Agricultural Sciences, 2022, 13, 117-129
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Contribution of Multiple Cropping Systems to Greenhouse Gas Mitigation in the Municipality of Abomey-Calavi in Southern Benin

Vidédji Naéssé Adjahossou[1*], Baï Sêdami Adjahossou[2], Outéndé Toundou[3], Babacar Thioye[4], Dossou Firmin Adjahossou[2], Julien Gaudence Mahutin Djego[5], Michel Boko[2]

[1]National University of Science Technology Engineering and Mathematics (UNSTIM), National Graduate School of Applied Biosciences and Biotechnologies (ENSBBA), National School of Applied Biosciences and Biotechnologies (ENSBBA), Biotechnology, Genetic Resources and Animal and Plant Breeding Laboratory (BIORAVE), Cotonou, Benin
[2]University of Abomey-Calavi, Cotonou, Benin
[3]Plant Physiology and Biotechnology Laboratory, Cotonou, Benin
[4]Joint Microbiology Laboratory IRD/ISRA/UCAD, Bel Air Research Centre, Cheikh Anta Diop University of Dakar, Dakar, Senegal
[5]Faculty of Agricultural Sciences (FSA), Applied Ecology Laboratory (LEA), University of Abomey-Calavi (UAC), Cotonou, Benin
Email: *adjahossou.naesse@unstim.bj, *vidnae@gmail.com

How to cite this paper: Adjahossou, V.N., Adjahossou, B.S., Toundou, O., Thioye, B., Adjahossou, D.F., Djego, J.G.M. and Boko, M. (2022) Contribution of Multiple Cropping Systems to Greenhouse Gas Mitigation in the Municipality of Abomey-Calavi in Southern Benin. *Agricultural Sciences*, **13**, 117-129.
https://doi.org/10.4236/as.2022.132010

Received: November 25, 2021
Accepted: February 6, 2022
Published: February 9, 2022

Abstract

In the world at large, while agricultural yields are increasing with constant land area, in Sub-Saharan Africa, more land is needed to increase production. In this region of Africa, agriculture therefore remains essentially extensive and contributes to environmental degradation, especially deforestation. Thus, the objective of this research is to assess and compare the quantities of greenhouse gases produced by multiple and mono-specific cropping systems. To this end, the quantity of greenhouse gases (GHG) produced by several cropping systems installed on an experimental farm in Kpotomey in the municipality of Abomey-Calavi (Benin) was estimated. The estimation of GHG quantities was made on the basis of IPCC work and data from the experiments carried out. Comparisons were made between mono-specific crops and multiple crops. The results show that the quantities of GHG emitted per ton of production are more or less identical and vary on average from 0.6 to 0.11 teqCO_2. However, the advantage of multiple cropping systems is that they reduce the clearing of new land and thus avoid about 31.5 tons of CO_2 if the plant formation to be replaced was a forest. Multiple cropping with moderate fertilization in the presence of organic matter increases production while preserving the environment.

Keywords

Multiple Cropping System, Reduction of GHG, Deforestation, Environment, Agroecology

1. Introduction

Since the end of the Second World War, agriculture has been subject to various influences, including the systematic assault of the market economy [1]. In some countries such as the United States and Canada, where extensive cultivation was practiced, the combination of single cropping, automation and mechanization, the use of chemical fertilizers and phytosanitary products, the selection of cultivated plants, irrigation and soil drainage, the selection of livestock and the use of artificial livestock feed have all led to higher yields in agriculture [2]. Production has thus been improved without increasing the area cultivated. The gain in area per ton of wheat grain corresponds to the same amount of land not subject to clearing and, at best, to the same amount of land available for reforestation [3].

However, the harmful effects of this hyper productivity on the environment soon became apparent in various forms, notably the salinization and/or acidification of soils, leaching in the fields, pollution of water tables, loss of organic matter in the soil, the creation of habituation phenomena in insects, etc. This agriculture also directly or indirectly involves a significant consumption of fossil energy and significantly contributes to additional greenhouse gas emissions. The environmental damage caused by the excessive use of chemical fertilizers and pesticides is therefore likely to cancel out the benefits of the productivity increases they bring [4].

It is therefore essential that this trend will be slowed down if the targets of the Kyoto Convention are to be met. However, the industrialized countries, whose agriculture is responsible for most of the pollution, do not intend to reduce the excessive will level of inputs and believe that developing countries that have not started the green revolution should practice sustainable agriculture, which is wrongly confused with organic or ecological agriculture, with a low level of inputs or low fossil fuel consumption [3].

