Chapter

Plant Invasion and N_2O Emission in Forest Ecosystems

Nasir Shad, Ling Zhang, Ghulam Mujtaba Shah, Fang Haifu, Muhammad Ilyas, Abbas Ali and Salman Ali Khan

Abstract

Nitrogen (N) is a key factor for any ecosystem and has been found limited for biomass production. More N in forest ecosystem and their efficient utilization will contribute to the maximization in their growth, competition, and reproduction. Invasive plants capture and utilize more N than native plants and accelerate N cycles through altering the structure and community of soil microbes and the litter decomposition rates, under microclimate conditions, resulting in an increase of N availability. All these factors are promoting the invasiveness of plants and cause further ecological and economic damage and decline in native biodiversity. Plant invasions affect soil microbial community, soil physiochemical properties, and litter decomposition rates, promoting N cycle and releasing more nitrous oxide (N_2O) into the atmosphere, further facilitating global warming, causing changes in the geographic ranges of some invasive species. Also, a better understanding of the mechanism, affecting factors, impacts, and control of the invasive species will lead to proper forest management. Proper and effective management will ensure the control of invasive species which includes invasive plant inventory, early deduction and rapid response, management plan and implication, and government support.

Keywords: global warming, plant invasions, greenhouse gases, nitrogen, forest management

1. Introduction

Biological invasion and global climate change pose threats to the loss of biodiversity, genetic diversity, agriculture output, and ecosystem service change worldwide, thus causing huge economic loss [1–5]. Furthermore, global warming causes global climate change in the present era. Various exotic components including water vapor, ozone, and greenhouse gases (GHGs) play a role in the atmosphere absorbing an amount of the emitted radiation from Earth's surface and then re-emitting it back to Earth, further increasing the surface temperature and resulting to disasters like floods, hurricanes, and drought [6–8]. N_2O, CO_2, and CH_4 are mostly produced naturally as a biological process and by anthropogenic activity. These GHGs amounted about 80% of total the GHGs [8, 9]. N_2O is a major long-lived GHG with a global warming potential of about 310 times greater than of CO_2 over a lifetime of 100 years [10] and is also involved in the atmospheric ozone depletion [11, 12], and >80% of global N_2O emissions are projected to be linked to soil microbial activity [13]. A reorientation of multidimensional problems between forest and climate changes is a complex issue. Climate change affects forest composition, and in addition, forest disturbances such as destruction and degradation further facilitate plant invasion which results to acceleration of the global GHG emissions [14–16]. Disturbances in the forest ecosystem lead to a loss of biodiversity, loss of biomass, and decreased forest regeneration potential [17]. The modification of abiotic and biotic factors will affect the exchange rate of GHG emission released into the atmosphere by forest soil, primarily through changes in microbial-mediated process and plant-derived process (e.g., photosynthesis) [18–20]. Therefore, adopting effective forestry and sustainable management practices will ensure productivity, N_2O mitigation, and biodiversity [21]. Soil N_2O production has been widely linked to soil microbial activity [12], which can be affected by litter and rhizosphere inputs of invasive plants [22], land-use legacy, and many other factors which are still unknown [23]. These changes to forest ecosystems can accelerate nutrient cycling and increase soil N_2O production to the atmosphere [24]. The world's forests are likely to face an increasing number of invasions in the future. It is necessary to identify the existing invasions and their potential for expansion and then set up invasive species management plan [25]. Managing forest invasion involves avoiding entry, eradicating nascent species, biological control, choosing host trees for resistance, and using cultural practices (silviculture and restoration) to mitigate invader impacts.

The problem on biological invasion is highlighted. It poses a threat to any ecosystem which includes forest ecosystems, causing economic and ecological damages worldwide. The factors contributing to plant invasion include microbial facilitation, global warming, and nutrients availability which make it more complex and still unknown. Based on the previous literature, we tried to understand and discuss the following issues: plant invasion in forest ecosystems, factors contributing to plant invasions, and soil N process and N_2O emission in the context of forest plant invasion. The aim of our study is to highlight the mechanism of plant invasion and its control and management in the context of sustainable forest management.

