UNIVERSITY OF AGDER

Master Thesis

The use of agglomeration and binders For biochar, spreading in agriculture

BY

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Abstract

Biochar is one of the most important food supplements that can be used to feed livestock, and it is a real addition to soil fertilizing. The discovery of biochar can support the climate, weather, and environment from degradation and poverty. Biochar production has become very popular, especially in the last years of this decade. It is considered a carbon material derived from an organic compound and produced by pyrolysis. A recent development has become an effective supplementary nutrition feed for cows, goats and all kinds of livestock.

It is very important to agglomerate biochar after adding nutrients to it; to spread it in the agricultural crop. The manufacture of biochar was studied, and it was found that binders must be added to biochar to be beneficial to crops. The compression and mechanical strength of grinding coal and linking it to the bonding materials were studied. Therefore, it was found that lignin granules are considered as binding materials. However, several effective and important binding materials were addressed for biochar formation in this study. The agglomerating process and spreading of biochar are fundamental to increase its efficiency in the soil. So the biochar granules are distributed and dispersed effectively within a specific distance.

Abstrakt

Biochar er en av de viktigste typene kosttilskudd som kan brukes til å fôre husdyr, i tillegg til gjødsling av jord. Biokulls potensiale er oppdaget som et bidrag mot forringelse av klima, vær, miljø og menneskelig fattig- dom. Bruk av biokull har blitt veldig populært, spesielt de siste årene på grund av dette. Biokull regnes som et karbonmateriale og er en organisk forbindelse, som produseres ved hjelp av pyrolyse. En nylig utvikling er, at biokull har blitt et tillegg til fôr og har blitt et effektivt kosttilskudd til kyr, geiter og alle slags husdyr.

Agglomerasjon av biokull etter tilsetning av næringsstoffer er viktig for å oppnå en god spredning på åkeren. Produksjonen av biokull ble studert og det ble funnet at det er nødvendig å tilsette bindemidler til biokull for at oppnå gode avlinger. Kompresjons- og mekanisk styrke av formalt kull og bindingsmekanismer ble studert. Ligningranulat ble vurdert som bindemiddel, men vi vil ta opp flere effektive og viktige bindemidler for produksjon av biokullagglomerater. Hele prosessen med agglomerasjon og av biokull er det svært viktig for å få biokullgranulene fordelt og spredt jevnt og innenfor en spesifikk avstand.

Thanks, and appreciation

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Chapter 1

1. Introduction

Biochar is charcoal made from wood and tree branches through pyrolysis, a process in which wood chips are exposed to a high temperature without oxygen. It is an important element added to the soil to make it more fertile [1,2]. Biochar can be stored in soil for thousands of years. It has the ability to mitigate climate change and to increase the fertility of the land and acidic soils. It was used by the people of the Amazon in South America. It is easy to transport because it is light in weight and has recently contributed to animal feed production [3]. Thai farmers have burned biochar in large quantities, obscuring their surroundings like fog, and used it as a soil fertiliser and fresh fodder. Biochar has been used in animal feeds, as it was found to be a strong disinfectant for animals, and when mixed with other nutrients, it is an important nutritional supplement for animals such as cows, goats, pigs, poultry, and sheep. It also has the ability to enhance milk production in cows [4]. It was found to protect animals from diseases and bacteria and is easily absorbed by the animal intestines. Thus, its uses for animal and agricultural productions have greatly increased [5].

Biochar made by pyrolysis increases water retention in the soil. It outperforms all other elements by attracting and retaining water and nutrients. Biochar preserves phosphorous and chemical additives. It was found to be relatively inert and thus stays a long time in the soil, from 100 to 1000 years. Biochar improves soil quality. Fertilisers produce nitrous gas (N_2O), which is 310 times stronger than carbon dioxide (CO_2) and damages agriculture, and biochar reduces the percentage of nitrous gas by 50% to 80% [6]. Biochar affects the climate by slowing down the release of greenhouse gases. It improves carbon sequestration in soils and thus reduces carbon dioxide emissions into the atmosphere [7]. When biochar is applied to the soil, it reduces methane gas emissions.

Food poisoning in cows has been an annually increasing recently, but after advanced studies, biochar and sauerkraut have been proven to control poisoning cases [8]. The use of biochar with poultry feed has been proven to increase the immunity of animals and feed efficiency [9].

1.1. Background on biochar

The history of biochar dates back to a long time ago, and its origin goes back to the ancient people of the Amazon of South America, as described in detail in a previous study [10]. The main objective of the development of biochar was to enhance soil fertility. People of the Amazon used traditional methods of collecting and cutting trees in forests. They would meet, take their food, and start their work in the morning. The workers distribute and cut tree branches and collect them in one place, where they burn it. After a certain period, they bury the tree branches in the soil to prevent oxygenation. When the burning process is finished, they open the system to cool.

Figure 1: Biochar sample from Oplandske Bio

Through thermal pyrolysis, that is, exposure to high temperatures without air, the buried tree branches turn into charcoal. Biochar was found to be stored for thousands of years underground throughout ancient times, but its.

Figure 2: Biochar granules [1]

properties are not affected by natural factors but enhances soil fertility. Ancient Americans called land that contains biochar ‘the beautiful land’. Biochar was discovered by chance, and it was found to be light in weight and easy to transport. Biochar is a solid element created at a temperature of 750℃. One of its most important benefits is that it increases soil fertility. It has been scientifically proven by geochemist Caroline Mazlio and economist Katneth Medlock, who were part of a research team that used mathematical equations to develop a model [1]. This model helped farmers estimate the availability of water by proving that adding biochar to the soil increases the water retention ability of the soil. They also found that sandy soil is more efficient than clay soil in retaining water. Owing to the pore holes in sandy soil that helps move water internally in the soil, it more efficiently retains water than clay soil. Studies have proven that when biochar was added to the soil in the southeast and northern regions of the United States, the abundance of water was maintained. Thus, the great importance of biochar has been recently proven. As a feed additive, it has been found beneficial to animals. It has an important cleansing effect on the animal stomach. It has benefits for increasing milk production in cows and fattening sheep and poultry [11].

1.2. Cases/experiments and preliminary research questions

The largest initiative has been made in the United Kingdom to study everything related to biochar. Experiments have been conducted, and data have been collected from long-term tests on biochar. The aim of the experiments was to determine the effects of biochar on the fruits and vegetables used on a large-scale in the United Kingdom and exported abroad. The research team consisted of Oxford Biochar Ltd, Earthwatch, and the Institute for Environmental Change of Oxford University. This experience is considered the biggest challenge in combatting climate change and food security and allowed people to participate. The experiment relied on people's participation and collecting as many results as possible on the impact of biochar on food production. The team agreed with the participants to allocate an area of 1 × 1 m from the area of any person, provided that 1 kg of biochar was used in this area, and to evaluate the effect of biochar on the area. The results will be collected later this year. Dr. Cecile Girardin of Oxford Biochar Ltd is the project leader. Oxford Biochar Ltd is a non-profit organisation that aims at developing biochar as a feed additive and spreading the sustainable use of biochar. The organisation focuses on the carbon cycle in a tropical forest ecosystem. Girardin's work focuses on the dynamic power of carbon above and below the ground, providing insights into the Amazon soil. Her focus has been on the study of the impact of biochar on the United Kingdom. More than 250 points will be collected about the study [12].

Recently, many developed countries, especially Norway, Sweden, and Denmark, have taken an interest in developing the biochar industry, which has become an important component of animal nutrition. The most recent conference between Scandinavia, Norway, Sweden, and Denmark was held in Denmark on February 17, 2022. The presenters talked about several things related to biochar, of which the most important was reducing the spread of bacteria that infect cows and livestock and increasing milk production of milk in cows and goats. The latest study presented by scientists specialising in biochar has proven that biochar enhances animal immunity and provides strength and vitality. It can also benefit poultry and pigs. When animals eat herbs, their stomachs sometimes get infected by worms and bacteria, which may cause the death of the animal or weaken the animal's immune system. However, biochar was found to have the ability to cure these diseases and nourish the animal's immune system [13].

