Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Environmental sustainability assessment of softwood and hardwood seedlings production in forest nurseries: A case study from Pakistan

Avaliação da sustentabilidade ambiental da produção de mudas de madeira macia e madeira dura em viveiros florestais: um estudo de caso do Paquistão

A. Yousaf[a], M. Hussain[a*], S. Ahmad[b], A. Riaz[c], S. Shaukat[d], S. W. A. Shah[d], R. S. Mishr[e], S. Akram[f], M. Majeed[g], A. Tabassum[h], M. Amin[i] and F. Jabeen[c]

[a]University of Haripur, Department of Forestry and Wildlife Management, Haripur, KP, Pakistan
[b]Bharia University Medical and Dental College, Department of Biochemistry, Karachi, Pakistan
[c]Jinnah University for Women Karachi, Department of Biochemistry, Karachi, Pakistan
[d]University of Tuscia, Department for Innovation in Biological, Agri-food and Forestry Systems – DIBAF, Viterbo, Italy
[e]University of Padova, Department of Land, Environment, Agriculture and Forestry, Legnaro, Italy
[f]University of Northern British Columbia, Faculty of Environment, Department of Ecosystem Science and Management, Prince George, Canada
[g]Technische Universität Dresden, Institute of International Forestry and Forest Products, Faculty of Environmental Sciences, Dresden, Germany
[h]MM Private Limited Tarbela KP, Haripur, Pakistan
[i]Shaheed Benazir Bhutto University, Department of Environmental Sciences, Sheringal, Dir (U), KP, Pakistan

Abstract

This article describes the environmental impacts of producing a single seedling in forest nurseries of selected districts (i.e., Haripur, Abbottabad, and Mansehra) of Hazara Division of Khyber Pakhtunkhwa, Pakistan using the life cycle assessment (LCA) approach. This study was based on the cradle-to-gate approach which begins with the pre-nursery stage and progresses toward the main nursery before transplanting seedlings into the plantation site. Data or life cycle inventory (LCI) of seedling production were collected through questionnaire surveys and personal meetings with forest nurseries managers and workers regarding consumption of different inputs such as electricity, diesel, fertilizers, herbicides, and polyethylene bags, organic manure, and water consumption. The SimaPro software version 8.5 and the CML2000 v2.05 environmental model was applied to perform life cycle impact assessment (LCIA) for a single seedling production in forest nurseries in the study area. In line with the objectives of the study, primary data regarding inputs and outputs of the nurseries were collected from 35 nurseries in the study area by using a random questionnaire method. In addition, secondary data were taken from online databases such as Eco-invent v.3.2 CORRIM and peer-reviewed published literature. For this study, a functional unit of a single seedling was considered. Production weighted average data were modeled in the latest environmental modeling software i.e., SimaPro v.8.5 for ten US-EPA most wanted environmental impacts, such as global warming potential (GWP), abiotic depletion (AD), eutrophication potential (EP), acidification potential (AP), freshwater aquatic eco-toxicity (FAE), marine water eco-toxicity (MWE), terrestrial eco-toxicity (TE), ozone layer depletion (OLD), photochemical oxidation (PO), and human toxicity (HT). The results showed that the highest environmental impact posed by a single seedling was marine aquatic eco-toxicity (11.31360 kg 1,4-DB eq), followed by global warming potential (0.02945 kg CO2 eq) and (0.01227 kg 1,4-DB eq) human toxicity. The primary reason for these environmental burdens was the use of synthetic fertilizers in forest nurseries and the consumption of fossil fuels in nursery mechanization and transportation activities. The total cumulative energy demand for a single seedling was (0.800 MJ) with more than 90% contribution from fossil fuel energy resources such as petrol and diesel. It is therefore highly recommended to use renewable energy resources and organic fertilizers instead of chemical fertilizers in forest nurseries to avoid and minimize greenhouse gas emissions (GHS) and other toxic emissions in the study area.

Keywords: forest nurseries, seedlings, environmental impacts, LCA, BTAP, Pakistan.

Resumo

Este artigo descreve os impactos ambientais da produção de uma única muda em viveiros florestais de distritos selecionados (Haripur, Abbottabad e Manshera) da divisão Hazara, de Khyber Pakhtunkhwa, Paquistão, usando a abordagem de avaliação do ciclo de vida (ACV). Este estudo baseou-se na abordagem "do berço ao portão", que

*e-mail: majid@uoh.edu.pk
Received: February 1, 2022 – **Accepted:** April 1, 2022