In developing countries, particularly in sub-Saharan Africa, the situation is less simplistic. The economization of agriculture and the globalization of all human activities have resulted in the coexistence of two types of agriculture, one to ensure the production of cash crops and the other to ensure food security. Cash crops follow the technical and normative itineraries applied in the Green Revolution models and, like them, generate the same nuisances [1]. On the other hand, the yields of food crops, in the absence of inputs, are constantly decreasing. This is a factor that accelerates the pace of deforestation by small-scale producers. With neither adequately trained human resources nor sufficient financial means to acquire fertilizers and equipment for a “green revolution”, agriculture in these countries is at an impasse. The realistic alternative is probably one that, starting from endogenous know-how, integrates new techniques concerning fertilization to ensure sufficient production to meet needs while preserving the environment. The aim of this research is to see how rational crop combination could enable more production while reducing environmental damage.

2. Materials and Methods

2.1. Presentation of the Study Environment

The Municipality of Abomey-Calavi is one of the eight (8) municipalities of the Atlantic Department. It is located between 6˚20' and 6˚42' north latitude and 2˚12' and 2˚23' east longitude [5]. **Figure 1** shows the geographical location of the Municipality of Abomey-Calavi.

This municipality is located in the south of the Atlantic department and is bordered to the north by the municipality of Zè, to the south by the Atlantic Ocean, to the east by the municipalities of Cotonou and Sô-Ava, and to the west by the municipalities of Ouidah and Tori-Bossito. It is the largest municipality in the department, covering 20% of the area of the department. It covers an area of 539 km^2 representing 0.48% of the national area of Benin [5].

The municipality of Abomey-Calavi is a municipality with ordinary status made up of 9 arrondissements, of which three (3) are urban and six (6) rural. These arrondissements are subdivided into 64 villages and 6 city districts, making a total of 70 villages [6].

The municipality of Abomey-Calavi has a significant hydrographic network.

Two important arrondissements of the municipality: Abomey-Calavi and Godomey, share with other neighbouring municipalities Lake Nokoué, which is the municipality's main water body. The Togbo River is the main water resource that crosses the Kpanroun district at the village of Bozoun [6].

The soil formations in the study area belong to the large tropical ferruginous complex.

The soils are clayey-sandy in texture and have a good organic matter content [7] and are made up of hydromorphic soils on alluvial-colluvial material, hydromorphic soils on clayey sediment of the terminal continental, white soils with a podzolic tendency and tropical ferruginous soils with no stains or concretions evolving on sands. They are found immediately south of the bar lands, from which they are separated by lagoons and marshes and they are well drained soils.

Finally, they are ferralitic soils on reworked sandy-clay materials and Cretaceous sandstones and ferralitic soils on loose sandy-clay sediment of the terminal continental. These soils are red and very thick, developed on the Terminal Continental of the Lower-Benin plateaus [5].

The experiments are carried out on tropical ferruginous soils.

