Evaluation of Greenhouse Gas Emissions from Small-scale Coffee Producers in Kiambu-Kenya Based on Calculations of the Cool Farm Tool

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Abstract— Coffee plays an important role in sustaining millions of livelihoods around the world. The effects of climate change on coffee are already perceivable. Coffee besides suffering from climate change is also a contributor. Understanding greenhouse gas (GHG) emissions from coffee supply chains is important for evaluating options for climate change adaptation and mitigation within the sector. In this study, data from 108 small scale farmers and three wet mills under Ndumberi Coffee Growers Cooperative was used to calculate the carbon footprint of coffee parchment and identify emission hotspots within different management levels. Management level was found to be the main cause of variation in carbon footprints. Carbon footprints for 1kg of fresh coffee cherries were between 0.04-0.07 kgCO_2e for high management level, 0.22-0.28 kgCO_2e for medium management level and 0.53-0.58 kgCO_2e for low management level. The main contributor to greenhouse gas emissions across all the management levels was the inputs of organic and inorganic nitrogen. At the wet mills the main source of greenhouse gas emissions was the processing wastewater. The carbon footprints at processing for 1kg coffee parchment were 2.64 kgCO_2e for Riabai wet mill, 2.62 kgCO_2e for Ngaita wet mill and 2.40 kgCO_2e for Ndumberi wet mill. From the results obtained, a site specific mitigation framework is proposed to suit the capabilities of different producers.

Keywords— Carbon footprint, climate change, greenhouse gases, management level

I. Introduction

AFTER oil, coffee is the most important tropical commodity traded by developing countries worldwide [1]. For many developing countries, coffee is the primary export product [2] and a vital contributor to foreign exchange earnings as it accounts for a substantial part of tax income and gross domestic product [3]. In 2012, more than six billion kilograms of coffee were shipped worldwide providing employment for about 26 million people in 57 producing countries [4]. The production of coffee takes place exclusively in poor nations with farmers residing in regions of Africa, Latin America, Southeast Asia and consumers living in Europe, North America and in rapidly developing areas of Asia [1]. According to the Fourth Assessment report of the Intergovernmental Panel on Climate Change, global temperatures are recorded to have increased by 0.74ºC during the 20th century [5]. Most scientists agree that this warming in recent decades has been caused by human activities such as burning of fossil fuels and deforestation, which have increased the amount of greenhouse gases in the atmosphere [6]. The effects of climate change are clearly perceivable, and are being felt worldwide. This is especially so for farmers who are dependent on climate for their livelihoods. In tropical and subtropical regions, rising temperatures will negatively affect food production and increase pest outbreaks. Agriculture, besides suffering from the effects of climate change, is also contributing significantly [5]. Agriculture alone is responsible for 12 percent of global GHG emissions, mainly as a result of poor agricultural practices [7].

In the coffee sector, there is need for climate change mitigation in agricultural supply chains [8]. Individual voluntary standards active in the coffee sector, such as Rainforest Alliance and the Common Code for the Coffee Community (4C Association) are already actively working on designing standards that can encourage and validate climate friendly coffee farming [9],[10]. Carbon footprint has become a widely used term and concept to define responsibility and abatement action against the threat of global climate change [11]. A carbon footprint is the sum of all the emitted greenhouse gases during the lifecycle of a product. The eventual aim of carbon footprint disclosure is to work on emission reduction along supply chains and to provide consumers with information that enables them to choose a product that is carbon friendly [12]. Exporters of agricultural products are being required to measure and take actions to reduce greenhouse gas emissions in their supply chains by retailers and cooperations in the European Union, the United States of America and several emerging economies [13]. In developing countries, the capacity to comply with this newly arising carbon standards is limited [12]. Worldwide standards and methodological frameworks have been developed in the context of carbon footprints. The developed standards aim to identify measure, reduce, mitigate and even neutralize the emission of products, events, companies or territories [13]. The British government through its department for environment food and rural affairs (DEFRA) and the Carbon

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Trust, teamed up with the British standards institute (BSI) to create a methodology for calculating GHG emissions embedded in goods and services by developing the Publicly Available Standard 2050 (PAS 2050) [14].