se inicia na fase pré-viveiro e progride em direção ao viveiro principal antes do transplante das mudas para o local de plantio. Os dados ou inventário de ciclo de vida (ICV) da produção de mudas foram coletados por meio de questionários e reuniões pessoais com o gerente e os trabalhadores dos viveiros florestais sobre o consumo de diferentes insumos, como energia elétrica, diesel, fertilizantes, herbicidas, sacos de polietileno, adubo orgânico e consumo de água. O software SimaPro, versão 8.5, e o modelo ambiental CML2000, v2.05, foram aplicados para realizar a avaliação de impacto do ciclo de vida (AICV) de uma única produção de mudas em viveiros florestais na área de estudo. Em consonância com os objetivos do estudo, os dados primários relativos às entradas e saídas dos viveiros foram coletados de 35 viveiros na área de estudo por meio de um método de questionário aleatório. Além disso, dados secundários foram obtidos de bancos de dados online, como Eco-invent v.3.2 CORRIM e literatura publicada revisada por pares. Para este estudo, foi considerada uma unidade funcional de uma única plântula. Os dados médios ponderados de produção foram modelados no software de modelagem ambiental mais recente, ou seja, SimaPro, v.8.5, para 10 impactos ambientais mais desejados pela US-EPA, como potencial de aquecimento global (PAG), depleção abiótica (DA), potencial de eutrofização (PE), potencial de acidificação (PA), ecotoxicidade de água doce (EAD), ecotoxicidade da água marinha (EAM), ecotoxicidade terrestre (ET), destruição da camada de ozônio (DCO), oxidação fotoquímica (OF) e toxicidade humana (TH). Os resultados mostraram que o maior impacto ambiental causado por uma única muda foi a ecotoxicidade da água marinha (11,31360 kg 1,4-DB eq), seguido pelo potencial de aquecimento global (0,02945 kg CO2 eq) e toxicidade humana (0,01227 kg 1,4-DB eq) eq). A principal razão para esses ônus ambientais foi o uso de fertilizantes sintéticos em viveiros florestais e o consumo de combustíveis fósseis nas atividades de mecanização e transporte de viveiros. A demanda total acumulada de energia para uma única muda foi de 0,800 MJ, com mais de 90% de contribuição de recursos energéticos de combustíveis fósseis, como gasolina e diesel. Portanto, é altamente recomendável usar recursos de energia renovável e fertilizantes orgânicos em vez de fertilizantes químicos em viveiros florestais para evitar e minimizar as emissões de gases de efeito estufa (GEE) e outras emissões tóxicas na área de estudo.

Palavras-chave: viveiros florestais, mudas, impactos ambientais, ACV, BTAP, Paquistão.

1. Introduction

Pakistan is sailing with states that have a little amount of forest land and may be affected by the climate change tsunami. Due to the large and destructive usage of wood, the country's previous record of 4% forest has been replaced by 3%, and it is diminishing day by day. Deforestation has resulted in severe climate conditions, such as earthquakes, landslides, floods, and soil erosion, all of which are exacerbated by extreme weather (Kharl and Xie, 2017). Large-scale international and national tree-planting projects are gaining popularity in many parts of the world, particularly as a way to improve sustainability while combating climate change (IPCC, 2019). International climate and sustainability policies reflect this interest, encouraging afforestation and reforestation as part of adapting to climate change efforts (UNDP 2019; UNFCCC, 2006, 2015). These are considered to be among the most effective 'natural climate solutions,' which are defined as 'conservation, restoration, and improved land management approaches that increase carbon stocks and/or avoid greenhouse emissions across worldwide forests, wetlands, agricultural lands, and grasslands' (Suryaningrum et al., 2021).

The Khyber Pakhtunkhwa province of Pakistan which occupies 40% of the country's land territory, had taken a bold step in preparing, developing, initiating, and executing the Billion Tree Tsunami Afforestation Project (BTTAP) (Bearak, 2016) under the Bonn Challenge platform in order to restore 150 million hectares of deforested and damaged land in the world by 2020 and 350 hectares by 2030. By the end of 2018, the government agreed to plant one billion trees that would not only increase the forest area but also ecologically, socially, and economically benefit the province by reducing deforestation, generating job opportunities, and engaging local communities. Since 2015, BTTAP has begun to increase the respective provincial forest area from 20% to 22% in four years (Bonn Challenge, 2019). Through this initiative, at least 30,000 hectares of extra forests were planted along with maintaining and improving the existing ones through a gradual afforestation program (IUCN, 2015). The BTTAP gained momentum after March 2015, when the provincial government made efforts to create a healthy human environment. Different kinds of nurseries were constructed across the province under this project (The Express Tribune, 2015). According to the WWF Pakistan study, nearly 160 million seedlings were confirmed until August 2015 and most of them were ready for plantation as well as nearly 2000 hectares were afforested (The Third Pole, 2016). Under the provincial forest department, Central Model Nurseries or Departmental Nurseries were raised and divided into tube nurseries and bare-rooted nurseries. By August 2015, 238.71 hectares of central model nurseries had been established according to the BTTAP / FD records (Kharl and Xie, 2017). Therefore, in this study we have collected data from the Hazara division, Pakistan to point out the environmental impact of nurseries.