2. Effects of global warming on plant invasion

The rising GHGs in the atmosphere such as N_2O emission and other global change components affecting temperature can help hinder or promote plant invasions [26, 27]. For example, species may increase in size with warming and decline of canopy transpiration [28, 29]. Furthermore, previous studies and models indicate that invasive plant often responds unpredictably to global change components [26]. The response of plant species to elevated temperature depends on the features of their ecological and physiological characteristics. The previous study demonstrated that invasive species (*Lantana camara)* respond significantly to elevated temperature with increasing allopathic effects and high growth rate, suggesting that global warming may increase the invasions of plant species [30]. The world's climate with rising temperature can change the interaction, physiology, phenology, and dispersal pattern of plant species, and the introduced species may have an advantage over the native species in terms of responding more to this climate change [29]. The introduction of alien plant species is considered to survive if the introduced range is likely to their native range, temperature being a key factor for their further expansion, reproduction, and growth [31, 32]. Global warming provides opportunity for invasive species to expand into regions where they could not previously survive and reproduce [4]. In addition, drought resulting from the climate change can affect biodiversity which further results in a warmer climate region, therefore damaging soil properties and affecting the plant nutrient uptake ability. These changes can threaten important biodiversity and foods for local populations. Drought and warm climate are likely due to an expansion of invasive species and can also lead to biodiversity loss and changes in frequency and intensity, which can affect seed germination, potential growth of young plants, and ecosystem services [33]. To date, global warming has been related to the rapid expansion of native plant populations [34, 35] and colonization of newly exposed land on local scale, although natural colonization of the region would occur. Consequently, under climate change, non-native species are likely to interfere with native biodiversity [36]. Climate change has also effects on plant-soil feedback such as the interaction among soil microbes and plants. Global warming as one of the components of climate change greatly affects input to the soil by litter production from decomposition [37, 38]. Warming affects seed germination of plants, for which invasive species show positive response specially in the summer season. Also, the total biomass of invasive species can be affected by global warming and they show high response in winter season compared to native species [39].

3. Forest plant invasions

The plant species in forest ecosystems can successfully grow when the introduced range is likely in their native habitat and can further expand and become invasive with unlimited soil resources, rising temperature, and soil microbial facilitation with a positive interaction to species [31, 32]. The success of plant invasion in forest ecosystems can be affected by many factors: rising temperature [30], landscape structure [40], and disturbance, especially harvest-induced disturbance which increased the abundance of invasive plant species [41–43]. The overstory harvest increases the microclimate temperature. Such factors and resources availability at the proper time can help the introduced species invade in forest ecosystems [44]. Such types of impact change in forest succession alter nutrients, carbon and water cycle, and the competition between native and invasive plant species is a much more threat to changes in ecosystem services. Plantation and regeneration forests are also at risk due to rapid plant invasions [45]. In order to impose an impact on ecological systems, invasive species not only required high-relative biomass, but they should also have characteristics that differ from those already present in the native species, which are necessary to drive ecosystem process [46]. The traits between invasive and native plants in forests can differ due to invasive species being assigned with higher resource utilization, fast-decaying leaf, more decomposition, high photosynthetic rate, relative growth rate, and higher specific leaf area [47–51]. Higher forest canopy cover can lessen the plant invasion, and it may limit the light source for invaded species when it is demanding for more light [52].

4. Forest management with plant invasions

Plant invasion in forest ecosystem is causing economic and ecological damage and threatens biodiversity conservation [52]. Forest management is required to identify the invasive species and its invasion stages and possible expansion and then set up a plan for its control [25], The inventory of invasive plants will help on proper management and planning. It is based on the invasive species status, distribution, and effects and threats to forest ecosystem [53]. Early deduction of invasive species and their identification, based on to confirm whether it is new to the area and measure its establishment, expansion to other areas as well as predict its impact on the forest ecosystem and loss will lead to effective management plan. The rapid response with effective management/plan can lessen the further invasion with daily basis monitoring [53].

