

REVIEW

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The sustainability of reforesting landscapes with exotic species: a case study of eucalypts in Ethiopia



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Abstract

Eucalypt reforestation has been a common feature of many countries, especially in the developing countries, such as Ethiopia. Farmers in Ethiopia plant large numbers of eucalypts on small areas of land and manage them to yield a variety of products, including leaves and small branches for fuelwood, and poles and posts for house building and other farm uses. Many people in Ethiopia are dependent on eucalypts as a source of fuel and house building material. The use of trees, especially eucalypts, as a living bank account, to be harvested when there is a need for cash, is widespread. This being the reality, the arguments for and against planting eucalypts in Ethiopia has been mounting from time to time, especially associated with water use, soil fertility, soil erosion, allelopathic effects, understory vegetation and plant diversity as well as wild animals. The paradox of reforestation using eucalypts results, mostly, from inappropriate species-site matching and poor management rather than the inherent biological characteristics of the species. Therefore, the debate on eucalypts under the pretext of concern for indigenous species and natural forests should shift to how both plantations established using eucalypts and indigenous species as well as natural forests can help in the enhancement of the socio-economic development and environmental conservation of countries, such as Ethiopia. Despite the claimed negative impacts of eucalypts, farmers in Ethiopia have utilized their traditional knowledge and experience in establishing and managing eucalypt stands. In addition, the available reports in Ethiopia are in favour of planting eucalypts since the authors acknowledge that: (i) the negative impacts can be minimized provided that the choice of species and site as well as the management of the stands are appropriate, (ii) the benefit derived can offset the losses that can occur from such plantations, (iii) no other species seems to replace them to bridge the ever-widening gap between demand and supply of wood and (iv) the profit derived from eucalypt plantations is considerably higher than cultivating crops. However, the choice of eucalypt species should be based on many criteria, for example maximum wood production, ecological sustainability, marketability of the planted species and usefulness of the species to the local populations. All these criteria involve not only a choice of species planted, but also a choice of plantation management methods from initial planting to final cutting of the trees. Careful selection of appropriate species and matching them with appropriate sites must be taken as prerequisite, and the right management practices should be employed.

Keywords: Allelopathic impact, hydrology, plant diversity, soil fertility and erosion, wild animals, policy implications

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Introduction

There has been an enormous increase in forest plantations in the tropics since the 1960s, and almost 40% of the global estate of 187 million ha of plantations was in the tropical and subtropical areas by 2000 [11]. The factors driving the expansion of forest plantations include past and continued destruction of natural forests, leading to huge gaps between demand and supply of forest products, e.g. in Ethiopia [2, 61], socio-economic and environmental benefits, unsatisfactory regeneration and failures of management in natural forests, land availability to establish forest plantations, high productivity of plantations per unit area, need to reverse deforestation and forest degradation through rehabilitation and restoration as well as carbon storage [11].

Evans and Turnbull [11] have summarized the major socio-economic benefits of plantation forestry as: (i) creation of a resource to meet demand for wood products and provide environmental services, (ii) development of flexible resources able to yield many kinds and sizes of product for internal consumption, export or both, (iii) using land often of little or no agricultural value, (iv) providing employment in rural areas, (v) enabling use of skills already common in agriculture and (vi) bringing development of an infrastructure of roads, communications, services, houses, shops and schools, often, to remote areas. Forest plantations also play a role in stabilizing soil, preventing soil erosion, controlling water runoff in catchment areas, providing shelter from wind and heat as well as against sand and dust storms.

One of the major challenges facing Ethiopia in striving for development is environmental degradation, manifested in the degradation of land, expressed in terms of soil erosion and loss of soil fertility, and water resources as well as decline or loss of biodiversity [61]. Deforestation is one of the major factors contributing to land degradation by exposing the soil to various agents of erosion. This has already led to the use of dung and agricultural residues for fuel instead of natural fertilizer.

In response to the decline of natural forest areas, Ethiopia started large scale industrial plantations with the primary purpose of supplying industrial round wood to produce sawn wood, wood-based panels and wood pulp in the early 1970s [2]. The area of forest plantations was estimated at 189,000 ha in 1990 [15], and it increased to 216,000, 419,000 and 972,000 ha in 2000, 2005 and 2010, respectively [2]. Of the total area of plantation forests, about 20% were classified as commercial plantations that produce timber for sawn wood and poles while the remaining 80% were non-industrial plantations, mainly woodlots and trees on farm. These plantations produce fuelwood and construction timber as well as non-timber forest products. They are mainly composed of exotic tree species with only a few

indigenous trees, and the main species in these plantations are *Eucalyptus* spp. (hereafter referred to as eucalypt and eucalypts for singular and plural, respectively), *Cupressus lusitanica*, *Juniperus procera*, *Pinus patula* and other species.