1.2.1. Preliminary research questions

Many questions revolve around biochar experiences. The main purpose of these questions is to exchange experiences and experience the maximum benefit from the use of biochar.
Dr. Abhishek Mukherjee investigated the extent to which biochar can be used in rice fields and examined the growth stages to best amend the soil. Mukherjee found that because carbon is more or less stable owing to the chemically occupied biomass, it is safe to sequester carbon and all its associated pollutants for a long time. Rice biochar increases rice production by 40% [14].

1.2.2. Biochar for use in fields

Adding biochar to the soil is beneficial to the soil. Biochar contains stable carbon. Carbon has been observed to remain sequestered for long periods in the soil compared with its state in the original biomass [15]. Biochar can be used with farm slurry and manure or in a sewage plant, where it is converted into manure to support soil fertility. Therefore, it may be loaded with nutrients that help in enhancing soil fertilising and increasing agricultural crop production [16].

1.3. Research objectives

The research investigated several things necessary for achieving the objectives of the Oplandske Bio factory in Norway, including knowing the use of biochar for agricultural fields, biochar pelleting methods, the most important types of binding materials that can be used for biochar, the methods of mixing nutrients with biochar and spreading them in fields, agglomeration pellet tests, and spreading test in the field.

1.4. Thesis structure

The thesis includes an introduction to the research, objectives, experiences, and involvement of others; the research objectives; and the thesis structure. The second chapter contains the most important methods of soil amendment and distribution and the spread of biochar in the fields, and information about Oplandske Bio, aggregate methods and machines, the effect of moisture,

grinding and sifting, and agglomeration assessment of biochar. The third chapter includes the binding materials for biochar, agglomeration testing, mechanical strength measurement, absorption and chemical properties, and agglomeration and dilution testing in the field. The fourth chapter contains the results of the tests and comparisons between the results. The fifth chapter includes the conclusion of the research, and the sixth chapter contains future studies.

1.5. Methods for charging biochar with nutrients

In Norway, Oplandske Bio is looking for the most important way to support biochar. Biochar is even used for animal nutrients and soil improvement methods. Biochar is charged with nutrients for animals as a food supplement to improve animal health. It is spread in fields to increase soil fertility.

1.5.1. Mixed biochar with compost

Usually, biochar is loaded with nutrients and must be agglomerated until pieces are obtained for scattering in agricultural fields. According to Schmidt [17], charging biochar by mixing it with compost is the best way to produce soils rich in humus. Thus, the compost produced from organic wastes such as rice straw contains timber, and pruning products provide the highest level of microbial stimulation, as nutrients are already combined with complex organic compounds. However, not all composts are the same [19]. The soil has to ‘digest’ it to weaken the compost over a long time, which allows for a lot of time to impede nutrients and microbial imbalance. A different activation variant should be used for this and not for biochar. The compost should have the characteristics of a crumbly structure and should not have an unpleasant odour [20]. The best way to add biochar to compost is by capping at 10% to the biomass. Frequent rotation of the mixture is important. If biochar is first added to the mature compost, then both should be mixed well in a 1:1 ratio. The mixture should be mixed in equal proportions at least 2 weeks before it is incorporated into the soil, stirred and mixed at least twice, and moistened well during this time . The mixture should show agglomeration. The spreading technique can be applied to the mixture after binding it with binders and agglomerating it in the Oplandske Bio plant.

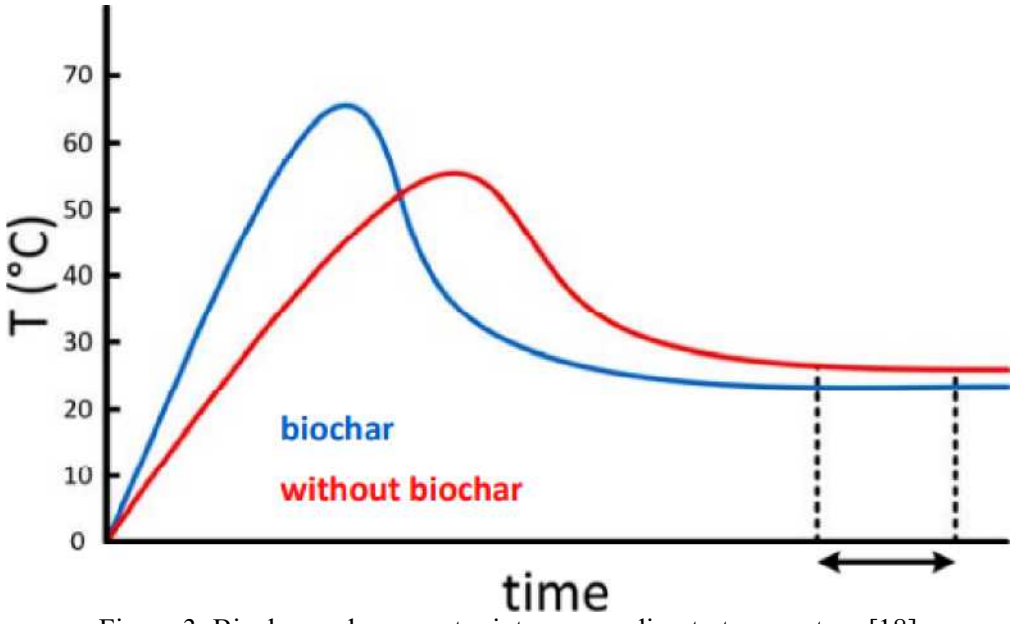

Figure 3: Biochar and compost mixture according to temperature [18]


Figure 4: Compost mixture with biochar [19]

1.5.2. Charging the biochar with livestock dung

It is preferable to mix one type of natural fertiliser with biochar. A positive effect can also be achieved with biochar. The ratio of biochar to compost manure should be approximately 4:1. If

the compost manure does not contain enough straw, it is better to add at least 10% of grass, corn forage, or green waste to the mixture [21]. The mixture must be prepared at least 14 days in advance and stirred well several times before entering the soil.

1.6. Mixing biochar by lactic acid fermentation

The biochar biomass mixture is sprayed with 3% sugarcane molasses. The most suitable mixture is cattle manure rich in straw with 10% grass cuttings, 3% solution of effective microorganisms, 10% biochar, and 1% rock our. The whole batch is compressed and tightly covered, for example, in a closed container or plastic bag in the garden [22]. After 14–21 days, smell from a little amount of lactic acid should emanate from the closed container. More biochar should be added back to the soil. Then, the mixture can be worked into the soil on the prepared surface.

1.6.1. Charging biochar with liquid fertiliser

In this method, biochar is mixed with liquid fertilisers such as urine slurry without traditional fertilisers such as a potassium, phosphorous, and sodium [23]. When mixing the mixture, the volume of the mixture is reduced by half because of the gas (N_2O) released, leaving only the nutrients during the separation process. After that, the mixture is dissolved in water with the addition of biochar. Thus, the biochar absorbs the liquid fertiliser [24].

1.7. Disadvantages of biochar

Although biochar application in the soil has many advantages, it also has several disadvantages such as the following:

1- Limits the activities of worms in the soil: When biochar is applied in the soil, the activities of worms, which are essential for soil productivity, are reduced.

2- Affects crop yield: Biochar increases agricultural production, but it also absorbs nutrients, causing the deficiency of vitamins and nutrients essential for plant growth.

3- Soil compaction: The frequent application of biochar causes soil compaction, which decreases crop yield.

4- Lowers the efficiency of pesticides: Biochar also affects pesticide application, reducing the efficiency of pesticides in the soil.

5- Soil degradation: The application of biochar could lead to soil degradation, making soil vulnerable to harsh climates.

