Naturalized vs. Introduced Grasses: What about Carbon Capture Capability?

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***Abstract*—Moors are ecosystems with great biodiversity that are considered as one of the main CO_2 sinks. Nowadays, moors have attracted the interest of worldwide population who are concern about environment protection and global warming. Nevertheless, there are productive and economic activities that are constantly threatening these ecosystems. Livestock is one the main economic activities for high Andean population. Producers use to underutilize the native vegetative material of the area and tend to use foreign forage species that are vulnerable to adverse weather conditions and require especial management mechanisms. This paper presents the study conducted for quantifying the carbon store capability of two types of pastures (naturalized and introduced) and their ability for increasing the accumulation of soil carbon. The applied methodology included the use of temporary sample plots. All storage components were analyzed (e.g. biomass, roots and soil). The obtained results demonstrated that naturalized pastures have mayor capability for capturing carbon.**

***Index Terms*—Carbon dioxide, carbon storage, biomass, pastures, naturalized grass, introduced grass.**

I. Introduction

Moors are typical ecosystems of high altitude and with great biodiversity. In South America, the moors are mainly located in Venezuela, Colombia, Ecuador and the north of Peru [1]. In Ecuador, the moors have been considered as priority areas that need to be conserved in order to protect their soils and vegetation [2], and also because this kind of ecosystems constitutes a relevant part of the extraordinary ecological biodiversity in this country [3].

There are many reasons that allowing highlighting the relevance of the moors in the world, one of them is regarding the huge wealth of plant species. Until now, 5000 species of plants have been described on the moors and only in the moors of South America there are 4000 species of vascular plants such as grasses, herbs and shrubs [1]. This type of vegetation has demonstrated to have spectacular conditions to withstand low temperatures at the night, high solar radiation during the day, low nutrient availability in the soil and, in some cases, seasonal drought situations [4]; which are features that appear due to the tropical position of the country, the presence of the Andean cordillera and the crossing of cold and warm currents near their ocean coasts.

The extent of moorland in Ecuador is 608272 ha, approximately 5% of the total agricultural land area [5]. It is estimated that about 2 million people live in this ecosystem and depend directly on it. Peasants who live in these areas are characterized by doing subsistence productive activities related to food safety. The main purpose is self-stock up of food for their family [6].

The main economic activity of this area is livestock, however, despite the moorland livestock has many functions such as: production of milk and milk products, meat production and fighting bulls, usually, it is a very inefficient and unprofitable livestock, but with great cultural roots [7].

The forage potential of the Ecuadorian moors was deciphered some years ago, and it was highlighted the agro-productive characterization of forage species that inhabit these ecosystems. In [8], authors conducted an study about livestock management using native and naturalized grasslands. As result of this study, some technological elements for underpinning and supporting sustainable livestock management were generated. Also, the study allowed identifies 4 promising forage plants such as *Arrhenatherum elatius.* If these species are managed in an adequate way then, they could overcome introduced grasses features.

However, Ecuadorian people are immersed in a submission and consumerism culture and they tend to assume that foreign things are the best. Agricultural and livestock activities are not immune to this reality. The producers, either through ignorance or lack of interest, waste the vegetative material from the area, preferring to use foreign forage species that are vulnerable to adverse weather conditions and require especial management mechanisms [9]. Producers are forced to indiscriminately use chemicals products (fertilizers) in order to ensure an adequate forage production activity that allows sustaining the livestock, causing an excessive rise in the production costs.

In this context, the ecological impacts caused by a livestock whose food base are introduced pastures are: 1) alteration of the native vegetation, 2) soil compaction and decrease its ability to retain water, 3) increased rates of erosion, loss of organic matter and soil acidification by overgrazing, and 4) increase of the agricultural frontier [1].

In other way, the relevance of the moors goes beyond the biodiversity; these ecosystems are considered as the biggest CO_2 (carbon dioxide) stocks. Also, the moors have won great interest, due the growing global concern about the

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environment and global warming, thanks to their great CO_2 retention capability [10].