Eucalypts have become the most planted species in the world, although reliable global estimates of areas of planted eucalypts are difficult to obtain. Published reports suggested that there are at least 12 million ha of eucalypt plantations all over the world [63]. Over 90% of these forests have been established since 1955, and from about one million ha in 1960, planting has approximately doubled each decade until the end of 1980s when the plantations covered about seven million ha, with variable annual planting estimated at about 175,000 to 200,000 ha. A large number of eucalypts have been planted throughout the tropical zone, and about 55 species of eucalypts have been reported from cultivation in Ethiopia, of which between five and ten are widely planted [17].

The major reasons that contributed to the widespread cultivation of eucalypts in various parts of the world include: great genetic diversity, availability and easy propagation of seeds, relative ease of plantation establishment and management, fast growth even on relatively harsh sites, efficient conversion of solar energy, superior performance than indigenous and most other exotic trees, when planted in the right situation, producing wood for poles, pulp and fuel more rapidly, tolerance to wide environmental conditions, e.g. drought resistance and tolerance to sites of low inherent nutrient status (require little fertilizer), wood of high specific gravity and calorific value, high coppicing ability, exceptional hardness and other fine qualities of their timber, superior short-length fibre for paper making and excellent charcoal, un-palatability or tolerance of most species to browsing/grazing (easy to protect), relative tolerance to diseases and pests, good economic returns, usefulness for shelter belts, erosion control, land reclamation and drainage as well as provision of non-timber forest products, e.g. honey and essential oils. [8, 12, 34, 47, 50, 63, 64]. Owing to these advantages, eucalypts are seen as ideal trees for both rural woodlots and larger plantations.

The decarbonization of the global economy has a high priority for the global economy. One of the core strategies is to offset carbon by reforesting landscapes [21]. Such reforestation is always controversial as it involves so many other factors, especially if the reforestation is using exotic species. This paper looks in particular at how Ethiopia has reforested its landscape over many decades using eucalypts and what can be learned from assessing the various controversial factors that have become associated with this reforestation. The application to other countries, especially emerging economies, is of

considerable relevance to the climate change agenda as well as the Sustainable Development Goals.

Eucalypts have been blamed for issues, including the drying-up of water courses, adverse effects on nutrient cycling and soil properties, the suppression of other vegetation and inability to control soil erosion. These are accusations made by authors from many countries, and they have tended to overshadow the benefits of the eucalypts [45].

No single fact should be taken as sufficient evidence to promote or to discourage the planting of eucalypts, though the results from several studies taken together may yield valid generalizations [7, 12, 22]. There is no question that trees in general and the eucalypts in particular utilize large amounts of water and nutrients, but the returns that can be realized in terms of biomass production per unit of input must also be considered, and all the other potential side effects examined.

Similarly, Davidson [8] argues that the criticisms would equally apply to other exotic trees planted in many countries, not just the eucalypts though eucalypts have been very successful species for reforesting many parts of the earth. Therefore, any balanced argument should compare the potential negative outputs from the exotic species as well as the potential economic gains, which are driving such investment. In the controversy over eucalypts, there has been a tendency for the negative aspects of the genus to be highlighted. In the following sections of the paper each of these factors, namely hydrology, soil (fertility, erosion and allelopathy), biodiversity (understory vegetation, wild animals and plant species diversity) and policy implications are reviewed based on the available literature before making some conclusions about the value of reforestation for socio-economic development without compromising both the biological and physical environmental well-being.

Hydrology and eucalypts

Eucalypts have been used to reforest vast areas of the world due to their ability to grow rapidly and provide a good source of wood for multiple economic purposes. The rapid growth means that they consume large amounts of water and most eucalypt species consume, on average, 785 l of water to produce kg^{-1} of biomass [8]. This raises fears over water resources and eco-hydrological effects [55].

Bewket and Sterk [3] and Zerga [69] indicated that among other types of land use changes, eucalypts and land degradation in the highlands of Ethiopia lead to decline in stream flows, especially in the drier season. Similarly, Chanie et al. [5] reported farmers' responses as eucalypts having dried up springs in the highlands. Eucalypts are known for their high transpiration rates ranging from 0.5 to 6.0 mm day^{-1} , and it has also been believed

that eucalypt plantations may extract water from shallow ground water [44, 55].

Even though eucalypt species are claimed to consume more water than any other tree species and agricultural crops, some studies showed that this is far from the reality. They have greater water use efficiency (i.e. they consume less water per unit of biomass produced) than most agricultural crops, conifers, acacias and broad-leaved tree species ([8, 12, 62] Table 1). Indeed, the water consumption of a tree is directly proportional to its ability to produce biomass; hence, it is essential to choose trees for reforestation based on their water consumption [60]. This is especially important if the trees are for offsetting carbon.