2.2. Plant Material

Two experiments were conducted on an agricultural farm located in Kpotomey

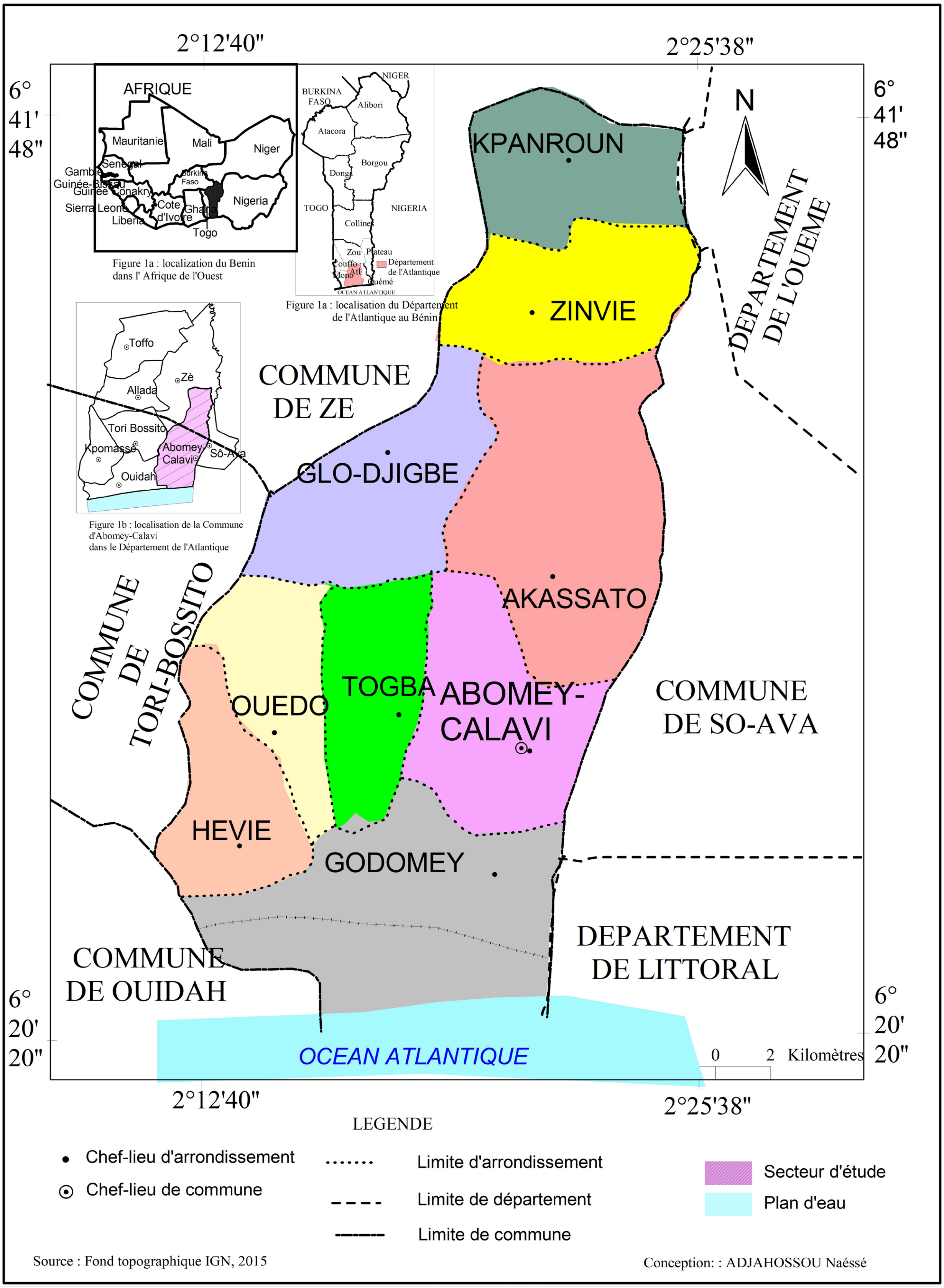

Figure 1. Geographical location of the municipality of Abomey-Calavi.

in the Municipality of Abomey-Calavi in Benin where the annual rainfall averages were 1200 mm.

- First experiment

A local variety of groundnut (*Arachis hypogea*) of the "spanish" group, with a vegetative cycle of 90 days, was planted at a density of 11.1 plants·m^{-2}. During the 2003-2004 agricultural season, groundnut was combined with three maize varieties: 1) the upright maize variety TZEEW (Tropical Zea Extra Early White) with a cycle of 80 days; 2) the semi-drooping variety DMR-ESRW (Downly Middew Resistent Early Streak White) with a cycle of 120 days; and 3) the protein-rich variety Obatanpa (QPM) with a cycle of 105 days.

- Second experiment

The trial was conducted during the 2010-2011 agricultural season. The Obatanpa composite, one of the maize varieties used in the first experiment, the pigeon pea, which is a common local variety taken from the market and the cassava variety BEN 86,052 were used.

2.2.1. Growing Conditions

The trials were conducted on a ferralitic soil whose fertility was improved by applying 100 kg·ha^{-1} of NPK (10 - 20 - 20) chemical fertilizer [1].

- First experiment

An additional 10 t·ha^{-1} of organic matter in the form of mulch was added. Water supply was provided by rainfall and by a supplemental irrigation system to cover the maximum demand equivalent to the ETP, estimated at 5 mm·d^{-1} [1].

- Second experiment

Eight (8) tons of *Leucaena diversifolia* leaflets and twigs were applied as organic fertilizer. Water supply to the crops was provided by rain [1].

