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Master Thesis

Biochar Production and Application for Sustainable Development: A Case Study in Nepal with the Woman Empowerment Project from NIDISI gGmbH

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Declaration

I declare that I have developed and written the enclosed thesis completely by myself and that I have not used sources or means without declaration in the text. Any thoughts from others or literal quotations are clearly marked.

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Abstract

The German NGO NIDISI gGmbH is currently implementing a Woman Empowerment Project in Nepal to combat the stigma associated with menstruation and provide access to compostable menstrual pads made from banana fibre. The banana fibre extraction factory built by NIDISI at Tribeni-Susta, Nawalparasi-west district in Nepal, where banana fibre is extracted and formed into banana paper as a pre-stage to the production of pads, faced challenges of groundwater contamination around the factory, which is used for banana paper production, as well as waste generation from the factory. The solution was to install a groundwater treatment system and a waste composting unit. Research have shown the ability of biochar to treat water pollution and improve compost quality, as well as the positive effect of biochar application on Nepalese soils which is acidic and degraded in nature. In this study, the impact of using biochar in water treatment and compost production at the banana fibre extraction factory was analysed.

The water treatment is made of a gravel filter, a sand filter, and a biochar filter. The compost has been produced manually as passively aerated pile and the process was monitored by temperature measurement. The biochar applied to the water treatment and to the compost has been produced by the soil pit Kon-Tiki kiln using bamboo as raw material. Biochar has also been produced by metal Kon-Tiki kiln using bamboo, banana leaves, and lantana, to compare the characteristics of the biochar based on the raw material used. Analysis of samples showed that the water treatment system successfully treated contaminated groundwater into drinkable water, and the bamboo biochar added to the compost enhanced the decomposition of the compost pile and reduced the phytotoxicity of the compost. The results also showed significant differences in the biochar produced with bamboo, banana leaves and lantana regarding yield, and nutrient content.

The results indicate that the use of biochar in the banana fibre extraction factory is beneficial overall, while addressing the problems of fertiliser shortage in Nepal and the production of banana agricultural waste. Further research is needed to apply the compost produced and analyse its effect on surrounding farmland. In addition, as bamboo and lantana can be used as cooking fuel, the addition of banana leaf biochar to the compost is considered to be the most beneficial as it can greatly reduce agricultural waste, but its impact on compost needs to be investigated.

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List of Abbreviations

AC	Activated Carbon
BC	Biochar
CEC	Cation Exchange Capacity
CO2e	Carbon Dioxide equivalent
EBC	European Biochar Certificate
FAS	Free Air Space
GHG	Greenhouse Gas
GI	Germination Index
HTT	Highest Treatment Temperature
IBI	International Biochar Initiative
ICAR	Indian Council of Agricultural Research
LCA	Life Cycle Assessment
NDWQS	National Drinking Water Quality Stand-ard
NGO	Non-governmental Organization
NMVOC	Non-methane volatile organic carbon
NPK	Nitrogen, Phosphorus, Potassium
OC	Organic Carbon
OM	Organic Matter
PCM	Pyrogenic Carbonaceous Material
PIC	Products of incomplete combustions
PM10	Particulate matter less than 10 µm
RRG	Relative Root Growth
RSG	Relative Seed Germination
SAP	Super Absorbent Polymer
SWAT lab	Soil, Water and Air Testing Laboratory
TCE	trichloroethylene
TKN	Total Kjeldahl Nitrogen
TSP	total suspended particulate
WEP	Woman Empowerment Project

1 Introduction

1.1 Introduction of NIDISI gGmbH – Woman Empowerment Project

NIDISI gGmbH is a German Non-Governmental Organization (NGO) based in Berlin. It was founded after the devastating 2015 earthquake in Nepal, to bring humanitarian aid. Over the years, the aid changed into long term development work, and NIDISI has now has four main projects in Nepal: Revalue Project, Happy Water Project, Education Project, and Woman Empowerment Project (WEP). There are currently 5 employees and 8 volunteers on the European side and 7 employees and 7 volunteers on the Nepali side.

The WEP team to which the author belongs is addressing the prevalent stigma surrounding menstruation in Nepal. In Nepal, menstruation is considered as impure and there are various restrictions, such as women not being allowed in the kitchen during menstruation, not being allowed to pray, and not being allowed to touch men, plants or food. In some areas, particularly in western part of Nepal, a strict custom called Chhaupadi still remains today, forcing women to spend their menstrual periods in small huts. Recognizing these restrictions and lack of education faced by women during their periods, the WEP aims to empower women by manufacturing compostable menstrual pads using banana fibre. To operate this initiative, a non-profit company called Sparśa has been established in Nepal, entirely managed by Nepalese people. The core concept of Sparśa involves recycling banana tree trunks, which are non-valuable and environmentally harmful agricultural waste, into absorbent eco-friendly menstrual pads as well as providing education and awareness campaign about menstruation.

This integrated approach not only seeks to empower women but also addresses environmental issues caused by plastic pollution and agricultural waste, presenting a comprehensive and sustainable solution to a multifaceted challenge.

1.2 Background and Objective

NIDISI planned to build two factories for pad production: one to extract banana fibres and mould them into banana paper, and the other to mould the banana paper into pads with other materials.

In July 2023, NIDISI built a first factory, banana fibre extraction factory (The Sparśa Fibre Factory), near the banana farms in Tribeni-Susta, Nawalparasi district, in the southern part of Nepal.

The factory faced two major challenges: the first was dealing with waste from the factory and the surrounding farm, and the second was that the groundwater used in the factory's production process was contaminated in the area.

As a solution to the factory waste treatment, it was decided to create compost. All waste from the factory is compostable, and the waste from the banana harvest is usually left or burnt in the field as huge amount of banana waste is a burden on the farmers. As a solution to the groundwater contamination, it was decided to create a water treatment system that could be made inexpensively using materials available in the area.

In addressing these two issues, attention was turned to biochar. Biochar can be made from a variety of biomass, and the benefits of biochar in soil application in Nepal have been reported, as well as its application in low-cost water treatment systems (BH Pandit et al. 2020; Pandit et al. 2018).

However, the properties of biochar and emissions during production are influenced by the conditions of the pyrolysis process and the feedstock (Weber and Quicker 2018; Cornelissen et al. 2016) and there are no or limited number of laboratories or facilities for analysing processes and raw materials in the area around the factory, thus only simple tests such as maturity test for compost can be carried out at the site.

Therefore, the purpose of this paper is to summarise the characteristics, production methods, use cases, and environmental and economic aspects of biochar, and to maximise the information gained and apply it to a case study currently underway in Nepal with NIDISI gGmbH's WEP to assess whether the application of biochar to the waste and water treatment system of a fibre extraction factory is beneficial. The ultimate goal is to promote the environmental and economic sustainability of Sparśa as well as banana farmers through the application of biochar to the water treatment system and to soil together with compost (co-compost).

1.3 Concept of Biochar

Biochar, a solid product of thermochemical conversion primarily through pyrolysis, is a porous and carbon-rich material that can be derived from various biomass sources such as bamboo, maize, banana peel, wood, etc. (Lehmann and Joseph 2009; EBC 2022; NR Pandit et al. 2021; Islam et al. 2019). Through the controlled application of heat in a low-oxygen environment, biochar retains a significant proportion of biomass carbon while undergoing a transformation process that imparts remarkable stability due to aromatic structure (Weber and Quicker 2018). Biochar applied to soil is thought to be stable for decades, hundreds of years, or even thousands of years (F. Verheijen et al. 2010; Kuzyakov et al. 2014; Lehmann and Joseph 2015).

Biochar research began with the discovery of Terra Preta, known as Amazonian Dark fertile land which was made by the ancient indigenous people (Bruckman and Pumpanen 2019; Lehmann and Joseph 2009; Hagemann et al. 2018; F. Verheijen et al. 2010). In recent years, biochar has become a focus of interest across a range of scientific disciplines and industries (Weber and Quicker 2018; F. Verheijen et al. 2010). This increased interest can be attributed to its potential for climate mitigation and agricultural sustainability. The fixed carbon within biochar is the carbon which previously withdrawn from the atmospheric carbon pool through the process of photosynthesis by biomass (Woolf et al. 2016; Roberts et al. 2010). Its carbon-rich composition and exceptional stability make it a valuable tool for carbon sequestration, therefore reducing the Greenhouse Gas (GHG) Emission particularly when applied to the soil (Lehmann et al. 2006; F. Verheijen et al. 2010; Smith 2016). It also has great impact in enhancing soil structure and fostering a conducive environment for microbial communities because of their porous structure (Lehmann and Joseph 2009; Pandit et al. 2018; Wang et al. 2023). In particular , the use of biochar as a soil amendment is effective in weathered and eroded tropical soils (J Lehmann and M Rondon 2006; Bolan et al. 2023; Biederman and Harpole 2013).

Despite growing public and scientific interest in biochar due to its close links to soil health and climate change mitigation, the term biochar is often defined slightly different in papers and has not been standardized (Luo et al. 2023). The differences between biochar, charcoal and activated carbon (AC) are also not well known.

According to the International Biochar Initiative (IBI) (2015), biochar is defined as "*solid material derived from the thermochemical conversion of biomass in an environment where oxygen sources are limited*". This definition was also supported by Lehmann and Joseph (2009). Although Lehmann and Joseph (2009) and F. Verheijen et al. (2010) define biochar as the appropriate term when carbonized organic matter is intentionally applied to the soil to improve soil properties, the application of biochar is very diverse and it is described as a multifunctional material nowadays (Hans-Peter Schmidt & Kelpie Wilson 2012; Weber and Quicker 2018; Hagemann et al. 2018).

There are several thermochemical conversion such as torrefaction, slow and fast pyrolysis, gasification, hydrothermal carbonization and flash carbonization which produce carbonized organic matter (Qian et al. 2015; Weber and Quicker 2018; Meyer et al. 2011). However, the European Biochar Certificate (EBC) guideline (2022) defines biochar as a product of the pyrolysis process of biomass, excluding carbonized products from torrefaction, hydrothermal carbonization, and coke production, while accepting charcoal from gasification as part of the pyrolysis process spectrum.

When talking about biochar, there is often confusion about the difference between biochar, charcoal and AC. Lehmann and Joseph (2015) introduced the umbrella term, Pyrogenic Carbonaceous Material (PCM), for all solid products of thermochemical conversion that contain some organic carbon. The term PCM includes biochar, charcoal and AC, and although the elemental composition and predominant chemical bonds of these three are similar, each has its own history, distinct attributes and, most importantly, specific usage (Hagemann et al. 2018).

Charcoal is defined as wood that has been carbonized and used primarily as a fuel or as a reducing agent in industry. Although Biochar and Charcoal are physiochemically the same, the only difference is their end use. Therefore, if the purpose of using "biochar" is as a fuel for cooking etc., where the carbon is ultimately oxidized to CO_2 when burned, it is classified as charcoal (Hagemann et al. 2018; F. Verheijen et al. 2010). The primary objective or indirect beneficial outcome of biochar is carbon sequestration (F. Verheijen et al. 2010; Lehmann and Joseph 2015; EBC 2022).

Schanz and Parry (1962) defined AC as "*any form of carbon capable of adsorption*". AC has the property of high porosity and high surface area as well as high reactivity at the surface (Heidarinejad et al. 2020; Ruiz et al. 2017). Therefore, it is mainly used to remove contaminants from the gas and liquid phases in applications such as wastewater treatment, desalination, air purification, etc. (Aktaş and Çeçen 2007; Heidarinejad et al. 2020; H Marsch 2006; Hagemann et al. 2018; Kosheleva et al. 2019). Due to the above-mentioned properties that are similar to those of biochar (Cao and Harris 2010), the proposed uses of biochar and AC have recently started to overlap (Hagemann et al. 2018).

AC differs from biochar in that biochar focuses primarily on environmental management (Lehmann and Joseph 2009) and is made from sustainable biomass resources, whereas AC focuses on the important role of adsorption as mentioned above, and can be made from any carbon source. There is also no need for AC to concern the sustainability of their production or the fate of the carbon after use, unlike biochar (Hagemann et al. 2018).

In addition, as the name suggests, AC undergoes an activation process to increase its microporosity and surface area (Ahmad et al. 2014; Lehmann and Joseph 2015), whereas biochar is generally not (Qiu et al. 2009; Lehmann and Joseph 2015). Activation methods can be broadly divided into physical activation, which is activated by oxidizing gases (in general) such as steam or carbon dioxide, and chemical activation, known as wet oxidation (Heidarinejad et al. 2020; Ahmad et al. 2014).

From the above information, this paper defines biochar as biomass solid residue derived from pyrolysis, which does not require activation and is intended to use for environmental quality improvement uses such as soil improvement and water treatment rather than for use as fuel for cooking and other purposes.

2 Production and Properties

The most common form of biochar, charcoal, has been around for thousands of years. In the past, people made charcoal in a simple way that is still used today (Weber and Quicker 2016). There are also advanced methods of producing biochar today to minimize emissions from the production process. This chapter will first discuss the two types of thermochemical conversion for biochar production, gasification and pyrolysis. It then focuses on the most common method, known as slow pyrolysis, where the effects of its parameters on biochar properties will be described. Finally, different approaches to biochar production, ranging from simple methods to advanced techniques, as well as challenges will be explored.

2.1 Thermochemical Conversion – Gasification and Pyrolysis

In gasification, biomass experience thermochemical process that converts biomass directly into syngas (Zhang and Zhang 2019) at the temperature greater than 700℃ (Bridgewater A.V. 2007; Qian et al. 2015). Since production of the syngas is the main purpose of gasification, amount of charcoal production is small (Meyer et al. 2011).

Pyrolysis is the most common method of biochar production (Qian et al. 2015). Biomass feedstock is thermochemically converted into solid residue, pyrolysis gas and oil in the absence or limited presence of oxygen with lower temperature than gasification, usually around 350-1000℃ (Bridgewater A.V. 2007; Roberts et al. 2010; Thomas. B. Reed 2002; EBC 2022). The process can be further divided into two categories, fast pyrolysis and slow pyrolysis, depending on heating rate and residence time (Roberts et al. 2010; Qian et al. 2015). The heating rate of slow pyrolysis is typically around 5-20$℃/min$, whereas rates in excess of 1000$℃/min$ can be achieved with fast pyrolysis. Slow pyrolysis can take from a few minutes to several hours, even several days, whereas fast pyrolysis can be carried out in as little as 2 seconds. (Abdullah et al. 2023). The difference in heating rate and residence time results in different yields of biochar and bio-oil, with fast pyrolysis yielding higher yields of bio-oil, and slow pyrolysis yielding higher yields of biochar (Qian et al. 2015).

In our case study in Nepal, the pyrolysis product required is solid residue i.e. biochar. Also, the kiln used to produce biochar in this case study was a “Kon-Tiki kiln” which is slow pyrolysis process kiln developed by the Ithaka Institute known for biochar production and utilization as well as development of European Biochar Certificate (EBC) (Hans-Peter Schmidt and Paul Taylor 2014). For these reasons, this paper focuses mainly on biochar produced by slow pyrolysis.

2.2 Effect of Slow Pyrolysis Process on Biochar

The yield of biochar and its physical and chemical properties depend mainly on two factors: the process conditions of slow pyrolysis, especially temperature, and the characteristics of the biomass used as feedstock. It is important to understand the properties of biochar because each field has different requirements for its properties.

2.2.1 Biochar Product Yield

Biomass consists of three major organic materials: hemicellulose, cellulose and lignin (McKendry 2002; Rutherford et al. 2012). Hemicellulose refers to a category of polysaccharides characterized by a branched chain structure. In contrast, cellulose, another type of polysaccharide, has an unbranched structure. Lignin, on the other hand, is a complex three-dimensional macromolecule featuring a diverse array of chemical bonds (Weber and Quicker 2018). Díez et al. (2020) reported that the proportion of each organic materials for herbaceous biomass, such as cereal straw, ranges from 26~32%, 33~38% and 17~19% by weight, respectively. As shown in Figure 1 adapted from the data obtained by Yang et al. (2007), these three components decompose at different temperatures in the pyrolysis process. Hemicellulose, the most reactive of the three, decomposes at temperatures between 220~315℃. Cellulose undergoes thermal decomposition at temperatures between 280~400℃ (Yang et al. 2007). Lignin is the main chemical component in charcoal production. Its high aromatic content, size and structural arrangement make it more resistant to thermal degradation than cellulose and hemicellulose (Haykiri-Acma et al. 2010). Thermal degradation of lignin occurs over a wide range of temperatures, starting at 200℃ and ending at as high as 900℃, as different functional groups decompose at different temperatures (Yang et al. 2007). The lignin content is a major contributor to mass yield of biochar, while hemicellulose and cellulose contribute significantly to the condensable gas yield (Bárbara Luísa Corradi Pereira et al. 2013; Lehmann and Joseph 2009). Therefore the proportions of these components and the treatment temperature, especially the highest treatment temperature (HTT) of the process, have the greatest influence on the product mass yield (Adriana Downie et al. 2012; Weber and Quicker 2018). Essentially, these two factors determine the extent to which the physical structure of the biomass is modified during processing, and consequently the physical and chemical properties of the resulting biochar. As discussed in the following chapter, HTT in particular is expected to be the most important of all the factors, as the fundamental physical changes (such as the release of volatiles) are depending on temperature (Lehmann and Joseph 2009).

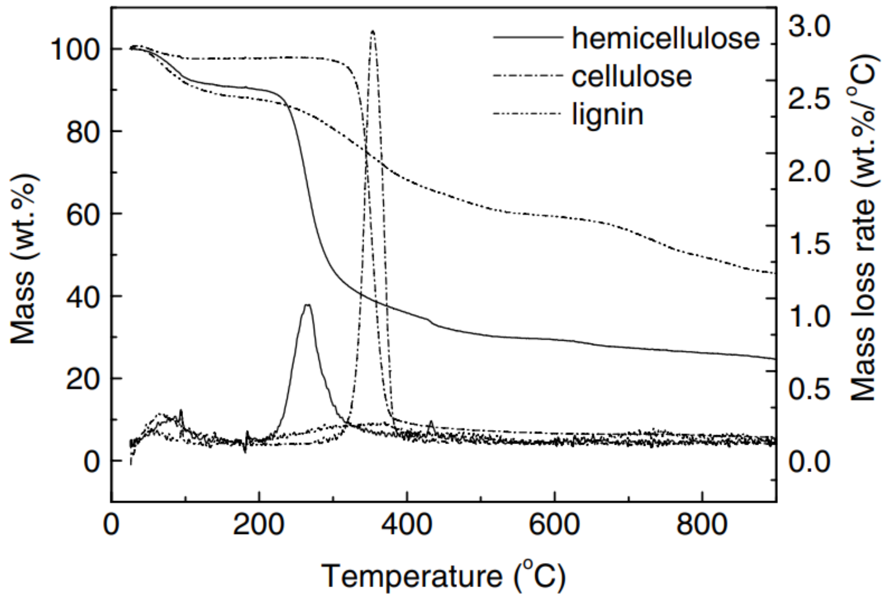

Figure 1. Thermogravimetric Analysis of Hemicellulose, Cellulose and Lignin with the constant heating rate of 10℃/min and Purified N (99.9995%) carrier gas at 120ml/min flow rate.

Source: adapted from Yang et al. (2007)

The water content of the feedstock is another parameter that must not be forgotten in terms of mass yield. A higher water content results in a lower yield and is therefore not suitable for biochar production (Weber and Quicker 2018). Especially when producing biochar using the Kon-Tiki kiln method, as used in our case study, Cornelissen et al. (2016) reported that the greater water content in the feedstock requires increased combustion energy for water evaporation and heating the feedstock to pyrolysis temperatures exceeding 300~400℃. This increased energy demand means that there may not be enough air to sustain ideal combustion conditions throughout the entire process. As a result, the feedstock material spends more time exposed to an insufficient amount of air for combustion, leading to incomplete combustion and higher levels of surface carbon oxidation, elevated ash content, and diminished biochar carbon yield.

2.2.2 Chemical and Physical Properties

In the pyrolysis process, the biomass feedstock goes through 5 stages: (i) weight loss with water evaporation at low temperature, (ii) hemicellulose degradation, (iii) cellulose degradation, (iv) lignin degradation, (v) then continuous degradation and further carbonization (Raveendran 1996; Rutherford et al. 2012).

The HTT plays an important role in pyrolysis process. When it reaches around 250~400℃, depending on the biomass, hemicellulose is completely (or almost completely) degraded and cellulose and lignin are partially degraded (Weber and Quicker

2018). This results in a significant loss of mass, predominantly in the form of volatiles. As the pyrolysis temperature rises, there is a shrinkage or volume reduction. Consequently, throughout the thermal conversion process, the mineral and aromatic carbon structure formed maintains the basic porosity and original biomass structure (Lehmann and Joseph 2009; F. Verheijen et al. 2010; Weber and Quicker 2018). As the temperature increases, volatile substances are further volatilized and the porosity of the biochar increases (Somerville and Jahanshahi 2015; Brewer et al. 2014), which in turn increase the total surface area of the biochar. However, decrease of the specific area of charcoal at high temperature was also observed by Pulido-Novicio et al. (2001). They tested the adsorption capacity of iodine with carbonized Sugi wood powder at varying temperature up to 1000℃. Although adsorption capacity reached the peak at 800℃, it decreases at higher temperature due to shrinkage of cell. A large surface area is a prerequisite for many biochar applications, as it is associated with many other biochar properties (such as cation exchange capacity (CEC) and water holding capacity, etc.) (Weber and Quicker 2018).

The increase in total pore volume due to the larger surface area is also inevitable (Lehmann and Joseph 2009). Pore sizes of biochar can be classified into three order of magnitude by their internal diameter; macropores (> 50nm diameter), mesopores (2nm< diameter < 50nm) and micropores (<2nm diameter) (Rouquerol 2014). The pore structure of biochar predominantly comprises micropores (Lehmann and Joseph 2009; Angın 2013). As different pores size range have different ways of being processed in the environment, pores size distribution of biochar is also an important parameter. For example, while nanometre-sized pores are less relevant to the question of water availability for plants, since plants cannot overcome the high capillary forces that hold water in very small pores (Brewer et al. 2014), these micropores contribute to their high adsorption capacity for molecules with small dimensions, such as gases and typical solvents (Rouquerol 2014).

Not only does the structural composition of biochar change significantly during the thermal conversion process, but the elemental composition also changes due to the desorption of functional groups such as hydrogen and oxygen-containing groups (Weber and Quicker 2018). Krevelen diagram published by Dirk van Krevelen (1950) shows changes in the atomic ratios of biomass main components such as carbon, oxygen and hydrogen during carbonization. As the HTT increases (beyond 500℃ ~600℃), carbonization becomes the dominant process. Most non-carbon atoms are removed, so atomic ratios such as H/C and O/C decrease during carbonization. Therefore, the carbon content increases proportionally, reaching up to 90% by weight for biochar derived from woody feedstocks (Antal and Grønli 2003; Demirbas 2004; F. Verheijen et al. 2010; Weber and Quicker 2018), accompanied by the release of more volatile matters with temperature rise (Manyà 2012). The H/C ratio, in particular, is known as a representative measure of the degree of carbonization, as hydrogen being closely associated with organic matter in biomass (Tan et al. 2015), and is therefore also used to estimate the degree of aromaticity (Uchimiya et al. 2010). The lower the H/C ratio, i.e. higher the HTT, more aromatic structure in the biochar (Chun et al. 2004; McBeath et al. 2011). The aromatic structure is highly persistent in the environment, leading to long-term carbon fixation of biochar in soil and also as a soil amendment (Weber and Quicker 2018).