Softwood and hardwood seeds were planted in the nurseries and then seedlings were transported to the plantation site. There were many resources, which were used in the production of seedlings, which includes seeds transportation, land preparation, seeds sowing, polyethylene bags, insecticides, herbicides, fertilizers, watering, fossil fuel, electricity, and transportation of seedlings from nurseries to plantation sites. However, these resources are responsible for greenhouse gas emissions (GHS). Therefore, the environmental sustainability assessment of seedlings production study was designed to fulfill the objectives of the study. Internationally different tools are used to evaluate the environmental sustainability of different products. Among these tools, we used the SimaPro 8.5 software to assess the effects of seedlings' production on the environment. However, in Pakistan, there is no comprehensive published life cycle assessment research on seedlings production. There are also few studies done in Pakistan on LCA regarding the carbon footprint of particleboard production (Hussain et al., 2017). Instead, international scientific literature contains countless environmental studies using LCA methodology done with the aim of evaluating the environmental profile of seedlings production in Malaysia, Italy, and the USA about the production of seedlings of oil palm, walnut tree, and forest resources (Halimah et al., 2010; Cambria & Pierangeli, 2011; Johnson et al., 2007).

In environmental policy, LCA can play a role in evaluating the environmental impact of a manufacturing process (Kouchaki-Penchah et al., 2016). It can also be used to identify possibilities for productivity growth and cost reduction (Rivela et al., 2006). In order to reduce greenhouse gas (GHS) emissions, many countries carry out studies on LCA (Kim and Song, 2014; Lee et al., 2004). In recent years, special attention has been paid to forestry activities to calculate their environmental profile to enhance worldwide competitiveness (González-García et al., 2014). LCA is a standardized approach to evaluating the environmental effects of materials, goods, and services throughout their manufacturing systems and to supporting sustainable decision-making policies (Baumann and Tillman, 2004). Due to the increase in global warming, products having less environmental and human health impact gain more consideration (Garcia and Freire, 2014; Kouchaki-Penchah et al., 2016). To achieve these goals, a life cycle evaluation (LCA) method may be useful (Remmen, 2007). Life cycle assessment is a comprehensive tool that can be used to assess the main environmental issues of a product and where they occur during the manufacturing process (Silva et al., 2013; Curran, 2013; Baumann and Tillman, 2004; Rivela et al., 2006; Rauf and Crawford, 2015). In many cases, to include the disposal of the product or their possible use and reuse, the LCA methodology is based on the cradle-to-cradle approach or cradle-to-grave framework. This gives the possibility to focus completely on the product's life cycle. However, a more restricted strategy is described (cradle to gate or gate to gate) to focus on certain stages of the life cycle assessment (McDonough and Braungart, 2002). Indicators are the outcome of the impact evaluation stage of the life cycle (Guinee et al., 2001). There are some impacts that have a localized effect on the environment (e.g., photochemical smog and eutrophication), while others produce worldwide effects (e.g., global warming and ozone depletion) (Azapagic and Perdan, 2000).

This study evaluates the total GHG emissions of seedlings production and seeds transportation, including insecticides, fertilizers, water, fossil fuels, consumption of electricity, and seedlings transportation to plantation sites in Pakistan. This study was conducted to evaluate the environmental sustainability of softwood and hardwood seedlings production in nurseries in Pakistan. The work could disclose the hot spots in terms of sustainability that is helpful in designing strategies and policies to promote sustainable nursery raising. To fulfill the objectives of this research, the following points were investigated: 1). to conduct life cycle inventory of inputs and outputs for softwood and hardwood seedlings production in nurseries of selected districts of Hazara division, Pakistan, 2). to identify the potential environment sustainability impacts associated with the production of seedlings on cradle-to-gate basis, and 3). to use this assessment for improving opportunities to mitigate the potential environmental impacts from seedlings production in nurseries in Pakistan.

2. Materials and Methods

2.1. Study area

The present study was conducted in the Hazara division of Khyber Pakhtunkhwa province of Pakistan from June 2019 to June 2020 as can be seen in Figure 1. This region was selected based on the presence of nurseries including forest and private.

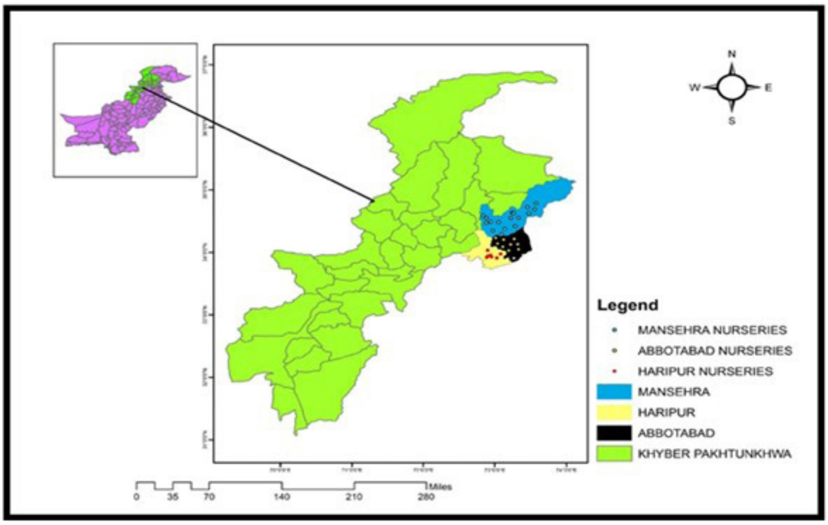

Figure 1. Location map of the study area.