To date, there is little information in scientific literature about carbon emissions in the coffee sector [15]. This is especially true for Kenya where very few studies on carbon emission in coffee have been done. The main purpose of this study was to determine the carbon footprint of a Kenyan smallholder production system using the Cool farm tool guided by PAS 2050. Additionally, the study sought to identify 'hot spots' of GHG emissions in the coffee supply chain, in order to determine where mitigation efforts should be focused.

II. Materials and methods

This study was conducted in Kiambu County focusing on farmers from Ndumberi Coffee Growers Cooperative Society. This Society has 2600 members with 2127 of them active. The average number of trees per member is approximately 200 (0.15 ha) with an average production of 3kg cherry per tree. It has three wet mills; Ndumberi, Ngaita and Riabai. The farmers mostly fall under the Upper midland Zone UM2 which is predominantly a coffee growing zone. 108 farmers were selected in total, 36 from each wet mill. Farmers were classified based on their management level which is characterized by yields i.e. high management 5 and above kg cherry per tree, medium management 3-4.9 kg cherry per tree and low management 0-2.9kg cherry per tree. The relative proportions of high, medium and low management farmers in the entire population were 22%, 16%and 62% respectively. These proportions were factored in the sample as required in PAS 2050 [14].

A. *Boundary and cut off level of the footprint*

This study focused on emissions at coffee production and initial processing level. Only emissions occurring within the operations of Ndumberi Cooperative were taken into account. This means emissions from growing coffee in smallholder farming systems to wet processing in the mills ending at when parchment is delivered to the dry mill.

B. *Defining the functional unit*

Two functional units were defined for this study the first was one kilogram coffee cherry and the second one kilogram coffee parchment. The former was used for footprints from farm level and the latter for footprints from processing level. The footprints were thus presented as kg CO_2e/kg coffee cherry and kg CO_2e/ kg coffee parchment respectively.

C. *Data collection*

An interviewer administered questionnaire was used to collect data from individual farms. Data on yield, fertilizer and pesticide use, manure use, land use changes, shade tree number and species, coffee tree number, transport, field energy use was obtained. The diameters of coffee trees and shade trees were measured in each farm and soil samples collected for analysis of soil organic matter and ph. At the wet mills, data on transport, water and energy use was obtained and wastewater samples collected for analysis of COD.

D. *Greenhouse gas quantification*

The cool farm tool was used for greenhouse gas quantification. Data from individual farms was fed to the tool which then calculated emissions in carbon dioxide equivalents.

III. Results and discussion

The climate of the study area is tropical with an average annual temperature of 18.7ºC. The soil is characterized as medium textured and well drained with organic matter of between 1.72 and 5.16% and ph. ranging between 5.5 and 7.3. The results in table I show that farms with a high level of management are the highest yielding while those with the lowest level of a management have the lowest yields.

There was a wide variation in fertiliser application rates amongst the farmers within all the management levels. The high management level farmers use the most fertilizers (127±13.3 kg/acre) and the low management farmers use the least (70±5.2 kg/acre). Low management level farmers tend toward a more organic system with more manure application than synthetic fertilisers. A regression analysis was carried out to see the effect of fertiliser application on coffee cherry yield. The regression analysis carried out for yield and fertiliser dosage did not show any significant variation in yield with respect to fertiliser dosage in medium and low management level farms (R^2 value of 0.01 and 0.05 respectively). In the case of high management level farms, there was a weak relationship between the two (R^2 = 0.3). This suggests that there may be several other factors affecting the yield of the crop and also indicates that excess fertiliser is not necessarily contributing to increased coffee production. Other practices such as composting, integrated pest management, pruning and crop residue management all contribute to increased yields without increasing the use of synthetic agrochemicals [13].