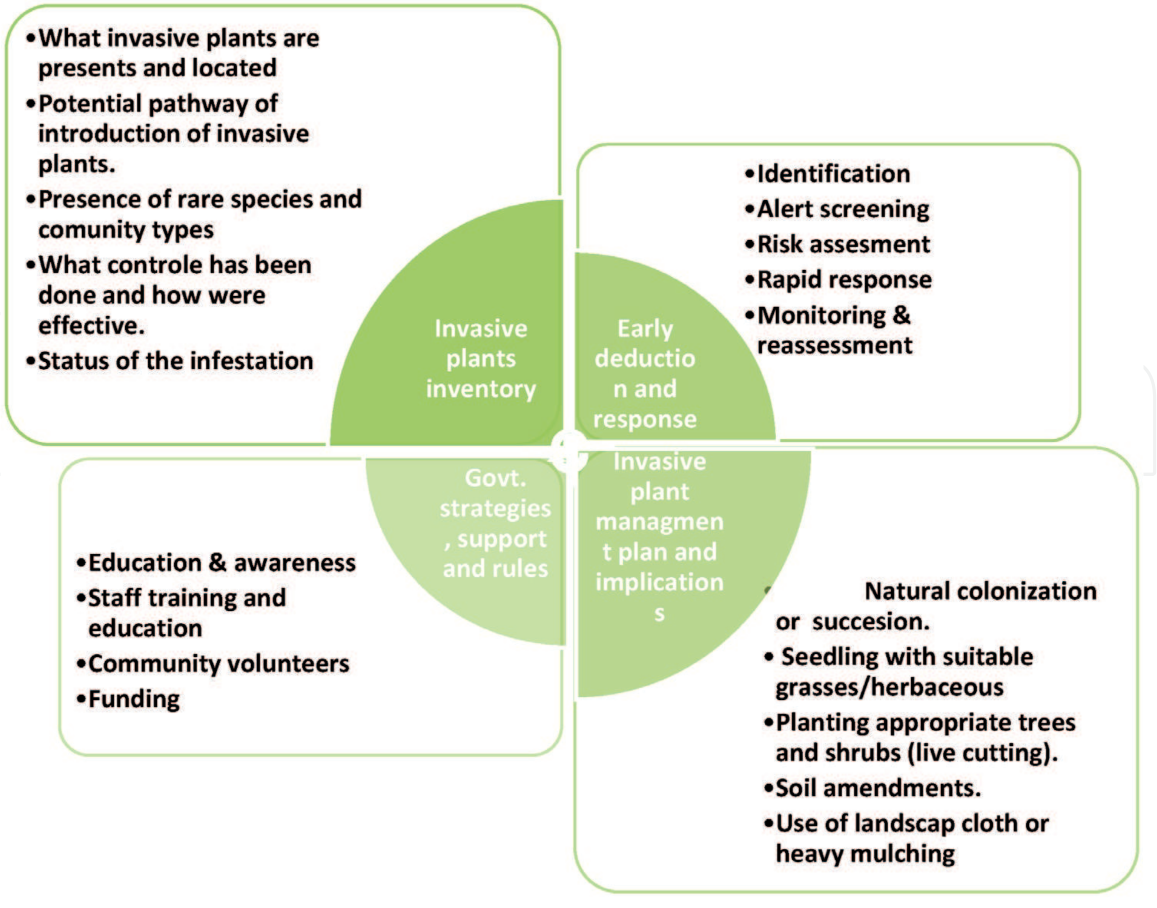

Figure 1.
A stepwise model is leading an effective forest management of invasive species (adapted from [53]).

Forest management includes prevention of arrival and dispersal of invasive species and their biological control as well as silviculture and restoration practices to lessen invasion impacts [45]. Restoration should be based on choosing plant species which suit to the condition of the target area [53]. For example, to increase the forests canopy cover may resist those invading species which demanding for more light, thus, invasive species with high resource demanding can be managed by proper way to minimize its further effects [54]. Also, a better understanding of the mechanism, affecting factors, impacts, and control of the invasive species will lead to a proper forest management. The (**Figure 1**) model is based on invasive species management, a stepwise model leading an effective management of species.