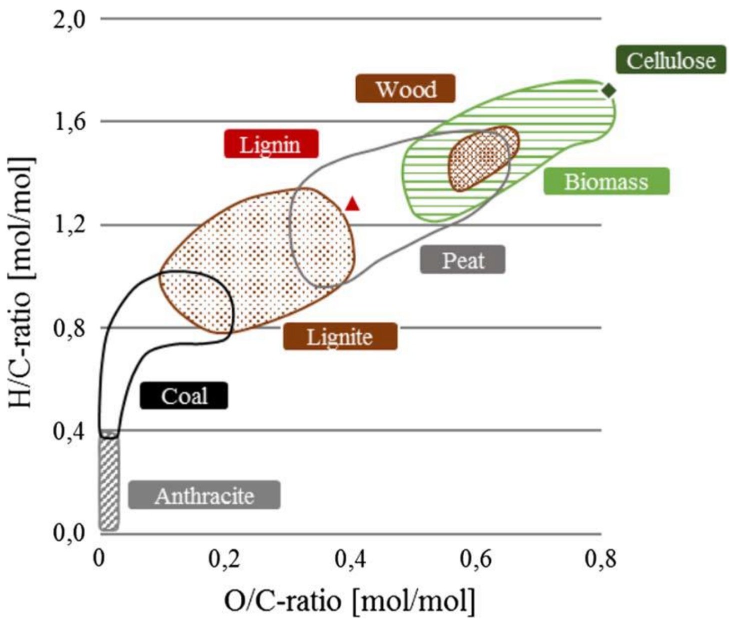

Figure 2. Van Krevelen diagram of carbonization process

Source : VAN Krevelen (1950)

Polarity of the biochar is indicated by the O/C and (O+N)/C ratio (Uchimiya et al. 2010; Tan et al. 2015). The lower O/C and (O+N)/C ratio show the loss of polar functional groups such as hydroxyl, carboxylate, and carbonyl at the high temperature (Ahmad et al. 2012; Tan et al. 2015; Weber and Quicker 2018), thus it may leads to increase the hydrophobicity and decrease the CEC of the biochar (Weber and Quicker 2018).

Hydrophilic substances are polar and have strong interactions with water due to hydrogen bonding, whereas non-polar hydrophobic materials, which lack polarity, have weak interactions with water but can interact strongly with non-polar liquid (Lag et al. 2022). Although It is believed that the higher HTT leads to have more hydrophobicity, some study such as Evy Setiawai et al. (2019) show that the hydrophobicity of biochar slightly decrease again at high temperature. Weber and Quicker (2018) concludes that the influence of increasing porosity at high temperatures may become more pronounced, resulting in increased water absorption by the char.

CEC reflects the negative surface charge of biochar (Xu et al. 2011), signifying the quantity of exchangeable cations that a material can retain (Lee et al. 2010). This parameter is employed to characterize the material's ability to bind certain nutrients (cations) in the soil, thereby influencing their availability for plant uptake (Manyà 2012). The biochar with the highest CEC are typically produced at relatively low temperatures because the surface area significantly increases compared to the feedstock, while a sufficient number of functional groups remain in the structure to impart negative charges (Weber and Quicker 2018).

Furthermore, the detachment of polar functional groups such as carboxyl, hydroxyl or formyl groups at high HTT results in a biochar with a higher pH (Ahmad et al. 2014). This is because the detached groups are mainly acidic in nature, and also because the amount of ash, which is alkaline, increases with increasing temperature (Weber and Quicker 2018).

2.3 Production Technologies

2.3.1 Low-Cost Technologies

Numerous low-cost technologies for charcoal (biochar) production are available. These methods either draw on ancient practices that have been used for centuries primarily to produce charcoal, or incorporate with metals, such as mild steel, to enhance efficiency (Cornelissen et al. 2016).

Some of the low-tech processes used to produce biochar are shown in the part below.

2.3.1.1 Traditional Earth Mound kiln

In low-income countries such as some African countries, traditional and improved earth mound kiln carbonization methods are still the most commonly used to produce charcoal from wood, mainly for cooking purpose (Schenkel et al. 1998; Pennise et al. 2001). It usually takes several days (2~7days) and average yield of charcoal is around 10~20 wt.% (Joko Sulistyo et al. 2002; Alphonse Nahayo et al. 2013).

Although many consider this method to be uniquely suited to local conditions in low-income countries due to its low investment, labour intensity, income opportunities and system mobility, it is highly controversial from an environmental perspective due to toxic gas emissions and the inefficiency of converting firewood into charcoal, which would ultimately lead to deforestation (Schenkel et al. 1998; Pennise et al. 2001; Alphonse Nahayo et al. 2013).

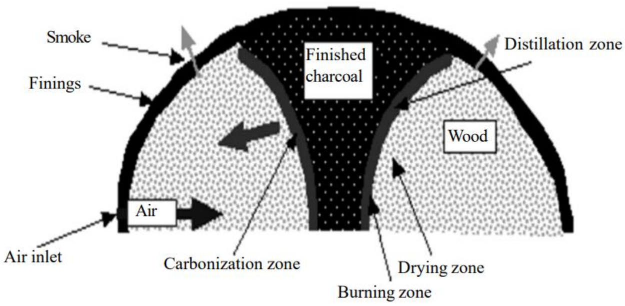

Figure 3. Traditional Earth Mound kiln

Source : Kayhan Menemencioglu (2013)

2.3.1.2 Retort kiln

Above mentioned negative environmental effects from traditional earth mound kiln encouraged the studies for cleaner and more efficient charcoal production process. Retort kiln was introduced to overcome these drawbacks of traditional kiln (Sparrevik et al. 2015; Adam 2009). As the gases generated by pyrolysis are recirculated in the combustion chamber and burnt internally, the emissions such as CH_4 and CO that promote air pollution can be reduced by 70-75% compared to traditional methods. Another advantage is that the conversion efficiency is 30% to up to 40% higher than with conventional methods and the operation time is 24-30 hours, which is shorter than the traditional method (Ankona et al. 2022; Dr Steve Sepp et al. 2014; Adam 2009). However, this technology require high investment cost, which can exceed 2000 € (Dr Steve Sepp et al. 2014) and construction and operation require skilled individual. Therefore it is not viable for people in low-income countries (Adam 2009). Another disadvantage is that about 50 kg of valuable wood has to be used to start the pyrolysis process (Sparrevik et al. 2015).

Figure 4. Left : Adam retort kiln, Right : Drum retort kiln

Source. Left adam retort kiln (Adam 2009), Right drum retort kiln (Sparrevik et al. 2015)

2.3.1.3 Flame Curtain Kon-Tiki kiln

The Kon-Tiki kiln was developed by the Ithaka Institute in 2014 based on the basic principle of smokeless fire, as seen, for example, in matches (Figure 5) (Hans-Peter Schmidt and Paul Taylor 2014). This technology has quickly spread to more than 100 countries nowadays (Cornelissen et al. 2023).

The principle of this biochar production method involves sequentially pyrolyzing layers of biomass in a conically shaped metal kiln or soil pit kiln (Figure 6). The flame curtain formed on top of the kiln, which shields the underlying biochar from oxygen, ensuring it does not oxidize, while cleanly burning pyrolysis smoke and gases. Due to convective and radiant energy from flames above and hot pyrolyzing layers below, the temperature reaches 680~750℃, initiate pyrolysis in the new layer. Proper layering timing and rate are crucial, avoiding excessive feedstock that produces smoke and insufficient feedstock that fails to maintain a protective flame curtain. Manual layering continues until the kiln is filled, and the pyrolysis process is quenched with mainly water (Hans-Peter Schmidt and Paul Taylor 2014; Cornelissen et al. 2016).

Cornelissen et al. (2016) produced biochar from Eupatorium, invasive shrub omnipresent in the region, using both soil-pit kiln and metal kiln and found that both methods met the EBC guidelines certificate. However, unlike soil-pit kiln, metal kiln has more constant temperature distribution due to the heat reflection from steel wall, ensuring more homogeneous and uniform carbonization condition and biochar quality. In addition, the metal outer layer heats combustion air before the air enters the combustion zone of the pyrolysis gases, thereby preventing a temperature drop in the zone and reducing the smoke formation (Hans-Peter Schmidt and Paul Taylor 2014). Furthermore, A vortex is created in the centre of the kiln as the combusted gases try to escape to the top while the heated combustion air enters through the outer rim from the top of the kiln. This stabilizes air supply for combustion, and the heavier-than-air gases generated by the biomass remain in the vortex until they are completely burned. This phenomenon allows for a smokeless fire. To generate this vortex in the soil pit kiln, a metal shield can be attached to the soil-kiln, as shown in Figure 6 (b). The metal-kiln can be also improved by introducing rim-shield shown in Figure 6 (c). The rim-shield is 10 cm higher than the kiln, which not only prevents wind from interfering the flame and cold air from entering directly from above the kiln, but also prevents the metal-outer wall from being cooled by the air and wind (Hans-Peter Schmidt and Paul Taylor 2014).

Compared to a retort kiln, although the price of metal kiln depends on the size and the country where the kiln is built, Kon-Tiki kiln can be constructed cheaper. Soil-pit kiln especially, can be built free of charge, since all that is required is to dig a conical hole in the ground. The production process is much faster, around 2~8hours depending on the moisture content of the biomass. In our case study, it took less than an hour. The start-up fuel is not required unlike retort kiln and operation is also easier, although at least one person must be around the kiln entire time to observe the production procedure and supply new layer of biomass (Cornelissen et al. 2016; Hans-Peter Schmidt and Paul Taylor 2014). For the above reason, this technology is very suitable for on-farm rural area production of biochar (Owsianiak et al. 2018).

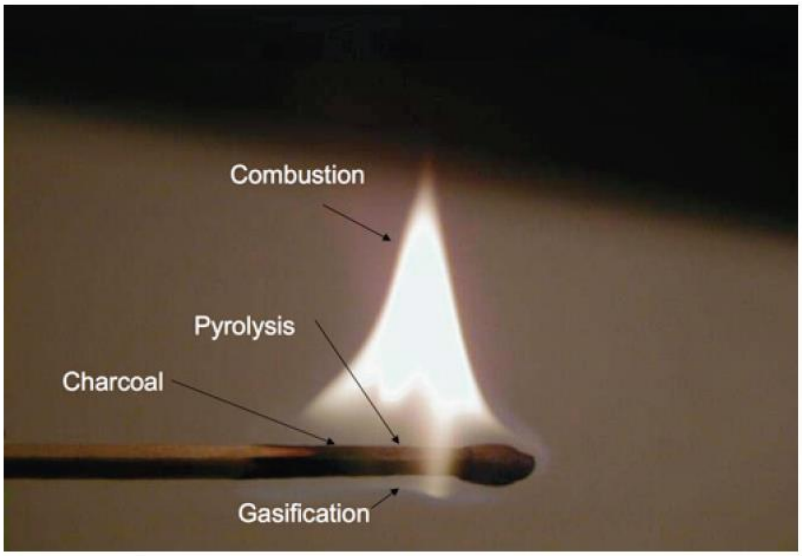

Figure 5. burning principle of match

Source adapted from Hans-Peter Schmidt and Paul Taylor (2014)(Hans-Peter Schmidt and Paul Taylor 2014)

Figure 6. Different type of Kon-Tiki kilns; (a) soil-pit kiln built by us in Nepal, (b) soil-pit kiln covered by metal shield (photo taken by the author at Ithaka Insitute in Nepal), (c) deep-cone metal kiln, and (d) metal kiln with metal rim-shield.

Source. (c) and (d) are adapted from Hans-Peter Schmidt and Paul Taylor (2014)

2.3.2 Large Scale and Modern Technology Production

Large-scale and modern technology biochar production not only produces biochar, but also recovers by-products such as biogas, oil, heat, etc (Yang et al. 2021; Roberts et al. 2010) for use in other applications. In addition, as will be discussed in a next chapter, the exhaust gases from biochar production are usually cleaner than those of low-tech plants because off-gas cleaning systems are installed. Here, some examples are shown.

A German company called Pyreg GmbH, for example, is manufacturing large-scale biochar production facility. The Figure 7 shows a schematic model of the production process withing the facilities called PX500 and PX1500, with fuel capacities of 500 $kW$and 1500 kW, respectively. Annual production of each facility are 300 tons and 900 tons, respectively, when using wood and operating 8,000 hours per year. The entire carbonisation process schematic is also shown in Figure 7. Various materials can be used as feedstock, including manure, wood chips and hay as well as tires, paint residues and many more. The emissions meet EU emission limit, and more than 99% of fine dust can be removed from the exhaust gas. The extracted heat during the process can be utilized as hot water, steam, oil, with heat outputs of 200 kW_{th} and 600 kW_{th} for the PX500 and PX1500, respectively (PYREG GmbH 2023).

The Swedish company ECOERA uses the PX500 and PX1500 to produce biochar and apply it to achieve the carbon removal by biochar-only (ECOERA Millennium Biochar and Carbon Emission Removal Service 2024). They also burn the syngas produced during pyrolysis and use for district heating.

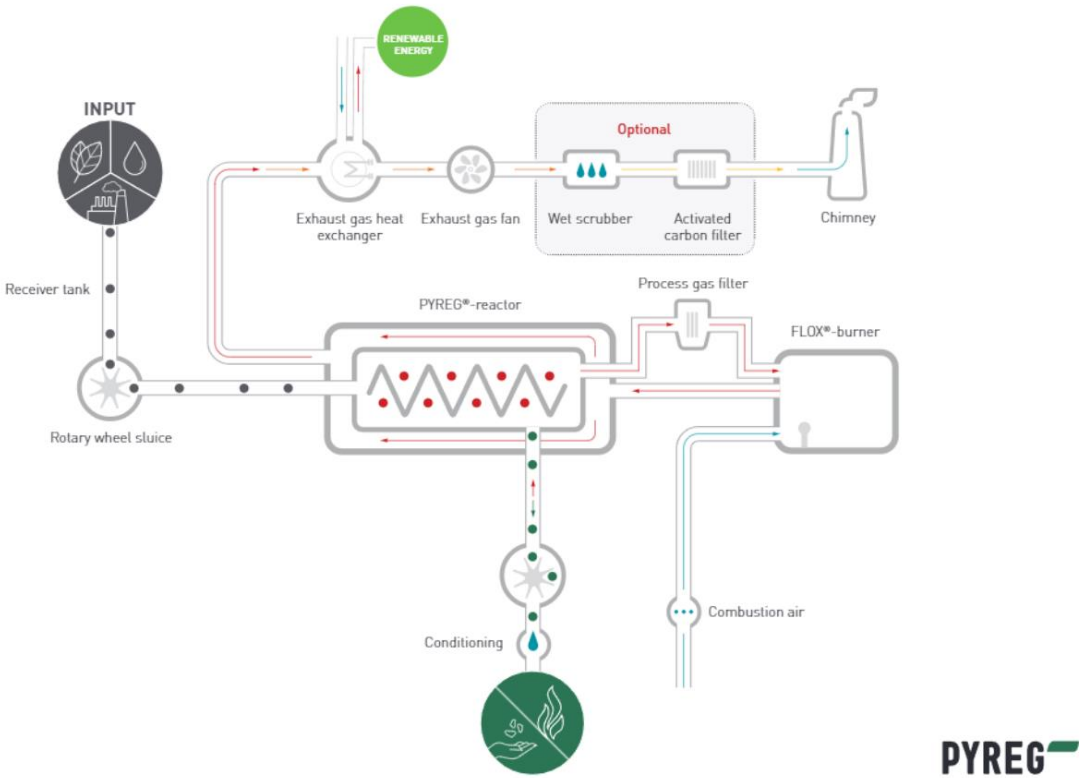

Figure 7. Carbonization technology model PX500/1500 from Pyreg GmbH and their process

Source : PYREG GmbH (2023)

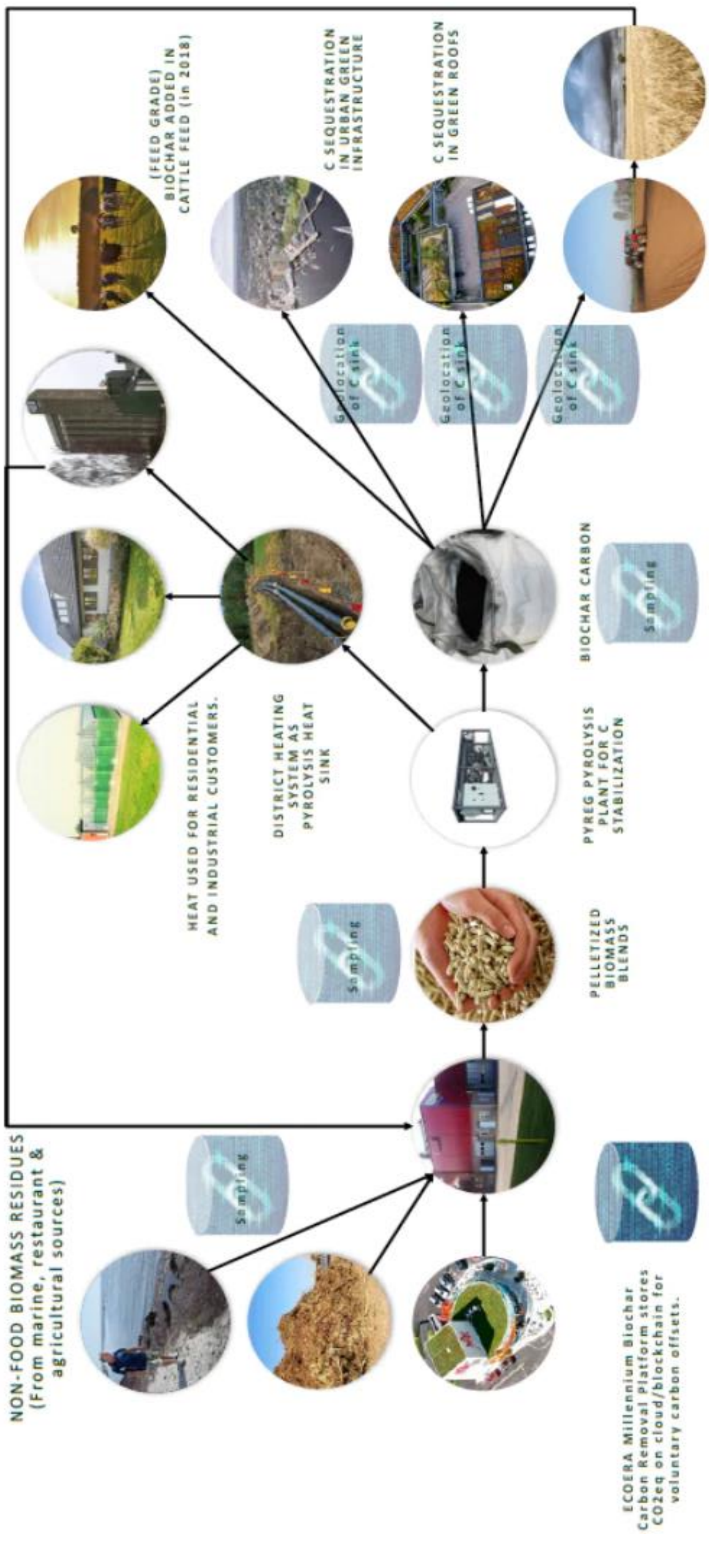

Figure 8. Carbon removal flow chart by ECOERA using biochar production.

Source : ECOERA Millennium Biochar and Carbon Emission Removal Service (2024)

In other examples, Peters et al. (2015) conduct life cycle assessment (LCA) with a simulation of a slow pyrolysis plant capable of processing 38,500 tons of dry feedstock per year with using Aspen Plus (Aspen Technology. 2024). The simulation relies on a kinetic reaction model that incorporates more than 150 individual pyrolysis reactions. Figure 9 shows the simplified version of Aspen Plus flowsheet for slow pyrolysis. Hot exhaust gases from combustor are used to dry the feedstock till 7% of moisture content and feedstock is ground to 3mm particle size for pyrolysis. The pyrolysis process occurs at a temperature of 450°C with a residence time of 2500 seconds, resulting in a mass distribution of 29.0% char, 40.8% bio-oil and 30.2% gas, allowing to produce 11,165 tons of biochar annually. The hot vapours (consisting of gas and uncondensed tars) are combusted directly in the combustor. This combustion not only provides the necessary process heat for the pyrolysis reactor and biomass dryer but also produces excess heat.

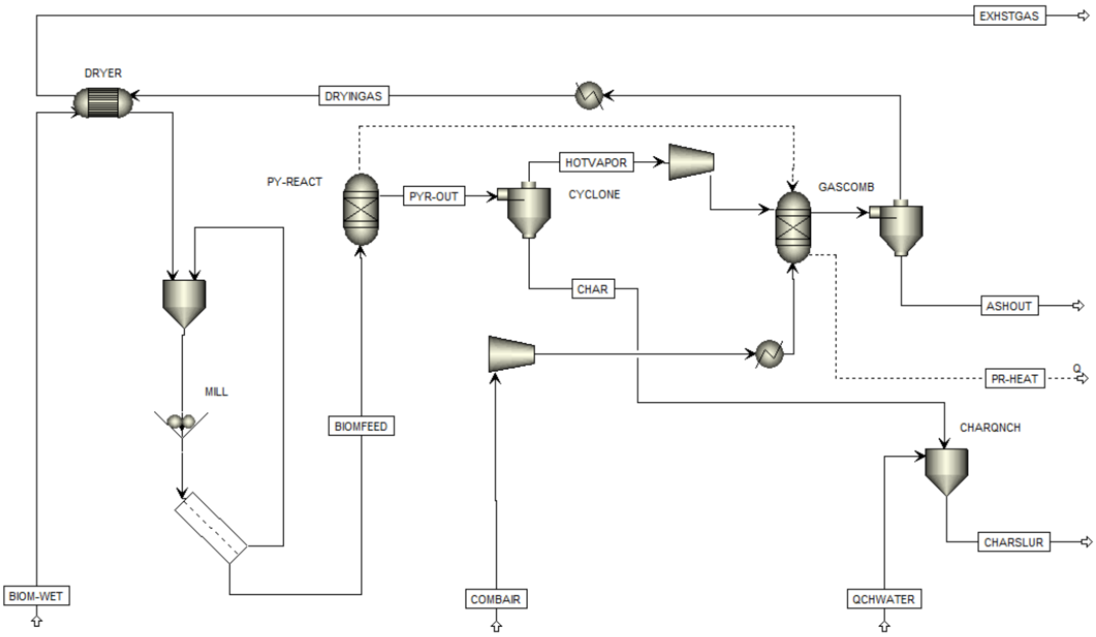

Figure 9. Simplified model of Aspen Plus for slow pyrolysis

Source : Peters et al. (2015)

2.3.3 Emission Factor Comparison

To achieve sustainability and climate mitigation through biochar production, it is imperative to focus on the emissions produced during biochar production, especially in the case of low-tech biochar production.