In arid regions, where water is limited, reforestation needs to consider that plants with deep spreading roots take most water while plants with shallow roots may be stunted or be unable to survive. Eucalypts have deep spreading roots. Thus, in low rainfall areas, eucalypt species may suppress other plants by competing for water, but this is unlikely to occur in areas of high rainfall [8]. If the planting is not well planned, it may reduce the groundwater level, thereby, affecting the water supplies of local people.

Based on research conducted in the Ethiopian highlands, Pohjonen and Pukkala [49] reported that *E. globulus* converted energy and available water into biomass more efficiently than exotic coniferous tree species.

Table 1 Water use efficiency or consumption of water per unit of biomass produced (sources: [8, 12])

Plant	Liters of water consumed kg^{-1} of biomass produced
Sorghum	250
Maize	250
Caw pea	500
Soybean	500
<i>Eucalyptus</i> (tree)	510
<i>Albizia lebbek</i> (tree)	580
Potato	600
Sunflower	600
Field pea	600
Horse bean	600
Pddy rice	600
<i>Syzygium cuminii</i> (tree)	610
Cotton/coffee/banana	800
<i>Acacia auriculiformis</i> (tree)	860
<i>Dalbergia sisso</i> (tree)	890
Conifers	1000
<i>Pongamia pinnata</i> (tree)	1300

Therefore, although some species of eucalypts may consume more water, which may lead to reduced water availability for other crops growing in association with the trees, they are more efficient in terms of converting water into biomass.

Davidson [8] also reported that at Nekemte (Western Ethiopia) with annual rainfall of 2158 mm, *Eucalyptus saligna* Sm. and *E. grandis* W. Hill could produce $46.6 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ without drawing on water reserves (rainfall only) compared to 16.4, 16 and $12.4 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ biomass production for the coniferous, acacia, and broad-leaved species, respectively. These figures reveal that for the same amount of water consumed, eucalypt produces a higher amount of biomass, which is economically profitable and acceptable for reforestation.

In swampy areas, the groundwater level is near or at the surface, and some species of eucalypts have been used to drain the water away by drawing it up through their roots. Mosquito-breeding swampy areas can sometimes be controlled in this way. But, if the work is not well planned, it may cause adverse effects in adjacent land by reducing domestic water and irrigation supplies [60]. Drainage removes swamps, which provide a habitat for mosquito larvae, thereby, reducing the risk of malaria. *Eucalyptus globulus* Labill. is useful for this purpose. This method has been used in various parts of Ethiopia.

The water use in eucalypt species is, therefore, comparable to other tree species and because of their high water use efficiency in rapidly creating biomass, they are more favored trees for reforestation. There are some cases where reforestation with eucalypts (or other tree species) has led to reduced water run-off and supply of streams or changes in water table levels, especially in regions with limited rainfall. However, in many well documented cases, eucalypt plantations do not have any significant negative impacts on hydrology. Key findings of many hydrological experiments [5] have revealed that eucalypts are highly effective in regulating their water consumption relative to available supplies and regulate their growth accordingly.

Eucalypts and soils

Eucalypts and soil fertility

The effects of eucalypts on soils have been studied in several countries over many years [28, 50]. Most of the concerns related to effects on soil quality deal with the depletion of nutrients [50]. Dessie and Erkossa [10], Kidanu et al. [26] and Chanie et al. [5] argued that eucalypts decrease soil nutrients within 20 m distance from the trees. A comparative study of eucalypts in a mixed plantation has revealed that eucalypt has three times more fine-root biomass in surface soil, which indicated that planting crops in association and adjacent to eucalypts should be

avoided [18]. However, dismissing eucalypt species as not being suitable for agroforestry misses the full scientific picture that they can extend nutrient cycling from deeper ground soil where other trees and crops do not have access [19]. Thus, the management of eucalypts in agroforestry becomes the main issue.

A study focusing on wetland conversion has indicated that there is significant difference between wetlands and converted land to dominantly eucalypts by reducing major nutrients from the converted land [35]. Similarly, soil nutrients and carbon pool under eucalypts were lower than the mixed plantation [18]. Chanie et al. [5] also reported that the soil under eucalypts becomes water repellent, and the perceptions of the local farmers agreed with the experimental findings by reducing the crop productivity of the land. In contrast to the above, Tadele and Teketay [59] have found that the maize dry matter production and grain yield planted on cleared felled eucalypts stand were significantly higher than the adjacent field. According to Hailu et al. [19], eucalypts do not overexploit the soil than the traditional fuel usage, such as litter and cow dung collection. Similarly, the study has indicated that due to non-browsed characteristics of eucalypts than other fodder trees, they are well-fitted for soil protection purposes if they are incorporated with avoidance of litter and bark collection in places with overgrazing practices. Generally, there is lack of clear scientific evidence that shows the impacts of eucalypts on soil nutrients that lead to soil degradation. It could be legitimate to raise such concerns under poor management where there is lack of species-site matching [8, 12, 42, 43].