To prevent seed digging by predators, including birds and small rodents, and insect attacks, maize and pigeon pea seeds were moistened with a solution containing ash and crushed *Azadiracta indica* leaves [1].

The sowing of seeds and planting of cassava was done in the direction of the slope (east-west).

2.2.2. Experimental Set-Up

- First experiment

The experimental set-up is composed of 4 randomized complete blocks (RCB). Each block consists of seven plots (3 m × 3 m), three of which have different maize sowing densities in monoculture and three with the same maize sowing densities in combination with groundnuts and one groundnut plot in monoculture. The combination of groundnut with three different maize varieties with different shapes constituted the treatments. The maize varieties used were Obatanpa, TZEEW, DMR-ESRW [1].

- Second experiment

The experimental set-up which is a Latin square, is made up of four (4) randomized blocks with total randomization. Each of the blocks is made up of four (4) plots (3 m × 3 m) including: a plot of maize in single-cropping, a plot of cassava in single-cropping, a plot of pigeon pea in single-cropping and a plot with the combination of maize, cassava and pigeon pea [1].

2.2.3. Data Collection and Processing

- Data collection

Weighing was carried out on the one hand with a "Five goals" scale with a maximum range of 20 kg and a sensitivity of 50 g and on the other hand, with an electronic scale with a maximum range of 3 kg and a sensitivity of 1 g [1].

At maturity, the maize cobs were partially dried on the ground before being harvested. The drying was continued off-field and the total dry matter and seed weights were determined. To avoid rotting of the inside of the roots and stems, they were cut into small fragments before drying.

The groundnut plants were pulled up so that no pods were left in the soil. Ten (10) useful plants per plot were harvested and dried on a drying area in Cotonou. The drying area was arranged so that the groundnut bunches were suspended in order to promote good aeration and avoid rotting. Weighing was done to evaluate the bioproduction, taking into account the edible and non-edible parts. These are leaves, stems and roots.

From 120 and 240 days of age respectively, cassava and pigeon pea leaves of the eight (8) useful plants per plot that have fallen are collected once a week. At maturity, the pea pods are harvested first, then the whole plant, including leaves, stems and roots, and the whole cassava. All harvested parts were weighed.

2.3. Determination of GHG Emissions from Cropping Systems

To determine the quantities of GHGs emitted, the method defined by the [8] was used. N_2O emissions from fertilizer use and CO_2 emissions from fertilizer manufacture and transport were also taken into account.

The use of fertilizer induces nitrous oxide (N_2O) emissions to soils, including indirect N_2O emissions due to the addition of nitrogen to soils by deposition or leaching. Direct and indirect N_2O emissions from the use of mineral nitrogen fertilizer were therefore determined.

- **Calculation of direct N_2O emissions**

$$N_2O_{Direct}\text{-}N = N_2O\text{-}N_{inputs}$$

with

$N_2O\text{-}N_{inputs}$: annual direct N_2O emissions from applied inputs (kg N_2O-N·year^{-1})

N_2O-N N inputs = $[(F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \times EF_1]$

- F_{SN}: annual amount of nitrogen fertilizer applied to the soil in kg N year^{-1};
- F_{ON}: annual amount of manure, compost, slurry and other organic materials applied to the soil in kg N year^{-1};
- F_{CR}: annual amount of nitrogen in crop residues (above and below ground) returned to the soil, including legumes, forages and grasslands in kg N year^{-1};

- F_{SOM}: amount of nitrogen mineralised as a result of carbon loss due to land use change, in kg N yr^{-1};
- EF_1 = 0.01: emission factor for N_2O emissions from nitrogen inputs in kgN_2O-N.

- **Indirect N_2O emissions calculations**

*For the calculation of indirect emissions, emissions from nitrogen leaching and deposition of previously volatilized nitrogen on the ground were determined according to the following equation:

$$N_2O_{Direct}\text{-N} = \left(N_2O_{(L)}\text{-N}\right) + \left(N_2O_{ATD}\text{-N}\right)$$

- $N_2O_{(L)}$-N: annual amount of N_2O from leaching from cultivated soils in areas where leaching occurs;
- N_2O_{ATD}-N: annual amount of N_2-N produced by deposition of previously volatilized nitrogen on cultivated soils in kg N_2O-N $year^{-1}$.

