemflow importance for nutrient cycling in both existing Brazilian plant species and biome diversity. *Tabebuia chrysantha*, *Cedrela odorata*, *Ocotea aciphylla* and *Larrea divaricata* were the most widely distributed species in Brazil; yet, the other species were either missing or difficult to find (Table 2).

The term "atmospheric deposition" stood out in the "stemflow" word cluster. Cayuela et al. (2019) argues that the atmospheric particulate matter is redistributed and deposited on plant leaves before they are carried into soil layers through SF and TF (throughfall). Lu et al. (2017) assessed the components and features of both SF and TF solutes from the *Pinus densata* forest in Tibet Plateau; their results suggested

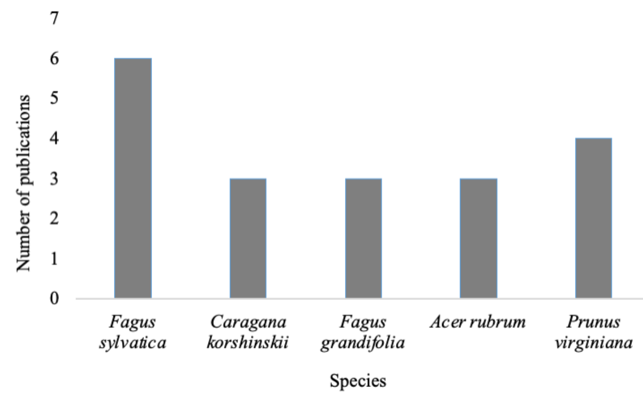

Figure 4 – Five most assessed species based on stemflow and nutrient cycling.

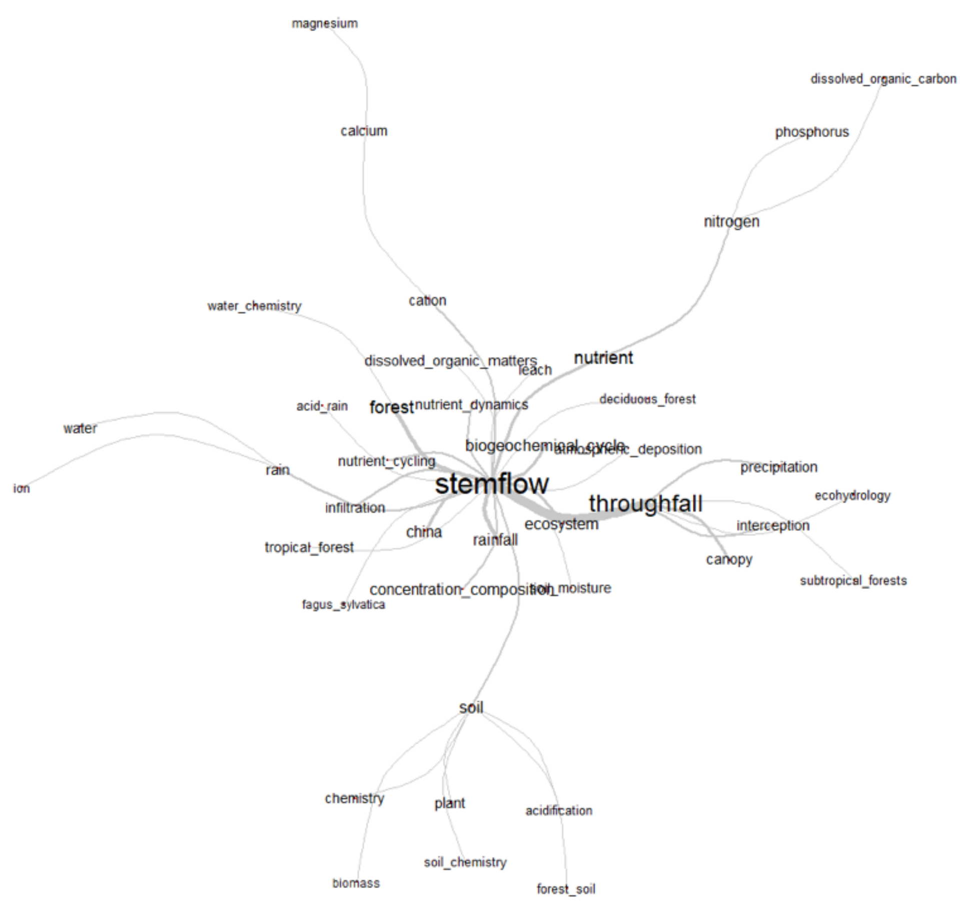

Figure 3 – Cluster of keywords from research about stemflow effect on soil nutrient flux, based on co-occurrence analysis.

that atmospheric deposition plays an important role in nutrient supply to the soil surrounding the trees. Türtscher et al. (2017) used SF to study the legacy of high atmospheric heavy metal deposition. Results of measurements taken from heavy metal contamination in *Fagus sylvatica* trees in Vienna have shown critical heavy metal levels in microsites affected by SF.