5. Forest plant invasions and soil N cycling

N is a key factor determining the outcome of interspecific competition in many ecosystems [55–57]. Previous literature found invasive plants dominant over the native plants because of they have more nutrient utilization, high photosynthetic rate, increased biomass production, more N availability from litter, high decomposition rate [58]. In addition invasive species produce fast-decaying litter [48]. Such characteristics of plant invasions can accelerate/increase soil N cycling by altering soil microbial community which further affects N_2O emission and forest ecosystem services in the invaded site [59, 60]. It may vary the types of plant invasion, such as woody plant invasion and N-fixing plants which have more significant impacts on N cycling than their alternatives. There is no difference between the responses of forests, wetlands, and grasslands to plant invasions [49].

N is a key nutrient, limiting factor for biomass production in forest ecosystems [57, 61]. No plant is suitable for all habitat to grow potentially [47, 62, 63]. However, invasive plants efficiently utilize resources showing maximization in growth, competition, and reproduction and improving their invasiveness characteristics [57, 62, 64, 65]. The N use efficiency of invasive plants is enhanced by many ways such as N fixation, photosynthetic N use efficiency, and N mineralization, allowing invasive species to have an advantage over native plant population [47, 56, 57, 66].

Rapid nutrient cycles especially N cycle may promote the invasiveness of plants [49, 59, 67, 68]. Also, increased N availability may affect the activity of soil microbial community with invasive plants and contribute to further invasion and provide a favorable environment for soil microbes [46, 59, 69]. Plant invasion changed (a) soil microbial community, (b) physiochemical properties, and (c) litter decomposition rate, which can affect the soil N cycle.

a. Plant invasion helps in the succession of soil microbes and promotes their functions, further facilitating plant invasions [70–72]. Some finding suggests that invasive plants in the invaded site may cause positive structural change in microbial community, which results in negative effects on native plant community, establishment, growth, and the whole ecosystem [56, 73]. Increasing the availability of N by invasive plants through changed in soil microorganism structure and community in result rapid decomposition, or through N_2 symbiotic fixation can further accelerate the N cycles [49, 58, 59, 74, 75]. These changes of plant invasion and especially the symbiotic N fixers have large effects on N cycles [58].

b. There is considerable evidence that plant invasion may alter physiochemical properties of soil. For example, invasive plants may cause soil moisture reduction with rapid evapotranspiration because of the long survival and rapid growth of invasive plants [75–77]. Some studies also observed a positive association between plant invasion and soil moisture [78]. Invasion of plants results in high pH value in soil, such as more ammonium and nitrate absorption result in acidification and alkalinization [78–80]. Si et al. [81] findings show that low-degree plant invasion increased soil pH value, but high-degree plant invasion did not. A decrease in soil pH values caused by invasive plants could improve the solubility of P in soil, which contributes to further plant invasion [82]. Such factors, soil pH, soil moisture, and temperature are regulating soil microbes, soil N availability, litter decomposition rate, and community structure, thus also affecting the physiochemical properties effects on plant invasions [83, 84].

c. Fast-decaying litter of invasive species increases soil nutrients, especially N [83]. Thus, invasive plants obtain more nutrients especially N, and fast decomposition might also impact N cycle and further promote plant invasions [83, 85, 86]. Leaf litter quality and remarkable condition in the surrounding environment created by plants such as an increase in soil temperature and moisture can affect litter decomposition rate [87]. Invasive plants are often found with higher leaf N concentration affecting litter decomposition rates [51].

Soil N availability and transformation (mineralization, nitrification and denitrification) process from unusable form to usable form for plants is a key factor for primary net production. The involved microbes in nitrification and denitrification process are associated with N_2O emission [12, 88]. More N_2O emissions from the forest soil further accelerate global warming, thus greatly affecting N inputs to the soil by litter production through rapid decomposition by invasive plants [37, 51].