Chapter 2

2. Literature Review

2.1. Biochar soil amendment

To obtain fertile soil, the land must be prepared for a valid agricultural production. Soil amendment, which is the addition of natural elements such as natural fertilisers or biochar, which are subject to operations and treatments. Natural fertilisers include algae, which improves the soil and water drainage and form tissues. Soil amendment increases the acidity of the soil; hence, peat moss is an important source of acid. The following are some of the ways to improve soil.

2.1.1. Choosing the appropriate soil acidity

Biochar is distributed as black powder rich in carbon, which has physical and chemical characteristics suitable for use in soil amendment in agricultural fields. Studies have shown that when cultivated into the soil, one of the important functions of biochar powder is its ability to increase water retention and microbial growth and reduce nutrient and heavy metal leaching. Biochar powder and fertilisers are highly porous, allowing water and nutrient retention in the soil [25]. Increased nutrient retention helps promote plant and microorganism growth. Microorganisms are important in the soil because they breakdown biomass residues into nutrients that can then be used by plants

The acidity level in the soil must be tested. Clay soil is rich in nutrients and is acidic and thus can be strong and cohesive. A soil sample must be tested in the laboratory to determine the soil pH, which is ideally between 6.3 and 6.8.

2.1.2. Adding organic materials

With this method, drainage is improved, making heavy soils lighter, as it provides microorganisms, which improve the soil [26].

2.1.3. Soil tilling

The soil must be stirred or mixed before planting. This is done systematically using digging machines. Digging is accomplished by ploughing and harrowing. Organic materials such as humus act like a biochar, which absorbs nutrients and water, thereby improving the fertility of soils of poor mineral content, such as sand.

Figure 5: A picture of a humus soil sample showing its benefits and colour [27]

2.1.4. Humus

Humus is the material formed from the remains of plants, earthworms, and living organisms found in the soil [27]. It is an important component of soil nourishment and is rich in vitamins such as potassium and calcium. Humus is one of the most important nutrients that support the soil, and its colour is black or brown, as that in Figure (5).

2.2. Benefits of biochar

2.2.1. Advantages of Being Carbon Negative

Biochar provides a lot of organic materials owing to its chemical components and nature [2]. It can retain water and underground nutrients such as nitrogen and phosphorous and to reduce the effects of climate change by releasing carbon in the soil, enhancing its properties. Biochar has the ability to sequester carbon in the soil for thousands of years, turning it into petroleum and natural gas. This occurs when biochar combines with the soil and the natural factors that determine the lifespan of biochar. Accordingly, fossil fuels are carbon positive and contributes to the supply of carbon dioxide and other gases. Thus, fossil fuels are a good alternative source of energy.

2.2.2. Other advantages

Biochar has become part of the many modern industries that are important in our lives. One of the most important industries that involve the use of biochar is the steel industry. Biochar also plays an important role in the concrete industry, where it strengthens concrete [28]. Biochar is a lightweight carbon component that is easy to transport from one place to another, which is important in reducing the burden of the workforce. In developed countries, biochar manufacturing processes involve burning, pelleting, and distribution, and several manufacturing methods will be discussed in later sections.

2.3. Spreaders and fertilisation equipment

Spreading fertilisers is a good technique for obtaining the best results. In the past, the traditional method of spreading manure was used, posing a danger to the farmer. Modern methods are now used that save time and are safe. Fertiliser spreaders are of different types, including projection sprinklers, portable handheld rotary fertiliser spreaders, and liquid fertiliser spraying machines [29]. Researchers have invented fertiliser spraying machines that allows for systematic spraying to obtain good production. The benefit depends on the use of fertilisers,

which provide soil nutrients such as phosphorous and potassium nitrogen [30].

2.4. Method for distributing manure over the field

The fertilisation mechanism used by any farmer depends on the physical properties of the fertiliser in terms of its solid and liquid components. It also depends on the quality of the fertiliser and how well the farmer follows the important fertilisation instructions. Some companies have developed many types of composting machines, which provide fertiliser for distribution according to the land area (length and width) of the farm. Density is important for fertiliser dispersal [31]. Table 1 shows the directional recommendations for the required granulation strength with respect to the required dilution width in the field. Every 1 kg of fertiliser covers an area between 12 to 16 m2, as shown in Table 1. In addition, the granular size of the fertiliser is important (Table 2), depending on the area that requires fertilisation.

Table 1: Fertiliser distribution [32].

Spread area (m^2)	Minimum requirement (kg)
12–16	1
18–20	2
24–28	3
30–36	4
>36	5

Table 2: Distribution of fertiliser volume according to the area of the field

Spread area (m^2)	Grain size (mm)
12–16	1.6
18–20	2.0
24–28	2.5
30–36	3.2

2.5. Calculation of energy consumption during pyrolysis

The amount of energy converted from biomass (wood chips) to biochar and the energy mass expended were calculated. The high heating value (HHV) and low heating value (LHV) were

calculated using equations 1 and 2 [32]. The LHV was determined according to the formula,

$$-\text{HHV (MJ/kg)} = -1.3675 + 0.3137\%\text{C} + 0.7009\%\ \text{H} + 0.0318\%\ \text{O} \quad (1).$$

$$\text{LHV (MJ/kg)} = \text{HHV} - m_{H_2O} \times \text{LH} \quad (2)$$

where

mH_2O: mass of water produced by the combustion of 1 kg of fuel, that is,

$$mH_2O = \text{W } 0/100 + \text{H}/100 \quad (3)$$

W0: relative humidity (%)

It is calculated using *H*, the percentage of hydrogen in the fuel LH_2O, the latent heat of condensation of water. For *T* = 0°C and *P* = 1.013 bar, LH_2O = −2.486 MJ/kg.

2.6. Case study of Oplandske Bio

Oplandske Bio is a Norwegian bioenergy company located in the central region of Norway, in Oppland. The factory manages the thermal analysis of renewable energy on a large scale in the region. It sells 40% of the steam for processing large meat from cows, which is its second most important product after biochar. Oplandske Bio is Norway's leading plant in Rudshøgda, in the municipality of Ringsaker. The wood chips used in the plant are obtained by a Programme for the Endorsement of Forest Certification-certified Forest company located 2 km away from the plant. The factory was established in June 2021.

Biochar production obtained quality certification in 2022. Biochar has a high carbon content of 92. Each ton of dry biochar contains 3.36 tons of CO_2. The Oplandske Bio plant has undergone a life cycle assessment to determine the emissions ratio for biochar, wood chips, and transportation and to confirm that 3 tons of carbon dioxide are stored for every ton of biochar. Biochar from the Oplandske Bio plant has been used in many industrial applications such as animal feed and concrete. Biochar from biomass pyrolysis reduces the risks of forest fires, diseases, and pests. It is spread in fields directly and indirectly to improve the soil, increase water and nutrient retention, and reduce the production of artificial fertilisers, which can have negative impacts on human health. Biochar has been used as an additive to animal feeds.

Figure 6: Oplandske Bio plant

2.6.1. Biochar production method using pyrolysis

Biochar results from the pyrolysis of biomass, which occurs owing to the lack of oxygen in the operating system. The Oplandske Bio obtains energy from wood chips, which are cut and prepared and then shipped to the plant according to the request of the factory management.

The wood chips are placed in a large box with a capacity of 40 m^2, as shown in Figure 8. After that, the factory automatically fills large bags with 12,000 m^3 of wood chips. The annual biochar production is 400 T/Y at a steam output of 40%.