Eucalypts cope with such variability through a root system that has intimate contact with the large volume of soil. With the extension of their roots deep into the soil, given their high degree of adaptability, they extract nutrients outside the realm of crops feeding zone. That is why the nutrient requirements of eucalypts are significantly lower than those of many agricultural crops [39, 40]. As a result, the species flourish with sustainable high yield without fertilizer on red ash and degraded land. Further, eucalypt plantations are not like natural forests that experience little disturbance. If it were a closed system, nutrients would have been recycled from decomposing litter back to the tree and increase the nutrient bank [62]. But, eucalypt is an open system and nutrients are removed from the site when the stem, leaves and bark are harvested for various uses [42, 43]. This means that the nutrient capital of the soil could be diminished. Therefore, the secret lies in nutrient mining. This is equally true for crops under poor management. Under viable environment, soil nutrient levels can be improved through sound management without the carrying capacity of land being overstretched.

Very few comparative studies have been made in Ethiopia on soil nutrients among plantations of different species, including eucalypts and the adjacent natural forests [1, 36, 37, 43]. These studies have shown that plantation stands of fast-growing exotic species, such as *E. globulus*, *E. grandis*, *E. saligna*, *Cupressus lusitanica* Mill. and *Pinus patula* Schiede ex Schltdl. & Cham. had lower nutrient contents than soils of the adjacent natural forest. This seems logical as they are fast growing, thereby drain, and consume more nutrients from the soil. Eucalypt species have high demand for nutrients, but this is incomparable with other tree species and much lower than agricultural crops. Teshome [62] pointed out that the nutrient consumption of fast-growing species like eucalypt species need to be well studied before conclusions and recommendations are made.

Eucalypts and soil erosion

Soil erosion is among the most important surface processes that results in land degradation in many places, especially in the tropics. Trees can influence soil erosion, mainly, through intercepting rainfall, which dissipates its kinetic energy. The rain drops that are intercepted, eventually, fall to the soil surface with reduced erosive energy, depending on the size and orientation of the leaves. Large leaves produce larger size droplets, which have greater impact on the soil. Accordingly, erosive energy of rain under the tree crowns would be least for *Casuarina* spp. with *Acacia* spp. (e.g. *A. auriculiformis*) and narrow-leaved eucalypts (e.g. *E. camaldulensis*) occupying the mid-range, and the broad-leaved eucalypts (e.g. *E. globulus*) at the top of the range for the eucalypts [22].

Jagger and Pender [22] reported that there is no evidence to single out the eucalypts for special criticism with regard to soil erosion. It has been hypothesized, however, that long term exposure to allelo-chemicals from the leaves of eucalypts may result in increased risk of soil erosion, which may have implications for sustainable land use over time [23].

Eucalypts have been found to impact on topsoil retention and soil erosion [10, 50, 58]. Some studies have concluded that eucalypts can worsen soil erosion as an indirect result of frequent disturbance from repeated harvesting [50]. Others argue that eucalypt plantations can help control soil erosion on sloped or degraded sites, but their efficacy depends on environmental factors, such as intensity of rainfall, soil condition, slope and the presence of ground vegetation and litter cover. Though few Ethiopia-specific case studies exist, the limited evidence available suggests that eucalypts may be ineffective choices for erosion control [58]. Rather, eucalypt trees are generally expected to lead to an increase in soil loss due to the reduced understory cover in densely planted eucalypt areas [50].

The litter, which accumulates under most eucalypt plantations, can help to form a protective barrier against erosion, but in many places the litter is collected for fuel or removed to reduce fire hazard. For instance, the depth of the accumulated litter under eucalypt stands in Munessa-Shashemene Forest Project area was, on average, 20–30 cm [62]. However, under eucalypt stands around Addis Ababa and very big towns, the accumulation of litter is very low as a result of human and livestock disturbances. People take away most of the litter and cattle and foot traffic compact the soil. If the litter had been left on the site, it would have been incorporated into the soil system to slow down runoff and improve infiltration, and a substantial amount of nutrients would, then, have been able to pass to the soil system, thereby, improving soil fertility [62]. However, as a result of litter collection, the ground under the trees is left bare, and the soil is exposed to erosion. Therefore, litter should be allowed to accumulate where possible, particularly on sites that are easily eroded.