2.2. Goal and scope of the study

This LCA study was conducted to achieve the objectives. Defining the study's goal and scope clearly, including the selection of a functional unit (Curran, 2016). This study is a cradle-to-gate life cycle inventory (LCI) of seedlings production in nurseries single seedling was taken as a reference unit. Nurseries owners were requested to provide the input and output data of seedlings production from June 2019 to June 2020. This study's scope includes all phases of nurseries cradle-to-gate which is existing in the present study area, which is consist of the preparation of land, seeds sowing, insecticides, herbicides, watering, fossil fuel, electricity, and transportation of seedlings from nurseries to plantation sites. This study offers a benchmark to formulate extensive research in the future on environmental sustainability and GHG emissions produced in the production of seedlings because no previous data is available on the LCA of softwood and hardwood seedlings production in Pakistan.

2.3. Functional unit

Functional unit is defined as the reference point in which inputs and outputs of the system taken into account are assigned. In the present study single seedling is taken as a functional unit (Mirabella et al., 2014). The related functional unit of the system was used to provide the seedling with food and non- food products handling connections. Hence, a single seedling is the suitable functional unit for this nursery LCA research.

2.4. System boundary of the study

The research system boundary is shown in Figure 2. This LCA study has a cradle-to-gate system boundary, which begins from the transportation of the fresh seeds from market to the end of the 12-months old seedlings transported to the plantation site. The present study system boundary includes pre-plantation inputs in production of seedlings in nurseries. System boundary of the study consisted of the main life cycle stages of seedlings production in nurseries of Hazara division, Pakistan, i.e. seeds bought in this step, seeds purchased from market or forests department and then transported to nurseries on vehicles running on petrol and diesel, after transportation of seeds land were prepared with the help of tractor, then organic and inorganic fertilizers were mixed in soil, seeds were sown in tubes and directly into the soil, after this regularly water were used for watering, then herbicides were used for protection of seeds from weeds, However in the end saplings were transported to the plantation sites.

2.5. Life cycle inventory

The compilation of an inventory of appropriate energy and material inputs and the environment publishes an inventory analysis of the life cycle (Curran, 2016). Primary data were collected regarding resource input/ output from Thirty-five nurseries of selected districts among Haripur, Abbottabad, and Mansehra of Hazara division. The questionnaire survey included the necessary transportation details, assessment of the use of various input energy like fossil fuel, electricity, polybags, organic and inorganic fertilizers along with plant protection chemicals insecticides, herbicides. Energy was used for machinery to water the seedlings, transportation of fertilizers, insecticides, herbicides, polybags along with transportation of seeds to the nursery, and in the end transportation of the seedlings to the plantations, were included in the inventory. The data uncertainty and quality assurance were calculated using the Equations 1, 2, and 3 as given below;

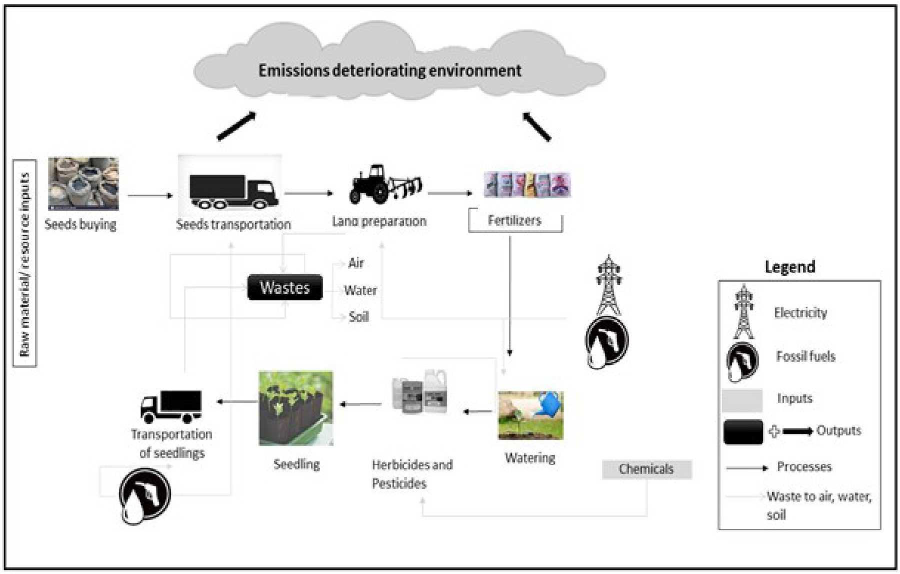

Figure 2. System boundary of the study.

$$\overline{x}_w = \frac{\sum wx}{\sum x} \quad (1)$$

$$Sd_w = \sqrt{\sum_{i=1}^{N} w_i \left(X_i - \overline{x\text{ w}}\right)^2 \left(\text{x} \frac{N'}{\left(N'-1\right)\sum_{i=1}^{N}\text{wi}}\right)} \quad (2)$$

$$CV_w = \frac{Sd_w}{\overline{x}_w} \quad (3)$$

Secondary data were collected from scientific literature, published research articles and online database, such as Eco-invent and Consortium for Research on Renewable Industrial Materials (CORRIM).