Yet, the term "soil moisture" in the "stemflow" cluster indicated that SF becomes a source of moisture to the soil. Research by Jian et al. (2019) in arid regions have confirmed that SF has positive effect on soil moisture balance in the root zone; moreover, it can improve soil moisture and structure in deeper layers. Studies conducted by Rosier et al. (2016) suggest that SF enhances and alters edaphic conditions

Table 2 – Species searched based on the keywords presented herein.

Author	Species
Cayuela et al. (2019)	*Quercus pubescens, Pinus sylvestris*
Chen, S. et al. (2019)	*Castanopsis cuspidata*
Duval (2019)	*Thuja occidentalis, Abies balsamea, Populus balsamifera, Fraxinus nigra, Picea mariana, Betula papyrifera, Alnus glutinosa*
Limpert and Siegert (2019)	*Quercus alba, Quercus stellata, Quercus pagoda, Quercus shumardii, Carya ovata, Carya glabra*
Liu et al. (2019)	*Cryptomeria fortunei, Quercus acutissima, Phoebe zhennan, Camptotheca acuminate, Padus racemosa, Pterocarya stenoptera, Michelia wilsonii, Cryptomeria fortune, Alnus remastogyne*
Schwendenmann and Michalzik (2019)	*Agathis australis*
Su et al. (2019)	*Cyclobalanopsis multinervis, Cyclobalanopsis oxyodon, Fagus engleriana, Quercus serrata*
Suescún et al. (2019)	*Quercus humboldtii*
Türtscher et al. (2019)	*Fagus sylvatica*
Attarod et al. (2019)	*Fagus orientalis, Picea abies*
Thieme et al. (2019)	*Fagus sylvatica, Picea abies, Pinus sylvestris*
Jian et al. (2019)	*Caragana korshinskii, Hippophae rhamnoides*
Chen, L.C. et al. (2019)	*Phoebe formosana, Machilus zuihoensis, Neolistea, konishii, Pasania hancei*
Bittar et al. (2018)	*Quercus virginiana, Juniperus virginiana*
Bigelow and Canham (2017)	*Acer saccharum, Fraxinus americana, Fagus grandifolia, Acer rubrum, Quercus rubra, Tsuga canadensis, Acer pensylvanicum, Malus pumila, Carpinus caroliniana, Crataegus brainerdii, Ostrya virginiana, Hamamelis virginiana, Prunus virginiana, Carya ovata, Prunus serotina, Picea rubens, Pinus strobus, Betula populifolia, Betula alleghaniensis, Betula papyrifera*
Lu et al. (2017)	*Pinus densata*
Rehmus et al. (2017)	*Purdiaea nutans, Alchornea pearcei, Graffenrieda emarginata, Podocarpus oleifolius, Alazatea verticilata, Clusia ducoides, Hyeronima moritziana, Ocotea aciphylla, Ocotea bentamiana, Miconia, Elaeagia, Matayba inelegans, Prunus opaca, Cedrela odorata, Heliocarpus americanus, Tabebuia chrysantha*
Siegert et al. (2017)	*Fagus grandifolia, Liriodendron tulipifera*
Schooling et al. (2017)	*Cercidiphyllum japonicum, Tilia cordata, Prunus virginiana, Acer rubrum, Fraxinus pennsylvanica, Quercus macrocarpa, Acer freemanii, Prunus padus, Fagus sylvatica, Quercus palustres*
Türtscher et al. (2017)	*Fagus sylvatica*
Kaushal et al. (2017)	*Morus alba*
Michalzik et al. (2016)	*Fagus sylvatica*
Zhang et al. (2016)	*Caragana korshinskii, Artemisia ordosica*
Rice et al. (2016)	*Acer rubrum, Symplocarpus foetidus, Impatiens pallida*
Álvarez-Sánchez et al. (2016)	*Astrocaryum mexicanum*
Berger et al. (2016)	*Fagus sylvatica*
Lu et al. (2016)	*Pinus densata*
Rosier et al. (2016)	*Fagus grandifolia, Liriodendron tulipifera*
Rossi and Ares (2016)	*Schinus johnstonii, Pappostipa speciosa, Chuquiraga avellanedae, Larrea divaricata*
Fukushima et al. (2015)	*Chamaecyparis obtuse, Cryptomeria japonica*
Aboal et al. (2015)	*Morella faya, Laurus novocanariensis, Erica arborea, Persea indica, Ilex perado*
Bade et al. (2015)	*Picea abies*

of the soil surrounding individual tree trunks, such as moisture, pH and mineral nutrients (Al, Cu, K, Mn) available to plants. However, SF effects may specifically vary among species and specimens. This fact assumingly explains the structural differences in the microbial community of the soil surrounding the tree trunks.