Global warming can be defined as the increase of the global average temperature. This situation has worsened between 1970 and 2000. During this period, an increase of 0.6 °C was recorded in the global temperature [11]. This problem is attributed to the accumulation of greenhouse gases (GHG) in the atmosphere, such as carbon dioxide (CO_2), methane, nitrous oxide, among others.

The GHG commonly derived from the use of fossil fuels, industrial processes and livestock systems and the constant pasture degradation, deforestation and changes in soil use; have also significantly contributed to the increase of CO_2 in the atmosphere [12], [13]. This gas (CO_2) is the responsible for the greenhouse effect apparition. It is relevant to mention that the majority of the emitted gas has an anthropogenic origin. However, according to the guidelines established in the Kyoto Protocol, there are two alternatives that lead to the reduction of these gases. On one hand there is the commitment to substantially reduce anthropogenic CO_2 emissions, and on the other hand, the protocol highlights the need to create, maintain and/ or protect ecosystems due to their utility as carbon sink. It is expected that the idea of safeguarding the integrity of natural environments is conjugated with the development of local and international mitigation projects framed on the principle of the clean development mechanism (CDM) [11].

This paper presents the study of carbon sequestration of two forage species; the first one is a promising grass, naturalized in Ecuadorians moors (*Arrhenatherum elatius*). The second one, is an introduced grass that is commonly used in the Ecuadorian livestock high Andean. Both of these species allow generating economic gains based on livestock activities, and also they are capable for giving environmental benefits to the communities that are responsible for manage and conserve them.

Even though, the monitoring of carbon sequestration constitutes an essential tool for climate change mitigation projects, few related researches have been conducted in Ecuador. The present study intends to contribute with the biodiversity conservation and also to generate alternatives for guiding the producer in the selection of the best pasture for his ecosystem. It is hoped that this research will contribute to the development of sustainable livestock that allows prioritizing the use and conservation of local natural resources.

II. State of the Art

Global warming was the main responsible of the increase in greenhouse gases during the past decade. The infrared radiation trapped by high quantity greenhouse gases such as CO_2, caused an increase of 25 percent since 1850. This excessive emanation is the result of fossil fuel combustion and mainly change land use [14].

The emission quantity of greenhouse gases in comparison with 1990 year, presents an increase of 41 percent [15]. Then, it is necessary that some measures are taken into account in order to reduce greenhouse gas emissions and increase carbon sequestration in soils and biomass.

The latest evidence of climate change in Ecuador revealed an unusual extreme weather events such as: increases in precipitation, drought and the trend of melting glaciers [16]. Considering that Ecuador have large moors areas I would be beneficial use them as CO_2 sinks in order to contribute with the reduction of global warming.

A. Greenhouse Effect

The greenhouse effect is an atmospheric phenomenon caused by certain gases in the atmosphere. These gases can keep the planet's temperature because they retain some of the energy from the sun [17].

Although this is a natural phenomenon, the anthropogenic effect, has changed the balance of that phenomenon, significantly altering the atmosphere concentration of greenhouse gases. This issue is causing extended greenhouse effect, whose main consequence is global warming due to increase of radiation retained by greenhouse gases.

CO_2 is considered as the gas of major influence on the greenhouse effect. It is the responsible for over 54% of the "extended" greenhouse effect. Although this gas appears naturally in the atmosphere, the human activity has led to a release of carbon stored at an unprecedented rate. Currently, annual emissions amount to more than 7.7 billion metric tons of carbon, of which 75% is due to the combustion of fossil fuels dioxide and 25% to changes in soil use and deforestation [18]. Plants have the ability to absorb 55% of CO_2 emissions. However, this atmospheric gas has a residence of 50 to 200 years. That means that if the emission of this gas is stopped, it would be necessary to wait more than a century in order that the concentration in the atmosphere decreases.

B. Global Carbon Cycle

There is strong evidence that human activities are disturbing the carbon cycle significantly and that the negative consequences of climate change induced are likely. As carbon dioxide is one of the main determinants of climate change further the understanding of the carbon cycle is of great importance.