2.6. Life cycle impact assessment (LCIA)

The data was collected from thirty-five nurseries. Environmental impact modeling was carried out using software SimaPro version 8.5. CML2 baseline 2000 V2.05 methodology in the SimaPro version 8.5 was used to analyze environmental impact categories (Curran, 2016). For effect evaluation, this methodology utilizes the damage-oriented strategy or endpoint approach. Categories of impacts included in this methodology are Ozone layer depletion (OLD), Photochemical oxidation (PO), Freshwater aquatic ecotoxicity (FAE), Human toxicity (HT), Abiotic depletion (AD), Eutrophication Potential (EP), Global warming potential (GWP100), Terrestrial ecotoxicity (TE), Marine aquatic ecotoxicity (MAE), and Acidification Potential (AP). The Eco-indicator set of effects was used because it includes an extensive set of effects for a range of impact classifications to fulfill ISO criteria.

2.7. Cumulative energy demand

The data were analyzed through SimaPro v8.5. This software was developed by PRé-Consultants. Categories of environmental impact were analyzed using CML 2 baseline 2000 V2.05 methodology in the SimaPro v8.5. Cumulative energy demand (CED) was evaluated for single seedling production in selected districts of the Hazara division during 2019-2020. The CED subcategories were renewable water and non-renewable fossil, non-renewable nuclear, and renewable biomass (Wang et al., 2016).

3. Results and discussion

3.1. Life cycle inventory of inputs and outputs for one seedling production

The materials that were used for single seedling production in the Hazara division during 2019-20 as input and outputs are listed in Table 1. In the present study, a single seedling production was considered to investigate its environmental impacts in the study area. For this, about 35 nurseries were visited and data regarding input/output were collected by using a questionnaire survey. Approximately (0.0001 L) consumption of fuel for land preparation to produce single seedling production in the selected districts of the Hazara division. In the production of a single seedling, production (0.0028 L) inorganic fertilizers were used which were mixed in the soil after the preparation of land. These fertilizers were bought from the market to increase the fertility of the soil in nurseries. Approximately (0.0007 kg) of seeds were bought from different seed shops where high-quality seeds were available. The average distance from seeds shops to markets to produce a single seedling was (0.0002 km). Most of the coniferous tree species' seeds are bought from high-altitude areas where people collect these seeds from forests like Gilgit, Chitral, and Mansehra. To buy seeds from the market, (0.00004 L) fuel was consumed for a single seedling annually according to the 35 nurseries that are visited during the questionnaire survey of selected districts of the Hazara division.

Table 1. Material input/output for single seedling production in selected districts of Hazara division during 2019-2020.

Input/output	Unit	Total
Consumption of fuel for land Preparation	L	0.0001
Fertilizer used	kg	0.0028
Seeds buy per year	kg	0.0007
Actual distance	km	0.0002
Fuel consumption	L	0.00004
Polythene bags used annually	kg	0.0059
Water used per Year	L	0.2977
Electricity used Per Year	kWh	0.0008
Generator Fuel per Year	L	0.0013
Herbicides for Protection of seedlings	L	0.00002
Organic Fertilizer used	kg	0.0356
Organic Dunk distance	km	0.00001
Organic Fuel consumption	L	0.00001
Distance of transplanting	km	0.0002
Fuel consumption	L	0.0001

About (0.0059 kg) of polythene bags are used annually to produce single seedlings in nurseries that are visited during data collection. These polythene bags sized 4×7 inches were bought from the market and then transported to nurseries. Approximately (0.2977 L) of water was used annually in single seedling production. Most of the water is taken from the irrigation system, rivers, floodwater, and tube wells to fulfill the requirements of water on a daily basis. In summer, 10 hours of watering was done for nurseries daily, while in winter it comes down to 6 hours daily. About (0.0008 kWh) purchased electricity was consumed to produce a single seedling in the study area. The electricity was purchased from the national grid station, which is the main source of power to run the nurseries in the study area. About (90%) of Pakistan, electricity was from hydel power. However, in developed countries they generate electricity through multiple sources such as nuclear and fossil fuels. The main reason was that most of the electricity was consumed for producing one seedling using water motors. In the present study about (0.0013 L) fuel was consumed by the generators for single seedling production. In Pakistan, the energy crises are at their peak, to tackle energy or power crises WAPDA do load shedding about 4 to 6 hours a daytime so, during load shedding time, they use a power generator to generate electricity to run the water machines in the nurseries (Hussain et al., 2017). These generators were run by using petrol in the present study area. About (0.00002 L) of herbicides were used for the protection of single seedlings in the selected districts of the Hazara division.

About (0.0356 kg) of organic dunk manure was used annually to produce one seedling production in the study area. Manure was bought from near villages where people have livestock and then transported to nurseries to fulfill the requirements. The average distance of buying organic manure for single seedling production was (0.00001 km). A tractor trolley was used for the transportation of organic manure. To buy organic manure for single seedling production about (0.00001 L) diesel was consumed annually according to the data collected from the study area. The average distance to transplant a single seedling produced in nurseries is (0.0002 km). These seedlings are transported to mountainous areas for afforestation practices to maintain the forest cover. Seedlings are also transported to urban areas for roadside plantations, agroforestry practices, etc. To transplant, a single seedling of about (0.0001 L) of fuel was consumed for the transportation of seedlings to planting sites. Most of the areas were mountainous, so high fuel consumption was recorded in the study area according to the data collected from 35 nurseries in three districts.