A common theme in eucalypt reforestation outlined in this paper is that scientific management of the forest can achieve much to alleviate problems that have started to prevent further reforestation initiatives using eucalypts. A realistic assessment of each area to be planted is needed to decide whether erosion will be a serious problem, and if so, whether it can be controlled. Some places may not be suitable for plantation establishment. Eucalypt plantations on steep slopes can provide effective erosion control if careful techniques, such as contour planting are used [60]. The root systems of selected species for catchment protection influence the soil binding capacity and as a result reduce erosion. *Eucalyptus globulus*, for instance, has a strong tap root and good lateral root system that makes it a very reputable species for catchment protection [60, 62].

With regard to soil erosion by water under trees, there is no evidence to single out eucalypts for special criticism. Erosive resistance (physical characteristics) of soils is more important than crop management and crop management is more important than the type of tree crop. Since, in nearly every example where the litter is removed, erosion increases substantially, it is important to focus more on ground cover and ground-level activities (cultivation, compaction by foot traffic, livestock grazing, trampling and harvesting/logging damage) rather than on the species of trees planted. On erosion-prone slopes, it is better to use a periodic, partial harvesting system based on cutting of trees along lines around the contour or removal of small patches in a mosaic pattern [8, 23, 60].

Allelopathy and eucalypts

Allelopathy is the release of chemicals from leaves or litter that inhibits the germination or growth of other plant species and, consequently, reduces the output of crops [14]. Allelopathic effects of eucalypts are among the issues dominating the agroforestry literature. Allelopathic exudates from eucalypt tree components have shown an inhibiting effect on undergrowth vegetation regeneration and growth [50]. Therefore, the issue of allelopathic impacts of eucalypts needs to be discussed.

Most of the studies put forward as evidence for eucalypts being strongly allelopathic involve laboratory studies of extracts on germination of seeds or early growth of potted plants, which may not accurately represent field conditions. Soil bioassay studies have been carried out with three agricultural crops: chickpea (*Cicer arietinum* L.), tef [*Eragrostis tef* (Zucc.) Trotter] and durum wheat (*Triticum turgidum* L.) under laboratory and field conditions in the Ethiopian highlands. According to the findings, bioactive compounds from the decomposing litter of *E. globulus* did not affect the test crop seed germination nor root growth. However, a litter extract with 5% dry matter concentration significantly hindered germination and root growth of the tested agricultural crops. On a farm field experiment, declining barley yield was observed near *E. globulus* plantation [24].

Results evidently vary across a wide spectrum of conditions from humid, fertile sites to dry, infertile ones. The magnitude of the negative effects is likely to be influenced by rainfall. Although it is likely that allelochemicals do accumulate in the soil, they are highly soluble and rainfall is likely to leach them out, and the effects of allelopathy are, thus, likely to be negatively correlated with rainfall. It has been noted that allelopathic effects are more severe in low rainfall regions prone to soil erosion than in drier regions. However, the hampering effect on growth of understory or adjacent intercropped crops may more often be the result of strong competition for water and nutrients than allelopathy. Farmers in the highlands of Ethiopia linked this effect to competition for water and nutrients [24].

The potential allelopathic effect of *E. camaldulensis*, *Cupressus lusitanica*, *E. globulus* and *E. saligna* on seed germination and seedling growth was investigated with four crops: chickpea, maize, pea and tef [42]. The results revealed that aqueous leaf extracts of all the tree species significantly reduced both germination and radical growth of the majority of the crops. It has been shown that the shoot and root dry weight increase of the crops was significantly reduced after ten weeks treatment with leaf extracts.

Allelochemicals can affect germination and growth of plants through interference in cell division, energy metabolism, nutrient uptake and possibly other factors [16,

42, 62, 68]. In this regard, eucalypt has toxic allelochemicals that consist of phenolic acids, tannins and flavonoids [68]. When released into the soil, these inhibit other plants and play a role in shaping plant communities. For instance, leaf decomposition product from eucalypts is shown to suppress germination and growth of chickpea, field pea, maize, and tef [42] while it exerted an antibiotic effect on soil microorganisms [30].

However, concentration matters. For instance, allelochemicals from decomposed eucalypt litter in high rainfall areas did not accumulate in sufficient concentration to affect seed germination and root growth of crops. Different strengths of water extract from leaves of eucalypts did not delay the onset of germination and seedling growth of *Olea* [30, 32, 68]. In fact, positive results have also been reported concerning the interaction of eucalypts with other plants [27]. The lack of susceptibility of certain crops and the regeneration of other species suggest that eucalypts provide some benefit rather than harm. Again, it is not only eucalypts, but other exotic tree species, such as *Grevillea robusta* A.Cunn. ex R.Br. showed allelopathic effects on most agricultural crops [62].

However, in Ethiopia, little attention has been given to allelopathy as a determinant of crop production and productivity [4, 26, 27] and plant community structure [29, 39, 51, 67]. Therefore, empirical information is needed to resolve such negative effects. Until then, eucalypt allelopathy can be minimized with sound management through compatible crops based on proper site selection of eucalypt species.