2.6.2. Oplandske Bio biochar production

1. Input 2128 dry tons/year
2. Biochar 392 tonnes/year
3. Efficient residual heat of 400 kW

4. Bitter ¡70 mm (uniform). Humidity of between 15% and 25%

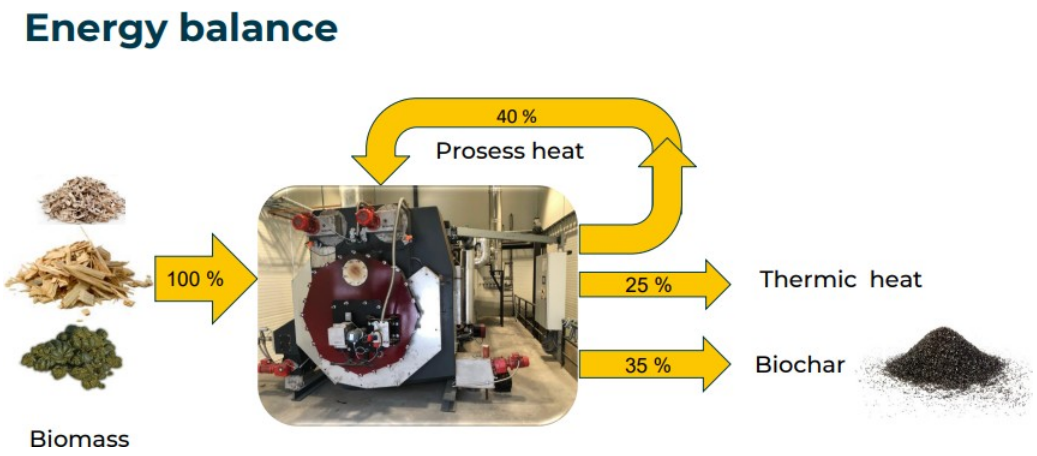

Figure 7: Energy balance [33]

Figure 8: Wood chips box

Figure 9: Biomacon C 400 1

Pyrolysis, also called dry distillation, is a process of heating biomass at a high temperature and oxygen supply. The process is used to extract one or more products: syngas and biochar, which all come from them. The thermochemical decomposition of nanocellulose (dry plant mass), either with or without limited oxygen supply. Oxygen restriction results in zero or chemically inert atmosphere, causing specific reactions between the desired reactants. The biosynthesis of residual combustible gases forms condensates. Biochar is the solid matter that appears during the process and the synthesis of permanent gases that remain when the process is completed.

2.6.3. Combustion

The internal combustion in a biomass machine is called heat expulsion. It occurs as a reaction between biomass and oxygen when mixed together at a very high temperature regimen. This process produces carbon dioxide, water vapor, and heat. The heat generated is used for other purposes, as we mentioned earlier [34]. Biomass has a long history, and the heat it generates has been used for many purposes. Figure 10 presents a diagram of biomass processing [35].

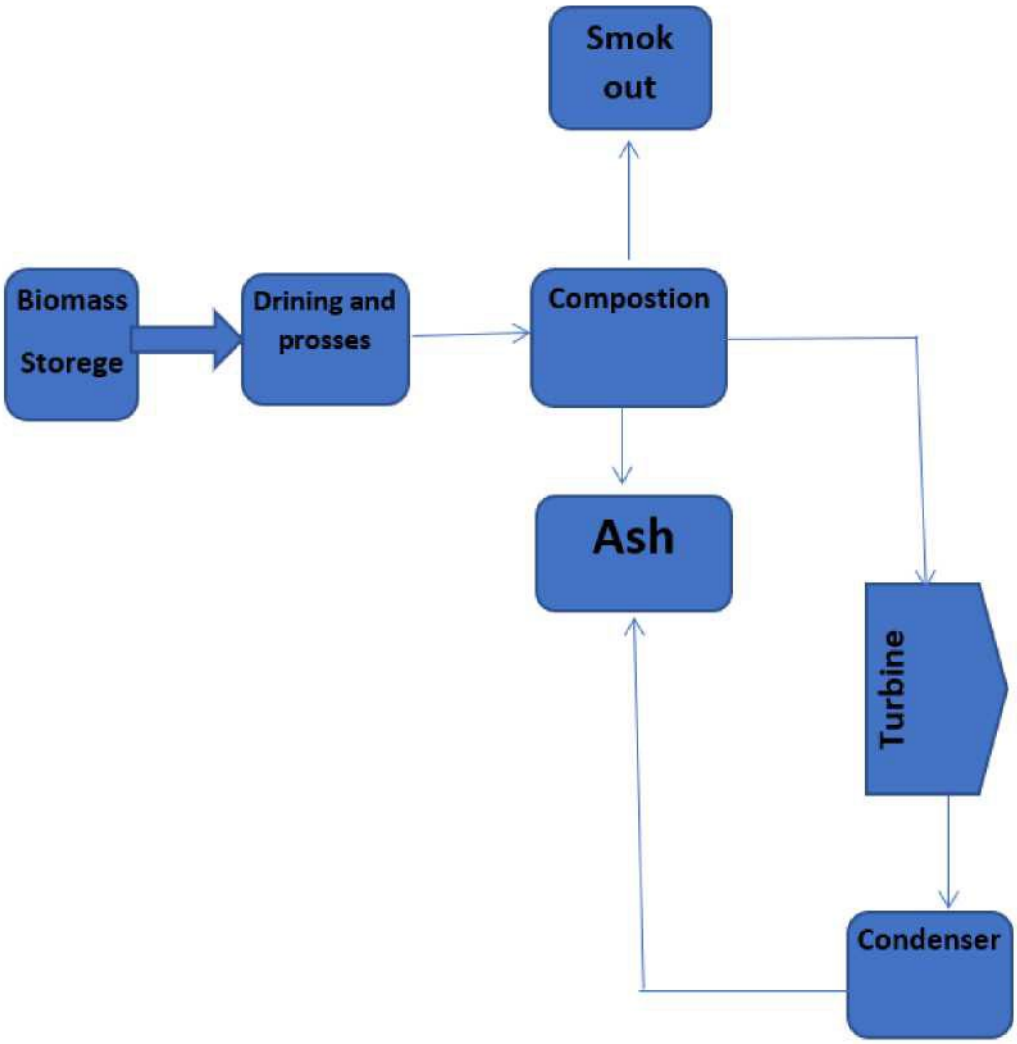

Figure 10: Simplified combustion scheme. [36]

Where the heat is used for other businesses, as we mentioned earlier [34]. The history of biomass goes back a long time, and its heat was used for many purposes. Figure 10 represents the biomass diagram.[35]

$$C_6H_2O_6 + 6O_2 = heat + 6CO_2 + 6H_2O \quad (4)$$

2.7. Agglomeration of biochar, binders, and nutrients

Once biomass is converted into biochar, it can be converted into powder form. Biochar powder and is dangerous. In this case, this can be due to its light weight and dust form, which results in losses in quantity [51]. Therefore, to make it beneficial, it must be agglomerated by mixing it with other materials or nutrients. The agglomeration process is characterised by excitability. Biochar is difficult to pellet on its own, so it must be combined and mixed with other organic fertilisers or other active food materials by using granulation methods such as pressing and pelleting.

2.7.1. Proportions of water and wood chips in Oplandske Bio

In the Oplandske Bio factory, wood scraps are added in a large box with a capacity of 40 m^2, and a percentage of water is automatically added by the operating system.

- Wood chip input – 12,000 m^3/year
- Biochar output - 1900 m^3/year
- Electric residual heat - 450 kW
- 3.6 GWh of 90ºC water
- Drying of wood chips
- District heating

2.8. Principles and machines

The main agglomeration process used in the plant is an old one. The conglomerate has been used in various manufacturing processes, including those in candy and food factories. The aim is to facilitate marketing operations. For the biochar agglomeration process, it is important to avoid biochar dust and facilitate the transportation process [37].

2.9. Pre-treatments

Before mixing biochar, it is subjected to three main pre-treatment processes.

2.9.1. Humidification

Before the biochar agglomeration process, a large amount of water is added, estimated at a preparation of 35%. Thereafter, other materials, which include almost all organic materials such as seed husks, bark, crop irregularities, and manure, are added to the biochar [38]. Pyrolysis is the breakdown of materials under heat in an oxygen-limited environment for biomass. Carbonation is often induced by heat exchange, where it begins at a temperature of 110℃ to 180℃. This is the first biochar treatment [39]. Water is dissolved when the biomass is heated at temperatures higher than 100°C and 150°, at which point the biomass begins to collapse. Water is chemically released along with small amounts of bound carbon dioxide and volatile organic components.