3.2. Environmental impacts posed by single seedling production in forest nurseries

The environmental impact posed by single seedling production in selected districts of Hazara division Pakistan during 2019-2020 is mentioned in Table 2. Then ten environmental impact categories were considered in this study: marine aquatic eco-toxicity, ozone layer depletion, abiotic depletion, eutrophication, acidification, human toxicity, freshwater aquatic eco-toxicity, photochemical oxidation, terrestrial eco-toxicity, and global warming potential. The highest environmental impact was posed by marine aquatic eco-toxicity (11.31360 kg 1, 4-DB eq) followed by global warming potentials (0.02945 kg CO2 eq) and human toxicity (0.01227 kg 1,4-DB eq), then freshwater aquatic eco-toxicity (0.00482 kg 1,4-DB eq) and abiotic depletion (0.00037 kg Sb eq), followed by acidification (0.00016 kg SO2 eq) and eutrophication (0.00003 kg PO4 eq) and photochemical oxidation (0.00001 kg C2H4 eq).

3.2.1. Abiotic depletion (AB)

Abiotic depletion is the reduction of natural resources, such as iron ore, minerals, and crude oil (González-García et al., 2011). It is one of the environmental impact categories, which can be assessed through a life cycle assessment. This is the most considered category in environment burdens in life cycle assessment. Abiotic depletion was estimated (0.00037 kg Sb eq) for single seedling production in the study area during the year 2019-2020 as summarized in Table 2.

3.2.2. Acidification

Acidification is defined as the gradual change in the pH of surface/ocean water due to the uptaking of CO_2 from the atmosphere. When carbon dioxide (CO_2) reacts with sea or ocean water, it becomes acidic in nature. Approximately 30-40% of carbon dioxide from human activities is absorbed by oceans, lakes, and streams (Eshleman et al., 1995). In the present study, acidification estimated for single seedling production in selected districts of Hazara division was (0.00016 kg SO2 eq).

3.2.3. Eutrophication

Eutrophication occurs when the concentration of minerals and nutrients increases in water bodies such as streams, lakes, rivers, and oceans which cause the growth of plants and algae (Chislock et al., 2013). In this process, the oxygen becomes depleted in the water body. The value of eutrophication was (0.00003 kg PO4 eq) for single seedling production in the study area.

3.2.4. Global warming potential

Global warming is the gradual increase in the rate of earth's average temperature due to greenhouse (GHGs) gases such as chlorofluorocarbon (CFC), carbon dioxide (CO2), and other excessive pollution caused by humans (Iritani et al., 2014). Due to the greenhouse effect, the lower atmosphere temperature increases and as a result, climate change occurs. About (0.02945 kg CO_2 eq) global warming potential was estimated for single seedling production in selected districts of the Hazara division.

Table 2. Environmental impacts posed by single seedling production in selected districts of Hazara division during 2019-20.

Impact category	Unit	Total
Abiotic depletion	kg Sb eq	0.00037
Acidification	kg SO2 eq	0.00016
Eutrophication	kg PO4 eq	0.00003
Global warming (GWP100)	kg CO2 eq	0.02945
Ozone layer depletion (ODP)	kg CFC-11 eq	0.000000003
Human toxicity	kg 1,4-DB eq	0.01227
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.00482
Marine aquatic eco-toxicity	kg 1,4-DB eq	11.31360
Terrestrial eco-toxicity	kg 1,4-DB eq	0.00015
Photochemical oxidation	kg C2H4 eq	0.00001

3.2.5. Ozone layer depletion

Ozone layer depletion is the gradual thinning of the earth's ozone layer in the atmosphere due to greenhouse gases (GHGs) and human activities (Hertwich et al., 2001). The ozone layer has the potential to prevent ultraviolet solar radiation to touch the earth's surface. These radiations are very dangerous and cause cancer in humans and plants. The value of the ozone layer for single seedling production was (0.000000003 kg CFC-11 eq) in the study area.

3.2.6. Human toxicity

The degree at which a mixture of substances (such as heavy metals) damages human health (Hertwich et al., 2001). It includes both generic and inherent toxicity relationships for emissions. About (0.01227 kg 1,4-DB eq) human toxicity was estimated for single seedling production in the selected districts of the Hazara division.

3.2.7. Freshwater aquatic eco-toxicity

Freshwater aquatic eco-toxicity refers to the impact on freshwater ecosystems (streams, springs, rivers, and lakes) from the emissions of hazardous substances to water, soil, and air. Freshwater is the major component of aquatic resources globally. It plays a pivotal role in human life and provides an environmental habitat. To prevent anthropogenic pollution, freshwater is considered to assess water contaminations and pollutants. In the present study approximately (0.00482 kg 1,4-DB eq) freshwater aquatic eco-toxicity was estimated in the study area.