The global carbon cycle is recognized as one of the main biogeochemical cycles due to its participation in the regulation of CO_2 concentration in the atmosphere. The increase of CO_2 concentrations in the atmosphere represents a factor which participate in the climatic change [19]. Plants are one of the most important CO_2 stores in the world and they are responsible of most of the carbon flows between soil and atmosphere [11]. The physiological processes that participate in this process are photosynthesis (CO_2 capture to transform carbohydrate) and respiration (oxidation of carbohydrates to release CO_2) [20]. During thousands of years these two flows have been balanced.

C. Carbon Stored in Soil Use Systems Relevant for Livestock

Kyoto Protocol established that the process for capturing carbon allows stimulating relevant changes in the soil use, stimulating a positive impact over the environmental and agricultural properties and the biodiversity. Grazing lands play a key role in the carbon sequestration. This kind of ecosystems participates in the regulation of atmospheric carbon [11].

The moors are ecosystems that offer significant environmental services and they are the source of one of the main resources for humans. These ecosystems have the capability for fixing atmospheric carbon, especially in soils. This fixing capability is due to the low temperature, high moisture and low mineralization rates of organic matter. For this reason, the moors have become potential carbon sinks [21].

In addition, the moors are considered strategic ecosystems that supply environmental services such as water regulation, and have a significant content of carbon which is accumulated not only in biomass (vegetation) but also in the soil organic matter; due to the low rates of decomposition that they present.

III. Case Study

A. Geographic Location

In order to identify the potential for carbon storage in two different types of forages (naturalized and introduced grasses), the low zone of Chimborazo Faunal Reserve was selected as case study.

Chimborazo Faunal Reserve is located in Chimborazo province in Ecuador country. The low zone has a surface area of 2610.38 hectares. This place has an altitude range of 3240 - 3600 masl. San Juan town, located in Chimborazo province was selected as study area.

B. Weather Conditions

Taking into account the similar conditions of climate, altitude, rainfall and accessibility, 2 communities belonging San Juan town were selected. The selected places were: UCASAJ and Santa Isabel communities. Table I summarizes the characteristics of the study area.

TABLE I: Main Characteristics of the Study Area

Characteristic	San Juan Province
Temperature Average	13.6 °C (12°C min and 16°Cmax)
Altitude Transition Area	3240 – 3600 masl
Precipitation transition zone	600 – 1200 mm
Life zone	Lower montane moist forest
Soil type	Alofanic

C. Selection and Establishment of the Study Sites

The principal criteria for considered the study sites were:

- Livestock as main productive activity of the farms.
- Pasture must be ready for pasturing
- Willingness of the owners of the farms

The forages that were selected as objet of study were: Naturalized and Introduced forage. In both communities, one place with this two kind of forages established was selected as study site. The most important specification of the forage was the age between 2 and 3 years

In this research, Naturalized forages are herbaceous grasses that have been introduced many years ago and have a high adaptation potential. If during the time passing, spontaneous naturalized flora tend to invade and domain, then these species have become in naturals, despite its origin. This is the case of *Arrhenatherum elatius* forage. This kind of grass does not require cultural practices and they are managed as native grass.

Introduced grasses are exotic species that are out they original place. Often, this species are selected by producers due to specific features, however, to ensure a high production, are necessary to carry out an intense management process, as cultural practices recurrent, fertilization and irrigation.

D. Research Method

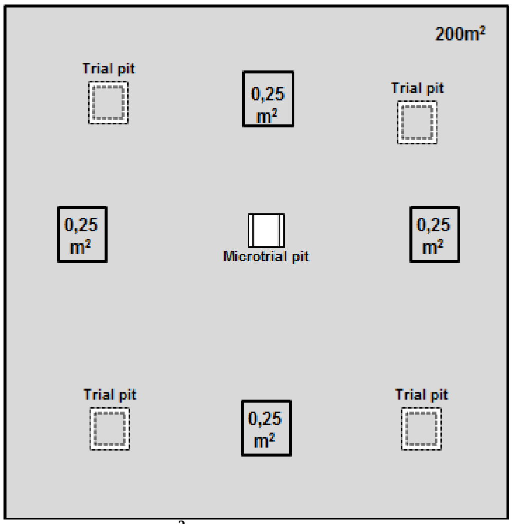
Following subsections describe the method used in this research, which was an adaptation of the research method recommended for different forage systems [11].