Biodiversity

Eucalypts and understory vegetation

One of the criticisms associated with eucalypts is that they prohibit the establishment of understory plant species. Eucalypts are usually taller than other plants of equal age due to their rapid growth as outlined above. This rapid production of a canopy determines the comparative gap that would be available for sunlight to penetrate through its canopy. When planted at high density, the shade created has adverse influences on the understory environment [69]. The consequence could be an understory vegetation-free surface. Dense stands of eucalypts not only affect the growth of colonizing woody species, but also nearby crops given the added competition for water and nutrients; so yields from crops close to eucalypts may not be as good as those farther from the edge. Therefore, it is not eucalypts rather the lack of sound management that is to blame [60]. On the other hand, not all eucalypt species cast heavy shadow to discourage understory plants. Some even cast less shade than broad-leaved trees because they usually have narrow, patchy crowns and leaves positioned downwards on the twigs [68].

Several eucalypt plantations in different agro-ecological zones showed greater richness of plant species than under adjacent natural forests. Further, the less dense plantations harbored more regenerated indigenous woody species than high dense eucalypt stands [32, 37, 52–54, 66]. This indicates that an inverse relationship exists between eucalypt density and diversity of the regenerated species. In relation to economic crops, wheat production was not affected by eucalypts on heavy clay soil [27]. When used as a shade tree for coffee, the cup quality was acceptable as that within the indigenous forest [56].

Because of shading and competition for water, the yields from agricultural crops close to eucalypt plantations are sometimes not as good as they are further away from the edge [60]. However, this needs to be considered in relation to the benefits to many crops of having eucalypt shelter belts that provide wind protection. It is widely accepted that shelterbelts increase crop yields. On the other hand, the study made by Onyewotu et al. [46] on the competitive effects between *E. camaldulensis* shelterbelt and an adjacent millet (*Pennisetum typhoides* Stapf and Hubb.) crop indicated that the yield of the crop grown very close to the belt was reduced because of competition with the trees for light, soil moisture and nutrients. On the other hand, the results indicated that the yield of millet nearby, but not immediately next to the shelterbelt, increased substantially.

Reforestation with eucalypts can enable agroforestry to work well if the trees are managed to provide the benefits of shelterbelts and nutrient recycling to upper soil levels where crops can access them, but not so densely spaced right next to crops. There are complex interactions between light and water requirements of different trees that make generalizations difficult, but there are several species of trees with larger leaves than eucalypts and, thus, cast more shade on crops. Eucalypts are again likely to be beneficial to agroforestry systems if managed scientifically.

Eucalypts and wild animals

Ethiopia has diverse wildlife of world importance. Yet, there has been the erosion of these resources due to the destruction of their habitat from introduction of agriculture, recurrent drought, war and conflict. Eucalypt plantations are also criticized for their impacts on wildlife biodiversity due to, among others, the unpalatability of eucalypt leaves reducing wildlife in an area [12, 41]. There is, thus, a debate on whether or not wildlife would remain in their newly established eucalypt habitats.

So far, eucalypt plantations have not been established in natural forests that harbor wildlife. Wild animals that used to inhabit the landscape would have been forced to migrate. Hence, the question is whether or not wildlife

will return if reforestation of the landscape occurs with eucalypts.

The subjective perception of many observers is that eucalypt plantations host lower populations of wild animals than a landscape that is now rehabilitated with indigenous species under a similar setting. The objective reality, however, is that with the establishment of eucalypts, the canopy has provided shade for the emergence of undergrowth vegetation and the regeneration of indigenous trees. Now that they have a suitable habitat, some of the wild animals have returned. As a case in point the scenic evergreen eucalypt plantations on Entoto Mountain that surrounds Addis Ababa host diverse wildlife even with large human population around and, thus, have become prime destinations of tourists [38, 25].

Further, the flowers of eucalypts that produce abundant pollen and nectar have been essential in the life cycles of many insects and birds. These are important in the pollination of crops, and bees provide additional benefit through production of honey. This has become a lucrative business to many rural communities. Under sound management, similar plantations could exploit such potential without adverse effect on the ecology or crops. Palatable leguminous trees, shrubs, forages, pastures, and grasses can also be established under appropriate sound management. Then, such rehabilitated areas can be made favorable to wild animals instead of the categorical blame of eucalypts as restriction to their proliferation [8, 9, 12, 15, 48].