3.2.8. Marine aquatic eco-toxicity

Marine aquatic eco-toxicity is the impact of hazardous substances on the aquatic ecosystem (Rand and Petrocelli, 1985). The value of marine aquatic eco-toxicity in the production of single seedling production was (11.31360 kg 1,4-DB eq) in the selected districts of the Hazara division.

3.2.9. Terrestrial eco-toxicity

Terrestrial eco-toxicity refers to the effect of toxic substances on the terrestrial ecosystem (Haye et al., 2007). About (0.00015 kg 1,4-DB eq) was calculated for unit single seedling production in the study area.

3.2.10. Photochemical oxidation

It is an air pollution phenomenon also called "summer smog". It forms in the upper atmosphere due to the reaction of emissions from fossil fuel combustion and sunlight (Baumann and Tillman, 2004). The value of photochemical oxidation in the production of unit single seedling production was (0.00001 kg C2H4 eq) in the selected districts of the Hazara division.

3.3. Cumulative energy demand for one seedlings production

Cumulative energy demand (CED) is defined as the total energy required to produce, use, and end-life of a product. CED is a method or way to investigate, examine and declare the product as sustainable on the bases of energy (Finnveden et al., 2009). The four impact categories that were investigated in the present study were renewable water, renewable biomass, non-renewable nuclear, and non-renewable fossil as summarized in Table 3. During the production process, different types of energy were required to run the machines for the manufacturing of single seedling production in selected districts of the Hazara division during 2019-2020. Electricity was the main energy source to run the nurseries for the production of seedlings. In the present study, the total CED for single seedling production in selected districts of the Hazara division during 2019-2020 was (0.800 MJ) from the four impact categories i.e., renewable water, renewable biomass, non-renewable nuclear, and non-renewable fossil, as summarized in Table 3. The highest contribution was from the non-renewable fossil fuels-based energy (0.766 MJ) followed by renewable biomass (0.021 MJ), renewable water (0.011 MJ), and the lowest contribution was from non-renewable biomass (0.001 MJ) as shown in Table 3.

3.4. Emissions inventory to air, soil, and water for single seedling production

Emission inventory results in hazardous substances to air, soil, and water from single seedling production in selected districts of the Hazara division during 2019-2020 as given in Tables 4-6 to 3.6. Most of the emissions

Table 3. Cumulative energy demand (CED) for single seedling production.

Impact category	Unit	Total
Non-renewable, fossil	MJ	0.766
Non-renewable, biomass	MJ	0.001
Renewable, biomass	MJ	0.021
Renewable, water	MJ	0.011
Total CED	**MJ**	**0.800**

Table 4. Emission inventory to air for single seedling production in selected districts of Hazara division during 2019-2020.

Substance	Compartment	Unit	Total
1-Propanol	Air	ng	388.747
2-Methyl-1-propanol	Air	ng	1.031
5-methyl Chrysene	Air	pg	0.001
Acrylic acid	Air	pg	167.688
Aluminium	Air	µg	370.257
Ammonium carbonate	Air	ng	3.624
Arsenic trioxide	Air	pg	0.011
Zinc oxide	Air	pg	0.012
Silicon	Air	µg	73.791
Sodium hydroxide	Air	ng	62.029

Table 5. Emission inventory to water for single seedling production in selected districts of Hazara division during 2019-2020.

Substance	Compartment	Unit	Total
Acetic acid	Water	ng	819.816
2-Butene, 2-methyl-	Water	pg	2.900
Ammonia	Water	µg	4.543
Asbestos	Water	pg	0.003
Calcium	Water	mg	127.893
Chloroacetyl chloride	Water	ng	1.686
Cyanide	Water	µg	4.095
Ethylene oxide	Water	ng	14.758
Hydrogen carbonate	Water	µg	32.112
Magnesium	Water	mg	59.598

Table 6. Emission inventory to soil for single seedling production in selected districts of Hazara division during 2019-2020.

Substance	Compartment	Unit	Total
2,4-D amines	Soil	ng	131.6
Aluminium	Soil	µg	120.4
Arsenic	Soil	ng	76.5
Bentazone	Soil	ng	12.2
Cadmium	Soil	ng	37.4
Carbon dioxide	Soil	µg	102.3
Chloride	Soil	µg	406.1
Dichlorprop	Soil	ng	39.2
Fipronil	Soil	ng	22.8
Flucarbazone sodium salt	Soil	pg	41.7

consisted of the production of single seedling inorganic fertilizers, followed by electricity consumption, petrol used in generators, and transportation. The substances that more contributed to air emissions were 1-Propanol (388.747 ng) followed by Aluminium (370.257 µg), and acrylic acid (167.688 pg), while water emissions were Acetic acid (819.816 ng) followed by Calcium (127.893 mg) and Magnesium (59.598 mg), instead of to soil were Chloride (406.1 µg) followed by 2,4-D amines (131.6 ng) and Aluminium (120.4 µg).