The following equation was used to calculate the emissions from nitrogen leaching ($N_2O_{(L)}$-N):

$$N_2O_{ATD}\text{-N} = \left[\left(F_{SN} * Frac_{GASF}\right) + \left(F_{ON} * Frac_{GASM}\right)\right] * EF_4$$

F_{SN} = annual amount of nitrogen fertilizer applied to the soil, in kg N $year^{-1}$;

F_{ON} = annual amount of manure applied to the soil;

$Frac_{GASF}$: 0.1 fraction of nitrogen volatilized from nitrogen fertilizers;

$Frac_{GASM}$: 0.2 fraction of volatilized nitrogen from organic matter;

EF_4: 0.001 N_2O emission factor related to the deposition of nitrogen, then to its volatilisation.

*To calculate the emissions from the deposition of previously volatilized nitrogen on the ground

(N_2O_{ATD}-N), the following equation was applied: phyto

$$N_2O_{(L)}\text{-N} = \left[\left(F_{SN} + F_{ON} + F_{CR}\right) * Frac_{LEACH\text{-}(H)}\right] * EF_5$$

with:

$Frac_{LEACH\text{-}(H)}$ = 0.3; the fraction of nitrogen added/mineralised in cultivated soils in areas where leaching exists.

EF_5 = 0.0075; N_2O emission factor related to nitrogen leaching.

- **Calculation of emissions during fertilizer production in the factory**

*__Mineral nitrogen__

To these emissions must be added the emissions resulting from the manufacture of nitrogen fertilizers. It is estimated that to produce one ton of nitrogen in the form of ammonia, approximately 1 toe in the form of natural gas is required, which corresponds to an emission of 2.4 t of CO_2. The production of one ton of ammonium nitrate is accompanied by an emission of 5 kg of N_2O, *i.e.* an emission of 4.228 $teqCO_2$ [9].

We have the following equation:

$$CO_2\text{-}CN_{mineral} = \left(FN_{mineral}/1000\right) * \left(2.4 + 4.228\right)$$

with:

$FN_{mineral}$: amount of mineral nitrogen used;

1000: conversion from Kg to ton.

*Phosphorus

To obtain one ton of phosphorus fertilizer, 18.3 tons of oil equivalent are needed in the form of oil

$$CO_2\text{-}C_{Phosphorus} = \left[18.3 * \left(F_{phosphorus}/1000\right)/42\right] * 3.2$$

with:

$F_{phosphorus}$: quantity of phosphorus used;

18.3: to produce 1 ton of phosphorus fertilizer, 18.3 toe are needed;

3.2: 1 ton of primary energy from oil emits 3.2 teqCO_2;

42: 1 toe ≈ 42 GJ.

*Potassium

$$CO_2\text{-}C_{Potassium} = \left[11.6 * \left(F_{potassium}/1000\right)/42\right] * 3.2$$

with:

11.2: to produce 1 ton of potassium fertilizer, 11.2 toe are needed.

*Transport

CO_2-Transport: [2.5 * distance travelled* 133/1,000,000 * (amount of mineral N + amount of phosphorus + amount of potassium)/1000]

with:

2.5: value to estimate the part of inert matter in the bag of fertilizer e.g. for 1 bag of 100 kg of NPK fertilizer 10 - 20 - 20: we have 50% NPK units and 50% inert matter.

133: are the grams of CO_2 to transport 1 ton for 1 Km.

1,000,000: Conversion from grams to tons.

A programming on Excel spreadsheets allowed to integrate all these elements in order to estimate the quantities of Greenhouse Gases (GHG) emitted per cropping system.

3. Results

Table 1 shows the amount of GHG produced in teqCO_2/ha.

The maize-groundnut association generated an average of 0.46 teqCO_2/ha per biomass production (grain and non-edible part). The three varieties of maize grown as single crops produced an average of 0.27 teqCO_2/ha per biomass production. It can be observed that groundnuts grown as single crops generated 0.46 teqCO_2/ha per biomass production.

Table 2 shows the amount of greenhouse gases emitted by producing one ton of edible parts.

The maize-arachid association produced an average of 0.11 teqCO_2 per ton of noble production (edible part). Mono-specific maize produced an average of 0.07 tCO_2e per ton of noble products. It can be observed that groundnuts grown as single crops generated 0.26 teqCO_2 per ton of groundnuts.

Table 1. Quantity of GHG emitted per unit of dry matter produced and per cropping system.