E. Sampling Intensity

In each one of the study sites, Temporary Sample Plots (TSP) were established. The area of the TSP used in the research was 200m^2. According to MacDicken [22], this size is recommended for inventorying forage systems in pastures. Therefore, it was established 2 TSP by each kind of forage.

F. Temporary Sample Plots (TSP)

Data collection was carried out in square plots of 200m^2. They were randomly placed within the pastures. Additionally, 4 subplots of 0.25m^2 were also randomly established within square plot. Fig. 1 depicts the distribution scheme of the defined temporary sample plots.



1 square plot of 500m^2: Delimitation of the area to be sampled.
4 subplots of 0.25m^2: Carbon storage in the forage.
4 Trial pits 50cm: Organic carbon in soil.
1 Microtrial pit 30cm: Soil bulk density.
Fig. 1. Scheme of temporary sample plot (TSP).

G. Sampling Method

In order to estimate the carbon sequestration in two different kinds of forages, 3 components involved in the storage process were evaluated. The considered components were: aboveground and underground forage biomass and soil organic carbon for each evaluated forage.

The process for determining the biomass (aboveground and underground) and the process for sampling the soil organic carbon are summarized below:

H. Biomass determination of the herbaceous stratum

Previous the sampling, in each pastures, activities for weed control were made, this activity is performed in order to take samples to evaluate only pasture. Subsequently, forage biomass was determined by collecting all the herbaceous material from 4 subplots located in the square plot (See Fig. 1).

All samples were weighed and the average value was recorded as the wet weight. A subsample of 200g was extracted to determine the dry weight of the sample in the laboratory.

I. Soil Organic Carbon

The determination of soil organic carbon in the 3 trial pits located in the TSP was carried out using a soil sampler tube. Samples of soil at a depth of 0-30 cm were collected. The samples were homogenized and a subsample of 200 g was taken to determine, in the laboratory, the organic carbon content.

The apparent density of the soil (BD) was calculated through the cylinder method described by Jadan, 2013 [23]. Cilinder method is defined as the weight per unit volume of soil.

J. Estimation Method of Carbon Storage

The estimation method used in this research, was the same used for the estimation of carbon storage in two soil use system of livestock importance in the Sumaco Biosphere Reserve cited in [11].

In that investigation, two stratums (woody and herbaceous stratum) were evaluated. In order to determinate the carbon storage of forage, a methodology proposed by herbaceous stratum was used.

The steps for estimating carbon sequestration taken from [11] are summarized below:

1) Aboveground forage biomass estimation was obtained in base of the dry weight determined in the laboratory of the grass sample obtained of subplots.
2) Underground forage biomass was estimating applying the relationship of 0.15 between root biomass and aboveground biomass
3) Once calculated the forage biomass (aboveground and underground biomass), the total biomass per forage (t/ha) was estimated. This result is present in t/ha.
4) The total biomass must be converted to carbon units (Mg/C/ha). This value was obtained applying the fraction 0.5 to the total forage biomass. This relationship was used according [24].
5) The soil organic carbon was determined through the organic carbon obtained in the laboratory, bulk density and sampling depth. The value obtained was expressed in Mg/C/ha for each forage.
6) The total carbon storage was obtained by adding the carbon stored in the biomass and the soil organic carbon.
7) The last step was the transformation of the carbon unit to equivalent carbon dioxide CO_2e. This value was determinated based on the global warming potential of greenhouse gases [25].

IV. Results

In order to determinate the capability for carbon capture and storage of two kind of forage (naturalized and introduced forages) in the Ecuadorian moors, an exploratory study that included field tests was conducted. Next subsections present the obtained results of the performed experiments.

A. Carbon Storage in the Forage Biomass

Once estimate the carbon storage in the biomass of naturalized and introduced forages, the aboveground and underground biomass was separately evaluated. Table II shows the values obtained in the 2 study sites. Thus, the main carbon storage biomass was the aboveground.

This component presented an average value of 0.82 t/ha in UCASAJ Town, in which the naturalized specie obtained a value of 1.03 t/ha, while, introduced species obtained a value of 0.61 t/ha. At the same time, in Santa Isabel Town the average value was 0.74 t/ha. In this place, the highest value obtained was 0.93 t/ha.