Pyrolysis of biomass mainly emits CO, CO_2, CH_4, total suspended particulate (TSP) (Particulate matter <10 µm (PM10) aerosol), and non-methane volatile organic carbon (NMVOC) such as C_2H_6 and C_2H_4. Nitrogen oxides (NO, NO_2, N_2O) are also emitted (Pennise et al. 2001; Lehmann and Joseph 2009; Donald L. Klass 1998; Cornelissen et al. 2016). Most of these gases are harmful not only to the human body but also to the environment. Methane, carbon dioxide, and nitrous oxide are the main contributors (Figure 10) to GHG in the Earth's atmosphere. They directly absorb a portion of the Earth's outgoing radiation, leading to an enhanced greenhouse effect and contributing to global warming (Matthew Brander 2012; Donald L. Klass 1998). Particulate matter, on the other hand, is described as the cause of a variety of health problems when inhaled, including nonfatal heart attacks, arrhythmias, worsening asthma, decreased lung function, decreased airway inflammation, and increased respiratory symptoms such as coughing and dyspnoea, etc. (Kim et al. 2015).

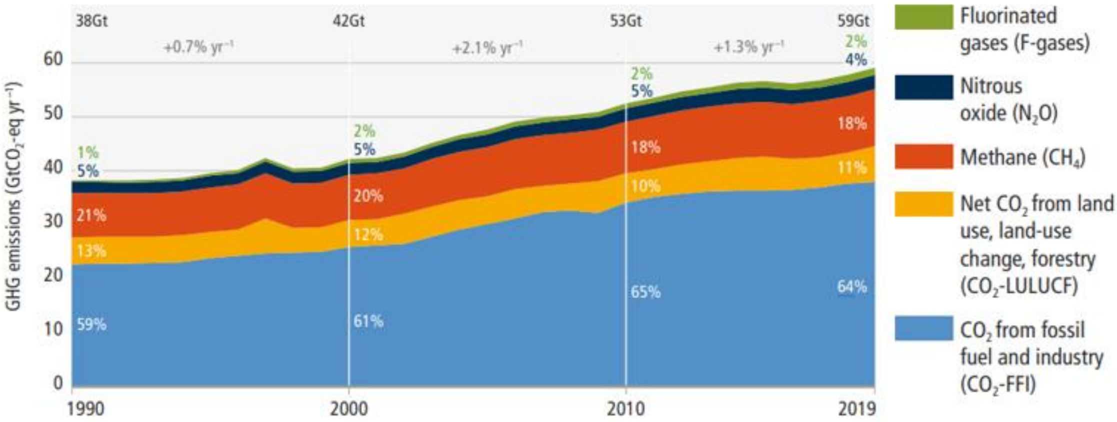

Figure 10. Anthropogenic GHG emission all over the world from 1990 to 2019

Source : adapted from P.R. Shukla et al. (2022)

Cornelissen et al. (2016) measured the emission factors of CO, CO_2, CH_4, NO_X, NMVOC, and TSP as well as products of incomplete combustions (PIC) as the summarize of $CO + NMVOC + CH_4$ from different types of Kon-Tiki flame curtain kilns such as metal kilns and soil-pit kilns. In their subsequent experiment (Cornelissen et al. 2023), same emission factors for biochar production by soil-pit Kon-Tiki kiln with different moisture content of biomass were measured. In both studies, the results were compared with the other biochar production technologies from different studies. For both emission measurements in 2016 and 2023 by Cornelissen et al. on the Kon-Tiki kilns, there were high standard deviations because the flame curtain conditions varied with each process run due to, for example, wind, oversupply of feedstock material, etc. Table 1 is based on the emission factor comparison table from Cornelissen et al. (2023). It compares biochar yield and exhaust gases from the soil-pit kiln with different moisture content of feedstock (Cornelissen et al. 2023), soil-pit kiln used in previous study of them (Cornelissen et al. 2016), different low-tech methods of biochar production with different biomass but using exactly same emission measurement equipment (Sparrevik et al. 2015; Pennise et al. 2001), and simulated emission factor from large-scale biochar production which is mentioned above (Peters et al. 2015). Cornelissen et al. (2016) report that CO and NO_X emissions from both metal and soil Kon-Tiki kilns were slightly lower than those from traditional and retort kiln, while CO_2 emission from Kon-Tiki kilns were much higher than others. These trends can be seen in the experiment in 2023 as well. Methane emissions reported in 2016 were more or less the same as for the other low-tech kilns. In contrast, in the 2023 experiments, methane emissions from dry and semi-dry biomass were not detected, while wet biomass produced a huge amount of methane, 605 g/kg biochar. It indicates the importance of using dried biomass for Kon-Tiki flame curtain biochar production method. As mentioned above, higher water content in biomass also results in more ash and lower biochar production from Kon-Tiki kiln especially (Cornelissen et al. 2016).

The reasons for the higher CO_2 emissions and lower CO for the Kon-Tiki kiln compared to the traditional and retort kilns are discussed by Cornelissen et al. (2016) as follows; Due to the Kon-Tiki kiln's proximity to the high temperatures of an open flame, a more amount of feedstock undergoes gasification than other methods. This leads to more complete combustion of pyrolysis gases, resulting in lower emission of CH_4 and CO, but increased CO_2 emission and lower yield. While a low yield rate is an important parameter in the production of charcoal made from wood for cooking because it promotes deforestation (Alphonse Nahayo et al. 2013), in the case of the Kon-Tiki kiln, it is not a major disadvantage because the biochar can be produced from agricultural waste or environmentally harmful biomass such as Eupatorium.

As can be seen in Table 1, emissions other than CO_2 are zero or close to zero for large-scale biochar production (Peters et al. 2015), indicating large-scale is the most environmentally friendly option when considering emission factors and by-product use. However, the cost of plants investment using these advanced technologies increases dramatically (can be > US $500,000 (Cornelissen et al. 2016)), and maintenance costs are also very high. Therefore, the implementation of these high-tech, large-scale biochar production facilities is not realistic in low-income countries, where most of the tropical climates in which biochar is considered most effective are located.

Table 1. Emission factor comparison from different biochar technologies

Run	Feedstock Mositure	Biochar yield	Biochar C	Biochar H	CO_2	CO	NMVOC	CH_4	TSP	NOx
	[%]	[wt.%]	[wt.%]	[wt.%]	g/(kg-biochar)					
Kon-Tiki soil-pit[a]	25.0	22.0	76	-	3800±1300	36±40	8±1	32±44	20±24	0.8±0.7
Kon-Tiki soil-pit dry[b]	14.7±3.4	24.8	81.2±1.6	2.62±0.30	3633	101 (60-181)	0.79 (0.00-2.82)	0.0	62 (29-97)	0.012±0.035
Kon-Tiki soil-pit half dry[b]	29.0±12.4	21.2	84.0±1.1	2.80±0.24	4668	118 (84-203)		0.0	69 (33-87)	0.004±0.008
Kon-Tiki soil-pit wet[b]	41.0±11.6	21.2	84.0±1.1	2.80±0.25	3049	206 (145-273)	-	605 (485-996)	21 (16-39)	0.000
Kiln literatures										
Traditional kilns [c]	12.2	30.1	55	-	2375	351	53	49	19	2.2
Retort kiln [c]	12.6	30.2	67	-	2602	148	7	35	11	1.7
Large-scale reactor [d]	7.0	29.0	81.68	2.7	3010	3.0E-07	0	0	0.05	0.7

a : Data from Cornelissen et al. 2016

b : Data from Cornelissen et al. 2023

c: Average value of two literature Sparrevik et al. 2015 and Pennise et al. 2001 used in Cornelissen et al. 2023

d: Data from Peters et al. 2015 used in Cornelissen et al. 2023

3 Applications of Biochar

Historically, biochar has mainly been used for soil improvement and therefore has mainly been applied to soil. Although such application is still common today, biochar is being used in various fields other than soil application due to its porous properties and surface electrostatic attraction/repulsion (Ahmad et al. 2014), and also due to the attention it has attracted to solving current environmental problems. This section focuses mainly on the soil improvement and water treatment applications of biochar, which is also used in our Nepal case study, and describes some other applications.

3.1 Biochar as Soil Amendment

The application of biochar to soils alters the physical and chemical properties of the soil and has a positive effect not only on the soil but also on the environment. In particular, the following changes in soils caused by biochar have been reported to be very effective on sandy, oligotrophic, and acidic soils (Jeffery et al. 2017; Cornelissen et al. 2016).

Although this also depends on the conditions of the pyrolysis process, biochar often possesses high Cation Exchange Capacity (CEC) values. According to Department of Primary Industry (2023), CEC above 10 $cmol/kg$ are desirable for optimum plant production, and soils with high content of swelling clay and organic matter may show CEC of 30 $cmol/kg$ or higher. The CEC values of biochar produced by Cornelissen et al. (2016) using the Kon-Tiki kiln with Eupatorium, Rice husk and Wood as feedstock, ranged from 40 $cmol/kg$ to slightly higher than 200 $cmol/kg$. Biochar produced by Yuan et al. (2011) by thermal conversion at 300°C, 500°C and 700°C using canola, maize, soya and peanut straws exhibited the lowest CEC of 183 $cmol/kg$ and the highest value of 304 $cmol/kg$. The CEC of soil reflects its ability to bind certain nutrients (cations) and make them available for uptake by plants (Manyà 2012). Combined with the porous nature of biochar, this reduces the leaching of nutrients that prevent soil acidification and contamination of surface and ground water (Laird et al. 2010).

In addition, the porous and high surface area of biochar not only increases the water-holding capacity of the soil, but also promotes population dynamics of soil biota and diversifies the soil microbial community (F. Verheijen et al. 2010; Laird et al. 2010).

Biochar has an alkaline pH of approximately 8-10 and has been reported to increase soil pH, particularly when used on tropical soil (Pandit et al. 2021; Pandit et al. 2018; Cornelissen et al. 2016). Low pH increases the concentration of aluminium in the soil, which is known to be toxic for plant growth in particular (Pandit et al. 2018), while reducing base availability and microbial activity, as well as phosphorus availability, because phosphate is tightly bound to aluminium oxides (Hale et al. 2013). High pH, on the other hand, promotes the depletion of trace elements, each of which is considered to have a negative effect on crop growth. Therefore, a soil pH of around 6.5, which is weakly acidic, is recommended (McLean 1970).

In a study by Yamato et al. (2006) in Sumatra, Indonesia, the combination of biochar and fertilizer 15-15-15 (NPK) significantly increased soil pH from 3.9 to 5.1. At the same time, soil Al^{3+} concentrations decreased from 2.67 $cmol/kg$ to 0.12 $cmol/kg$. The pH and Al^{3+} concentrations were not much different from the control plot where only fertiliser was applied.

Jeffery et al. (2017) carried out the meta-analysis in global scale regarding biochar application to soil. Biochar application in temperate regions with moderate soil pH and high fertility showed little or no increase in crop yields, whereas in tropical regions, it increased yields by 25% on average. In addition, BH Pandit et al. (2020) applied biochar to banana-based agroforestry in the middle hill area of Nepal. Biochar was produced using the Kon-Tiki soil-pit kiln from Eupatorium and twigs from animal feed leftover. Banana yields were compared under the following conditions: compost alone, mineral NPK alone, compost mixed with biochar (BC), biochar quenched the pyrolysis process with cow-urine (Urine-BC) mixed with compost, and Urine-BC mixed with compost and NPK. As can be seen the result in Figure 11, the effect of biochar application on crop yield is very significant, especially when mixed with the fertilizers such as NPK and compost. It can also be seen that the effect of biochar produced by the Kon-Tiki kiln increases when the pyrolysis process is extinguished with cow-urine instead of water.

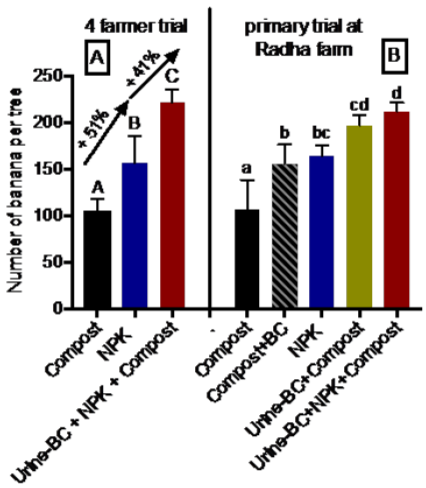

Figure 11. The number of bananas harvested 18 months after planting and fertilization.

Source : BH Pandit et al. (2020)

3.2 Biochar for Water Treatment

Due to its large specific surface area, porous structure and surface functional groups, biochar has been reported not only as a soil amendment but also for the removal of pollutants such as heavy metal, organic pollutants and other pollutants such as nitrate from contaminated water (Tan et al. 2015). The various proposed mechanisms for the adsorption behaviour of these pollutants on biochar, as summarized by Tan et al. (2015), are shown in Figure 12. Although the removal efficiency depends on the characteristics of the biochar and is therefore dependent on the biochar feedstock and thermal conversion process (Ahmad et al. 2014), biochar has attracted attention as an alternative adsorbent to activated carbon (AC) because it can be derived from renewable resources and can be produced at low cost, making it suitable for low-income countries (Gwenzi et al. 2017).

As discussed in Chapter 2.2.2., when biochar is exposed to temperatures above 500℃ during pyrolysis, its surface tends to become less polar and more aromatic because of a decrease in oxygen and hydrogen containing functional groups, which may increase the adsorption of organic pollutant (Gwenzi et al. 2017). Ahmad et al. (2012) report increased adsorption of trichloroethylene (TCE) by biochar derived from soybean and peanut shells at 700℃ compared to 300℃ due to high aromaticity and low polarity. They also mention that there is not much difference in TCE removal of biochar produced at 700℃ compared to AC. On the other hand, biochar produced at relatively low temperatures (i.e. high polarity) is reported to be effective to remove polar compounds such as norflurazon and fluoridone which are used as herbicides (Sun et al. 2011).

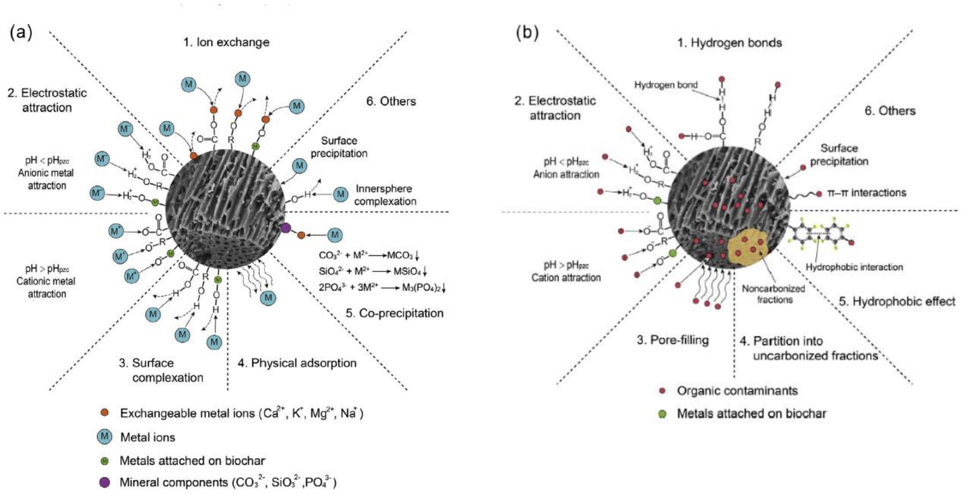

Figure 12. Conceptual diagram of the removal mechanism of a) heavy metals and b) organic pollutants from aqueous solutions by biochar.

Source : Adapted from Tan et al. (2015)(Tan et al. 2015)

It has also been reported that biochar can effectively remove phosphate from aqueous solution. Biochar used for phosphate removal can also be used as a slow-release fertiliser for soil, although care should be taken when the same biochar is also used to remove other toxic compounds (Tan et al. 2015; Yao et al. 2013).

3.3 Other Applications

Some other actual or potential application example of biochar are presented here.

3.3.1 Use in Construction Material

Due to its porous nature, biochar has a low thermal conductivity and its use in concrete or plaster is believed to improve its thermal insulation performance and thus expected to reduce the energy used for heating and cooling (Gupta and Kua 2017; Hans-Peter Schmidt & Kelpie Wilson 2012). Hans-Peter Schmidt (2014) mix 50% biochar with 20% clay and 30% sand to make biochar-clay plaster to apply for wine cellar. It was observed that humidity level of the cellar was kept between 60-80% all year round, resulting in a significant reduction or prevention of mold and other harmful microorganisms. Biochar also absorbs odours and toxins, making it useful for warehouses and agriculture-related buildings (Hans-Peter Schmidt & Kelpie Wilson 2012).

3.3.2 Support Agent for Biogas Production

Sangkhom Inthapanya et al. (2012) reported that the addition of biochar made from rice husks to methane gas production in a batch biodigester using cattle manure increased 31% of gas production after 30 days of continuous fermentation. They hypothesize that this phenomenon is due to the large specific surface area of the biochar applying the microorganism habitat involved in anaerobic degradation.

In addition to these applications, other potential and in-practice usage of biochar include precursors for catalyst production, air purification, filling material of pillow additive to fabric material, etc. (Sakhiya et al. 2020; Hans-Peter Schmidt & Kelpie Wilson 2012; Qian et al. 2015).

4 Economic and Ecological Aspect of Biochar

Biochar can be derived not only from valuable wood, but also from agricultural waste and sewage sludge that has lost its usefulness, providing an effective means of treating agricultural waste. In addition, the by-product of the production process, syngas, can be used as a source of renewable energy (Yang et al. 2021; Roberts et al. 2010). The multiple benefits of biochar extend to improving soil properties and therefore increasing crop yields, particularly in tropical soils, as discussed in Chapter 3. It also acts as a carbon sequestration due to its stability when applied to soil. While there is strong evidence that the production and use of biochar can help reduce greenhouse gases, it is important to recognize that its effectiveness depends on several influencing factors. It is also recognized that the production and use of biochar is currently economically burdensome (Cornelissen et al. 2016; Bach et al. 2016).

Yang et al. (2021) investigated the environmental impacts associated with the introduction of biochar in China through LCA analysis using Gabi 8.70 LCA software. The study focused on biochar production from residues of the most common crops in China using a modern slow pyrolysis process. Operations such as crop residue collection and biochar application were powered by electricity, and diesel was used for transportation. The energy produced in the form of bio-oil and pyrolysis gas was used to offset electricity generation from coal-fired sources. Biochar was used as a soil amendment in a sustainable manner, including carbon sequestration, increased crop yields, reduced fertilizer use, reduced N_2O emissions from the soil and increased soil organic carbon content. Their results from this study showed that converting 1 ton of crop residues into biochar could potentially capture 920 $kg\ CO_2\ equivalent\ (CO_{2e})$.

A similar study estimating the climate change impacts of biochar using LCA analysis was conducted by Roberts et al. (2010). The analysis focused on an industrial-scale slow pyrolysis facility in the United States, with an emphasis on biochar production from corn stover, yard waste and switchgrass feedstocks. The full life cycle of the biomass was considered, from collection and transport to the pyrolysis plant, as well as on-site combustion of syngas and oils produced during pyrolysis process for heat. Processes avoided by extending the system, such as natural gas production and combustion, composting and fertilizer production were included. Land use change, carbon sequestration potential and soil N_2O emission reduction from biochar application were also within the defined system boundaries. In contrast to the LCA by Yang et al. (2021), increased crop yield due to biochar application to soil were not considered because targeted soil in United States was relatively productive soil, and not deteriorated soil. This study also reveals negative net GHG emissions for stover and yard waste biochar production, indicating reductions of -864 and -885 $kg\ CO_{2e}$ per ton of dry feedstock, respectively. However, the switchgrass biochar system resulted net GHG emitter

($+36\ kg\ CO_{2e}/\ ton\ dry\ feedstock$k), depending on the method used to account for indirect land use change impacts. They emphasized that care must be taken in the choice of feedstock to avoid negative consequences.

Despite this attention and claims of biochar's high potential to mitigate global warming, biochar farming has been limited (Fytili and Zabaniotou 2018). At present, the biochar market is not well established, there is significant price variation due to the wide range of biochar quality and labour costs across countries, and considerable uncertainty about future prices, thus trade remains minimal (Campbell et al. 2018). Moreover, the incorporation of biochar in agriculture is a relatively recent concept. Despite the existence of voluntary quality standards such as the European Biochar Certificate (EBC) and the International Biochar Initiative (IBI) Standard, national and international legislation in the EU are not sufficiently equipped to regulate both the production and application of biochar (Meyer et al. 2017). Awareness among farmers regarding long-term benefits of biochar application to soil is also low (Maroušek et al. 2019), and biochar is used as an alternative to charcoal because farmers prefer immediate profit from energy utilization than long-payback related to soil improvement (Maroušek et al. 2018; Vochozka et al. 2016). The two LCA analyses mentioned above (Yang et al. 2021; Roberts et al. 2010) also report that transport between the biochar production site to the actual site of use has a small impact on GHG emissions (depending, of course, on distance and number of transports), but a significant impact on the price of biochar.

It should also be noted that technologies using large scale modern technology, such as mentioned in 2.3.2 and those used in the LCA described above, are very expensive to implement and maintain, thus such technologies cannot be the option to implement for farmers, especially for those in low-income countries (Cornelissen et al. 2016). When the author, I, contacted Pyreg GmbH, the German company mentioned in Chapter 2.3.2, they replied that their system cost approximately one to three million euros to implement.

For these reasons, it is essential to increase awareness and markets for biochar, but currently small-scale biochar production in close proximity to the feedstock and application sites is recommended. This method is very effective and economically feasible, especially in low-income countries where tropical soils are, expected to increase crop yields and where large machines are not affordable (Maroušek et al. 2019; Robb et al. 2020).

As described also in Chapter 3.1, BH Pandit et al. (2020) compared two villages in the middle hills of Nepal regarding banana agroforestry with and without using biochar for a period of two years (The difference in yield with different treatments of biochar is shown in Figure 11). The results show that the number of households below the Nepalese poverty line (<97,250 Nepale Rupee per year/household : assuming a household size of 5 persons) became lower in the biochar-used village than in the non-biochar-used village due to enhanced banana agroforestry.

Furthermore, Pandit et al. (2018) analysed maize and mustard yields and their cost-benefit over three years of adding different amounts of biochar ($5\ ton/ha$, $10\ ton/ha$, $15\ ton/ha$, $25\ ton/ha$, and $40\ ton/ha$). The biochar was produced from the Eupatorium using a traditional earth mound kiln in Nepal. The results showed that the gross margin was highest at $15\ ton/ha$ of biochar application, 53% higher with considering carbon credit and even 21% higher without carbon credit compared to the control (non-biochar) area.

Robb et al. (2020) also predicted that in high-income countries in temperate climates, scenarios involving large-scale biochar projects with co-production capacity that focus on income sources other than crop yield increases would be financially unfeasible. On the other hand, in low-income countries in tropical climates, a case that emphasizes yield increases in high-value crops and includes technologies focused on small-scale biochar production is projected to be financially viable.

These results show that the small-scale production and application of biochar by farmers themselves helps them economically. It also leads to the mitigation of global warming by biochar. However, as mentioned in Chapter 2.3.3, small-scale biochar production produces more emissions than large-scale biochar production using state-of-the-art equipment (Cornelissen et al. 2016). Therefore, care should be taken, for example, to use feedstock with low moisture content when using a Kon-Tiki kiln (Cornelissen et al. 2023). Further research is also needed to develop technologies and methods for small-scale biochar production that are in the same price range but with lower emissions (Cornelissen et al. 2016; Sparrevik et al. 2015).