The non-palatability of most eucalypt species to browsing and grazing animals [8, 12, 47, 63] and incapability of providing adequate food and habitat for wildlife [12, 41, 60] can, thus, reduce wild animals in an area compared with areas of indigenous vegetation. However, this problem can be alleviated by establishing mosaics of plantations, natural forests, pastures, grasslands and croplands. It is important to note that the biodiversity of a natural forest and that of eucalypt plantations are not comparable. The natural ecosystems are very diverse while the biodiversity of eucalypt plantations is limited, but can be used to encourage return of much more diversity if managed for that purpose. Mammals and birds that used to live in natural forests can be encouraged to return to a forest replanted with a mixture of exotic species by leaving open spaces occasionally, and allowing undergrowth to return and provide the habitats necessary for a better ecology to thrive.

Eucalypts and plant species diversity

One of the major criticisms that have been debated over the years among scholars and the public concerning eucalypts is its impact on local flora. As can be gathered from the criticism outlined above, eucalypts are seen to affect

the flora as they drain water and adds toxic chemicals into soils. However scientific studies do not support these generalizations. Eucalypt reforestation can be used to enable a range of native species to be reintroduced after they have been removed due to agriculture or other land degradation. Eucalypts have been shown to have potential in encouraging the recruitment, establishment and successions of native species, which promote biodiversity improvement [53, 54]. Regeneration of *Junipers procera* Hochst. ex Endl. under eucalypt plantations was also observed at Entoto, Addis Ababa, Ethiopia [52, 65].

Mostly, eucalypt plantations in Ethiopia are feared as ecologically hazardous and destructive to natural ecosystems, but eucalypts have multiple economic functions, and can be managed as important conservation trees at the beginning of the restoration process on degraded sites. Eucalypt plantations in southern Ethiopia were used as buffer zones to reduce impact of deforestation and degradation of the natural forest [53, 54, 70]. Thus, eucalypt plantations have reduced deforestation of natural forests, which, in turn, provides a chance for regeneration of natural forests and improvement of biodiversity richness.

Additionally, eucalypt plantations can be used to foster natural forest re-colonization and succession processes [29, 53, 54]. They can also facilitate the regeneration of native woody species in the plantation through reducing soil erosion and facilitating attractive conditions for seed germination [29]. In addition, conservation design can enable eucalypt plantations to foster the regeneration of other native woody species in degraded areas by providing protection [19, 52, 60].

Plantation stands of eucalypts and other tree species have been shown to foster or catalyze the regeneration of native woody species under their canopy if they are established close to seed sources and protected from human and livestock disturbances, thereby, enhancing biodiversity [39, 51, 60].

The studies made by Mihretu [38] and Kidane [25] indicated that there is a good natural regeneration of *J. procera* under *E. globulus* plantations at Entoto hills in Addis Ababa. The juniper has grown effectively on the eroded areas competing well with the eucalypt trees. Similarly, the studies made by Senbeta [51] and Moges [39] at Shashemene Munessa Forest Project Area clearly showed that plantation stands of *E. globulus*, *E. saligna*, *C. lusitanica* and *P. patula* have been found to foster the natural regeneration of several native woody species like *Podocarpus falcatus* (Thunb.) R. Br. ex Mirb., *Prunus africana* (Hook.f.) Kalkman, *Syzygium guineense* (Willd.) DC. and *Croton macrostachyus* Hochst. ex Del. The source of seeds for the naturally regenerated native woody species is the adjacent natural forest.

Many of the allegations on eucalypts and other exotics, e.g. the allegation of hampering flourishing of native

biodiversity, have been disproved by many recent research findings [31, 33, 39, 52, 54, 67]. Rather, eucalypts are considered as a potential foster species that can nurse the rapid re-colonization of native species when planted close to seed sources, e.g. secondary forests, and designed and managed properly.

Policy implications of reforestation with eucalypts

As Janz and Persoon (2002) expressed, there are serious shortcomings in the supply and use of information needed for policymaking in the forest sector, particularly those of developing countries. It should be underlined that for a successful forest policy process, it is often necessary to know, among several other things, more about plantations and their role for rural communities. There is a general prejudice against forestry operations, particularly against fast-growing tree plantations, compared with agriculture [6]. However, there is a global and local need for reforestation of landscapes and, hence, a more sustainable earth will need to carefully manage the information on how to make such reforestation programs effective, resulting in multiple benefits.

This is particularly important in Ethiopia, which has such a long history of reforesting its landscape with eucalypts after hundreds of years of degrading the land [20]. The current policy environment regarding plantation establishment of eucalypts in Ethiopia does not favor of the species. There is no encouragement to raise eucalypt seedlings in government nurseries and distribute them to smallholder farmers. The policy practice of discouraging and, in some cases, banning planting of eucalypts by farmers needs rethinking. Considering the dwindling natural forests in Ethiopia, it would be necessary to encourage deriving charcoal, poles and firewood from plantations of fast-growing species, such as eucalypts, to prevent further loss of natural forests [63].