2.9.2. Biochar grinding machine

The biochar grinding machine has different speeds and a speed gradient switch ranging from 1 to 5000 rpm. The biochar grinding machine contains a mesh with apertures ranging from 0.8 to 4 mm. The milling machine has a glass sampling container. Grinding biochar helps the agglomeration process produce pellets. Biochar is absorbed by the soil, which facilitates its distribution. Biochar used in powder form in agricultural fields has side effects, producing dust in the air, which is inhaled by people, causing respiratory problems, and leads to losses to neighbouring agricultural areas. It is not desirable for farmers or customers, so we resort to the process of agglomerating and granulating biochar.

Figure 11: Biochar grinding machine

2.9.3. Binding materials

Binders are important for biochar agglomeration and granulation, especially when additives are used. Lignin is unaffected by moisture and maintains the physical properties of biochar; thus, it is considered the best binder [40].

Lignin is the material extracted from the outer wall of wood. It is a complex chemical compound that comprises a quarter to a third of dry mass. When used as a binder for biochar, lignin prevents biochar from being affected by humidity after the biochar manufacturing process is completed. Other binders such as food starch have poor mechanical resistance [41]. Sodium hydroxide produces solid biochar when used as a binder. Calcium hydroxide exacerbates the humidity of biochar. Borregaard uses lignin in powder and liquid forms at the specifications shown in Table 3,

Table 3: Specification of the binder materials

Borregaard Binder Material	DP-38210	DP-38320
Dry matter %	Minimum,	53.0 ± 3.0
pH (in 10% solution)	4.5 ± 1.0	4.3 ± 0.8

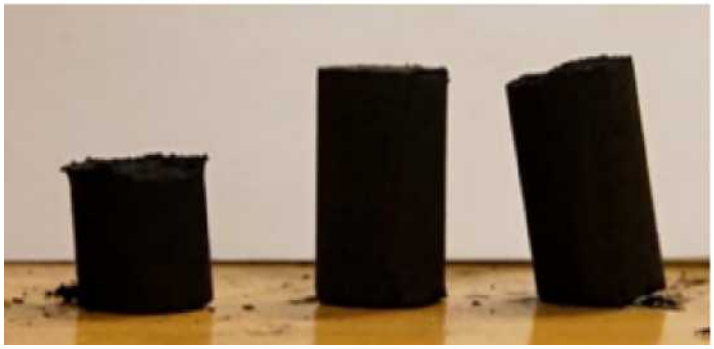

Figure 12 Biochar pellet samples

2.10. Agglomeration tests

Table 4 shows the tests for the agglomeration and pellet formation of biochar. The binder used was in powder form, and biochar was ground using a 2-mm-diameter mesh.

Table 4: The mixtures ratio

Components of the mixture	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Biochar powder (g)	22.0300	12.0400	14.2100	18.6200
Binder material (g)	20.65	2.15	1.06	4.13
Water (g)	9.35	22.51	27.68	23.74
Drying time (h)	24	24	24	24
Settling time (h)	0.1	0.1	0.1	0.1

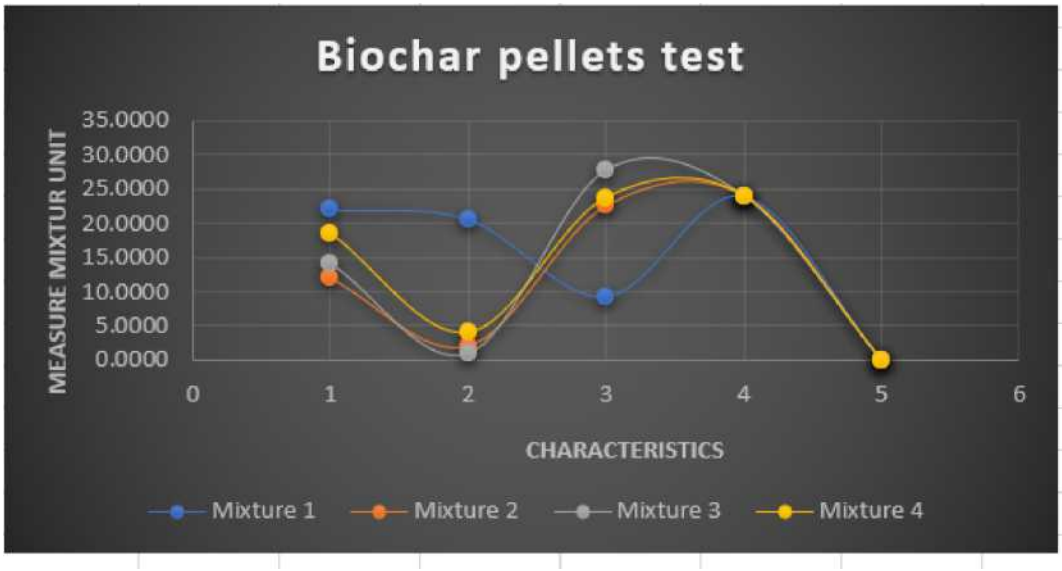

Figure 13: Biochar pellet test

2.10.1. Other tests

In tests 5 and 6, grinding grades with a mesh diameter of 2 mm were used with binder powder. In tests 7 and 8, a liquid binder with a 0.8-mm mesh was used.

Table 5: The mixtures ratio

Components of the mixture	Mixture 5	Mixture 6	Mixture 7	Mixture 8
Biochar powder (g)	3	3	3	3
Binder material (g)	3	4	1.15	2
Water (g)	3.84	3.12	3.17	2.51
Drying time (h)	24	24	24	24
Settling time (h)	24	24	24	24

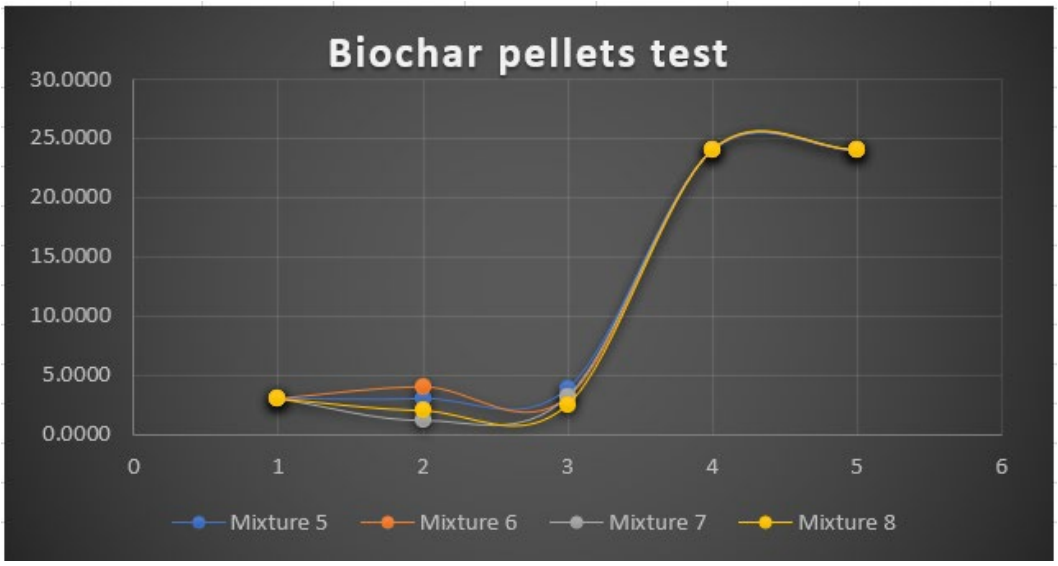

Figure 14

: Biochar pellet test

Figure 15: Deformation of biochar pellets due to the excess binder in test 2

2.10.2. Other tests

The results of the use of binder powder with biochar grinding using a 0.8-mm-diameter mesh are shown in Table 6.