5 Case Study: The Banana Fibre Factory of the Women Empowerment Project of NIDISI gGmbH, located in Nepal

5.1 Woman Empowerment Project (WEP) in NIDISI gGmbH

In Nepal, menstruating women are considered impure during their period. According to Karki et al. (2017), 89% of women in Nepal reported experiencing menstruation-related restrictions, such as avoiding temples, not attending religious and social gatherings, not touching plants or male family members. Many have limited access to menstrual products, with only 15% of women using menstruation pads, while 83% using clothes (Karki et al. 2017). In addition, more than half of menstruating women do not have adequate knowledge about menstruation and most information comes from female family members and little education is provided in schools (Karki et al. 2017; UNICEF 2018).

Furthermore, according to NIDISI interviews with 840 Nepalese women, 90% of used sanitary products are disposed of in the environment, such as buried in the ground or thrown into rivers and ponds. Sanitary pad may contain up to 90% plastic, and pads discarded in the environment or in landfills can take up to 500~800 years to decompose, raising concerns about environmental plastic pollution (Panjwani et al. 2023; Aridi and Yehya 2023).

To combat stigma around menstruation and providing access to environmentally friendly menstrual products, NIDISI gGmbH launched the Woman Empowerment Project (WEP) in Nepal in 2020.

After various research, development, and investigations, Sparśa, women-led social enterprise, was established in 2022 in Nepal. Sparśa manufactures and sells innovative compostable sanitary pads made from banana fibre. Profits from the sales of the pads will fund the Sparśa Ambassador Program, which delivers menstrual awareness campaigns to school children and adults, aiming to challenge cultural beliefs and taboos surrounding menstruation. Also, by employing women living in poverty, Sparśa aims to provide financial independence.

So far, the awareness campaign on menstruation has already reached more than 8000 participants. In addition, face-to-face interviews were conducted with 840 Nepalese women and girls in 14 regions to gain insight into their menstrual experiences, product availability, expectations of menstrual pads, etc.

In the future, NIDISI would like to scale up the model across Nepal and other countries in the Global South where there is still a strong stigma around menstruation and where the majority of banana production takes place.

5.2 The Sparśa Pads

Figure 13.The Sparśa Pad and its Layers.

To make the pads as environmentally friendly as possible, all raw materials are compostable and sourced from local or nearby suppliers, and the production process is chemical-free. The first layer, which touches the woman's body, is made of non-woven cotton, providing softness and comfort; the second layer is made of banana fiber and works as core absorbent of the pad; The third layer is bioplastic, made from cornstarch, to ensure waterproofness and prevent leakage.

Of these three layers, the banana fibre layer is made by Sparśa from extracting the banana fibres to shaping them into an absorbent mattress. In July 2023, NIDISI established a Fiber Extraction Factory in Tribeni-Susta, Nawalparasi west district, southern Nepal, where fibre is extracted from banana trees and processed into banana paper. The banana paper produced is sent to another factory, Sparśa Pad Factory, in Bharatpur, which is currently (as of 4th February) under construction and will eventually be processed into menstrual pads along with non-woven cotton and bioplastic.

It takes 6 g of banana fibre to make one pad; the target is to extract 15 kg of fibre per day in the fourth year of production, i.e. to sell 96,750 boxes of eight pads per box per year.

5.2.1 Reasons for Choosing Banana Fibre as Pad Adsorbent.

Bananas is the general term for a plant belonging to the genus Musa which are generally grown in the humid lowlands of the tropics (mainly between 40°N and 40°S from the equator) (Rahmad Mohd Taib 2019; Seymour 1993). Although this genus comprises of many species, their growth processes can be described as common for all (Anne Vézina et al. 2020). In Sparśa Fibre Extraction Factory, Musa paradisiaca AAB group (also known as Banana Malbhog) is used to extract fibre (Julia PESCHEUX-SERGIENKO. 2021).

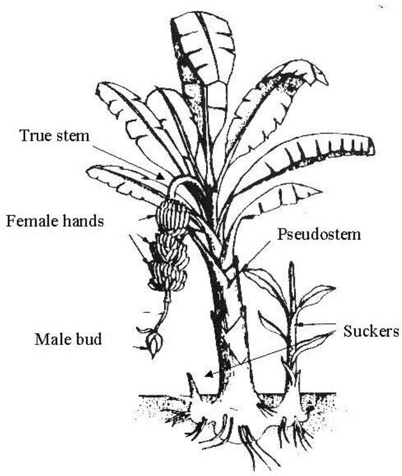

Figure 14. Schematic diagram of the banana plant

Source : OECD (2009)

A banana tree grows and can be harvested in about one year. In fact, banana trees only bear fruit once in their lifetime, so they need to be cut down after the fruit has been harvested.

From our investigation, each banana tree after harvesting of fruits weighs approximately 30kg to 40kg. According to the Indian Council of Agricultural Research (ICAR) - National Research Center for Banana (ICAR 2022), approximately 60 tons of banana agricultural waste per hectare of banana plantation area is generated. As the total banana production area in Nepal is 21,413 [ha], the potential amount of banana waste reaches 1,284,780 [tons]. In addition, Nawalparasi west district, where the factory is located, has the second largest banana production area of 2,200 [ha] in Nepal, which would generate approximately 132,000 [tons] of banana waste. Therefore, a huge amount of agricultural waste is produced by bananas every year.

Although some banana leaves are used to protect banana fruit during transport (Figure 15, Right), most banana plants become waste and are usually left to rot or burned in the field because of their large volume and the burden they place on farmers. This is the first reason why banana was chosen to extract fibre.

Figure 15. Left) Banana fruits harvesting, Right) Banana fruits transportation (photo taken by the NIDISI in 2023)

The second reason is that banana fibre is known for its strength and ability to absorb moisture (Saxena and Chawla 2021). NIDISI compared the water-holding capacity of the Sparśa Pad prototype with sanitary pads commonly sold in Nepal and Germany (shown as NEP – Nepal and GER - Gemany in Figure 16 and Figure 17). Green in the graph shows the Sparśa Pad, orange shows pads with super absorbent polymer (SAP) and blue shows pads without. The results show that Sparśa Pad has high water retention properties despite being a natural base product.

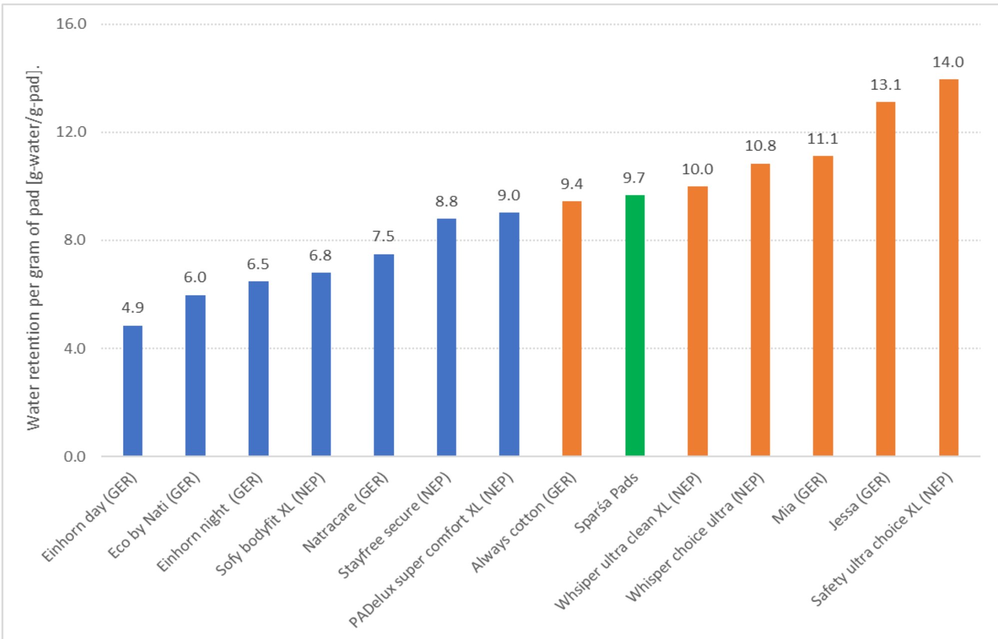

Figure 16. Water retention of sanitary pads per gram of pad - NIDISI internal research

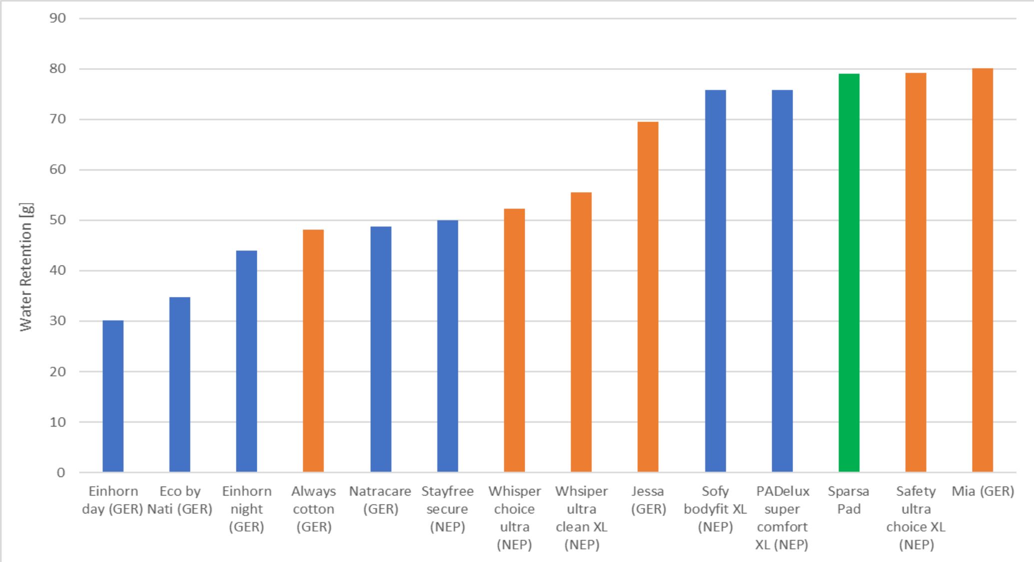

Figure 17. Water retention of sanitary pads - NIDISI internal research

5.3 Background and Objective of Case Study

This case study was conducted at the Sparśa Fiber Extraction Factory located in Tribeni-Susta, Nawalparasi west district, Province No.5.

5.3.1 Information of Tribeni-Susta and Nawalparasi West

Figure 18. Map of Nepal

Source : Election Commission Nepal (2074/2017)

Nepal is a landlocked country bordering India and China, divided into seven provinces and further divided into 77 districts. Despite its small size, Nepal has a very diverse topography and can be divided into three main topographical areas: Himal, Pahad and Terai (Election Commission Nepal 2074/2017; World Bank Group 2021).

Himal is a high mountain region with altitude range from 4,877m to 8,848m, where location of 8 of the world's 14 mountains over 8000m; Pahad is a hilly region with an altitude of 610m to 4,876m. The region forms the largest part of the country's landmass - 68% - and Nepal's capital, Kathmandu, is part of this area; Terai is a lowland area below 610m above sea level and is the southern border strip with India. Terai is also known as granary of Nepal, where agriculture is prevalent (World Bank Group 2021).

Tribeni-Susta, where the Sparśa Fibre Extraction Factory was built, is located in Nawalparasi west of province No.5 (Lumbini Province), and topographically belongs to Terai (Nepal Archives 2016). Tribeni-Susta covers the area of 91.23 $km^2$and its population is 40,655 in 2021 (City Population 2023). Its main occupation is agriculture and it is a famous Indian religious place of prayer (Gyawali 2008). The meaning of Tribeni is the meeting point of three sacred rivers, namely Sona, Tamasar, and Saptangandaki (Gyawali 2008). According to the population census from the Government of Nepal (2023), in Nawalparasi West, more than half of the households use tubewells or hand pumps as their main source of drinking water, and about 41% of the households use wood or firewood as their main cooking fuel. In addition, less than 10% of the households are engaged in small non-agricultural businesses such as transport, cottage industry, etc.

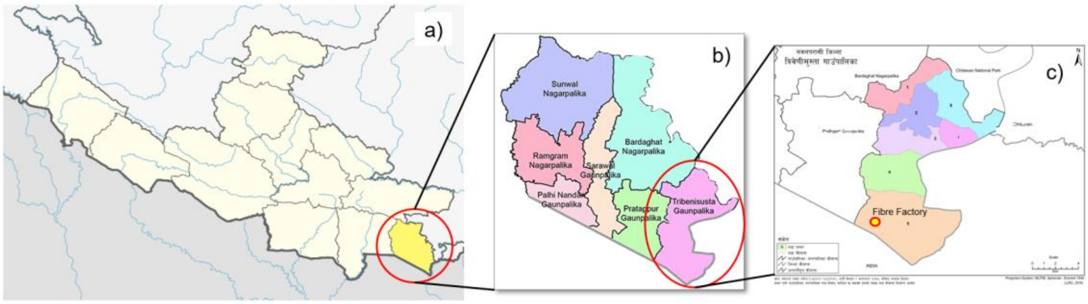

Figure 19. a) Location of Nawalparasi West (yellow) in Lumbini Province – No.5, b) Location of Susta in Nawalparasi west, and c) rough Location of Sparśa Fibre Extraction Factory (red – yellow) in Tribeni-Susta.

Source : a)&b) are adapted from Wikipedia (2024) page of Nawalparasi west, c) is adapted from Nepal Archives (2016)

5.3.2 Sparśa Fibre Extraction Factory

The Sparśa Fibre Extraction Factory located in Tribeni-Susta was built in order to extract banana fibre and produce banana paper which is the preliminary stage of making pads.

A survey of the farmers around Tribeni-Susta was conducted in 2022 to decide where to build the factory. As a result, it was built at the red-yellow dot point in Figure 19 c) in July 2023. Most of the farmland around the factory is managed by a single family who was interested in and cooperative with our project. They grow bananas, sugar cane, rice, etc. The survey showed that there is a potential of about 44800 banana trees per year in the area (Jeremy Berdy 2022).

As can be seen from the Figure 20, the factory is surrounded by the banana plantation, from which banana trunks are collected after the fruit harvest to extract fibre at the factory.

Figure 20. Sparśa Fibre Extraction Factory

The banana paper production steps at the factory are explained below.

1. <u>Pseudo-Stem (so-called Banana Trunk) Collection</u>
   First, banana pseudo-stem (Figure 14) is collected from the nearby banana plantation. The banana pseudo-stem is a type of leaf (Anne Vézina et al. 2020). However, because it looks like a trunk, it is often called a banana trunk. In this paper, banana trunk refers to this pseudo-stem.

Figure 21. Banana pseudo-stem – banana trunk

2. <u>Trunk Cutting and Fiber Extraction</u>
   As can be seen from the cross-section of the banana trunk shown in Figure 21, banana trunk is composed of tightly overlapping leaf sheets (Leaf sheaths (Anne Vézina et al. 2020)). By cutting the trunk in half, the sheets can be easily separated, and the fibres extracted from each sheet.

Figure 22. Trunk cutter (left) and banana fibre extraction (right)

3. <u>Drying and Cutting Fiber</u>
   The extracted fibres are dried in the sun and cut into lengths of about 5 cm for the following steps.

Figure 23. Drying of banana fibre

4. <u>Cooking and Rinsing Fiber</u>
   The fibres are then boiled for 30 minutes and rinsed in order to separate the cellulosic fibres from other components that remain attached to the fibres and to further disinfect and clean the fibres.

5. <u>Refining by the Hollander Beater</u>
   Refining is then carried out using a Hollander Beater, which is the most important machine for obtaining the absorbency of the banana pads. Widely used in the pulp and paper industry, this machine refines cellulosic fibres into pulp by cutting them (again), separating all the fibres from each other, creating fibrils, and hydrating the fibres.

Figure 24. Hollander beater

6. Forming into Banana Paper
The last step in the fibre factory is to make banana paper from the pulp obtained in the previous process, to facilitate the following steps for pad production in the other factory. The production of Banana Paper was inspired by the traditional handmade papermaking process using mould and deckle. Moulded banana paper is pressed to remove moisture and dried in the sun.

Figure 25. Banana paper formation

5.3.3 Motivation of Biochar Case Study at the Fibre Factory

There are two main reasons why biochar was chosen for case studies at the factory, which are presented here.

5.3.3.1 Application for agricultural and factory waste treatment

As mentioned above in chapter 5.2.1, banana plantations generate a huge amount of agricultural waste after harvesting the edible parts of bananas, most of which is left on farmland to decay or openly burnt in field. This practice is also the case around our fibre extraction factory (Figure 26).

Figure 26. Banana waste left in the field after harvesting around the factory.

The Sparśa adds value to those wastes by extracting fibre from what are essentially agricultural wastes and producing compostable menstrual pads. However, investigations by NIDISI found that the amount of fibre that can be extracted from one banana trunk (approximately 20kg per trunk) is only around 150 g (dry weight), with the rest being waste from the factory. In addition, the only banana waste handled in the factory is the banana trunk, while the leaves are left in the fields. Furthermore, when the author interviewed the farmers who supply the factory with banana trunks, they said that in their area they generally use fertilizer imported from India and that they cannot secure enough fertilizer due to the low quantity of this imported fertilizer.

As all waste produced in the factory and left in the field is green waste, NIDISI has set the goal of achieving a circular economy and treating factory waste as well as reducing agricultural waste by producing compost mainly from factory waste and using it on the banana plantations of the farmers who provide the banana trunks. Ultimately, the project also aims not only to eliminate fertilizer shortages, but also to reduce the use of chemical fertilizers.

To achieve these goals, the author found that the use of biochar could be effective in NIDISI case. Biomass, the raw material for biochar, is readily available due to the surrounding agricultural land, and the effectiveness of biochar utilization for agriculture in Nepal has been reported (BH Pandit et al. 2020). The author also considered that if biochar could be made from agricultural waste such as banana leaves, it would also lead to a reduction in agricultural waste.

5.3.3.2 Application for water treatment.

The process of forming paper from banana fibre requires the use of large quantities of water, which is pumped up from groundwater and used at the factory. Although the availability of groundwater in the Terai region has highly productive shallow aquifers and robust recharge (Pathak 2019), the groundwater in Nawalparasi district is often contaminated. Several papers have reported severe contamination by Arsenic in the Nawalparasi district, as well as by Iron, nickel and manganese (Diwakar et al. 2015; Gyawali et al. 2022; Yadav et al. 2014).

To create as hygienic environment as possible for the production of menstrual pads, the treatment of process water was required. Therefore, it was decided to introduce a water treatment system combining a gravel filter, a slow-sand filter, and a biochar filter, which has a high-water purification capacity, which can be made from materials available in the vicinity and is relatively inexpensive.

Kearns et al. (2014) found that a multibarrier system, comprising a gravel filter, sand filter, and biochar adsorption unit arranged in series, effectively removed organic contaminants. They reported that this system demonstrated a removal efficiency of 50%-100%, comparable to that of commercial activated carbon.

5.4 Methodology of Biochar Application

5.4.1 Biochar Production and Yield

5.4.1.1 Kon-Tiki Kilns

The Ithaca Institute is a non-profit research foundation based in Europe with an office in Nepal as well. It is a leading international network focused on carbon strategies, with expertise in agronomic methods of carbon sequestration and biochar production and is the institution that developed the Kon-Tiki kiln. The Ithaka Institute has conducted a number of soil fertility experiments in Nepal using biochar produced with the Kon-Tiki kiln.

The author visited the Institute in Nepal in May 2023 to learn about biochar production and application. Later soil-pit Kon-Tiki kiln (Figure 27) was introduced at the fibre factory to start biochar production. The biochar used in the water treatment system and composting process shown chapters below are bamboo biochar produced in 2023 using the soil-pit Kon-Tiki kiln.

Although the soil-pit kiln was effective in producing biochar, it was often destroyed due to the heavy rains that occur during rainy season in Nepal. As it was labour intensive to rebuild it each time, the author designed and ordered a Metal Kon-Tiki kiln (Figure 28) at a Nepali local metal shop located in Bharatpur in January 2024 and has been using the Metal Kon-Tiki kiln at the factory since February 2024.

Figure 27. The soil-pit Kon-Tiki kiln made by the author and colleagues.

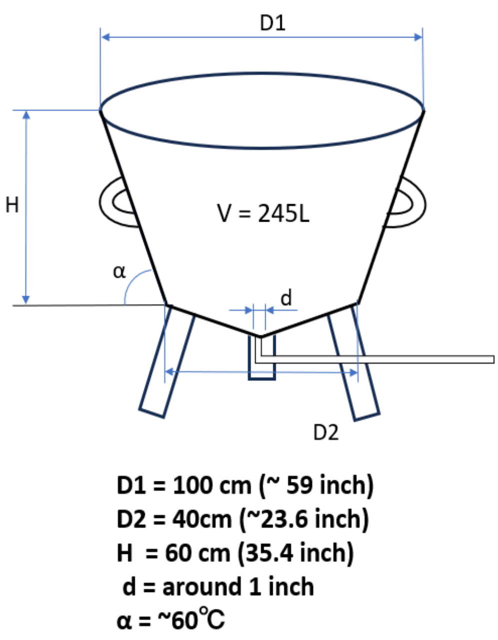

Figure 28. Metal Kon-Tiki kiln design (left) and actual kiln (right)r

5.4.1.2 Material and Production Process

The feedstock chosen to produce biochar at the factory was biomasses available in the vicinity of the factory.

The production which has been made with the soil-pit Kon-Tiki kiln in 2023 used bamboo that had been utilized for the construction of the fibre factory and was subsequently no longer needed. In Nepal, bamboo is useful in many filed of work such as building supports, construction of buildings, barricades on farms, etc., and most of the bamboo which is broken or damaged is utilized for cooking and for heating during the winter season.

Bamboo was also used in the production of biochar using the metal Kon-Tiki kiln in February 2024. In addition to bamboo, banana leaves coming from after harvesting of the bananas of the field around the factory, and Lantana (Figure 29), an invasive species that grew around the factory, were used for biochar production with Metal Kon-Tiki kiln.

The method of biochar production using the Kon-Tiki kiln is described below. The production process for both kilns and for each raw material is relatively the same, although banana leaves in particular were dried in the sun (Figure 30) due to their high moisture content. To determine the yield of biochar from each feedstock, the production process was separated for each biomass, and raw material feedstock and the weight of each feedstock before (raw material) and after (dried Biochar) production was measured.

1. Weight each dried biomass with the digital scale.
2. Pile the biomass in the bottom of the kiln and light the fire.
3. When the biomass begins to turn to ash (surface turns white), add another layer of biomass.
4. Repeat this process until the kiln is full or the biomass is used up.
5. When the surface of the last layer is almost completely white, quench the process with water.
6. Remove the solid residue remaining in the kiln (biochar) and dry it in the sun, then the dried biochar is weighed.

Figure 29.Picture of lantana growing around the factory.

Figure 30. Banana leaves dried under the sun.

Figure 31. Production process of biochar

5.4.2 Composting - Waste Treatment from the Fiber Factory

Although some biowaste treatment systems exist such as fermentation, composting was chosen as the method of the factory waste treatment for the following reasons.

- All the waste from the factory and its surroundings are green waste which is compostable.
- Farmers around the factory are suffering from fertilizer shortages.
- Some papers show that the positive effect of biochar co-composting application in Nepali soil (BH Pandit et al. 2020; Schmidt et al. 2017).
- Although it requires knowledge such as turning timing and temperature control, composting is inexpensive to start and requires no maintenance.
- Therefore, by sharing knowledge with local workers, they can start composting on their own and help to alleviate local fertilizer shortages.