TABLE II: Biomass Production of Two Kinds of Grasses (Naturalizaed and Introduced). Data Obtained from Two Communities of San Juan Town: Chimborazo Moors, Ecuador

Storage components	UCASAJ		Santa Isabel	
	AE	RG	AE	RG
Aboveground biomass (t/ha)	1.03	0.61	0.93	0.55
Underground biomass (t/ha)	0.15	0.09	0.14	0.08
Total carbon biomass (Mg C/ha)	0.59	0.35	0.54	0.32

Note: AE: *Arrhenatherum elatius (Naturalized grass)*, RG: *Rye grass (Introduced grass).*

The value of carbon capture in the underground biomass corresponds to a lower storage stock but not least important. This value has a direct relationship with aboveground (Fig. 2).

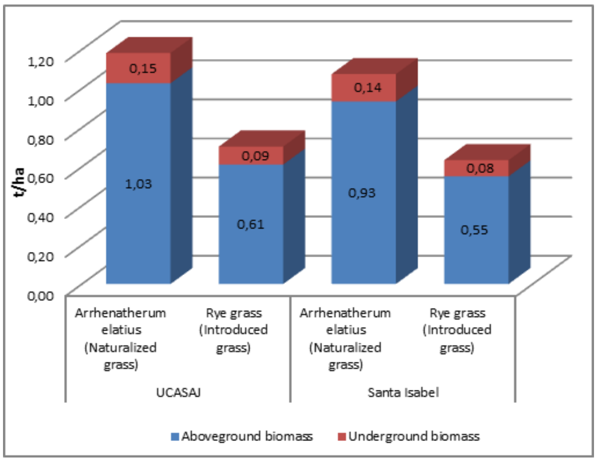


Fig. 2. Biomass production of two kinds of forage (naturalized and introduced) in communities of San Juan Town, Chimborazo moors.

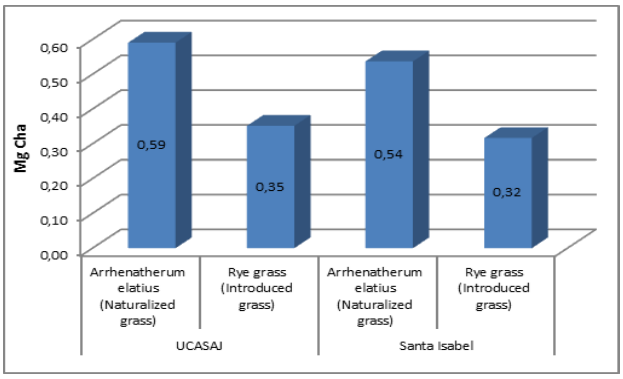


Fig. 3. Total carbon Biomass storage of two kinds of forages (naturalized and introduced) in two communities of San Juan Town, Chimborazo moors.

The biomass production presents a bid difference between the forage evaluated. In both towns, the naturalized grasses recorded the highest biomass production compared with introduced grasses with a numerical difference of 0.1 t/ha (Fig. 2).

Regarding the quantity of carbon storage showed in Fig. 3, Naturalized grasses registered the highest value with 0.59 Mg C/ha and 0.54 Mg C/ha in UCASAJ and Santa Isabel respectively, while introduced grasses obtained 0.35 and 0.32 in the same places. These results evidenced that, the naturalized forage like *Arrhenatherum elatius*, are capable for producing more biomass than the introduced forages (*Rye Grass*). This production was obtained despite adverse environmental conditions prevailing in the study area.

In other way, it is important to highlight that biggest carbon stock was the soil, in which, the carbon is storage due the physiologic process of the plants and organic matter accumulation, in this context, the naturalized forage trans located more carbon than introduced grasses (Table III).