Table 6: The mixtures ratio

Components of the mixture	Mixture 9	Mixture 10	Mixture 11	Mixture 12
Biochar powder (g)	4.06	4	4	4
Binder material (g)	1	3	1.07	3
Water (g)	3.6	3	4	3
Drying time (h)	24	24	24	24
Settling time (h)	24	24	24	24

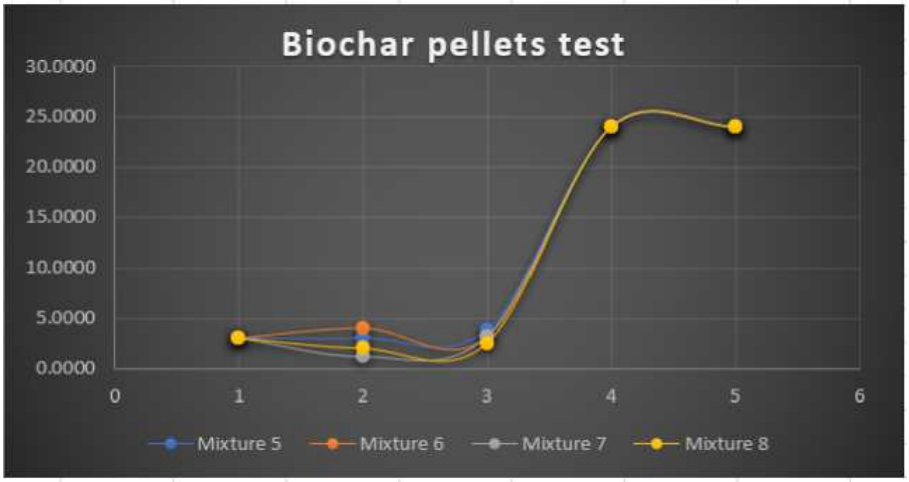

Figure 15: Biochar pellet test

2.11. The physical strength of biochar particles and field distribution

Biochar usually has a positive physical effect on the soil. A previous study conducted in 2007 reported that biochar inputs of more than 50 tons per hectare can reduce the tensile strength of biochar [42]. As soil has a high tensile strength, when the total soil tensile strength was decreased, the tensile strength of the biochar applied was less than the soil tensile strength. Therefore, the physical properties of biochar and their effects on the soil help the growth of trees and improve seed germination.

The lower tensile strength of the soil allows the roots to grow and penetrate into the ground more easily [43]. Seed germination and fungal growth in low-tensile soil are improved. The dorsal density of the soil is affected, and it is another physical property affected by the addition of biochar. Biochar is characterised by a low and loose density due to the proliferation of bacteria, which can be carried in small and large populations in the air and in water [44].

The porous structure of biochar particles indicates that it has a fairly high surface area and is considered important for biological processes, Biochar is also a soil aggregate, which means that it provides the overall stability of soils against loosening when exposed to disruptive forces such as ploughing and water/wind erosion [45].

High aggregate stability of biochar-supported soils indicates healthy levels of material content, organic activity, biological activity, and soil nutrient cycling. Studies have also confirmed that biochar can provide benefits with similar functions to soils, with high overall stability, such as protecting organic matter and soil biota, and retaining nutrients and water.

Figure 16: Agglomeration pellet method

2.12. Spreading machines

Fertilization spreaders vary according to their size and technology. Some of them work manually and some of them work with a motor. It also varies according to capacities. But in this test, it used a spreader that works with Tractor . the engine speed 540rpm.

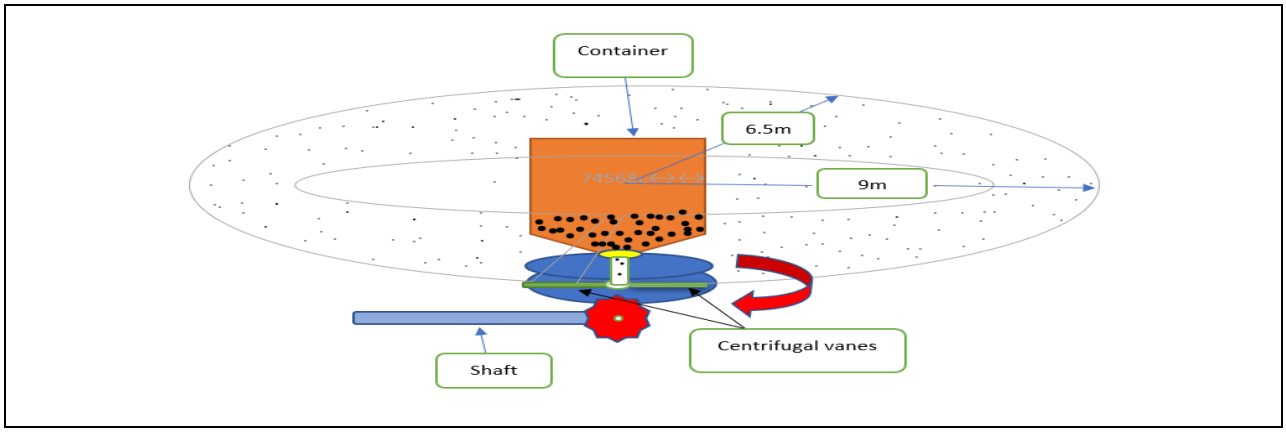

Figure 17. Spreader machine

2.13. Evaluation of agglomerates and spreading

To evaluate the agglomeration and palletisation process, proportion mixing was performed manually and weighed on an accurate electronic device. For biochar palletisation, a manual biochar pellet press was used. The biochar pellets produced were satisfactory according to the first test.

2.14. Agglomeration: prilling, granulation, and palletization

In the biochar granulation process, biochar must be ground into powder form. In powder form, biochar is difficult to add to the soil because it is light in weight. It cannot be distributed over the field because it volatilises with air. In addition, traders have difficulty procuring biochar in powder form [46]. If treatment is required, adding solutions make it more effective. These solutions are considered binders and are hydroxypropyl methylcellulose. The results showed that after testing the three solutions, the biochar produced was spherical and ranged in size from 1 to 4 mm. On the basis of the results, biochar can be granulated using wet cylinder granulation, with adjustment of the process parameters. The main problem of biochar powder is that its size ranges from 1 to 600 μM. In the fields, it is easily blown away when used as a soil amendment without any modifications. When biochar particles are airborne, they can negatively affect the health of exposed occupants, causing respiratory irritation [47].

2.15. Biochar transport

The current market has attempted to sell biochar and estimated the transport cost of biochar, which is variable [48].

1-Feedchar as feed additive for farm animals – comprises 15% of the material; 10% is exported to Switzerland, and 1% is exported to Sweden.

2- Soil improver for farmers and urban tree planting – 80.5% of this biochar is used; 70% in Norway and 30% in Sweeden.

3- Test material for Biocrete - 2.5%, all in Norway.

4- Test material for heavy industry - 2.0%, all in Norway.

The transport cost is highly variable. The transport cost per cubic meter depends a lot on the amount to be transported. To transport a full lorry of 24 large bags to Stockholm costs 7000 NOK. A full maxi trailer with 36 large bags cost 30,000 NOK to transport to Switzerland, and one bag costs 900 NOK to transport to Oslo. One full lorry of 16 bags costs 5600 NOK to transport just outside Oslo. Thus, both the amount to transport and transport distance are determinants of the transport price.

Chapter 3

3. Materials and Methods

3.1. Applied materials (description of the materials used)

The materials used were biochar from the Oplandske Bio plant and binders from Borregaard. The binding materials were lignin powder and liquid, which were tested with. Water was also an essential component of the biochar mixture.

3.2. Mixture composition

The Oplandske Bio biochar contains fixed carbon (94.3%), ash (1.89%), and volatiles (3.81%). The pyrolysis temperature is 650°C. The biochar mixture is added with water and binders at varying proportions, as shown in Figure 15.