5.4.2.1 Waste Generation in the Process of Making Banana Paper.

In the banana paper production process explained in chapter 5.3.2, the waste is coming from 3 different steps.

Figure 32. Waste from banana production processes – banana leaves (left), unusable part and heart of Trunk (middle), and slurry (right).

Process 1. Banana Leaves - Banana Trunk Collection process

When banana trees are cut down, the trunk is collected by the factory. However, the banana leaves are not collected and therefore become agricultural waste.

Process 2. Unusable Part of Trunk and Heart of Trunk – Trunk Separation process

In the banana trunk separation process, only the leaf sheaths suitable for banana fibre extraction are chosen, thus the remaining sheaths become factory waste. In addition to this, heart of the trunk is not appropriate for fibre extraction and therefore also becomes waste.

Process 3. Slurry – Fiber Extraction process

When the fibres are extracted by the fibre extraction machine, non-fibre part of the trunk are collected under the machine. As the leaf sheaths of bananas have a very high moisture content, the waste collected under the machine, so-called Slurry, also has a high moisture content.

5.4.2.2 Waste Characteristics

Bacteria, fungi, and actinomycetes, among other microorganisms, are primarily responsible for the decomposition of organic matter in composting. These microorganisms utilize carbon compounds for both energy generation and their growth, while nitrogen is crucial for both protein synthesis and cellular reproduction (Robert Rynk et al. 2021) . Therefore, the carbon to nitrogen ratio (C:N ratio) is therefore one of the most important parameters in compost production. The C:N ratio of compost is recommended to be in the range of 25-40, or at least the range of 20-60 is considered appropriate, as these microorganisms need to consume about 25 times more C than N through respiration and loss of carbon as $CO2$ (Robert Rynk et al. 2021). In order to prepare a successful composting, it is necessary to know the carbon and nitrogen content of each waste.

The carbon and nitrogen content of each waste and each waste proportion from a single banana tree, based on the NIDISI investigation (Jeremy Berdy 2022) and reference (Lekasi et al. 1999), are shown in Table 2. Carbon and Nitrogen content and proportion of each waste. The proportional ratios are values obtained immediately after the banana tree has been cut and are not dry weights. These values are only a guide for the preparation of recipes, as the weight of each banana tree can vary considerably, especially the weight of the unusable part and the leave, depending on the condition of the banana tree.

Table 2. Carbon and Nitrogen content and proportion of each waste

Waste Material	Banana Top (Leaves)[a]	Slurrys[a]	Unusable part Trunk[b]
carbon [%]	10.5	3	54
nitrogen [%]	0.5	0.2	1.01
Proportion from one banana tree [wt.%]	0.54	0.18	0.28

*Source : *a) value come from Jeremy Berdy (2022),*
**b) value come from Lekasi et al. (1999)*

5.4.2.3 Compost Production and Process

5.4.2.3.1 Compost Recipe and its Characteristics.

The recipes for the compost produced at the factory were made mainly based on the amount of each waste coming from the factory and the C:N ratio of less than 40, which is within the range of desired C:N ratio proposed by the Composting Handbook (Robert Rynk et al. 2021). The C:N ratio calculation presented below was based on Blakey (2024) provided by the University of California – Agriculture and Natural Resources. The carbon content of biochar is not available-C for microorganism utilization and therefore does not need to be taken into account when calculating the C:N ratio (Robert Rynk et al. 2021).

$$40\ wt.\%\ Banana\ Top * 10.5\%\ C + 25\ wt.\%\ Slurry * 3.0\%\ C + 35\ wt.\%\ Unusable * 54.0\%\ C = 23.85\ wt.\%\ C \quad (1)$$

$$40\ wt.\%\ Banana\ Top * 0.5\%\ N + 25\ wt.\%\ Slurry * 0.2\%\ N + 35\ wt.\%\ Unusable * 1.01\%\ N = 0.604\ wt.\%\ N \quad (2)$$

$$23.85\ wt.\%\ C / 0.604\ wt.\%\ N = 39.5\ parts\ C\ to\ 1\ part\ N \quad (3)$$

Table 3. Recipe of basic compost

Compost recipe	value
Banana Top [wt.%]	40
Slurry [wt.%]	25
Unusable [wt.%]	35
C/N ratio of Mixture	39.5

Biochar added to the basic composting recipe shown in Table 3 was bamboo biochar made with soil Kon-Tiki kiln. In general, the addition of 2-10% (by volume) of biochar to compost provides the benefits of biochar improvement in terms of reduced ammonia and greenhouse gas emissions and improved compost quality (Marta Camps and Thayer Tomlinson 2015; Robert Rynk et al. 2021). Therefore, 5 vol.% and 10 vol.% biochar added compost as well as no biochar added compost were made at the factory. In this paper, the compost without biochar (0% biochar addition) is designated A0, the compost with 5 vol.% biochar is designated A5 and the compost with 10 vol.% biochar was designated A10.

Before starting the composting process, moisture content, free air space (FAS) and bulk density were measured according to the methods described in the Compost Handbook (Robert Rynk et al. 2021). These three indicators are essential for understanding saturation and aeration within the compost which affect the composting decomposition as water and oxygen are vital for microbial activity (Robert Rynk et al. 2021). However, due to lack of equipment at the factory, the measurement of moisture content can only be carried out by the Hand-Squeeze Test (Appendix 8.1.1), which is the easiest but unprecise method. As FAS and bulk density are highly dependent on moisture content of composting pile, the results of these measurements are recorded as a reference to start composting. The bulk density and FAS measurements, measurements results, and their recommended value are shown in the Appendix 8.1.2.

5.4.2.3.2 Composting Process

In making the compost pile, the banana top (leave) and unusable part of the Trunk were too large to compost, so they were reduced in size using a cutter before being mixed into the compost pile.

The size of the compost pile was changed during the process for reasons described in Chapter 5.5.2 and therefore not be described here, but each waste was first weighed using the digital scale and then mixed to create the pile.

The composting area is located next to the factory (Figure 20) and is 14.4m long and 9m wide, with an area of 129.6m^2.

A total of six were made - four A0 (A0-1, A0-2, A0-3 and A0-4), one A5 and one A10 piles -. All piles were made as passively aerated piles, which are simply free-standing piles. In passively aerated piles, the oxygen supply required by the micro-organisms in the compost is mainly provided by the exchange of air in and out of the compost by thermal convection (Figure 33). Turning was performed according to the temperature-based turning principle proposed by the Composting Handbook (Robert Rynk et al. 2021) shown in Appendix 8.2. Temperature plays a dual role in the composting process, serving as both a cause and an effect. As a cause, it impacts the speed of biochemical reactions and the behaviour of organisms involved. As an effect, biological activity generates heat, consequently altering the temperature. This interrelationship establishes temperature as a reliable measure of composting progress. However, it's important not to rely on temperature alone in the composting process, as low or falling temperatures can be caused by factors such as too small a pile size, too little or too much moisture, extremely cold ambient temperatures or the near completion of the composting process, which the turning process cannot correct. Turning the compost mixes the materials, facilitating movement between hotter and cooler areas, thereby preventing stagnation commonly associated with static composting systems due to material inhomogeneity and uneven passive aeration (Robert Rynk et al. 2021).

To measure surface and core temperatures of the compost for temperature-based process monitoring, temperatures were measured at depths of approximately 25 cm and 50 cm (core of the pile) using a 50 cm long stem thermometer shown in Figure 34.

Composting takes place mainly within two temperature ranges: mesophilic phase, between 20-45℃, and thermophilic phase, between 45-75℃. The range below 20℃ is called psychrophilic. It's important to note that different types of microorganisms thrive in different temperature environments (Robert Rynk et al. 2021).

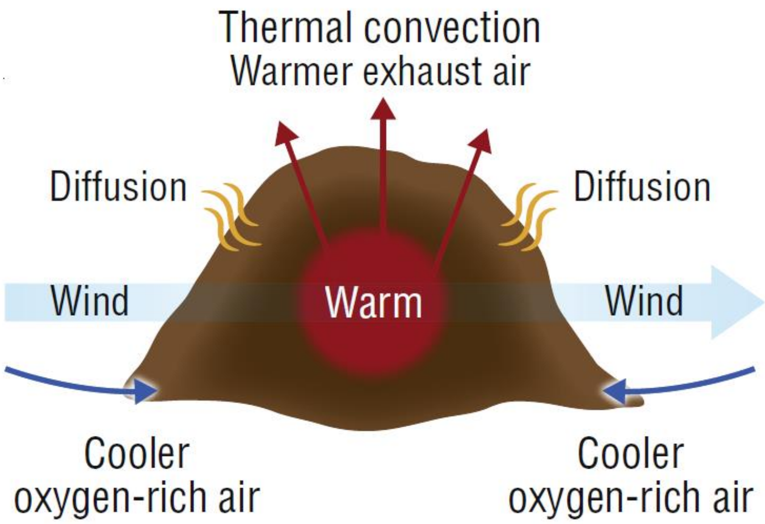

Figure 33. Principle of passive aeration

Source. Adapted from The Composting Handbook - Robert Rynk et al. (2021)

Figure 34. Thermometer (left) and temperature measurement (right)

5.4.3 Process Water Treatment for the Fiber Factory.

The process water treatment system built at the fibre factory was inspired from the 300L (Aqueous Solutions 2022b) and 2000L (Aqueous Solutions 2022a) multi-barrier water treatment system developed by the Aqueous Solutions.

5.4.3.1 Water Usage at the Factory

Water is used in three main processes described in chapter 5.3.2., and assuming that 15 kg of banana fibre will be extracted per day, as per our fourth year target (chapter 5.2.1) and make banana paper from all of it, the respective water need is as follow.

Process 4. Cooking and Rinsing Fiber

Our team's study assumed that approximately 16.7 litres of water is required for 1 kg of banana fibre in cooking process and 17 litres of water in Rinsing Process. A fibre mass loss of approximately 30% after Process 4 and 10% mass loss after Process 5, Refining by the Hollander Beater, are assumed. Thus, approximately 25 kg of fibre is used in these two processes, with the respective water consumption as follows.

- Cooking Process: 417.5 L/day
- Rinsing Process: 425 L/day

Process 5. Refining by the Hollander Beater

The volume of water required to use the Holland Beater at one time is 320 litres, which can feed approximately 8 kg of fibre (dried fibre measured before cooking process) at one time. The Holland Beater is therefore considered to be use 2 times a day, which means that approximately 640 L per day of water is used in this process.

The total water consumption for these two processes per day is 1482.5 L. In addition, taking into account the rinsing of the respective machines at the end of the day, approximately 2000 L/day of water is required.

5.4.3.2 Process Water Treatment System Set-Up

Figure 35. Process water treatment system

Figure 35 shows the overall view of the process water purification system for production process of banana paper designed by the author and established by us at the factory. The treatment system consists of a gravel filter, a slow sand filter and a biochar filter. All of these materials are available in the neighbourhood or can be produced by ourselves. However, it is difficult to buy already separate sized sand and gravel around the factory. Therefore, the screening filters were created by us, and the sizes were sorted (Figure 36) in order to divide them into the appropriate size for each filter layer shown below.

- Large Stone layer : > 50 mm
- Coarse Gravel layer: 20 mm ~ 50 mm
- Pea Gravel layer : 8 mm ~ 20 mm
- Coarse Sand layer : 2.5 mm ~ 8 mm
- Slow Sand layer : < 2.5mm

Figure 36. Stone, gravel and sand sorting process

A description of each tank is given below. Note that the height and width of the tanks in the diagram were measured by us and are approximate.

1. Groundwater Storage Tank – 1000L Tank
   Groundwater pumped up from underground is first stored in this tank and flows by gravity to the next tank. The pump on/off is controlled by a float switch, which is set to automatically start the pump when the water level falls below a certain level.

2. Gravel Filter – 750L Tank
   The groundwater stored in the storage tank flows into the first treatment system, the gravel filter, from the bottom side of the tank. As shown in Figure 37, it consists of Large Stone layer, Coarse Gravel layer and Pea Gravel layer. The function of the tank is to allow solid matters in the groundwater to settle at the bottom. Occasionally (once every 2~3 months), a 2-inch pipe at the bottom is opened to flush out the solid matters that have deposited at the bottom of the filter. A floating valve is installed at the inlet to prevent the tank from overflowing.

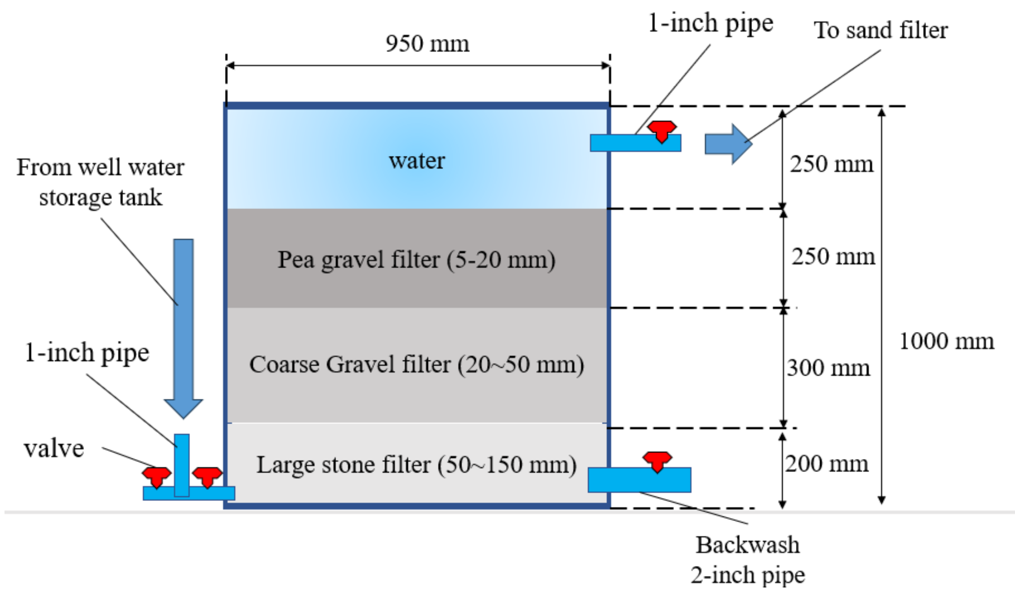

Figure 37. Design diagram of gravel filter tank

3. <u>Slow Sand Filter – 750L Tank</u>

After solid matters have been removed by the gravel filter, water flows into the slow sand filter tank from the top of the tank and flows downwards in contact with fine sand (Figure 38). Physical abrasion removes smaller particles that could not be removed by the gravel filter, while some pathogen cells adhere to the sand grains by adsorption. Gradually, a natural biofilm of beneficial micro-organisms develops within the top 1-2 cm of the sand. This biofilm functions to intercept, compete with and prey upon microbial pathogens, as well as removing biodegradable dissolved organic matter and certain synthetic chemical water contaminants (Aqueous Solutions 2022a). Over time, the biofilm and fine particles that form and settle on the surface of the sand filter will reduce the water flow rate in the tank. If left untreated, the treatment system will not be able to provide the daily volume of water required by the factory, so the surface of the sand filter is occasionally (every 3 months) agitated with a stick to suspend the biofilm and particles from the surface, and the valve at the top of the sand filter is opened for cleaning.

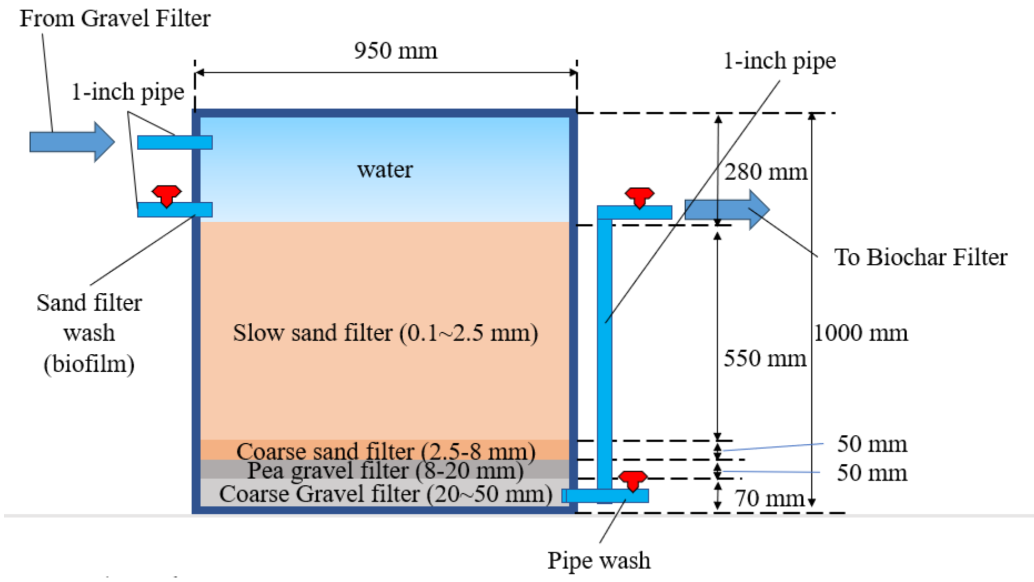

Figure 38. Design diagram of sand filter

4. <u>Biochar Filter – 750L Tank</u>
   In the biochar filter tank, the water after being treated in sand filter enters from the top of the tank and flow downwards through the biochar bed. Fine micropores within the biochar attract dissolved chemical contaminants, resulting in their adsorption to the biochar surface. In addition, a limited biofilm of beneficial microorganisms is present within the biochar. Through the mechanisms of adsorption and biodegradation, synthetic chemical water contaminants are effectively removed by the biochar filter layer (Aqueous Solutions 2022a).

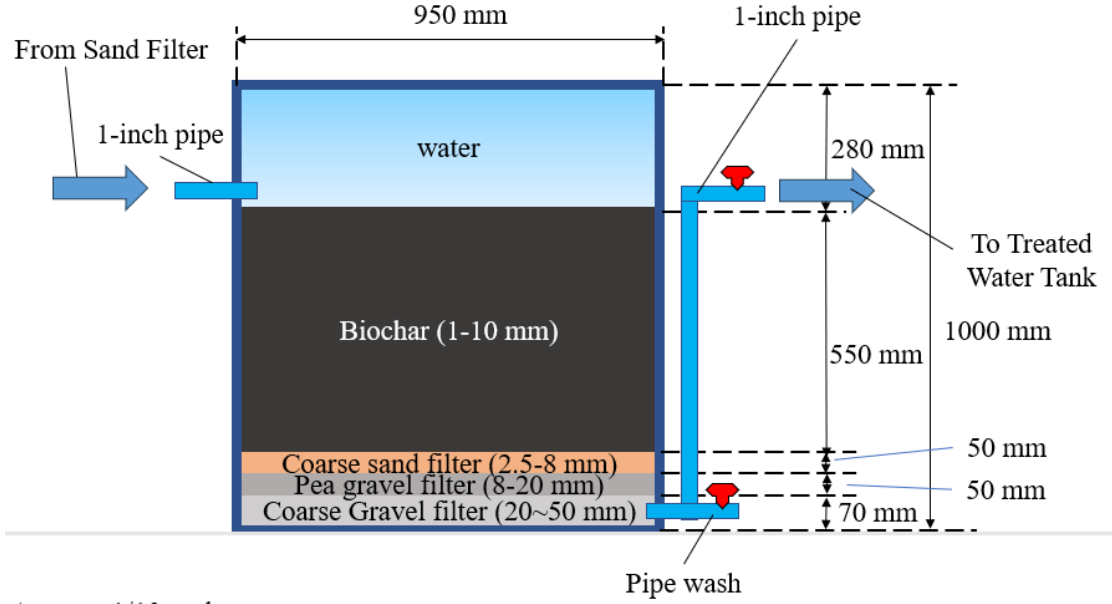

Figure 39. Design diagram of biochar filter

5. <u>Fresh water storage tank 5 - 500L Tank and 6 - 2000L Tank</u>

After all three treatments (gravel filter, sand filter, and biochar filter) have been completed, the treated water is first stored in the 500L fresh water tank which is on the ground. Treated water stored in a 500L tank is pumped up to a 2000L tank at a height of approximately 3m, then supplied to the factory production process and toilets, via gravity.

In both the 500L fresh tank and the 2000L, a floating switch is introduced, and they are interconnected to each other to ensure a smooth pumping system. If the floating switch is higher than a certain water level (+), i.e. tank is filled with water, and lower than a certain water level (-), i.e. there is no water in the tank, the operating conditions of the pumps are as follows:

i) 2000L tank (+) & 500L tank (+) : pump is off.
ii) 2000L tank (+) & 500L tank (-) : pump is off.
iii) 2000L tank (-) & 500L tank (+) : pump is on.
iv) 2000L tank (-) & 500L tank (-) : pump is off.

5.4.4 <u>Samples Analysis</u>

5.4.4.1 Sample Analysis in the External Laboratory

Water, Biochar, Compost and Farmer's Soil samples analysis were conducted in the external laboratory, Soil, Water and Air Testing Laboratory Pvt. Ltd. - SWAT Lab - located in Kathmandu. The methods of testing for each parameter are described as method on the right-hand side of the results-sheet table which can be found in Appendix 8.1 and is not detailed here.

5.4.4.1.1 Biochar

The Biochar samples which were sent to the SWAT lab were Banana Leaves Biochar, Lantana Biochar, and Bamboo Biochar made in 2024 by the Metal Kon-Tiki kiln. Samples were examined for pH, Organic Carbon (OC), Available Phosphorus, Available Potassium, Total Kjeldhal Nitrogen (TKN). TKN serves as a method for quantitatively analyzing the combined amounts of organic nitrogen, ammonia (NH3), and ammonium (NH4+) present in a compound during chemical analysis (VELP - Scientifica 2022).

5.4.4.1.2 Water Samples

Two water samples each were taken from well water (untreated water), water after sand filter, and water after biochar filter (treated water). The test parameters were conducted according to the National Drinking Water Quality Standard (NDWQD) in Nepal. These parameters and their limit values can be found in results.

5.4.4.1.3 Soil Sample

A total of six soil samples were collected from two farm plots at three different depths (<15 cm, 15~30 cm and 30~60 cm). The collections were taken according to the SWAT laboratory guidelines: the first sample was from banana farmland immediately adjacent to the fibre factory where bananas are still growing (Figure 40 left), and the second was from farmland where sugarcane had just been harvested (Figure 40 right). These two sites were chosen because they are the farmland where our composting will be applied, and according to the guidelines, the chosen land prefer not to be recently fertilized or prefer to be harvested already. Samples were examined for pH, Organic Matter (OM), Available Phosphorus, Available Potassium, soil type, TKN and Carbon to Nitrogen (C/N) ratio.

Figure 40. The soil sampling site –
banana farm (left) and sugarcane harvested site (right)

5.4.4.1.4 Compost sample analysis.

Composting samples A0-1, A0-2, A0-34, A5, A10 shown in 5.4.2.3.2 were analysed for the same parameters as in the soil sample analysis, except for soil type, in order to investigate composts from different recipes (with and without biochar) and different composting periods. The A0-3 and A0-4 compost samples were mixed before sending all the samples to the SWAT lab for analysis and are therefore represented as A0-34.