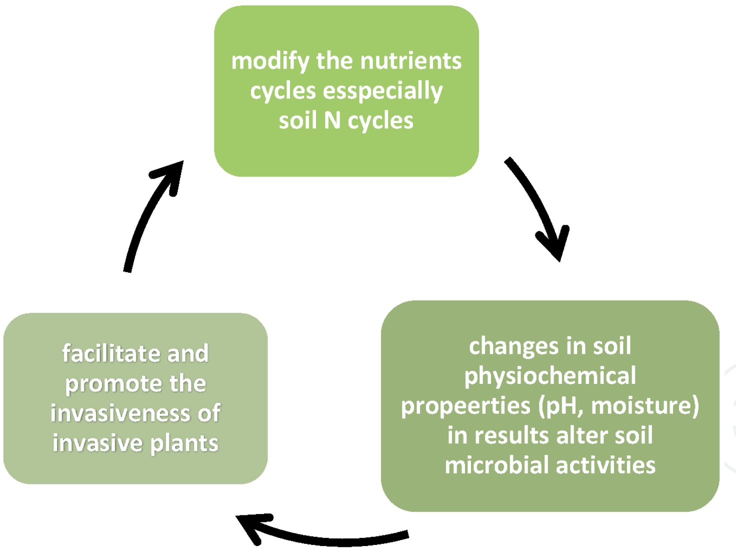

Figure 2.
The dynamic feedback diagram between invasive plants, soil properties, and soil N cycles (modified from [89]).

Invasive plants are often found with high soil N content because of the fast-decaying litter production [48], which may affect the activity of soil microbial community, providing favorable environment to them [59, 69], such as increase in soil temperature [87], which may not be the same case for native species (**Figure 2**).

6. Forest plant invasions and soil N_2O emissions

Nitrous oxide is a major GHG which contributes to the depletion of ozone layer and is released from soils [90]. It has been widely linked to soil microbial activity [12]. Soil biota can be affected through litter and rhizosphere inputs of invasive plant species and may stimulate nutrient release via litter effect. Furthermore, invasive plants support more decomposers [22] and can modify soil enzyme activity [91], as well as fast-decaying litter from the invasive species [48], land-use legacy and many other factors alter soil microbial communities [23], further accelerate N cycling and increasing N_2O emissions altering the atmosphere composition [24]. The emission of N_2O to the atmosphere further facilitating global warming is expected to change the geographic ranges of some invasive species [26, 92], creating new opportunity for the establishment and development of introduced species, and can also affect the phenology of invasive species [93]. We define that more N concentration causes more N_2O emission. Hall et al. [16] show that canopy N concentration has effects on N_2O emission where the canopy concentration of invasive species was higher than that of native plants, especially in the summer season, and vary between forest types. By comparison remote estimates of canopy N in either season did not properly predict N_2O emission in the dry forest ecosystems. However invasive *Morella faya* increased N_2O emission in dry and wet forest ecosystem but the effects was most significant when the forest canopy dominated by Morella faya individual and with few other plant species in the overstory or understory. In addition, an increase in the soil pH and abundance of nosZ and nirK genes results in decreasing N_2O emission [94].

7. Conclusion

Plant invasion alters ecosystem service which results to huge economic loss and ecological loss worldwide. There are many factors behind the invasive plant success.

Some of these factors, such as climate change, underline the microbial mechanism of invasive species, micro-climate that created by invasive plant, more nutrients capturing by invasive plants and more N availability make more complexity which may not be experienced by native species. Previous literature of invasive plants demonstrated their impact complexity and changed the structure and function of ecosystem permanently. Thus, effective control of invasive species needs more attention nationally and internationally to lessen its further damage, leading to sustainable forest management. As well a better understanding of the mechanism, affecting factors, impacts, and control of the invasive species will lead to proper forest management, which include invasive plant inventory, early deduction and response, management and its implication, education and awareness, and indeed government support. Forest managers must pay special attention to species and regional wildlife at risk due to plant invasions. Future studies on the underlying microbial mechanism of invasive plants under the context of global climate change are still necessary to determine the role of the microbial community on plant invasion success.

Acknowledgements

The study was fanatically supported by Research Funding of Jiangxi Agricultural University (9232305172) and First-Class Discipline of Forestry of Jiangxi Province.

Conflict of interest

The authors declare no conflict of interest.

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