TABLE I
AVERAGE COFFEE YIELDS

Management level	Farmer locations		
	Riabai	Ndumberi	Ngaita
High	1406	1510	1806
Medium	415	449	458
Low	238	304	342

The product carbon footprint for coffee is lowest for high management level farmers and highest for low management farmers. At farm level the carbon foot prints ranged from 0.04 to 0.07 kg CO_2e per kg coffee cherry for high management level farmers, 0.22-0.28kg CO_2e for medium management farmers and 0.53-0.58 kg CO_2e for low management farmers. Fig. 1 shows the effect of management level on carbon footprints across the three coffee growing areas. The differences in carbon footprints per kg cherry are explained by the fact that the product carbon footprint is based on the production or yield. All emissions arising from a production system are allocated to the amount of coffee produced. High management level farmers produce the most coffee thus despite using a higher amount of input the overall emission is low compared to the other management levels. The reverse is true for the low management level farmers.

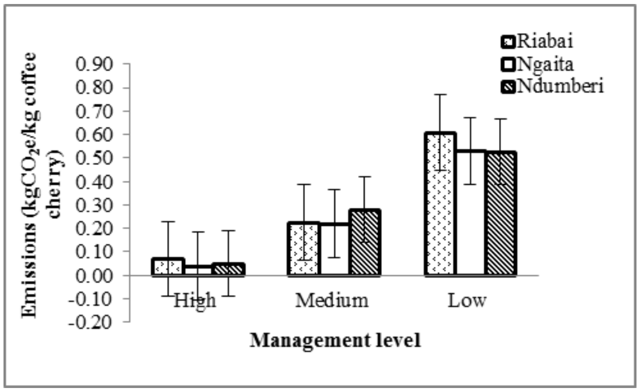

Fig. 1 Emission variation with management level

A breakdown of the various emission sources shows that the major emission source at farm level is the production and use of synthetic fertilisers. Fig. 2 shows the various emission sources at farm level. Fertiliser production and nitrous oxide emissions account for 96 % of the total on farm emissions, in contrast to this pesticides account for 1%, transport of cherry from the farm 1% and crop residue 2%. Fertilizer emissions are divided into induced nitrous oxide emissions and emissions occurring from the production of these fertilisers. Nitrous oxide emissions occur from microbial processes in soils. The process of oxidation of ammonium to nitrates and reduction of nitrate to gaseous forms of nitrogen are the sources of N_2O emissions in agriculture [16]. N_2O emissions from soils are the dominant sources of atmospheric N_2O, contributing to about 57% of the total annual global GHG emissions [17]. GHG emissions from the production of fertilisers are the result of industrial processes such as ammonia production, phosphoric acid production and nitric acid production [18].

At the dry mills coffee from each wet mill is treated autonomously [19], thus the pricing for coffee is different for each wet mill. For this reason the total average footprint for each coffee growing area was determined as in fig. 3. The footprints per kilogram cherry were 0.33, 0.28 and 0.30 kg CO_2e farmers from Riabai, Ngaita and Ndumberi respectively.

The process of wet milling requires substantial amounts of water. The average amount of water used for coffee processing at the wet mills was obtained as 12.58m^3 per tonne coffee cherry processed. After the wet processing, the remaining wastewater retains large amounts of decomposing sugars (COD 2500mg/l). When this water is not treated, it represents a source of pollution mainly if dumped into local water bodies. Additionally, the process releases gases such as methane which has a higher global warming potential than carbon dioxide.

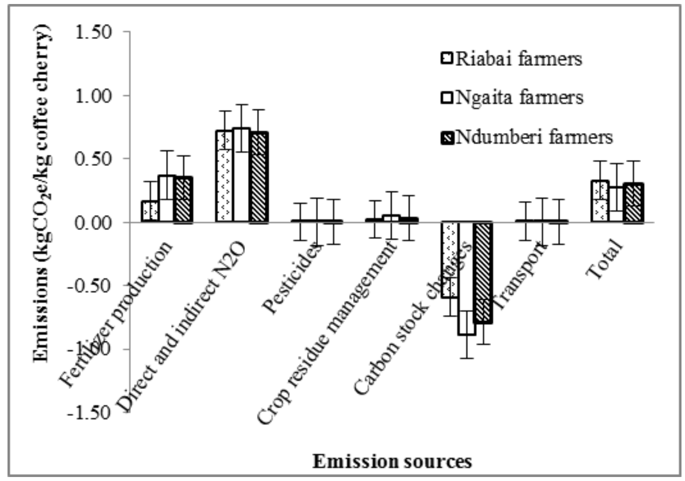

Fig. 2 Emissions from different sources at farm level

The total processing emissions for Riabai, Ngaita and Ndumberi wet mill were 2.64, 2.62 and 2.40 kg CO_2e/kg coffee parchment respectively. The emissions from wastewater are the highest accounting for 93% of processing emissions from the wet mills as shown in fig. 3.

