Evaluating Sewage Sludge Compost: Biofuels Production on Disused Open Pit Mines in Northern Spain

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Abstract: - During the last decades the Asturian Carboniferous Central Basin (ACCB) has been exploited by means of open-pit and underground mining. Even though it is regarded as a crucial economic activity worldwide, mining has a significant negative impact on environment. Due to its nature, especially opencast mining inevitably leads to serious degradation on ecological and aesthetic values of the landscape. Topography and drainage, air, soil and water quality, vegetation including forest ecosystems, noise levels and ground vibrations, human health and habitation can be listed as the typical parameters that are mainly affected by opencast mining activities. When the extraction of reserve is over, the altered landscape has to be reclaimed in order to relieve the damaging effects of opencast mining and restore the landscape and its immediate surroundings. Although these are soils with very poor conditions, these lands can be used for the production of solid biofuels through short rotation energy crops. The main objective lies in the search for the species that best adapt to the conditions of the environment, since there is hardly any organic matter and the nitrogen content is scarce. The biofuels produced can help meet the 20-20-20 target, which is a commitment that aims to reduce 20% the consumption of primary energy and greenhouse gas emissions and increase renewable energy production by 20%.

Key-Words: - Post-mining recultivation, energy crops, biofuels, mining land management, forestry biomass.

1 Introduction

The forecast for the year 2020 is that 20% of the energy consumed in the European Union (EU) processes from renewable energy sources [1]. In order to comply with the EU's energy and climate objectives, it would be necessary for part of this energy to come from biomass as it is a sustainable option, as well as being considered as a promising alternative at present, since the confirmation of the negative effects on the environment of the use of fossil fuels, made the most developed countries, including Spain and the EU, adopt commitments to promote the use of clean and renewable energy sources [2] [3]. Therefore, it is predictable that the use of biomass as an energy source will increase by 45% from 2006 to 2020, which would represent 8% of the expected increase in renewable energy in the European Union [4].

Among the advantages it presents, we can highlight the diversity of its resources and conversion technologies which makes it an extremely versatile energy source, capable of replacing fossil fuels in a sustainable and environmentally friendly manner and contributes to the reduction of greenhouse gases [5].

In this context, the woody biomass, and within it the forest biomass, is considered as an attractive source of renewable energy, with thermal and electrical applications [6]. In addition to other possible advantages, as pointed out by [7] that indicate that the establishment of biomass plantations for the production of energy would serve as a recovery activity in rural areas, the neutral CO_2 balance or even the recovery of degraded areas. All these reasons mean that the installation of forest crops with bioenergy purposes can be considered a promising future option.

This type of plantation is known as energetic forest crops (Internationally Short Rotation Coppice "SRC"). Among the many advantages they present, it stands out that they can be installed in a wide range of land types, including marginal lands [8]. [9] recommended planting SRC on marginal lands, in parallel with other options for sustainable land management. In this way, the use of SRC in poor land also contributes in the long term to improving soil quality and biodiversity, as well as protecting groundwater and preventing soil erosion.

In this context, a research project set up in spring 1995 aimed to investigate for the first time the extent to which widely available mining substrates would be suitable for cultivation with hybrid poplar clones [10].

Regarding the uses of energy produced with biofuels, these can be for heating, cooling and production of hot water in the domestic sector (single-family homes, neighborhood communities, neighborhoods or entire municipalities), heat for industrial processes and electricity generation. In summary, the entire set of energy sources comprising the biomass can have both thermal and electrical applications.

2 Restoration of degraded mining land

Coal mining in the North of Spain has involved the production of significant quantities of ore during the last decades. The mineral produced is used for the production of electricity in electrical power plants.

During mining, significant amounts of soil and overburden have to be moved in order to access the coal seams beneath. For deep mines, there is less disruption to the surface in terms of soil and overburden removal but there is a significant amount of removal of weight bearing coal and related rocks which must be replaced to avoid collapse or subsidence. For surface mining, there can be significant amounts of overburden and soil which need to be removed, stockpiled and then either disposed of or returned to the site for back-fill and contouring. However, during this stockpiling period, maintenance of these materials is important with respect to safety and maintaining the integrity and potential reinstatement.