There is a need for care when comparing policy and actual practice because stated intentions in policy documents, sometimes, bear no relation with how policies are interpreted and applied [57]. In another concern, interventions to support market prices for the products of tree growing and to ensure producers have access to markets may be as effective as or more effective than subsidies. Agricultural policies should be complementary to tree growing. Subsidies for credit, price supports and incentives, including measures affecting land and tree tenure, should be seen in parallel to both agricultural crops and tree growing, such as eucalypts, by farmers to avoid policy measures that are likely to distort decisions and favor one at the expense of the other [13].

Eucalypt trees have been a major part in recent Ethiopian history, and the species will continue to figure prominently in the life of both rural and urban people [40]. The paper has shown consistently that poor management should be blamed rather than eucalypts for the

various issues examined, including water, soil fertility, erosion, toxic exudates, and impacts on wild animal and biodiversity. Many countries, including emerging nations, like Ethiopia, are facing the impacts of climate change while needing to feed a growing population and creating a more equitable society. The harmonization of forest and agricultural policy unquestionably helps combat food insecurity and poverty, but it can be a major tool in combatting the impacts of climate change and, at the same time, achieving the SDGs. Hence, its justifiable place in the development policy of the country means that individuals and communities can be encouraged to accelerate the establishment of commercial exotic plantations, such as eucalypts, while sustainably managing, utilizing and conserving natural forests, which together can help create a more sustainable earth.

Conclusions

Eucalypts have become the most preferred species for plantation establishment by farmers due to their economic benefit, and the huge demand of fuelwood and construction materials. In Ethiopia, eucalypt plantations constitute 58% of the total plantation followed by *Cupressus lusitanica*, *Juniperus procera* and pines. In recent years, planting of eucalypts has been associated with controversies and criticisms based on ecological and socio-economic arguments in Ethiopia and elsewhere. Hence, eucalypts have been blamed for some problems, including the drying-up of water courses, adverse effects on nutrient cycling and soil properties, suppression of other vegetation, allelopathic effects as well as the inability to support biodiversity and wild animals. Whether these criticisms are based on facts and empirical evidences or arise from deliberate bias or, even, lack of accurate information may be questioned.

The paradox of reforestation using eucalypts results, mostly, from inappropriate species-site matching and poor management rather than the inherent biological characteristics of the species. Therefore, the debate on eucalypts under the pretext of concern for indigenous species and natural forests should shift to how both plantations established using eucalypts and indigenous species as well as natural forests can help in the enhancement of the socio-economic development and environmental conservation of countries, such as Ethiopia. It is very interesting and encouraging to observe that despite the claimed negative impacts of eucalypts farmers in Ethiopia have utilized their traditional knowledge and experience that have accumulated over the years. For instance, the farmers plant dense stands and periodically coppice only part of the stand at a time so that there is a multi-layered canopy, and they allow grass to grow beneath [60]. Farmers in Ethiopia plant large numbers of eucalypts on small areas of land and manage

them to yield a variety of products, including leaves and small branches for fuelwood, and poles and posts for house building and other

farm uses. Farmers who have insufficient land to have woodlots often grow a few large trees, which can be harvested and sold when cash is required. The use of trees, especially eucalypts, as a living bank account [60, 63], to be harvested when there is a need for cash, is widespread. Many people in Ethiopia are absolutely dependent on eucalypts as a source of fuel and house building material. This being the reality, the arguments for and against planting eucalypts in Ethiopia has been mounting from time to time.

As pointed out by Teketay [60], despite the growing concern against planting eucalypts, most of the reports available on eucalypts in Ethiopia are in favour of planting them since the authors acknowledge that: (i) the negative impacts can be minimized provided that the choice of species and site as well as the management of the stands are appropriate, (ii) the benefit derived can offset the losses that can occur from such plantations, (iii) no other species (be it indigenous or exotic) seems to replace them in the near seeable future to bridge the ever-widening gap between demand and supply of wood and (iv) the profit derived from eucalypt plantations is considerably higher than cultivating crops. However, the choice of eucalypt species for plantations should be based on many criteria, for example maximum wood production, ecological sustainability, marketability of the planted species (e.g. commercial production of timber) and usefulness of the species to the local populations. All these criteria involve not only a choice of species planted, but also a choice of plantation management methods from initial planting to final cutting of the trees.

From the foregoing discussion, it appears that there does not seem to be any profound reason why eucalypt planting should not continue in Ethiopia until such time that alternative species are discovered [60]. The establishment of eucalypt plantations could take different forms, e.g. huge number of small woodlots, groups, belts, lines and single trees scattered throughout the rural, but also urban areas. However, it has to be strongly emphasized that careful selection of appropriate species and matching them with appropriate sites must be taken as prerequisite, and the right management practices should be employed.

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Consent for publication

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