4. Discussion

This study is the first to calculate the environmental sustainability assessment of seedlings production in Pakistan. The LCI data for single seedling production are presented in Table 1. The results of the life cycle impact assessment for single seedling production and the relative contribution to the environmental impact categories are presented in Table 2. Our results are in accordance with previous research in Italy (Cambria and Pierangeli, 2011). In our study, it is observed that Marine aquatic eco-toxicity (11.31360 kg 1,4-DB eq), Human toxicity (0.01227 kg 1,4-DB eq), and Global warming (GWP100) (0.02945 kg CO_2 eq) have the highest environmental impact. Another important study (Halimah et al., 2010) in Malaysia considers the transportation of inputs to the nursery (polyethylene bags, seeds, fertilizers, etc.). This aspect was also considered in our study, while was not considered in the previous case study in Italy (Cambria and Pierangeli, 2011).

5. Conclusions and recommendations

5.1. Conclusions

This study was aimed to conduct an environmental sustainability assessment of softwood and hardwood seedlings production in selected districts of Hazara division, Pakistan. In the present study about (0.0001 L) fuel was used for land preparation to produce a single seedling. To produce a single seedling (0.0028Kg) fertilizers were used, seeds bought (0.0007 Kg), seeds bought distance (0.0002 Km), fuel consumption (0.00004 L). About (0.0059 Kg) Polythene bags and (0.2977 L) were used for a single seedling. Approximately (0.0008 kWh) purchased electricity was consumed and about (0.0013 L) fuel was used in the generator, and (0.00002 L) herbicides were used to produce a single seedling. In the present study about (0.0356 Kg) organic manure was used, (0.00001 Km) organic manure distance, and about (0.00001 L) fuel used to produce a single seedling. Approximately (0.002 Km) distance for transplanting and about (0.0001 L) fuel for transplanting of a single seedling. Abiotic depletion was estimated (0.00037 kg Sb eq) for single seedling production in the study area during the year 2019-20. In the present study acidification estimated for a single seedling in selected districts of the Hazara division was (0.00016 kg SO_2 eq). In this process, oxygen becomes depleted in the water body. The value of eutrophication was (0.00003 kg PO_4 eq) for single seedling production in the study area. About (0.02945 kg CO_2 eq) global warming potential was estimated for single seedling production in selected districts of the Hazara division. The value of the ozone layer for single seedlings was (0.000000003 kg CFC-11 eq) in the study area. About (0.01227 kg 1,4-DB eq) human toxicity was estimated for single seedlings in selected districts of the Hazara division. In the present study approximately, freshwater aquatic eco-toxicity (0.00482 kg 1,4-DB eq) was investigated for single seedling production in the study area. In the present study highest value for marine aquatic eco-toxicity (11.31360 kg 1,4-DB eq) was investigated in the selected districts of the Hazara division. The value of terrestrial eco-toxicity (0.00015 kg 1,4-DB eq) was estimated in the study area. About (0.00001 kg C_2H_4 eq) photochemical oxidation was investigated for single seedling production in selected districts of Hazara division, Pakistan. The total cumulative energy demand for a single seedling was (0.800 MJ) in the selected districts of Hazara division, Pakistan during 2019-2020.

5.2. Recommendations

The present study was carried out on "environmental sustainability assessment of softwood and hardwood seedlings production in selected districts of Hazara division, Pakistan. Numerous studies were conducted on environmental sustainability assessment, while no study was conducted on environmental sustainability assessment of seedlings production in Pakistan. However, many studies were conducted in other countries e.g., Malaysia (Halimah et al., 2010), Africa (Muleke et al.,2012), Italy (Cambria and Pierangeli, 2011), Southern Africa (Böhringer et al., 2003). Therefore, it is a dire need to conduct a study on the assessment of resource flows based on the LCA of the seedlings production in the Hazara division which illustrates total emissions from nurseries. This study also provides baseline or benchmark information for future research to formulate plans to reduce environmental burdens, because no prior research is available on environmental sustainability assessment of softwood and hardwood seedlings production and its impact on the environment in Hazara division, Pakistan.

This study will be useful for Forest Department KP, Academia (Universities and Colleges), students, and organizations such as EPA-Pakistan, Ministry of climate change Islamabad, etc. This study will also provide a benchmark for other nurseries managers to assess the sustainability of their production. This study is also the ever first study on the environmental sustainability assessment of seedlings production in Pakistan. This study also provides an environmental profile of seedlings production in the study area which will help in putting in writing an environmental product declaration (EPD), an EPD is just like Ecolabel which tells us the resources consumption and associated emissions from production. A sophisticated and widely used environmental impact modeling software for the life cycle assessment of seedlings production set process in the study area i.e., SimaPro software v.8.5.1; was used. The seedling's production and fuel consumption had the highest influence on all the ten categories of environmental effects. There was no nursery in the study area that installed any pollution control devices/systems. So, it is highly recommended to install pollution control systems and other precautions to diminish environmental burdens from nurseries of Hazara division, Pakistan. The use of renewable energy resources is recommended to avoid and minimize GHS and other toxic emissions from nurseries in the study area.

Acknowledgements

The authors would like to thank the forest department, private nurseries owners, and their managerial staff for their contribution to data collection in the Hazara division of Khyber Pakhtunkhwa province of Pakistan. Any estimations, findings, conclusions, or recommendations expressed in this article are those of the authors and do not certainly reflect the views of the contributing entities.

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