TABLE III: TOTAL CARBON STORAGE OF TWO KINDS OF PASTURES (NATURALIZAED AND INTRODUCED). AVERAGE OBTAINED FROM TWO COMUNITIES OF SAN JUAN TOWN: CHIMBORAZO MOORS, ECUADOR

Storage components	Pastures	
	AE	RG
Total carbon biomass (Mg C/ha)	0.56	0.33
Soil organic carbon (t/ha)	281.34	257.40
Total carbon (Mg C/ha)	281.90	257.73
CO_2 estimated (t CO_2e/ha)	1034.59	945.88

Note: AE: *Arrhenatherum elatius*, RG: *Rye grass*.

Carbon contents stored in the soils are the product of the constant flow of organic matter provided by the plant biomass. Then, according to the obtained data, naturalized forages have higher flow of organic matter. The soil organic matter is the main determinant of biological activity. The amount, diversity and activity of soil, fauna and microorganisms are directly related to the organic matter. Organic matter and biological activity that they generate have great influence on the chemical and physical properties of soils [26].

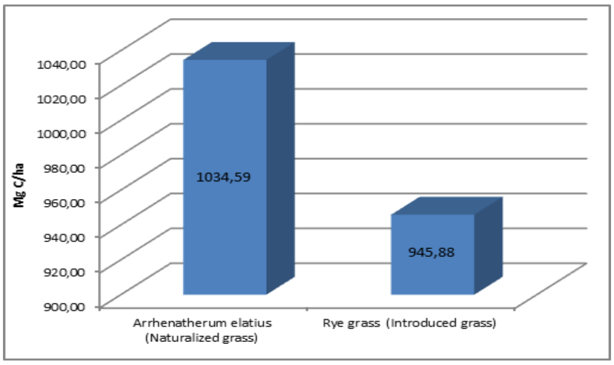


Fig. 4. CO_2e (t/ha) two kinds of forages (naturalized and introduced) in two communities of San Juan Town, Chimborazo moors.

It is relevant to mention that for these both types of forages, the management process is completely different. In one way, introduced forages management is more arduous because they are more vulnerable to ecological conditions and adverse environmental. In order to increase the production of the pastures, producers must use conventional techniques that are not environmentally friendly.

From the results it was possible to determinate that, naturalized grasses obtained the highest total carbon storage registered (1034.59 Mg C/ha), while introduced grasses registered 945.88 Mg C/ha (see Fig. 4). These results showed that naturalized grasses help to increase the organic matter of the soil and the carbon accumulation.

Some related research works stated that the quality (nutritional value) of naturalized grasses, is similar and in some cases superior than introduced grasses quality [27]. In addition that, considering the capability of the naturalized grasses for living under moors conditions, without extreme culture practices, they can be considered as an important source of livestock food and a significant resource of carbon storage in the soil.

V. CONCLUSIONS

Carbon storage in plants depends of the biomass production. In this context, the obtained data showed that approximately 87% of the registered biomass corresponds to the aboveground component, while roots carbon storage was only 13%.

Comparing the biomass production capability of two types of evaluated grasses; naturalized ones got the highest value of biomass production in both evaluated places. Introduced grasses were overcoming with 0.24 and 0.22 Mg C/ha in UCASAJ and Santa Isabel towns respectively. The results showed that, the introduced grass production was affected by the extreme climatic conditions which are considered as common features of moors.

Regarding the quantity of carbon storage, UCASAJ town registered the highest values in both evaluated grasses. This result could be explained by the intense economic activity of UCASAJ against subsistence livestock activity of Santa Isabel. Therefore, it is possible to conclude that there is a higher flow on organic matter in this ecosystem.

This study allowed determining that the most important carbon sink is the soil. The major quantity of carbon was stored in the naturalized pastures soil. It is possible to see in Table III that there is a difference of almost 24 t/ha between both kind of pastures soil.

Finally, naturalized grasses have the capability for storing more quantity of CO_2e than introduced ones (See Fig. 4.). Therefore, naturalized pastures could be considered as a relevant carbon sink due to their ability for taking huge quantities of CO_2 through the photosynthesis process and the subsequent transformation into biomass.

Future work is focused on to study the feasibility for implementing a mechanism that allows characterizing naturalized pastures through spectroradiometry techniques [28]. This mechanism could be useful to estimate geographic areas in which these kinds of pastures are predominant. Therefore, it could be possible to estimate the total carbon capture in these ecosystems.

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