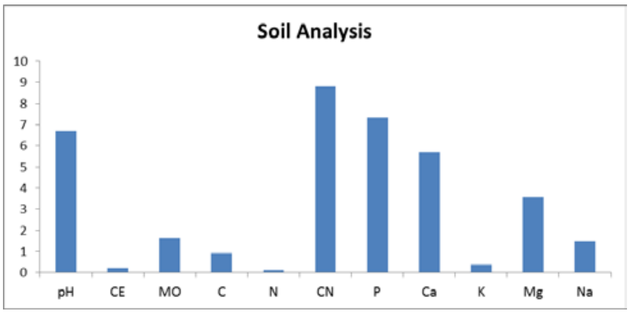
Figure 1. Open pit coal mine. Exploitation phase

Figure 2. Open pit coal mine. Restoration phase

In addition to the alteration in the water network, open-pit mining produces an important impact on the landscape, with visual impacts that must be restored to the end of the extractive activity. The restoration of affected lands is one of the main costs in open-pit mining. The first phase consists of the topographic restitution and the creation of a water drainage network that gives stability to the restored lands, avoiding erosion phenomena as a result of the circulation of runoff water. Later a layer of vegetal earth is added and it is finished with the hydroseeding of the lands.

One of the main objectives of the restoration of lands affected by mining activity is the improvement of soil properties. Figure 3 shows the results of the edaphic analysis in the restored soils, where the reduced percentage of organic matter and nitrogen can be appreciated.

Figure 3. Soil analysis in restored areas



The restoration can be approached from two points of view: environmental or protective restoration, and productive restoration. The environmental restoration is based on the repopulation with autochthonous arboreal species, with a slower growth, and a short-term economic benefit is not sought.

On the other hand, through productive restoration, short-term restored land is valued by planting fast-growing energy crops. With this type of crops, much higher growth is achieved and by applying shorter cutting shifts, economic benefits are obtained from the first years using the biofuels obtained for the production of energy. Although the initial investment is higher in the case of productive restoration, the profitability is much higher than in the case of environmental restoration.

3 Methodology

In 2008 research began on a restored surface of old mining operations with an extension of 7.5 ha that were planted with forest energy crops using different clones of poplar, willow and birch. In total, 3 trials were carried out in different recovery areas: Mozquita, Cantil I and Cantil II, between 2008 and 2010.

Figure 4. Plantations in restored mining areas. General view

Figure 5. Trial with poplar clone

The study area is characterized by an average annual temperature of 13°C and an average annual precipitation of 1,115 mm, of which 345 mm falls during the growing season (May–September). The climate is oceanic with high annual precipitation and, although summer precipitation is relatively low in some areas, physiological drought does not occur in any part of the region, which is located entirely within the European Biogeographic Atlantic Region.

Soil formation is at an early stage and the soil structure is still unstable. The steep slopes of the terrain minimize groundwater effects. The physiography of the plots was characterized by a mean slope of 19% and an elevation ranging from 508 to 597 m above sea level.

The first of the plantations was carried out in 2008, the factors to be studied in this first trial were: the type of clone, the density of plantation (two levels: 10,000 and 15,000 plants ha^{-1}) and the treatment (F0=Control F1=300 kg ha^{-1} NPK 6:20:12 and 4 l ha^{-1} glyphosate, F2 = 600 kg ha^{-1} NPK 6:20:12 and 4 l ha^{-1} glyphosate).

The amounts of fertilizer to be used were chosen in view of the results obtained in the soil analysis prior to planting, taking into account the maximum amount of nitrogen allowed to be applied in vulnerable areas, which is 170 Mg ha^{-1}.

The information regarding the growth was obtained following the protocol described by the [11] for the data collection in willow and poplar plantations in short rotations. According to their indications, the number of shoots per strain, the height of each one of the shoots (m) and the basal diameters (at 0.25 m from the ground) and normal (at 1.30 m) of all of them were measured.

4 Results

The results of biofuel production reflect encouraging figures for some of the crops that have been tested, reaching productions even higher than those obtained by native species in natural soils in the vicinity of the restored lands.

Table 1 shows the results obtained, with maximum productions reached of 95 t ha^{-1} of wet biomass for poplar clones AF2 (populusxcanadensis), with a level of fertilization F2, of 600 kg ha^{-1} NPK. After five years of growth, the annual productions are of 19 t ha^{-1} year $^{-1}$.

Table 1. Biofuels production from poplar clones

Fertilization	Humidity (%)	Production (t/ha)	Production (t/ha/year)
F0	46	25	5
F1	50	75	15
F2	43	95	19

In addition to the annual productions, samples have also been analyzed to know their properties. Table 2 shows the laboratory results, including the calorific value of the biofuel obtained on a dry basis.