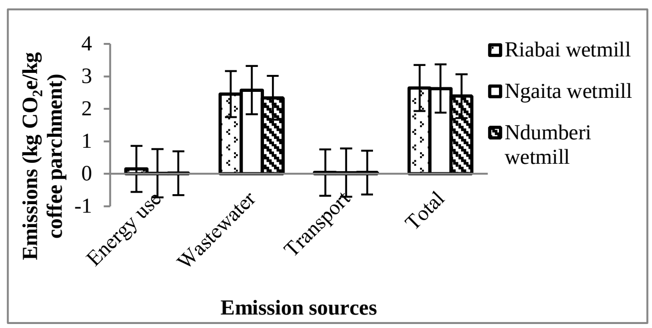

Fig. 3 Emissions from different sources at processing level

The total carbon footprint from farm to processing was calculated for each wet mill as in table II. A cherry to parchment conversion ratio of 1:0.2 was used to convert on-farm emissions to emissions per kg coffee parchment. This ratio was obtained from the data from the three wet mills based on cherry received and parchment produced. DEFRA and BSI [15] classify emissions of 1-3kg CO_2e per kg product as high intensity and >5kg CO_2e as very high intensity. Based on this, the coffee carbon footprints obtained tend towards very high intensity emissions thus effective mitigation options are required to reduce these footprints.

Effective climate change mitigation practices should focus on those factors that show the highest contribution to the total amount of GHG emissions emitted in coffee production. From the results obtained, emissions arising from all fossil fuel use, pesticide production and crop residue contribute to only about 6% of the total carbon footprint. The hot spots identified by this study are: fertilizers applied at farm and wastewater as a result of the wet milling process. These emissions are collectively responsible for 94% of total emissions in the supply chain evaluated. Carbon stock changes also contribute significantly to the carbon footprint. Mitigation strategies should therefore focus around conserving and increasing the

TABLE II
TOTAL CARBON FOOTPRINT FOR EACH WET MILL

Wet mill	Emissions at farm level		Emissions at processing level	Total emissions
	kg CO_2e/kg coffee cherry	kg CO_2e/kg coffee parchment	kg CO_2e/kg coffee parchment	kg CO_2e/kg coffee parchment
Riabai	0.33	1.65	2.64	4.29
Ngaita	0.28	1.40	2.62	4.02
Ndumberi	0.30	1.50	2.40	3.90

on farm carbon stock, reducing emissions arising from fertiliser production and application and reducing the emission arising from the generation and discharge of wastewater. From the experience in researching the coffee farms in Kiambu, it was noted that coffee production systems vary greatly depending on various factors such as input level, geographical location and economic level of the farmer. Mitigation strategies should therefore be tailored to the specific nature of the respective coffee production system.

IV. Conclusion

The purpose of this study was to get an insight into the sources of GHG emissions in selected coffee farms with different levels of management. The study found that farms with a high level of management emit less GHG than traditional or farms with a low management level. Emissions from fertilizers are the major determinant in overall GHG emissions in coffee cultivation and therefore fertilizer management is the most crucial management practice in terms of reducing GHG emissions at farm level. The use of better management practices in coffee cultivation can substantially reduce GHG emissions as these practices have a lower reliance on manufactured fertilizers. At processing level, wastewater from pulping and fermentation forms the bulk of processing emissions. GHG mitigation options in the coffee supply chain include: balanced fertilizer application (over application of fertilizer substantially increases GHG emission but does not appear to increase yields), residue management which aides in carbon sequestration in the soil and finally better wastewater treatment process before release to the atmosphere.

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