5.4.4.2 Compost Maturity Test

The application of immature compost has negative effects, such as reduced yield and inhibition of germination (Terman et al. 1973; Tiquia et al. 1996). To check the maturity of the compost produced at the fibre factory, a seed germination bioassay was performed to analyse phototoxicity. This study used the seed germination bioassay technique from Tiquia and Tam (1998), the protocol being detailed below. However, due to the resource limitation, the test was able to be conducted only once at the end of the composting phase.

Each compost was mixed with distilled water in a ratio of 1:10 and the mixture was stirred with a spoon every 20 minutes for 2 hours, then filtered. 15 mL from the filtered solution was smeared on gauze placed in a petri dish, on which five Rettich Daikon seeds were placed and kept in the dark for 96 hours. The control solution was distilled water.

After 96 h, to determine the Germination Index (GI) of all samples, the number of germinated seeds as well as the length of each root was measured and compared with the control (distilled water).

The GI was calculated as follows.

$$Relatice\ Seed\ Germination\ (RSG)$$
$$= \frac{Number\ of\ seed\ germinated\ in\ the\ compost\ extract\ sample}{Number\ of\ seed\ germinated\ in\ the\ control\ extract} * 100\ [\%] \tag{4}$$

$$Relative\ Root\ Growth\ (RRG)$$
$$= \frac{Mean\ root\ length\ in\ the\ compost\ extract\ sample}{Mean\ root\ length\ in\ the\ control\ extract} * 100\ [\%] \tag{5}$$

$$Germination\ Index\ (GI)$$
$$= \frac{RSG * RRG}{100}\ [\%] \tag{6}$$

5.5 Results and Discussion

5.5.1 <u>Biochar Production</u>

Biochar produced from banana leaves, lantana, and bamboo is shown in Figure 41. As can be seen in the figure, the biochar made from banana leaves has almost no shape left, while the lantana biochar has a little, and bamboo has almost retained its shape. As the flame curtain layer of the biomass is undergoing gasification (Cornelissen et al. 2016), the banana leaves quickly turn to ash as the leaves are thin. The banana leaves therefore had to provide an almost constant supply of feedstock, while the lantana, which is like a branching tree, also provided an almost constant supply of feedstock due to its thinness and rapid combustion. Bamboo, on the other hand, only needs a new layer of biomass every few minutes, depending on the size of the flame, and does not quickly turn to ash.

The yield of each biochar is shown in Table 4. The highest yields were obtained with bamboo, which is similar to the results obtained in another study using a Kon-Tiki kiln, shown in Table 1*,* and the lowest for banana leaves. This is probably due to the same reason as above, the high proportion of ash in banana leaf. The lack of structure may also be the reason for the low yield, as the biochar flows with the water during water quenching at the end of the production process. This is also expected from the fact that the water from the quenching was very transparent in the case of bamboo and black and non-transparent in the case of banana leaves, as well as lantana. Notably for yield calculation, there were losses, particularly in drying phase of biochar after production: drying is done by sun-drying, which takes approximately one week, during which losses can happen, when, for example, the wind-blows.

Figure 41. Produced biochar: banana leaves (left), lantana (middle), bamboo (right)

Table 4. Yield [wt.%] of each biochar.

Biomass of Biochar	Yield [wt.%]
Banana Leaves	14.5
Lantana	18.5
Bamboo	23.9

5.5.2 Compost Process and Temperature

Based on the size of the composting area and the recipe shown in Table 3, a $2m^3$ compost pile was initially planned, which was estimated to be 1194 kg. However, after the actual composting process started, it was found that it was difficult to turn a compost pile weighing over 1000 kg by hand with a shovel, so the first A0-1 was started with 298.5 kg, which is a quarter of the size of the originally planned compost pile.

The temperature of A0-1 (Figure 42) rose to 54.7℃, and the temperature above 50℃ lasted only 3 days. Although the mesophilic temperature range (20-45℃) can take composting degradation process effectively, the Composting Handbook (Robert Rynk et al. 2021) recommends a temperature of 55℃ or higher which is in thermophilic temperature range (45℃ - 75℃) for several days (e.g. three days) for sterilization of compost, and the U.S. EPA (2002) recommends for at least 15 days for windrow compost when making biosolid compost. According to The Composting Handbook, human and animal pathogens experience a reduction of over 99.999% after undergoing three days of composting above 55℃, and most plant pathogens should also be killed. Also, the thermophilic range speeds up the decomposition of material, meaning a faster composting process.

Based on Table 11.1 Process Monitoring Guide in the Composting Handbook, two reasons were suggested as to why the temperature of the A0-1 compost pile did not rise above 55°C and the thermophilic range did not last long: first, the small size of the compost makes it susceptible to outside air temperature. The second is that the moisture content of the compost pile is too high. Islam et al. (2021) reported that composts made from a mixture of banana pseudo stem, mushroom media waste, and chicken manure failed to reach the thermophilic phase due to high proportion of banana pseudo stem with high moisture content in composts. Therefore, in subsequent piles, the slurry which contains a very high moisture content was pressed and mixed after removing as much liquid as possible. Also, the size of the piles was increased to 597 kg, which is half the size originally planned, 1197 kg.

As a result, in all piles, temperatures at least 50 cm deep reached up to around 60°C, with temperatures above 55°C lasting for more than three days. However, in this study, in order to see the difference between piles with and without biochar, the piles were not mixed together to increase the size of the pile, even though degradation progresses, and the piles become smaller and more susceptible to outside temperatures. This may explain why the temperature did not increase much after the first thermophilic phase, as the temperature inside the piles was more easily influenced by the outside temperature. This can be seen from the fact that mixing A0-3 and A0-4 at approximately 80 days raised the temperature from around 20°C to approximately 30°C. The temperature of A0-34 (A0-3 and A0-4 mixed pile) was then measured later again, but did not rise above 30 °C, so the temperature measurement was stopped for all piles and the samples were sent to the lab.

Considering the effect of the biochar addition to the compost pile for composting procedure, Jindo et al. (2012) observed increased temperature for biochar amended composting pile and slightly-longer period of thermophilic phase. Pile A10 experienced the highest temperatures of all the piles, but no long-term of high temperature were observed in this study. In the case of the A10 pile, a temperature difference of more than 10 °C was observed between a depth of 50 cm and 25 cm. This is thought to be due to the effect of the added bamboo biochar. The bamboo biochar in the compost pile was crushed by hand and there were small and large pieces of biochar. The added biochar, especially the large pieces, creates an air pocket that makes the surface of the pile more sensitive to the outside temperature. Therefore, to reduce this effect, the biochar should be shredded into smaller pieces.

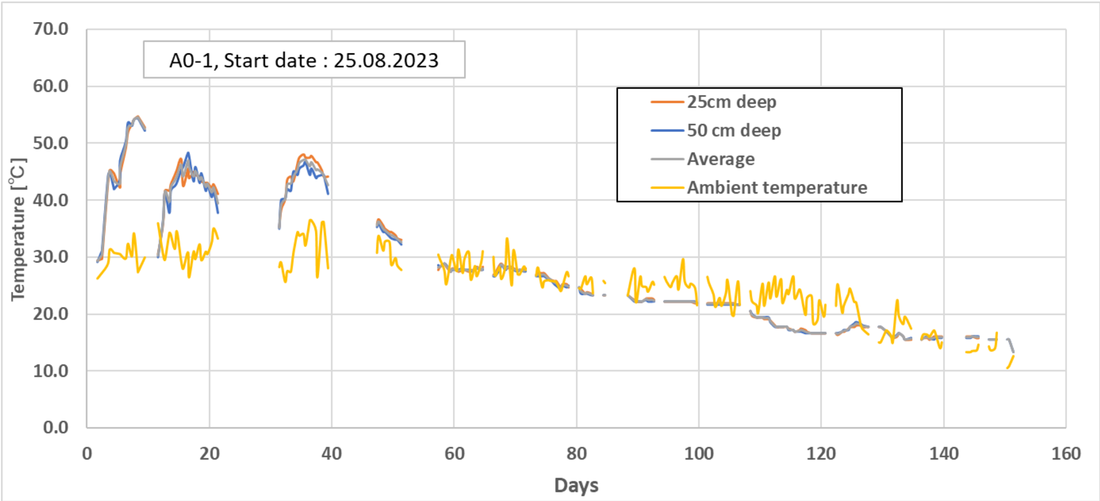

Figure 42. Temperature change of compost - pile A0-1

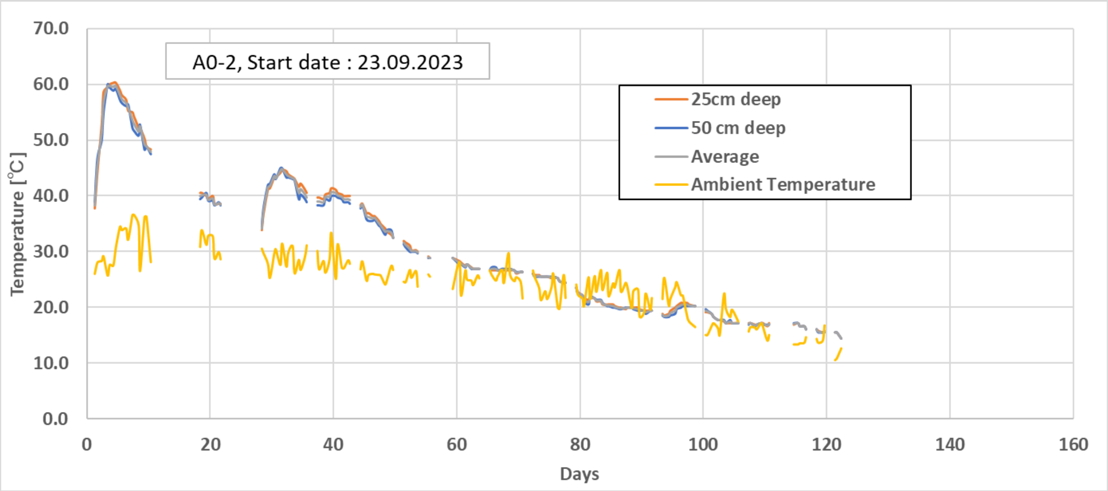

Figure 43. Temperature change of compost - pile A0-2

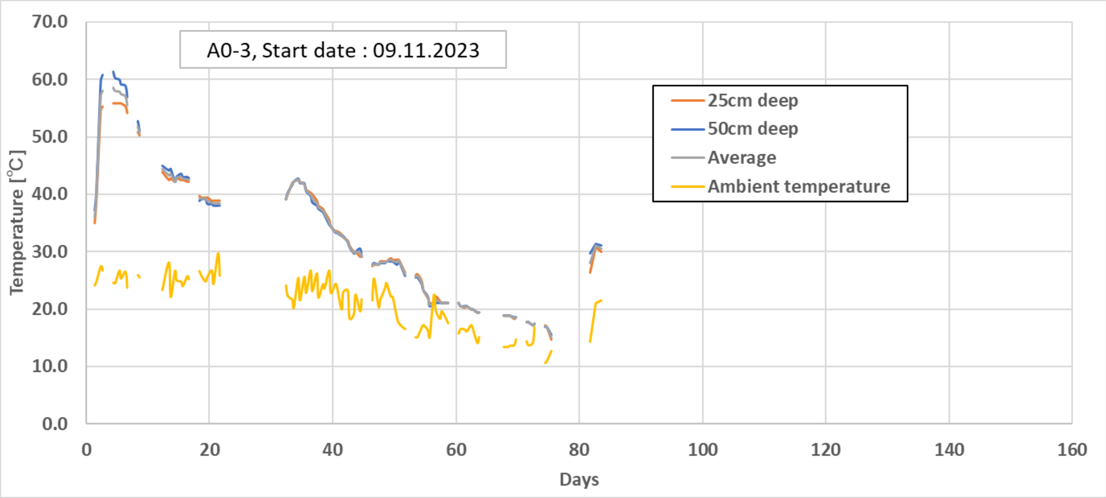

Figure 44. Temperature change of compost - pile A0-3

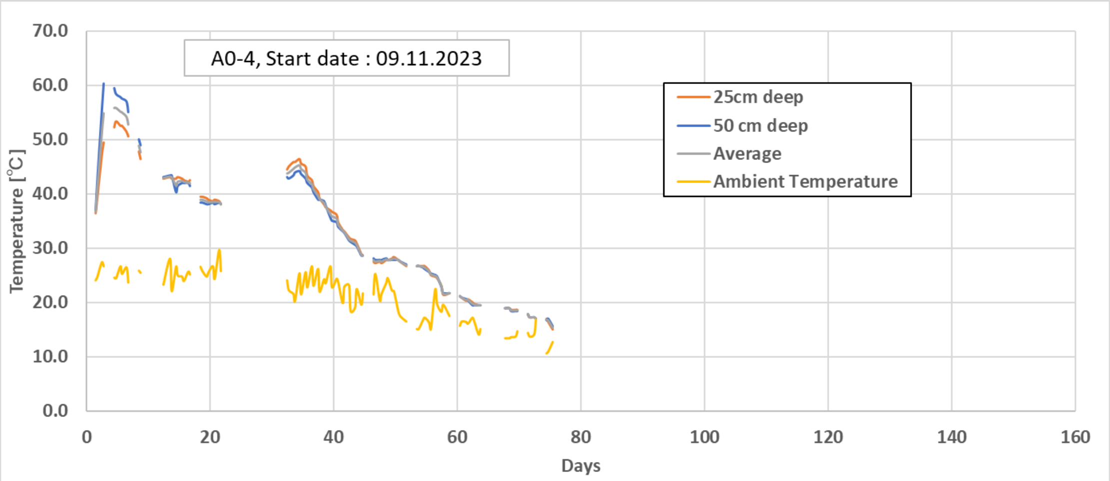

Figure 45. Temperature change of compost - pile A0-4

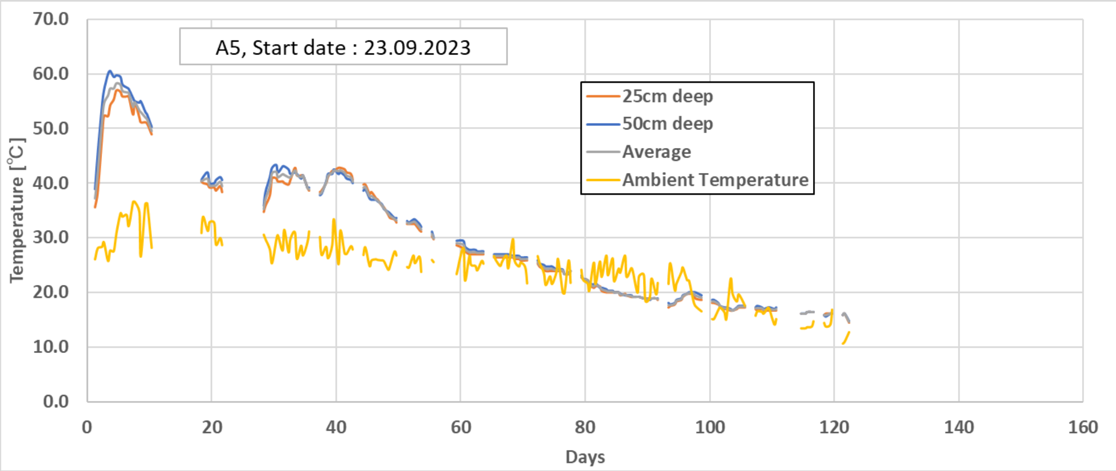

Figure 46. Temperature change of compost - pile A5

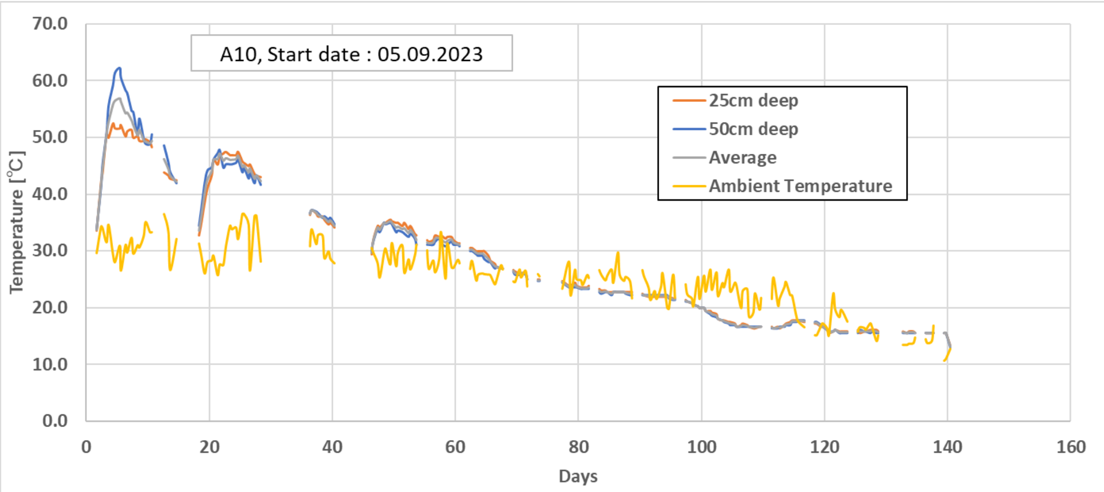

Figure 47. Temperature change of compost - pile A10

5.5.3 Compost Maturity Test Result

The samples used in the experiments were collected on 22 January 2024. The Table 5 shows the number of days since each pile was made at that time. A0-3 and A0-4 are the youngest piles, and these two piles were mixed on 22 January to increase the size of the pile and to see its temperature change, and then sampled, hence the name of one sample shown below is A0-34.

Table 5. Number of days elapsed since piles were made as of 22 January 2024.

Pile	Date started	Number of days elapsed as at 22.01.2024
A0-1	25.8.2023	151
A0-2	23.9.2023	122
A0-3	9.11.2023	75
A0-4	9.11.2023	75
A5	23.09.2023	122
A10	05.09.2023	140

Figure 48 shows the maturity test after 96 hours and Table 6 shows the results of this experiment. Germination Index (GI) values below 50% denote a medium phytotoxicity, while those falling between 50% and 80% signify mild phytotoxicity. GI values surpassing 80% indicate the absence of phytotoxicity (Paradelo et al. 2008).

The results show that the absence of phytotoxicity except for the A0-34 sample. Those results are indicating that the compost is mature (except for A0-34 sample). As can be seen from the Table 6, deviations in GI within the controls were observed because one of the seeds did not germinate in one control. The GI was highest for A10, which was mixed with 10 vol.% biochar, followed by A5, which was mixed with 5 vol.% biochar. The results show that the addition of biochar has a positive effect on GI.

A0-34 showed the lowest phytotoxicity with a value of 76, which was as expected since the pile was enlarged by mixing A0-3 and A0-4 piles on 22 January and the temperature of the pile were still increasing.

Pile A0-1 has the relatively low GI index despite having the longest composting days. This may be due to the fact that the A0-1 pile did not experience temperatures above 55°C for several days for compost sensitization, indicating the importance of several days of exposure to temperatures above 55°C.

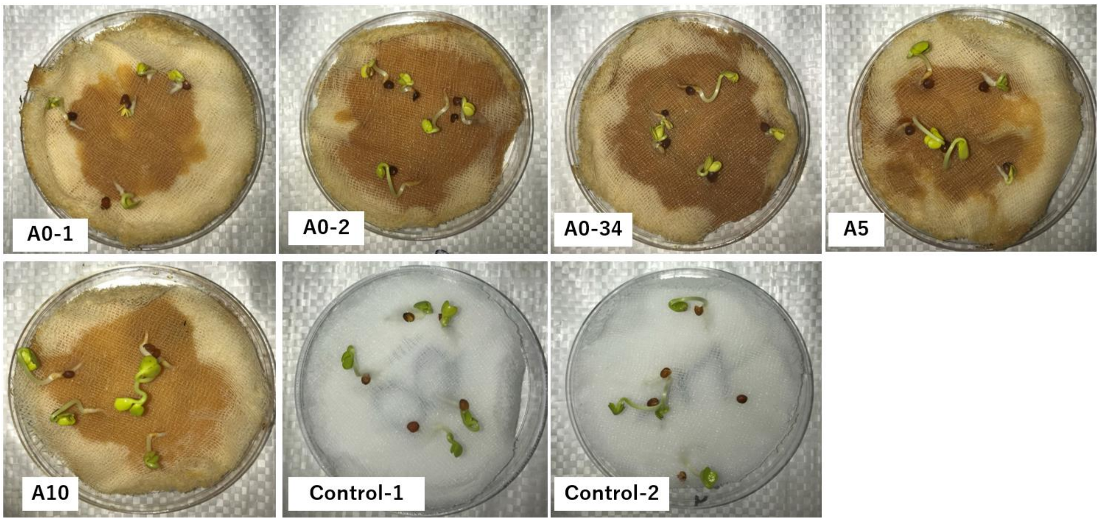

Figure 48. Compost maturity test

Table 6. Germination index result

	Mean radical length [cm]		Number of germinated seed		Glowth Indiex
Pile	**96h**	**RRG**	**96h**	**RSG**	**GI**
A0-1	2.04	107	5	111	119
A0-2	2.14	113	5	111	125
A0-34	1.3	68	5	111	76
A5	2.3	121	5	111	135
A10	2.9	153	5	111	170
6	1.9	100	5	111	111
Control (distilled water)	1.9	100	4	89	89
Control (distilled water)	1.9	100	5	111	111

5.5.4 <u>Analysis Result from SWAT Lab</u>

This section presents a summary of analysis results conducted by the SWAT lab in Kathmandu. The original results are all attached in Appendix 8.1, where the experimental methods are also described.

5.5.4.1 Biochar Analysis

Table 7 shows the results of analysis of banana leaves, lantana and bamboo biochar.

All three types of biochar (from banana leaves, lantana, and bamboo) have pH levels above 7, indicating alkalinity as it was expected. However, these are slightly higher than the results for biochar produced by Cornelissen et al. (2016) using the Kon-Tiki kiln with Eupatorium and mix of Eupatorium and wood, which are 9.8 and 8.6 respectively.

The organic carbon (OC) content varies significantly among the biochar samples, with lantana biochar having the highest organic carbon content at 22%, followed by banana leaf biochar at 13.61%, and bamboo biochar at 5.56%. These OC results show a very low OC content of biochar, especially in the case of bamboo, compared to the results of Rabbani et al. (2020) who produced biochar from animal bones, maize stover, wood chips, coconut palm and nutshells, the OC contents of which were 18.0%, 46.2%, 51.3%, 28.0% and 15.31% respectively. The method used in the SWAT laboratory to measure OC is loss of weight on ignition (Motsara and Roy 2008), which measures OM content by first heating the sample to 105°C to remove moisture, then heating the sample to 400°C in an oven for 4 hours and measuring the difference in weight before and after the oven process. The OC value is calculated by assuming that the soil organic matter contains 58% organic carbon. The OC results therefore also indicate the low OM content of biochar, suggesting that this biochar contain a lot of inorganic content. The fact that the EBC (2022) states that biochar normally contains 35% to 95% organic carbon also suggests that the present results are very low in organic carbon and that further analysis should be carried out to investigate the accuracy of the results. On 9th April 2024, the re-analysis of the biochar OC content with same method was carried out at the SWAT lab. The result of re-analysis showed that the 16.66%, 31.96%, and 16.19% of OC content for banana leaves, lantana, and bamboo, respectively. Although, the OC content of bamboo still shows the lowest value, the value was three times higher than the last analysis. It is likely that there was a calculation error in the previous analysis carried out.