Table 2. Biofuels analysis

Parameter	Biofuel
Immediate analysis (% dry basis))	
Humidity	11.25
Ash	1.3
Volatile matter	82.82
CF	15.98
Elemental analysis (% dry basis)	
C	49.76
Humidity	5.99
N	0.58
S	0.03
O	42.34
HCV (kcal/kg, dry basis)	**4,673**
LCV (kcal/kg, dry basis)	**4,379**

The use of the biofuels produced will be destined to the production of energy. After five years of growth, the plantation was harvested for the first time. Depending on the slope of the land in which the plantation is located, this cut could be mechanized, assuming a reduction in costs. The processed material is extracted from the forest and transported to a stock for a while, producing the natural drying of the biomass.

According to the tests that have been carried out, in the North of Spain humidity drops up to 35%. When the required percentage of humidity has been reached, the forest biomass will be chipped, which would be ready for use as a fuel. Table 3 summarizes the production of thermal energy from the fuels that have been obtained.

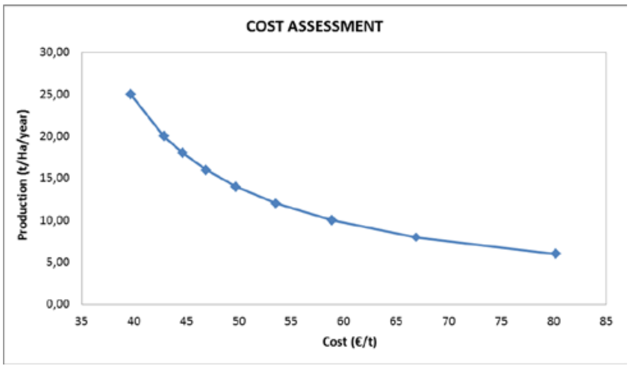
With the amounts of forestry biomass that have been obtained, the production of thermal energy is 242,903.98 kWht ha^{-1}, which if we convert it into annual production, after five years of growth, the energy production would be 48,580.80 kWht ha^{-1} year $^{-1}$.

Table 3. Energy production

Energy production	
Biomass production (t ha^{-1})	95
Humidity (%)	43.00
Humidity dry (%)	35
LCV (kcal kg^{-1})	2,200.00
Energy production (Wht kg^{-1})	2,556.88
Energy production (kWht ha^{-1})	242,903.98
Energy production (kWht ha^{-1} year^{-1})	48,580.80

Regarding the study of costs, a study has been carried out based on the annual production of biomass. Figure 6 shows the cost of the final product, in € t^{-1} as a function of production, in t ha^{-1} year^{-1}. As production increases, fuel costs are reduced, since the cost of the initial investment and annual fertilization treatments do not depend on the growth or amount of biomass generated.

Figure 6. Costs Assessment

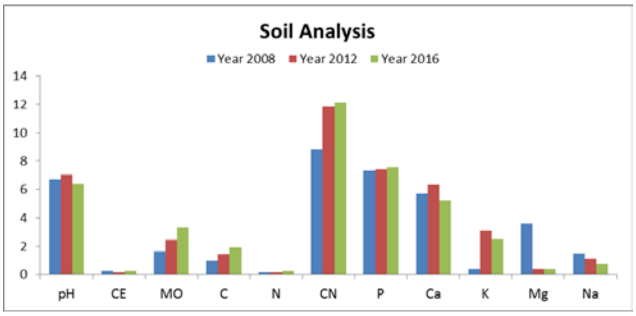


Due to the resprouting capacity of the species with which we have worked, the initial investment of the plantation would only need to be carried out at the beginning of the project.

Periodically, an analysis of the parameters of the soil has been carried out since the beginning of the trial in 2008, in order to see the evolution of the edaphic parameters and to know the transformation of the characteristics of the soil in which it is located the plantation.

Figure 7 shows the evolution of the edaphic parameters of the soils throughout the life of the plantation, with a significant improvement in the contents of organic matter and % Nitrogen among others.

Figure 7. Soil properties evolution



5 Conclusions

The exploitation of coal in open pit mines in the North of Spain has occupied large areas of land that are currently being restored. The restoration of mining operations is an obligatory activity for mining companies according to current legislation. The impacts derived from the mining activity must be corrected in the final phase of restoration, returning the landscape to an aspect similar to the original one, prior to the mining exploitation.

The restored lands can be used for the production of biofuels through repopulation with fast-growing energy crops and high planting densities. Certain poplar clones seem to grow rather well on a degraded mining soil with high pH, even when slightly polluted with heavy metals. Organic fertilization was more efficient than the contribution of mineral fertilizer, also producing a continuous supply of nutrients over longer time and reducing the risk of washing.

In addition to the production of renewable energy and capture of CO2 emissions, this activity involves the generation of a new economic activity in abandoned land and the creation of jobs in depressed areas due to the closure of mining operations.

Acknowledgements

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