3.3. Biochar recharged with liquid fertiliser (NPK 7-1.3-5)

In this method, biochar was mixed with NPK 7-1.3-5 liquid fertiliser to improve and increase soil efficiency, as the components of liquid fertiliser and speciation were nitrogen (a total of 7%: nitrate nitrogen, 1.8%; ammonium nitrogen, 1.8%; and urea nitrogen, 3.5%), phosphorus (a total of 1.3%: vattenl¨osligt, 1.3%), and potassium (a total of 5%: FatnLucLight, is 5%) [49]. The test was conducted in the UIA laboratory, in the ratios provided in Table 7.

Table 7: Ratios of biochar recharged with liquid fertiliser and sunflower oil

Compound of the mixture	Mixture 13	Mixture 14
Biochar powder (g)	4	4
Binder powder (g)	3	3
Water (g)	3.38	0.82
Oil (g)	2	0
Liquid fertiliser (g)	0	4
Drying time (h)	24	24
Mechanical strength (MP)	0.22	0.33
Density (kg/m^3)	728	759
Settling ti	24	24

Figure18: Recharging biochar by sunflower

3.4. Biochar recharged with sunflower oil and liquid fertilizer

In this method, biochar was charged with sunflower oil at the proportions shown in Table 7 to increase soil efficiency and fertility.

3.5. Laboratory experiment

Agglomeration methods have been adopted by placing the mixture in small containers at varying proportions. Thus, the ratios are changed in each experiment to obtain better results. The results from each sample are obtained after 24 hours of drying in the laboratory. To evaluate the best sample of coal pellets, the sample must be evaluated for its mechanical strength and general condition in terms of shape, cracks, hardness, fragility, and water absorption. We also measured its density. These evaluations are important in the dissemination and dispersal of biochar in fields and in determining the extent of biochar absorption in the soil. To obtain the ideal results, the same ideal proportions of the mixture must be used to make a larger quantity of biochar pellets and as a reference or reliable measurement.

3.6. Density

To calculate the density of biochar, several methods have been used, including the use of a Vernier calliper. Five measurements of the biochar pellets were taken in each test, and the average value was calculated for each test to accurately calculate density. The pellets were cylindrical in shape. In the following equations, m is the mass of the single pellet, ρ_{Av} is the average density, r is the radius of the pellet, and l is the length. Mass was determined using a balance scale, with a readability of 0.1 mg, while radius and length were measured using a Vernier calliper with a precision of 0.01 mm.

$$A = \pi r^2 \quad (5)$$

$$V = A * L \quad (6)$$

$$V = \pi r^2 * L \quad (7)$$

$$\rho_{Av} = m/v \quad (8)$$

3.7. Mechanical strength

The compressing strength Ts was measured using a hardness tester (Amandus Kahl, Germany), where the area of the biochar ball was measured, and then the ball was pressed through a spring that moved through the piston. The compressive strength is indicated in kilograms. On the spring grid, the value of the equivalent breaking mass (ms) could be determined. The device is controlled with the button control until the ball breaks. [50]

$$TS = F/\pi r l^2 \quad (9)$$

$$A = \pi r^2 \quad (10)$$

$$TS = F/A \quad (11)$$

$$TS = mg/\pi r l \quad [Pa] (12)$$

3.8. Multicote 4 15-7-15(4)-TO 4M

$$A_{Av} = 4/3\pi r^2 \quad (13)$$

$$Ts_{Av} = F/A \quad (14)$$

The shape of the compost grain was circular. The mechanical strength of Multicote was 1.4 Mp.

Figure 19: Mechanical strength machine

Figure 20: Multicote 4

3.9. Comparison of mechanical strengths between the Multicote 4 fertilizer and biochar pellets from mixture no 10

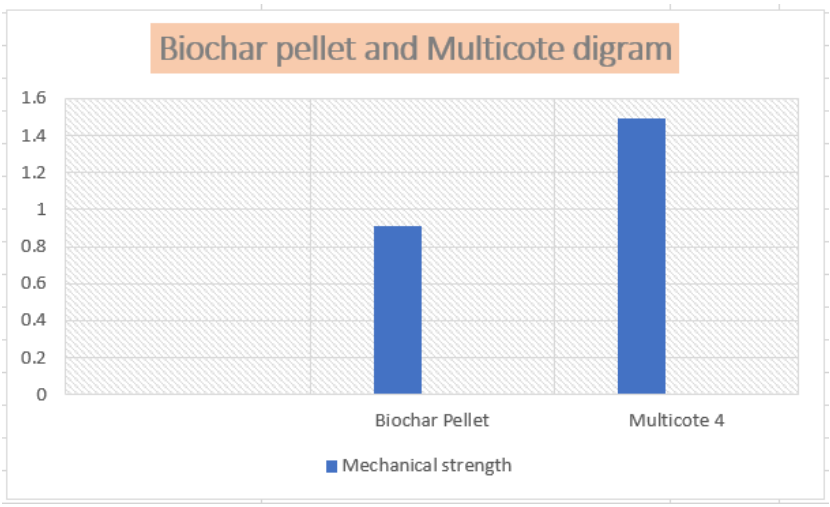

Figure 21: Mechanical strength comparison

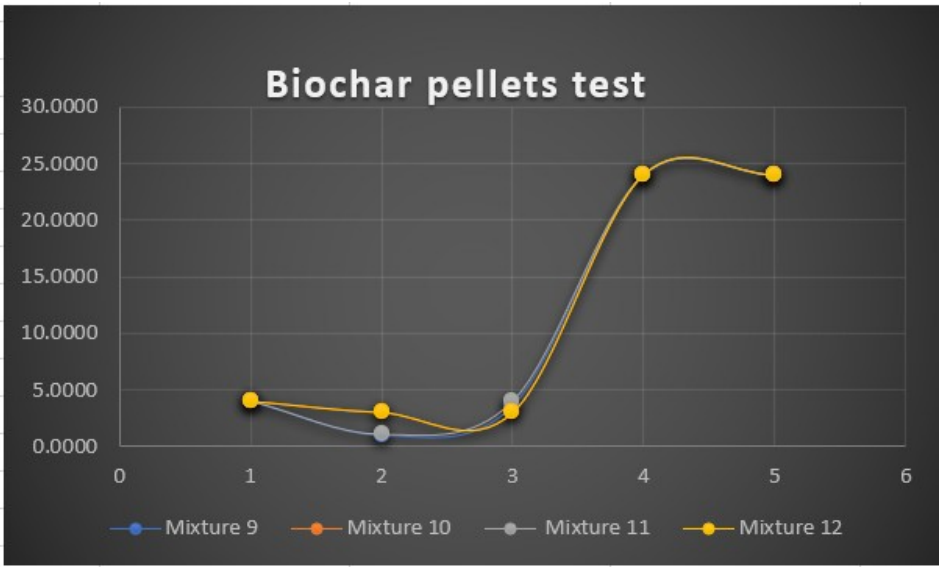

Figure 22: Agglomeration pellet method

3.10. Density, mechanical strength, and pellet pressure values

The biochar pellets in the primary samples were compressed using hand pressure in each test (Table 8).