The levels of available nutrients vary among the different biochar samples, with bamboo biochar showing the highest available potassium content which his 3546 mg/kg, while lantana biochar having the highest content of total Kjeldahl nitrogen at 0.71%. Compared to the nitrogen content of lantana biochar which shows average 8.8 g/kg (0.88%) obtained by Abishk Saxena et al. (2021), this study shows a slightly lower value. Firstly, the other studies (Abishk Saxena et al. 2021) analysed total nitrogen (TN), which include TKN, nitrate, and nitrite content (VELP - Scientifica 2022), may have influenced the slightly higher values in their study. Secondly, The study compares different pyrolysis temperatures between 300℃ and 550℃, and the higher the temperature, the results show the lower the TN (Abishk Saxena et al. 2021). the Metal Kon-Tiki kiln has a temperature of approximately 680-750℃ (Hans-Peter Schmidt and Paul Taylor 2014), which is higher than the pyrolysis of Abishk Saxena et al. (2021), and therefore the nitrogen content became lower.

Table 7. Biochar analysis result.

Biochar	**Unit]**	**Banana leave**	**Lantana**	**Bamboo**
pH	-	10.4	10.2	10.1
Organic Carbon (OC)	wt.%	13.6	22.0	5.6
Available Phosphorus	mg/kg	365	371	256
Available Potassium	mg/kg	1110	1350	3546
Total Kjeldhal Nitrogen (TKN)	wt.%	0.48	0.71	0.52

5.5.4.2 Process Water Treatment System Analysis

The average of the two water samples results from each water samples, without treatment, after sand-filter and after biochar-filter (fully treated), are shown in Table 8. The limit values of the National Drinking Water Quality Standards (NDWQS) of Nepal (in Appendix) and the EU 2020/2184 DIRECTIVE (EU directive 2020) for drinking water quality are used for comparison.

Values in black bold indicate values greater than NDWQS, and the results shows that the groundwater in the vicinity of the factory was contaminated by turbidity, iron, manganese, E. coli and Total Coliform.

After passing through the sand filter, the water met the NDWQS and EU directive standards for all parameters. This means that it is safe to use for the banana paper production processes at the factory, and also that the factory workers can safely drink this water instead of the contaminated groundwater that local people usually drink. The calcium content of the water from after the sand-filter increase significantly comparing with the groundwater. This may be due to the increase in pH after slow sand filter treatment likely promotes the precipitation of calcium carbonate, which was observed on the surface of the biochar filter layer (Figure 49), resulting in the observed decrease in water hardness and the increase in calcium content due to the formation of solid calcium carbonate particles. After biochar filter tank, the calcium value decreased which became lower than that of the well water. Even though all the parameters meet the drinking water quality, some items, such as nitrate and ammonium, are higher than after sand filtering.

As a result, the contaminated groundwater was cleaned until drinkability by the sand filter and the influence of the biochar filter could not be significantly identified. Therefore, if the impact of biochar is to be confirmed, biochar filters should be installed before sand filters. This order was used in this study because the Aqueous Solution water treatment system (Aqueous Solutions 2022a) was used as a reference.

Table 8. Summary of water analysis result

Parameters	unit	NDWQS	EU directive	Well water	After sand filter	After Biochar filter
Color	TCU	5	-	4	0	0
Conductivity	µS/cm	1500	2500	650	615	540
pH	-	6.5-8.5	6.5-9.5	7.85	8.05	7.3
Taste and Odour	-	noobj	-	noobj	noobj	noobj
Turbidity	NTU	5	-	**24.92**	0.175	0.125
Ammonia	mg/L	1.5	0.5	0.22	0.05	0.2
Aluminium	mg/L	0.2	0.2	0.02	0.05	0.05
Arsenic	mg/L	0.05	0.01	0.007	0.006	0.005
Fluoride	mg/L	0.5-1.5	1.5	0.52	0.55	0.54
Nitrate	mg/L	50	50	1.99	2.13	2.34
Choride	mg/L	250	250	65.48	34.99	38.98
Calcium	mg/L	1000	-	32.78	129.86	12.02
Copper	mg/L	1	2	0.02	0.02	0.02
Iron	mg/L	0.3	0.2	**1.99**	0.08	0.08
R.Chlorine	mg/L	0.1-0.5	-	<0.04	<0.04	<0.04
Manganese	mg/L	0.2	0.05	**0.305**	0.015	0.02
Sulphate	mg/L	250	250	7.85	11.3	12.27
Total Hardness	mg/L as $CaCO_3$	500	-	466	404	462
Zinc	mg/L	3	-	0.23	0.25	0.05
E.Coli	CFU/100mL	0	0	**9**	0	0
Total Coloform	CFU/101mL	0	0	**15**	0	0

NDWQS : National Drinking Water Quality Standards (2079)

EU directive : DIRECTIVE (EU) 2020/2184 on the quality of water intended for human consumption

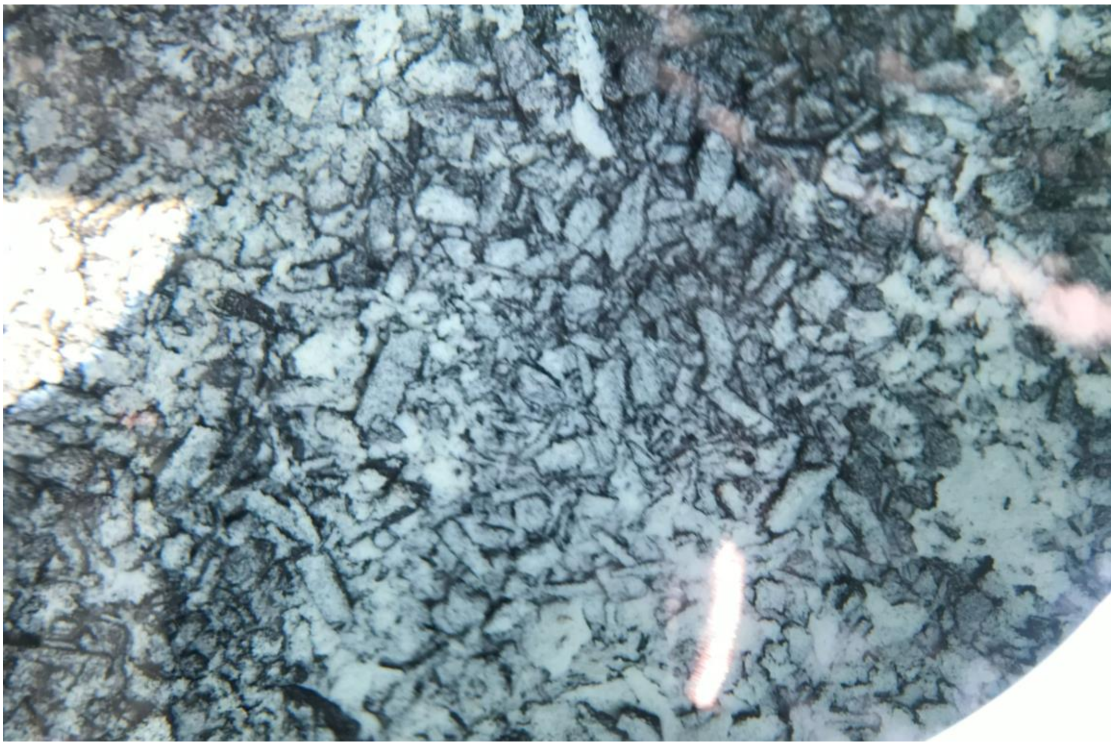

Figure 49. Surface of the biochar filter layer (possibly precipitated calcium)

5.5.4.3 Compost Analysis

Table 9 shows the results of the compost analysis.

The pH levels varied across samples, with A0-34 displaying the highest pH at 9.8, while A5 exhibited the lowest at 8.6. According to the analysis of Islam et al. (2021), banana pseudo stem show a pH of 10.41, indicating high alkalinity, which may be a factor in the high pH in all composts in this study. The results of this study are also in agreement with the pH of banana peel compost by Kalemelawa et al. (2012), pH 9.3 ~ pH 9.7. Their argument suggested that the high concentration levels of potassium found in banana waste react with bicarbonate acids generated during the mineralization of organic matter, resulting in the formation of potassium hydroxide (KOH), a strong base, which increase the pH value of compost. Although the finished compost pH exceeding 9 is slightly surpasses the suggested range of pH 6–8, it is common in the decomposition process of organic materials (Barreira et al. 2008).

Organic matter (OM) content ranged from 28.56% in A10 to 52.23% in A0-34. In comparison with A0-1, 2 and 34, the more aged composts are more degraded and have lower OM. This trend is also observed in the C/N ratio, with the decrease in the C:N ratio being mainly due to the decomposition of organic matter (Kalemelawa et al. 2012; Islam et al. 2021). Jindo et al. (2012) also report that the OM degradation of composting pile was reflected by the low C:N value. The addition of biochar resulted in lower OM compared to A0 compost of the same or nearly the same date (A5 and A0-2, A10 and A0-1). Malińska et al. (2014) reported slightly higher OM degradation rates in composts mixed with biochar than in those not mixed. This is not only because the addition of biochar facilitates decomposition by providing more air pathways, but also because the biochar provide and enhances microbial activity (Jindo et al. 2012).

While available potassium is lower in composts with biochar than in composts of more or less the same age, available phosphorus shows mixed trends, with A5 showing the highest value of 311.58 mg/kg, but A10 showing the lowest value of 197.17 mg/kg. This trend for phosphorus regarding biochar addition to compost is also observed for total nitrogen. In the study carried out by Muhammad Irshad et al. (2011) on compost production utilizing animal manure, it was observed that the peak concentration of phosphorus occurred in the extract during the initial stages of composting, while the lowest potassium concentration was detected in the later stages of composting. This feature can be seen in the A0 piles produced in this study, but not in the piles with biochar. In particular, the A5 pile had a higher phosphorus concentration despite a longer composting time than the A0-34 pile, the same as the A0-2 pile. Compared to A10, which also had biochar added, the potassium concentration of A5 pile was also higher despite a shorter composting period. A possible hypothesis from these results is that the biochar added to the compost may not have been evenly distributed within the piles, as the biochar was hand-crushed, resulting in small and large sizes of biochar. Therefore, the results may vary greatly depending on which part of the compost was taken for chemical analysis and how much biochar was present in the sample analysed. As this study could only analyse samples once due to budgetary constraints, further analysis is needed, and the results should be averaged.

In all the compost pile, the potassium is consistently higher than other nutrients. These results are consistent with those of Kalemelawa et al. (2012), who stated that the high potassium content in banana waste was a factor, suggesting that composts made from banana waste could be a good source of K fertiliser.

Table 9. Compost analysis result.

Compost	unit	A0-1	A0-2	A0-34	A5	A10
pH	-	9.1	9.4	9.8	8.6	9.5
Organic Matter (OM)	%	34.4	40.3	52.2	38.5	28.6
Available Phosphorus	mg/kg	272	275	286	312	197
Available Potassium	mg/kg	2726	2256	1738	1978	1690
Total Kjedhal Nitrogen (TKN)	%	0.82	0.79	0.84	0.86	0.74
C/N ratio	%	24.3	29.6	36.1	26.6	22.4

5.5.4.4 Soil Analysis

Table 10 and Table 11 show the results of soil analysis from two agricultural sites, the banana site and the sugarcane site.

Table 12 indicates the rating of soil chemical properties (pH, Organic Matter (OM), and Total Nitrogen) given by "Nepal, Soil Management Directorate, Ministry of Agricultural Development" shown in the paper by Panday et al. (2019), who studied soil properties in the Dang district belonging to Terai, Nepal. Table 13 provides an interpretation of the nutrient levels of phosphorus and potassium in the soil and their desired ranges (Donald S. Loch 2006; The Ohio State University 2022).

It can be seen that the pH above pH 8.0 in all cases indicating strong alkalinity, except for the sugarcane soil less than 15 cm deep, which also shows moderate alkalinity. Biochar amendment is particularly effective in degraded soils with low pH, so it is unlikely to have a significant effect of biochar application when biochar is applied to these tested soils. However, the high pH may be caused by agricultural field burning (Moraes et al. 1996), a traditional agricultural practice in surround area, which also contributes to air pollution in the area. Therefore, these traditions should be discontinued and soil improvement using biochar should be promoted.

OM in soils is recognised to affect soil fertility and productivity in a variety of ways (Johnston 1986; Megan Fenton et al. 2008). High levels of OM in agricultural soils have many benefits, such as improving water infiltration and soil aeration, increasing soil water holding capacity, increasing soil CEC, providing food for soil organisms, increasing soil microbial biodiversity and activity, which helps to suppress pests and diseases (Megan Fenton et al. 2008). All soil samples in this study contain less than 2.50% OM, indicating that the OM content of the sampled soils is low.

TKN content of each soil samples also show low level, except in the banana soils at depths less than 15 cm and 15-30 cm which show medium nitrogen level. For Available Phosphorous and Available Potassium, potassium level was less than the desired level and phosphorus level remained in the range of the desired level suggested by The Ohio State University (2022) in all samples except for the soil samples from 15 cm to 30 cm deep in banana farmland.

This soil analysis shows that nutrient levels such as OM, TKN and potassium are low. This finding suggests that these values could be improved by factory made compost, which has overall nutrient levels much higher than those of the soils, supporting the importance of factory-made compost being returned to the farmer.

Table 10. Banana farming soil analysis result

Banana Soil	unit	Banana <15cm	Banana 15~30cm	Banana 30~60cm	Average
pH	-	8.90	8.50	8.80	8.73
Organic Matter (OM)	%	1.82	2.10	1.46	1.79
Available Phosphorus	mg/kg	27.9	69.7	24.5	40.7
Available Potassium	mg/kg	85.2	180.0	88.2	117.8
Total Kjedhal Nitrogen (TKN)	%	0.15	0.11	0.08	0.11
C/N ratio	%	6.96	10.82	10.08	9.29

Table 11. Sugarcane farming soil analysis result

Sugarcane Soil	unit	Sugarcane <15cm	Sugarcane 15~30cm	Sugarcane 30~60cm	Average
pH	-	7.50	8.30	8.60	8.13
Organic Matter (OM)	%	1.67	1.34	1.70	1.57
Available Phosphorus	mg/kg	20.9	20.0	32.7	24.5
Available Potassium	mg/kg	98.4	87.6	96	94.00
Total Kjedhal Nitrogen (TKN)	%	0.10	0.07	0.08	0.08
C/N ratio	%	9.86	10.24	12.55	10.88

Table 12. Rating of soil chemical properties given by Nepal, Soil Management Directorate, Ministry of Agricultural Development

Soil Properties	Range	Class
pH	< 5.5	Strongly Acidic
	5.5 ~ 6.2	Moderately Acidic
	6.21 ~ 7.0	Neutral
	7.1 ~7.8	Moderately Alkaline
	> 7.8	Strongly Alkaline
OM [%]	< 1.00	Very low
	1.10 ~ 2.50	Low
	2.51 ~ 5.00	Medium
	5.01 ~ 10.00	High
	> 10.00	Very High
Total Kjeldahl Nitrogen (TKN) [%]	< 0.05	Very low
	0.05 ~ 0.10	Low
	0.11 ~ 0.20	Medium
	0.21 ~ 0.40	High
	> 0.40	Very High

Source : Adapted from the article written by Panday et al. (2019)

Table 13. Phosphorus and potassium soil nutrient level

Element	Nutrient Level[a]		Desirable Ranges[b]
P [mg/kg]	< 10	Very low	20 ~ 50
	11 ~ 20	Low	
	21 ~ 30	Medium	
	31 ~ 40	High	
	> 40	Very High	
K [mg/kg]	< 40	Very low	100 ~ 170
	40 ~ 80	Low	
	80 ~ 200	Medium	
	200 ~ 400	High	
	> 400	Very High	

*Source : * a : value adapted from Donald S. Loch (2006) and * b : value adapted from The Ohio State University (2022)*

6 Conclusion

This study has been carried out within the Woman Empowerment Project at NIDISI gGmbH to find out whether the biochar application can be advantageous to waste and water treatment of the banana fibre extraction factory located in Tribeni-Susta, Nawalparasi district of Nepal.

The literature review of biochar found that Nepalese soils are effective of biochar application because they are acidic and tropical soils in nature, and that the use of small-scale biochar production in the vicinity of feedstock and application field is the most effective in terms of crop yield increase and economic feasibility in low-income countries. However, the small-scale biochar production has the potential to release high emissions and requires careful attention to the operation such as drying of the feedstock and the proper supply of feedstock in terms of Kon-Tiki kiln biochar production.

In a case study at the banana fibre extraction factory, biochar was produced using soil pit Kon-Tiki kiln from bamboo in 2023 and metal Kon-Tiki kiln from bamboo, banana leaves and Lantana in 2024. The biochar produced by the metal Kon-Tiki kiln were analysed and sent to the laboratory for chemical analysis. The bamboo biochar produced from soil-pit kiln was applied to a process water treatment system built at the factory for the banana paper production processes and was also applied to composting system to treat organic wastes from the factory. During the composting process, the temperature of all piles was measured, and the composts produced were self-analysed with a maturity test - seed germination bioassay, and also sent to the laboratory for chemical analysis. In addition, samples from the water treatment system and soil samples from the farmland where the produced compost will be applied were also sent to the laboratory for analysis.

As a result of water samples analysis, it was found that the groundwater around the factory were contaminated with iron, manganese, E.coli and total coliform. However, our low-cost water treatment system which contains gravel filter, sand filter, and biochar filter was able to purify groundwater and meet the drinking water quality in Nepal. Therefore, it is safe to use for the factory production process and safe for factory workers to drink. As the inhabitants of the surrounding area are usually drinking those contaminated groundwater, it is hoped that in the future this finding will be used as a way to give more local people access to clean and safe drinking water.

Regarding the biochar amendment to the compost, the biochar addition increases the highest temperature of composting process but did not keep high temperature longer which was reported in another study (Jindo et al. 2012). In a maturity test using extract from the different composts, the biochar addition shows the positive impact on Growth Index (GI) as the biochar added composts show the first and second highest GI among all the piles. Chemical analysis of compost also showed that the addition of biochar to the compost promoted the decomposition of organic waste.

Soil sample analysis revealed quite high pH in the soil, which could interfere with biochar added compost application. However, this is probably due to the traditional practice of agricultural field burning, which also has an impact on air pollution, so this tradition should be discontinued and soil amendment with biochar should be promoted.

Overall, the biochar usage for our case study is considered to be advantageous as it works as water treatment filter and has positive effect on compost mixing. Although only bamboo biochar made by soil pit Kon-Tiki kiln was used in the production of biochar-blended compost in this study, the use of banana leaves biochar should be mainstreamed in the future, as biochar production can contribute to agricultural waste reduction in this way, and bamboo and lantana has other potential uses such as for cooking while banana leaves are left in the field. As a next step, it would be interesting to investigate the impact, such as crop yield and soil characteristics, of the use of compost with and without biochar on the farmland around the plant over several years.

It is the goal and hope of the author that the compost recipe developed in this study will help to produce high quality compost and lead to an increase of compost production in the factory in Nepal, thereby reducing the amount of agricultural waste generated by the banana, the shortage of fertilisers that plague the surrounding farmers, and the use of chemical fertilisers and pesticides.

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8 Appendix

8.1 Composting Pile Method of Free Air Space (FAS), Bulk Density, and Moisture Content (Hand-squeeze test) Measurement

8.1.1 Hand-Squeeze Test for Moisture Content

Box 11.2 Procedures and interpretation for the hand-squeeze test for moisture content

1. Reach into the pile or composite sample bucket and grab a handful of composting material,
2. Squeeze the material hard with your hand, check for drips,
3. Release your grip and allow the material to stay in your hand, smear some between your finger and thumb,
4. Inspect the material and your hand, and,
5. Use the "Rule of Thumb" in Table 11.3 to estimate percent moisture content.

Table 11.3 Rules of Thumb for estimating moisture content by the hand-squeeze test.

Observation—description	Estimated moisture content
• Water flows freely out of your hand	Greater than 65%
• A few drops of water are visible between your fingers	60%–65%
• You don't see any water between your fingers. When you open your hand, a sheen of moisture is clearly visible.	55%–60%
• No sheen of water is visible and a ball of compost remains in your hand. If you tap the ball gently, it remains intact.	50%–55%
• A ball of compost forms but break apart during tapping.	45%–50%
• After squeezing, the compost does not remain in a ball when opening your hand	40%–50%
• No ball forms and a dry talcum-like feel remains on your hand after discarding the material.	Less than 40%

Figure 50. Moisture Content Measurement – Hand-Squeeze Test

Source: Oshins. C (2021) adapted from Robert Rynk et al. (2021)

8.1.2 FAS and Bulk Density Measurement

The FAS and bulk density measurements were conducted using the methods in the Composting Handbook (Robert Rynk et al. 2021). The procedures are shown below.

Tools

- A bucket bigger than 20L.
  - To find the position of the bucket corresponding to 20L, 20 kg of water was filled into the bucket and the position of the water surface was marked as 20L.
- Digital scale.
- Compost sample.

Procedures

1. Measure the weight of the bucket.
2. Take samples from several locations in the compost pile and mixed.
3. Fill approximately one-third of the bucket with mixed compost.
4. Raise the bucket to a level where the bottom is roughly 15 cm above the ground, then release it onto a hard, flat surface. Repeat this process, dropping it a total of 10 times.
5. Add compost sample up to two-thirds of the bucket.
6. Repeat the Step 3
7. Add compost sample up to the mark indicating 20 litres in the bucket.
8. Repeat the Step 3
9. Add more material to the bucket to the 20L line.
10. Measure the final weight (bucket + compost sample) and determine the bulk density using the following formula.

$$Bulk\ Density\ [kg/L] = \frac{Filled\ Bucket\ weight - Empty\ bucket\ weight}{Bucket\ volume\ (20L)} \quad (7)$$

$$Bulk\ Density\ [kg/m^3] = 1000 * Bulk\ Denisty\ [kg/L] \quad (8)$$

11. Add water to the bucket little by little so that the air bubbles penetrate the surface.
12. Continue until the water covers the surface of the compost in the bucket (20L line) and weigh the bucket again, then determine FAS using the following equations.

$$Weight\ of\ water\ added\ [kg] = weight\ of\ bucket\ after\ adding\ water - weight\ of\ bucket\ before\ adding\ water \quad (9)$$

$$Volume\ of\ gas - filled\ pore\ space\ [L] = weight\ of\ water\ (kg)/1kg/1L \quad (10)$$

$$FAS\ [\%] = 100 * \frac{Volume\ of\ gas - filled\ pore\ space\ [L]}{Volume\ of\ bucket\ content\ (20L)} \quad (11)$$

Table 14 shows the result of these measurements and shows the recommended value of bulk density and FAS from the Composting Handbook.

Figure 51. Bulk density and FAS measurements at the fibre factory.

Table 14. Result of bulk density and FAS measurement

bucket [kg]	0.86
waste + bucket [kg]	12.8
waste [kg]	11.94
bucket [L]	20
density [kg/L]	0.597
density [kg/m3]	597
bucket + waste + water [kg]	19.54
volume of gas - filled pore space [L]	6.74
FAS [%]	33.7

Table 15. Recommended value of bulk density and FAS

	Acceptable value	**Ideal range**
Bulk Density [kg/m^3]	< 700	400 - 600
FAS [%]	30 - 60	30 - 40

Source : The Composting Handbook - Robert Rynk et al. (2021)

8.2 Temperature Based Composting Pile Turning Operation

The turning processes based on the composting pile temperature proposed by the Composting Handbook are described below (Robert Rynk et al. 2021).