The analysis of articles addressing dissolved organic matter (DOM) was based on both "stemflow" cluster and on its subclusters, mainly "cations", "calcium" and "magnesium". Dissolved organic carbon (DOC) is part of the "nitrogen" subcluster. DOM is important for both vertical and horizontal nutrient transport in forest ecosystems (Wang et al., 2019). DOM features during leaching can highly vary depending on forest type; this variability is mostly evident when there are changes in seasonal leaves and rainfall conditions (Van Stan and Stubbins, 2018; Chen, S. et al. (2019); Duval, 2019). DOM is part of the biogeochemical cycles of carbon and nutrients, as it carries ions and encourages soil growth. Both chemical concentration and its properties in the water flow path of forest ecosystems depend on their sampling site and transformation processes (Thieme et al., 2019).

Research conducted by Schwendenmann and Michalzik (2019) has demonstrated that the following data are also measured in order to assess nutrient cycling status during forest restoration processes: water input and output in the ecosystem; DOC leaching and water migration coefficients; nitrogen flux.

The word "phosphorus" stands out in the subcluster "nitrogen". Atmospheric deposition can significantly increase the amount of P available in the soil of many tropical forests — phosphorus (P) is considered a limiting nutrient. This effect takes place due to the increased deposition of P-rich aerosol particles (dry deposition) and fog droplets (wet deposition) on leaf surface (Vandecar et al., 2015). Results of the research conducted by Álvarez-Sánchez (2016) on palm *Astrocaryum mexicanum* implied that its SF is an important pathway for both P and nitrogen input into the soil of this tropical forest of palms.

The terms "subtropical forests" and "tropical forest" make up the "throughfall" and "stemflow" clusters, respectively, and the word "China" is highlighted close to the "stemflow" cluster. Despite the growing number of publications on the topic addressed herein, most of them come from China, whose vegetation consists mostly of subtropical forests. Thus, the number of studies conducted in tropical forests remains insufficient. This statement is supported by the fact that the entered keywords did not show results of studies carried out in Brazil, only in Ecuador and Colombia. Thus, the knowledge gap on the role played by different species in the biogeochemical cycle — mainly the stemflow process — of tropical forests remains.

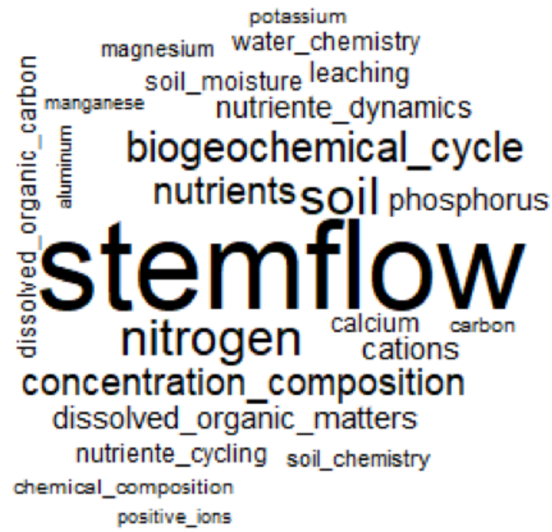

Figure 5 – Word cloud showing the main topics associated with stemflow-driven nutrient dynamics.

The word cloud generated from published articles mainly focused on SF was analyzed in order to substantiate the previous analysis. Results have shown that the most common keywords were "stemflow", "nitrogen", "concentration", "composition", "biogeochemical cycle", "dissolved organic matter", "soil nutrients" and "atmospheric deposition". Such results emphasize the importance of stemflow for nutrient leaching, since SF improves ion availability in the soil (Figure 5).

Conclusions

Stemflow is a fundamental component for nutrient leaching, since SF improves ion availability in the soil. Only a few studies provided an overview of the importance of stemflow for nutrient cycling in Brazilian plant species and biome diversity. Based on the searched databases, forty-seven (47) articles were published between 2015 and 2019, thirty seven (37) in Scopus, and 10 in Science Direct databases. Five (5) articles are listed both in Scopus and Sicence Direct databases. Asia comprised most of the publications related to the aforementioned topic over the last 5 years, whereas South American research on the role played by different species in stemflow — mainly during the biogeochemical cycle — remains scarce. Research regarding the stemflow effect on biogeochemical cycling and soil dynamics is still insufficient, and full understanding thereof still requires many further studies.

Contribution of authors:

Lima, M.T.: Formal Analysis, Methodology, Writing — Original Draft, Writing — Review and Editing. Tonello, K.C.: Formal Analysis, Methodology, Supervision, Validation, Visualization, Writing — Review and Editing. Bramorski, J.: Formal Analysis; Methodology; Validation, Visualization, Writing — Review and Editing. Arruda, M.M.: Formal Analysis; Methodology; Writing — Review and Editing. Matus, G.N.: Formal Analysis; Methodology; Writing — Review and Editing.

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