Table 8: Results of the density and mechanical strength measurements

Test No.	Density (kg/m^3)	Mechanical strength (Mp)
1	884.6	0.222
2	870	0.119
3	795	0
4	778	0.069
5	596	0.617
6	943	0.866
7	761	0.287
8	932	0.330
9	843	0.359
10	656	0.991
11	795	0.178
12	680	0.559

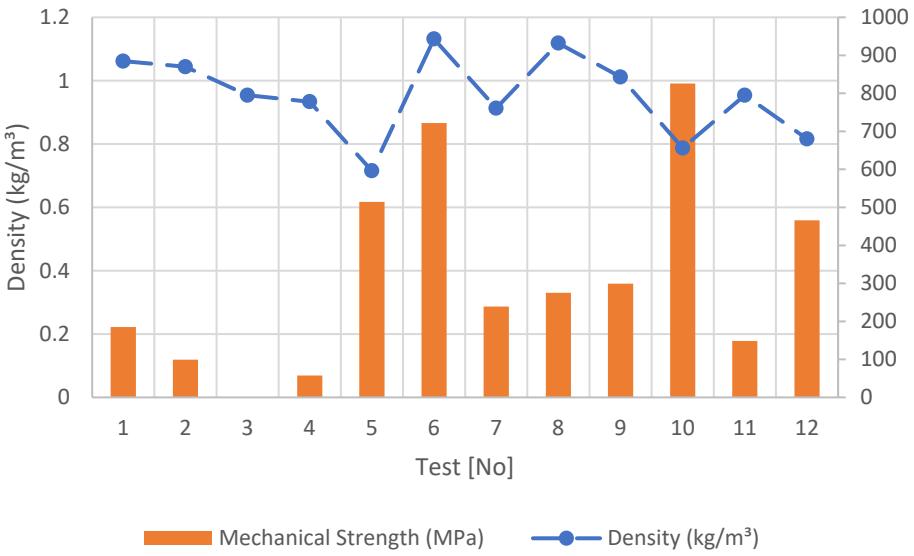

Figure 23: Graph of the densities and mechanical strengths of the biochar pellets

3.11. Processing of biochar pellets by agglomeration machine

About 2500 grams of biochar were crushed and agglomerated to make an appropriate amount for the biochar scattering test. I took the same proportions for mixture number 10. The machines proposed for making biochar pellets did not work. When turning the shaft of the machine manually, the mixture moves in a horizontal direction. The biochar pellets fall over each other due to the force of gravity. Figure 24

Figure24 .Agglomeration machine

Figue25. Biochar pellets

The mixture was placed, rolled and pressed manually into a container and then cut to from it into biochar pellets. Afterwards, pellets were placed at the same drying temperature and squeezed to produce an appropriate amount for the biochar scattering process in figure 25

Figure 26, Biochar spreading test

Chapter 4

4. Results and Discussion

The most important recommendations to help the Oplandske Bio plant is to grind biochar. A biochar crushing machine has been developed to produce biochar in powder form. We also recommend taking advantage of the biochar powder that remains after the biochar production process, which is usually found inside the biochar manufacturing machine. After the grinding process is completed, biochar must be mixed with nutrients; in this case, we suggest using compost. Compost consists of organic waste such as rice straw, redwood, hay, tree pruning products, or animal waste. It should not have an unpleasant odour. It should be mixed with biochar in a 1:1 ratio. The mixture must be mixed well at least 2 weeks before it is combined with the soil and moistened. Biochar has a high potential to bring significant benefits to the environment through its soil amendment and remediation capacities, as it has the potential to improve soil quality. It can increase the yield of agricultural crops by creating good soil conditions for optimum water and nutrient uptakes, which can lead to sustainable agriculture globally.

4.1. Results on agglomeration

Figure 13 shows a chart of the proportions of biochar, lignin binder, and water presented in Table 4. The experiments were conducted with different ratios, as shown in Table 4, to determine the best sample for the testing process. First, we took safety and security measures in the factory to avoid risks from biochar dust, binders, and laboratory equipment. Biochar was grinded using a biochar mill with a 2-mm mesh. The samples were mixed in the indicated proportions, and biochar pellets were made at a manual pressure on the piston at approximately 2 Mp. The formed biochar pellets were placed in small containers for drying with a desiccator at 105°C. The results of the four tests were poor because the mechanical strength of the pellets was weak. The binder used in the four experiments was lignin. The physical state of the pellets was fragile. Their densities were also measured (Table 4). Table 5 shows the new ratios from the four tests of the

biochar and lignin binder. The amount of lignin was increased. The lignin used in mixtures 5 and 6 is lignin was in powder form. As for mixtures 6 and 8, liquid lignin was used. The mixture remained stable for 24 hours. After that, biochar pellets were dried for 24 hours. The results of mixture 6 showed deformation and warping of the biochar pellets, resulting from the increase in the percentage of lignin, which was more than the amount of biochar powder at the rates shown in Table 5. The results showed an increase in mechanical strength compared with the rest of the samples in Table 4. Table 8 shows the results of the mechanical strength and density measurements for each mixture. Table 6 presents the new and different ratios from Tables 4 and 5. A large amount of biochar was ground at a higher degree, using a biochar grinding machine with a 0.8-mm-diameter mesh hole. Lignin powder was used in test 10. The results were good in terms of the general shape and mechanical strength of the biochar pellets compared with the results of mixture 9. This was due to the softness of the biochar powder, ground using an 0.8-mm mesh. For mixtures 11 and 12, liquid lignin was used. The results showed weak mechanical strengths (Table 8). The results of mixture 13 showed slight cracks in the biochar pellet samples compared with the results of mixture 10.

Other experiments were conducted with a mixture of sunflower oil and biochar. As shown in Table 7, the results indicated weak mechanical strengths. The other test was to mix biochar powder with liquid fertiliser in the proportions shown in Table 7. The test results indicated weak mechanical strength. The compound mixture increased the fortification of the soil and enhanced the growth of farm crops.

A comparative test was performed between the mechanical strengths of the Multicote 4 fertiliser and the biochar pellets for mixture 10, and the results were similar (Chart 21, page 43).

- Results on making a large amount of biochar

The machine proposed to make biochar pellets, Figure 24, failed completely to make biochar pellets. Therefore, the biochar pellets crumbled and tumbled into each other when placing the mixture and pressing in a circular motion. However, it's due to terrestrial gravity. The second point is that a very soft mixture comes out through the machine's slots, even for the dry mixture. The reason is that the mixture is moved and pressed horizontally, and the biochar pellets fall vertically. Alternatively, the mixture was placed

and distributed on the tray and was cut manually, as shown in figure 25

- Result om spreading test

The process of spreading biochar was tested on the field, where the height of the spreader was 70 cm. The shaft operates at 540 rpm. The radius of the spreader biochar particles was measured from the machine to the last point of biochar and was 9m. The width of the area where the biochar is spread is about 6.5m. The experiment was very successful. Every 2.5 kg of biochar covers an area of 18 m.

Chapter 5

5. Conclusion

Finally, we suggest the use of biochar to improve soil fertility. Biochar can be used to treat agricultural soils to reduce acidity. It has the ability to supplement soil microbes, which in turn improve soil fertility. Biochar is used in many applications, including as feed supplements to improve agriculture. The agglomeration of biochar with nutrients was used so that biochar can be formed into pieces of different sizes by using sieves. Thus, the process of sorting sizes is important. Biochar should also be spread and distributed according to the required distances in meters.

Chapter 6

6. Future works and outlook for biochar

The outlook for the Oplandske bioenergy plant for biochar must be developed to increase energy production. The factory is now working with one machine for biochar production. The plant needs to mix biochar with nutrients to increase agricultural production. Farmers must increase their agricultural production, so as a future vision, biochar as a fertiliser must be developed. Biochar washing machines must be added to the bioenergy plant. The agglomeration of biochar is important for Oplandske bioenergy. It is important to modify the current production line into two production lines to support biochar and other biochar products for fertilisers. Biochar sieves are important for sorting biochar into different sizes required by the labour market. Some biochar products are used for cats and cows, so we recommend them to be in various sizes. Biochar is the future outlook considering that the world is now focusing on enhancing agricultural production. The most important challenges and views of the world regarding biochar are to develop biochar for all possible applications in the area of energy consumption and in other areas that support the use of biochar in various fields. For the future of Oplandske bioenergy, we recommend using a grinding machine and mesh with a diameter of 0.8 mm to grind the biochar to a new grade to increase the bonding strength of the coal buttons. The second and most important recommendation is to use strong binders to reduce the cost and increase the mechanical strength of biochar pellets.

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