- The temperature trend displays a consistent decrease over a span of several days, for example, such as an average decline of 1℃ per day over 7 to 10 days.
- The mean temperature within the central area of the windrow gradually declines from an initial peak, typically around 65℃, until it falls below a predetermined threshold, such as 50℃.
- The temperatures recorded at various locations within the pile, at the same depth, exhibit significant variability.
- There's a notable difference between the average temperature at the core of the windrow and the average temperature 15 cm below the surface, with the core registering more than a 10℃ decrease in temperature.

8.3 SWAT Lab Analysis Result

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Bulbule Marga 10, Thapagaun, Kathmandu, Nepal

BIOCHAR ANALYSIS REPORT

Name of Client:	Haruto Nakao	**Lab Code:**	24/02-1304 (1)
Collector:	Manak Chaudhary	**Location:**	Tribeni Susta
Source:	Banana Biochar	**Sampled By:**	Client
Sampling Date:	2024/02/13	**Test Performance Date:**	2024/02/22-2024/03/01
Receipt Date:	2024/02/20	**Issued Date:**	2024/03/03

Parameters	Results	Unit	Method
pH	10.4	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Moisture Content	8.23	%	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B I-5,27-30
Organic Carbon	13.61	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus	364.75	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium	1110	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen	0.48	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition

NOTE

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3. Statements of conformity have been made without taking Measurement Uncertainty into account except when specifically requested by the customer.

Analyzed By
Aalekh Bhattrai

Checked By
Chemist Ansu Thapaliya

Authorized By
Er. Lokesh Sapkota

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BIOCHAR ANALYSIS REPORT

Name of Client:	Haruto Nakao	**Lab Code:**	24/02-1304 (2)
Collector:	Manak Chaudhary	**Location:**	Tribeni Susta
Source:	Lantana Twig Biochar	**Sampled By:**	Client
Sampling Date:	2024/02/13	**Test Performance Date:**	2024/02/22-2024/03/01
Receipt Date:	2024/02/20	**Issued Date:**	2024/03/03

Parameters	Results	Unit	Method
pH	10.2	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Moisture Content	9.94	%	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B I-5,27-30
Organic Carbon	22.00	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus	370.79	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium	1350	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen	0.71	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition

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BIOCHAR ANALYSIS REPORT

Name of Client:	Haruto Nakao	**Lab Code:**	24/02-1304 (3)
Collector:	Manak Chaudhary	**Location:**	Tribeni Susta
Source:	Bamboo Biochar	**Sampled By:**	Client
Sampling Date:	2024/02/13	**Test Performance Date:**	2024/02/22-2024/03/01
Receipt Date:	2024/02/20	**Issued Date:**	2024/03/03

Parameters	Results	Unit	Method
pH	10.1	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Moisture Content	34.74	%	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B I-5,27-30
Organic Carbon	5.56	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus	256.39	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium	3546	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen	0.52	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition

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WATER ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (1)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Well Water (without treatment)	**Sampled By:**	Client
Sampling Date:	2024/05/02 (12PM)	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters	Results	Unit	NDWQS	Method
Physical				
Color	2	TCU	5	2120 B. APHA 23rd edition
Conductivity	650	µS/cm	1500	2510 B. APHA 23rd edition
pH	7.9	-	6.5-8.5	4500 H+ B. APHA 23rd edition
Taste and Odour	noobj	-	noobj	-
Turbidity	**25.48**	NTU	5	2130 B. APHA 23rd edition
Chemical				
Ammonia	0.2	mg/L	1.5	4500 NH_3 F. APHA 23rd edition
Aluminium*	0.02	mg/L	0.2	3111 B., APHA, 23rd edition
Arsenic*	0.006	mg/L	0.05	Arsenic Test Kit Method
Fluoride*	0.49	mg/L	0.5 -1.5	3111 B., APHA, 23rd edition
Nitrate	1.96	mg/L	50	4500 NO_3^- B. APHA 23rd edition
Chloride	84.97	mg/L	250	4500-Cl- B. APHA 23rd edition
Calcium	28.86	mg/L	1000	3500-Ca D. APHA 23rd edition
Copper*	0.02	mg/L	1	3111 B., APHA, 23rd edition
Iron	**2.0**	mg/L	0.3 (3)	3500-Fe B. APHA 23rd edition
R. Chlorine	<0.04	mg/L	0.1-0.5	4500-Cl B., APHA 23rd edition
Manganese*	**0.31**	mg/L	0.2	3111 B., APHA, 23rd edition
Sulphate	7.47	mg/L	250	4500-SO_4 E., APHA 23rd edition
Total Hardness	434	mg/L as $CaCO_3$	500	2340 C. APHA 23rd edition
Zinc*	0.04	mg/L	3	3111 B., APHA, 23rd edition
Microbiology				
E. Coli	**9**	CFU/100ml	0	Eosin Methylene Blue Agar for Rapid Direct Count of E. coli, AJPH, 2011
Total Coliform Count	**15**	CFU/100ml	0	9222 B. Standard Total Coliform Membrane Filter Procedure using Endo Media

NDWQS=National Drinking Water Quality Standard (2079)
Noobj= not objectionable
Note:

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3. Statements of conformity have been made without taking Measurement Uncertainty into account except when specifically requested by the customer.
4. *These parameters are not within the scope of Nepal Standard.

Remarks: Except Turbidity, Iron, Manganese, E coli and Total Coliform all the observed values of other tested parameters are found to be within the limit of NDWQS 2079.

Analyzed By
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WATER ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (2)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Well Water (without treatment)	**Sampled By:**	Client
Sampling Date:	2024/05/02 (12PM)	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters	Results	Unit	NDWQS	Method
Physical				
Colour	2	TCU	5	2120 B. APHA 23rd edition
Conductivity	650	µS/cm	1500	2510 B. APHA 23rd edition
pH	7.8	-	6.5-8.5	4500 H+ B. APHA 23rd edition
Taste and Odour	noobj	-	noobj	-
Turbidity	**24.35**	NTU	5	2130 B. APHA 23rd edition
Chemical				
Ammonia	0.24	mg/L	1.5	4500 NH_3 F. APHA 23rd edition
Aluminium*	0.02	mg/L	0.2	3111 B., APHA, 23rd edition
Arsenic*	0.007	mg/L	0.05	Arsenic Test Kit Method
Fluoride*	0.54	mg/L	0.5 -1.5	3111 B., APHA, 23rd edition
Nitrate	2.01	mg/L	50	4500 NO_3^- B. APHA 23rd edition
Chloride	45.98	mg/L	250	4500-Cl- B. APHA 23rd edition
Calcium	36.07	mg/L	1000	3500-Ca D. APHA 23rd edition
Copper*	0.02	mg/L	1	3111 B., APHA, 23rd edition
Iron	**1.98**	mg/L	0.3 (3)	3500-Fe B. APHA 23rd edition
R. Chlorine	<0.04	mg/L	0.1-0.5	4500-Cl B., APHA 23rd edition
Manganese*	**0.30**	mg/L	0.2	3111 B., APHA, 23rd edition
Sulphate	8.23	mg/L	250	4500-SO_4 E., APHA 23rd edition
Total Hardness	498	mg/L as $CaCO_3$	500	2340 C. APHA 23rd edition
Zinc*	0.42	mg/L	3	3111 B., APHA, 23rd edition
Microbiology				
E. Coli	**9**	CFU/100ml	0	Eosin Methylene Blue Agar for Rapid Direct Count of E. coli, AJPH, 2011
Total Coliform Count	**15**	CFU/100ml	0	9222 B. Standard Total Coliform Membrane Filter Procedure using Endo Media

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Remarks: Except Turbidity, Iron, Manganese, E coli and Total Coliform all the observed values of other tested parameters are found to be within the limit of NDWQS 2079

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WATER ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (3)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Well Water (after Sand Filter)	**Sampled By:**	Client
Sampling Date:	2024/05/02 (12PM)	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters	Results	Unit	NDWQS	Method
Physical				
Colour	0	TCU	5	2120 B. APHA 23rd edition
Conductivity	620	µS/cm	1500	2510 B. APHA 23rd edition
pH	8.0	-	6.5-8.5	4500 H+ B. APHA 23rd edition
Taste and Odour	noobj	-	noobj	-
Turbidity	0.17	NTU	5	2130 B. APHA 23rd edition
Chemical				
Ammonia	0.05	mg/L	1.5	4500 NH_3 F. APHA 23rd edition
Aluminium*	0.05	mg/L	0.2	3111 B., APHA, 23rd edition
Arsenic*	0.007	mg/L	0.05	Arsenic Test Kit Method
Fluoride*	0.56	mg/L	0.5 -1.5	3111 B., APHA, 23rd edition
Nitrate	2.29	mg/L	50	4500 NO_3^- B. APHA 23rd edition
Chloride	48.98	mg/L	250	4500-Cl- B. APHA 23rd edition
Calcium	136.27	mg/L	1000	3500-Ca D. APHA 23rd edition
Copper*	0.02	mg/L	1	3111 B., APHA, 23rd edition
Iron	0.08	mg/L	0.3 (3)	3500-Fe B. APHA 23rd edition
R. Chlorine	<0.04	mg/L	0.1-0.5	4500-Cl B., APHA 23rd edition
Manganese*	0.01	mg/L	0.2	3111 B., APHA, 23rd edition
Sulphate	9.82	mg/L	250	4500-SO_4 E., APHA 23rd edition
Total Hardness	398	mg/L as $CaCO_3$	500	2340 C. APHA 23rd edition
Zinc*	0.44	mg/L	3	3111 B., APHA, 23rd edition
Microbiology				
E. Coli	**0**	CFU/100ml	0	Eosin Methylene Blue Agar for Rapid Direct Count of E. coli, AJPH, 2011
Total Coliform Count	**0**	CFU/100ml	0	9222 B. Standard Total Coliform Membrane Filter Procedure using Endo Media

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4. *These parameters are not within the scope of Nepal Standard.

Remarks: All the observed values of tested parameters are found to be within the limit of NDWQS 2079.

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WATER ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (4)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Well Water (after Sand Filter)	**Sampled By:**	Client
Sampling Date:	2024/05/02 (12PM)	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters	Results	Unit	NDWQS	Method
Physical				
Colour	0	TCU	5	2120 B. APHA 23rd edition
Conductivity	610	µS/cm	1500	2510 B. APHA 23rd edition
pH	8.1	-	6.5-8.5	4500 H+ B. APHA 23rd edition
Taste and Odour	noobj	-	noobj	-
Turbidity	0.18	NTU	5	2130 B. APHA 23rd edition
Chemical				
Ammonia	0.05	mg/L	1.5	4500 NH_3 F. APHA 23rd edition
Aluminium*	0.05	mg/L	0.2	3111 B., APHA, 23rd edition
Arsenic*	0.005	mg/L	0.05	Arsenic Test Kit Method
Fluoride*	0.54	mg/L	0.5 -1.5	3111 B., APHA, 23rd edition
Nitrate	1.97	mg/L	50	4500 NO_3^- B. APHA 23rd edition
Chloride	20.99	mg/L	250	4500-Cl- B. APHA 23rd edition
Calcium	123.44	mg/L	1000	3500-Ca D. APHA 23rd edition
Copper*	0.02	mg/L	1	3111 B., APHA, 23rd edition
Iron	0.08	mg/L	0.3 (3)	3500-Fe B. APHA 23rd edition
R. Chlorine	<0.04	mg/L	0.1-0.5	4500-Cl B., APHA 23rd edition
Manganese*	0.02	mg/L	0.2	3111 B., APHA, 23rd edition
Sulphate	12.78	mg/L	250	4500-SO_4 E., APHA 23rd edition
Total Hardness	410	mg/L as $CaCO_3$	500	2340 C. APHA 23rd edition
Zinc*	0.05	mg/L	3	3111 B., APHA, 23rd edition
Microbiology				
E. Coli	0	CFU/100ml	0	Eosin Methylene Blue Agar for Rapid Direct Count of E. coli, AJPH, 2011
Total Coliform Count	0	CFU/100ml	0	9222 B. Standard Total Coliform Membrane Filter Procedure using Endo Media

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Remarks: All the observed values of tested parameters are found to be within the limit of NDWQS 2079.

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PO Box: 25752, Kathmandu, Nepal
Bulbule Marga 10, Thapagaun, Kathmandu, Nepal

WATER ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (5)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Well Water (after Biochar Filter)	**Sampled By:**	Client
Sampling Date:	2024/05/02 (12PM)	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters	Results	Unit	NDWQS	Method
Physical				
Colour	0	TCU	5	2120 B. APHA 23rd edition
Conductivity	690	µS/cm	1500	2510 B. APHA 23rd edition
pH	7.8	-	6.5-8.5	4500 H+ B. APHA 23rd edition
Taste and Odour	noobj	-	noobj	-
Turbidity	0.13`	NTU	5	2130 B. APHA 23rd edition
Chemical				
Ammonia	0.2	mg/L	1.5	4500 NH_3 F. APHA 23rd edition
Aluminium*	0.05	mg/L	0.2	3111 B., APHA, 23rd edition
Arsenic*	0.005	mg/L	0.05	Arsenic Test Kit Method
Fluoride*	0.54	mg/L	0.5 -1.5	3111 B., APHA, 23rd edition
Nitrate	2.44	mg/L	50	4500 NO_3^- B. APHA 23rd edition
Chloride	37.98	mg/L	250	4500-Cl- B. APHA 23rd edition
Calcium	10.42	mg/L	1000	3500-Ca D. APHA 23rd edition
Copper*	0.02	mg/L	1	3111 B., APHA, 23rd edition
Iron	0.08	mg/L	0.3 (3)	3500-Fe B. APHA 23rd edition
R. Chlorine	<0.04	mg/L	0.1-0.5	4500-Cl B., APHA 23rd edition
Manganese*	0.02	mg/L	0.2	3111 B., APHA, 23rd edition
Sulphate	11.23	mg/L	250	4500-SO_4 E., APHA 23rd edition
Total Hardness	492	mg/L as $CaCO_3$	500	2340 C. APHA 23rd edition
Zinc*	0.05	mg/L	3	3111 B., APHA, 23rd edition
Microbiology				
E. Coli	0	CFU/100ml	0	Eosin Methylene Blue Agar for Rapid Direct Count of E. coli, AJPH, 2011
Total Coliform Count	0	CFU/100ml	0	9222 B. Standard Total Coliform Membrane Filter Procedure using Endo Media

NDWQS=National Drinking Water Quality Standard (2079)
Noobj= not objectionable
Note:

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3. Statements of conformity have been made without taking Measurement Uncertainty into account except when specifically requested by the customer.
4. *These parameters are not within the scope of Nepal Standard.

Remarks: All the observed values of tested parameters are found to be within the limit of NDWQS 2079

Analyzed By	Checked By	Authorized By
Aalekh Bhattrai	Chemist Ansu Thapaliya	Er. Lokesh Sapkota

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WATER ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (6)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Well Water (after Biochar Filter)	**Sampled By:**	Client
Sampling Date:	2024/05/02 (12PM)	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters	Results	Unit	NDWQS	Method
Physical				
Colour	0	TCU	5	2120 B. APHA 23rd edition
Conductivity	390	µS/cm	1500	2510 B. APHA 23rd edition
pH	6.8	-	6.5-8.5	4500 H+ B. APHA 23rd edition
Taste and Odour	noobj	-	noobj	-
Turbidity	0.12	NTU	5	2130 B. APHA 23rd edition
Chemical				
Ammonia	0.2	mg/L	1.5	4500 NH_3 F. APHA 23rd edition
Aluminium*	0.05	mg/L	0.2	3111 B., APHA, 23rd edition
Arsenic*	0.005	mg/L	0.05	Arsenic Test Kit Method
Fluoride*	0.54	mg/L	0.5 -1.5	3111 B., APHA, 23rd edition
Nitrate	2.24	mg/L	50	4500 NO_3^- B. APHA 23rd edition
Chloride	38.98	mg/L	250	4500-Cl- B. APHA 23rd edition
Calcium	13.62	mg/L	1000	3500-Ca D. APHA 23rd edition
Copper*	0.02	mg/L	1	3111 B., APHA, 23rd edition
Iron	0.08	mg/L	0.3 (3)	3500-Fe B. APHA 23rd edition
R. Chlorine	<0.04	mg/L	0.1-0.5	4500-Cl B., APHA 23rd edition
Manganese*	0.02	mg/L	0.2	3111 B., APHA, 23rd edition
Sulphate	13.03	mg/L	250	4500-SO_4 E., APHA 23rd edition
Total Hardness	432	mg/L as $CaCO_3$	500	2340 C. APHA 23rd edition
Zinc*	0.05	mg/L	3	3111 B., APHA, 23rd edition
Microbiology				
E. Coli	0	CFU/100ml	0	Eosin Methylene Blue Agar for Rapid Direct Count of E. coli, AJPH, 2011
Total Coliform Count	0	CFU/100ml	0	9222 B. Standard Total Coliform Membrane Filter Procedure using Endo Media

NDWQS=National Drinking Water Quality Standard (2079)
Noobj= not objectionable
Note:

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4. *These parameters are not within the scope of Nepal Standard.

Remarks: All the observed values of tested parameters are found to be within the limit of NDWQS 2079.

Analyzed By
Aalekh Bhattrai

Checked By
Chemist Ansu Thapaliya

Authorized By
Er. Lokesh Sapkota

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SOIL ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (9)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Soil (Banana, S-1-1)	**Sampled By:**	Client
Sampling Date:	2024/01/29	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters		Results	Unit	Method
pH		8.9	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Organic Matter (OM)		1.82	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus		27.89	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium		85.2	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen		0.15	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition
	Clay	20	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 23-29
	Sand	7.96	%	
	Slit	72.30	%	
	Soil Type	Silt Loam		
C: N ratio		6.96	-	-

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SOIL ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (10)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Soil (Banana, S-1-2)	**Sampled By:**	Client
Sampling Date:	2024/01/29	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters		Results	Unit	Method
pH		8.5	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Organic Matter (OM)		2.10	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus		69.71	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium		180	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen		0.11	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition
	Clay	14	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 23-29
	Sand	8.75	%	
	Slit	77.25	%	
	Soil Type	Silt Loam		
C: N ratio		10.82	%	-

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Aalekh Bhattrai

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SOIL ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (11)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Soil (Banana, S-1-3)	**Sampled By:**	Client
Sampling Date:	2024/01/29	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters		Results	Unit	Method
pH		8.8	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Organic Matter (OM)		1.46	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus		24.46	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium		88.2	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen		0.08	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition
	Clay	16	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 23-29
	Sand	8.34	%	
	Slit	75.66	%	
	Soil Type	Silt Loam		
C: N ratio		10.08	%	-

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SOIL ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (12)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Soil (Sugarcanes , S-2-1)	**Sampled By:**	Client
Sampling Date:	2024/01/29	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters		Results	Unit	Method
pH		7.5	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Organic Matter (OM)		1.67	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus		20.88	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium		98.4	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen		0.10	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition
	Clay	20	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 23-29
	Sand	9.92	%	
	Slit	70.08	%	
	Soil Type	Silt Loam		
C: N ratio		9.86	%	-

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SOIL ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (13)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Soil (Sugarcanes , S-2-2)	**Sampled By:**	Client
Sampling Date:	2024/01/29	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters		Results	Unit	Method
pH		8.3	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Organic Matter (OM)		1.34	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus		20.01	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium		87.6	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen		0.07	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition
	Clay	24	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 23-29
	Sand	3.04	%	
	Slit	72.96	%	
	Soil Type	Silt Loam		
C: N ratio		10.24	%	-

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SOIL ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (14)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Soil (Sugarcanes , S-2-3)	**Sampled By:**	Client
Sampling Date:	2024/01/29	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters		Results	Unit	Method
Physical				
pH		8.6	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Organic Matter (OM)		1.70	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus		32.65	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium		96	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen		0.08	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition
	Clay	22	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 23-29
	Sand	6.24	%	
	Slit	71.76	%	
	Soil Type	Silt Loam		
C: N ratio		12.55	%	-

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Aalekh Bhattrai	Chemist Ansu Thapaliya	Er. Lokesh Sapkota

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COMPOST ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (15)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Compost (Sample-3, AO-1)	**Sampled By:**	Client
Sampling Date:	2024/01/29	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters	Results	Unit	Method
pH	9.1	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Organic Matter (OM)	34.42	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus	272	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium	2726.4	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen	0.82	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition
C: N ratio	24.33	%	-

NOTE

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COMPOST ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (16)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Compost (Sample-4 , AO-2)	**Sampled By:**	Client
Sampling Date:	2024/01/29	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters	Results	Unit	Method
pH	9.4	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Organic Matter (OM)	40.31	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus	275.39	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium	2256	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen	0.79	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition
C: N ratio	29.55	%	-

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COMPOST ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (17)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Compost (Sample-5, AO-35)	**Sampled By:**	Client
Sampling Date:	2024/01/29	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters	Results	Unit	Method
pH	9.8	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Organic Matter (OM)	52.23	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus	285.61	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium	1737.6	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen	0.84	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition
C: N ratio	36.06	%	-

NOTE

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3. Statements of conformity have been made without taking Measurement Uncertainty into account except when specifically requested by the customer.

Analyzed By
Aalekh Bhattrai

Checked By
Chemist Ansu Thapaliya

Authorized By
Er. Lokesh Sapkota

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SWAT/F/C/04
Version no: 01
Issue no: 02
Revision no: 03
Effective date: 2021/08/01

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PO Box: 25752, Kathmandu, Nepal
Bulbule Marga 10, Thapagaun, Kathmandu, Nepal

COMPOST ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (18)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Compost (Sample-6, A5)	**Sampled By:**	Client
Sampling Date:	2024/01/29	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters	Results	Unit	Method
pH	8.6	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Organic Matter (OM)	38.47	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus	311.58	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium	1977.6	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen	0.86	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition
C: N ratio	26.55	%	-

NOTE

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Bulbule Marga 10, Thapagaun, Kathmandu, Nepal

COMPOST ANALYSIS REPORT

Name of Client:	Sparsa Nepal	**Lab Code:**	24/02-1289 (19)
Collector:	Aalekh Bhattarai	**Location:**	Nandanagar, Susta-5, Nawalparasi (west of Bardaghat)
Source:	Compost (Sample-7) A10	**Sampled By:**	Client
Sampling Date:	2024/01/29	**Test Performance Date:**	2024/02/08-2024/02/23
Receipt Date:	2024/02/06	**Issued Date:**	2024/02/25

Parameters	Results	Unit	Method
pH	9.5	-	Laboratory Testing Procedure for soil and water sample analysis, 2009 Chapter B II-1, 31-34
Organic Matter (OM)	28.56	%	Guide to Laboratory Establishment for Plant Nutrient Analysis, FAO, 2008 Chapter 3, 38-39
Available Phosphorus	197.17	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-6, 56-60
Available Potassium	1689.6	mg/Kg	Laboratory Testing Procedure for soil and water sample analysis, Irrigation Research and Development, Government of Maharashtra, India, 2009 Chapter B II-7, 61-65
Total Kjeldhal Nitrogen	0.74	%	4500-N_{org} C. Semi Micro Kjeldahl Method 23rd edition
C: N ratio	22.41	%	-

NOTE

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