Crop systems	GHG produced in tCO_2/ha
Single-crop	
Groundnut	0.46
Maize TZEEW	0.25
Maize Obatanpa	0.27
Maize DMR ESRW	0.28
Combination of crops	
Groundnut-TZEEW	0.47
Groundnut-Obatanpa	0.46
Groundnut-DMR ESR	0.45

Table 2. Quantity of GHG emitted per ton of edible parts and per cropping system.

Crop systems	GHG in tCO_2/ton of noble parts
Single-crop	
Groundnut	0.26
Maize TZEEW	0.08
Maize Obatanpa	0.06
Maize DMR ESRW	0.06
Combination of crops	
Groundnut-TZEEW	0.12
Groundnut-Obatanpa	0.10
Groundnut-DMR ESR	0.10

Table 3 shows the amount of greenhouse gases emitted by the maize, cassava and pigeon pea cropping systems.

The cropping system combining maize, cassava and pigeon pea generated 0.60 $teqCO_2$/ha. The maize, grown as a single crop, produced 0.26 $teqCO_2$ per hectare. Cassava generated 0.32 $teqCO_2$/ha in monoculture. Pigeon pea produced 0.38 $teqCO_2$/ha.

Table 4 shows the amount of GHG emitted per kg of production and per cropping system for the maize-corn-pigeon pea combination.

The cropping system combining maize, cassava and pigeon pea produced 0.06 $teqCO_2$/ton of edible parts. Maize grown as a single crop generated 0.07 tCO_2e/ton of noble products. Cassava grown as a single crop generated 0.05 $teqCO_2$ per ton of noble products. Pigeon pea produced 0.04 $teqCO_2$ per ton of noble products.

Table 3. Quantity of GHG emitted per unit of dry matter produced and per cropping system for the maize-cassava-pigeon pea combination.

Crop systems	GHG produced in tCO_2/ha
Single crop	
Maize	0.26
Cassava	0.32
Cajanus	0.38
Combination	
Maize-Cassava-Cajanus	0.60

Table 4. GHG emissions per kg of production and per cropping system for the maize-corn-pigeonpea combination.

Crop systems	GHG emissions per kg of production (teqCO_2/ton)
Single-crop	
Maize	0.07
Cassava	0.05
Cajanus	0.04
Combination	
Maize-Cassava-Cajanus	0.06

4. Discussion

Agriculture accounts for 13.5% of global greenhouse gas (GHG) emissions [3]. In France, these emissions were 105 Mt CO_2eq in 2010, *i.e.* 20% of total emissions [10]. The main greenhouse gases produced by the various cropping systems, whether monocropping or multiple cropping, are carbon dioxide (CO_2) and nitrous oxide (N_2O), which is a gas mainly of agricultural origin as pointed out by [11]. In addition to the CO_2 released by the use of fossil energy during the manufacture and transport of the applied chemical fertilizer, the carbon dioxide emissions linked to the metabolism of the crops were also taken into account.

In Benin in general, without the application of fertilizer, the average yield of maize in rural areas is about 800 kg/ha. The application of 100 kg of NPK (10 - 20 - 20) gave an average yield of 4186 kg/ha for the three maize varieties tested. In order to obtain the same amount of grain on the farm, 5.25 hectares would be cleared, resulting in the emission of about 31.5 tons of CO_2 if the replaced plant formation was a forest.

The results of the experiments show that the amount of GHGs emitted varies according to the crop species and the cropping system, whether it is single or multiple. The production of maize varieties generated about half the amount of GHGs produced by groundnut production.

Organic fertilizers have both activating and stimulating effects on biological activity in the soil [12]; they increase the production of nitrous oxide (N_2O) ([13] [14]). These amendments bring nitrogen and carbon to the soil. As part of this nitrogen is already in mineral form (NH_4^+), there are very high emissions of N_2O from the first rains after the application. In addition, legumes, thanks to rhizobium, fix atmospheric nitrogen in the soil, thus increasing the stock of leached nitrogen and the amount of N_2O emitted when this stock is not used. As a result, nitrogen-fixing plants such as groundnuts and pigeon peas emit more GHGs than cereals and tubers.

It can be observed that GHGs increase as yield increases. This is because fertilization, one of the main factors in productivity, generates GHGs in proportion to the amount of fertilizer applied, from the manufacture of the fertilizer to its use in the field and its transport. On the other hand, high yields are underpinned by high metabolic activity, which is accompanied by subsequent GHG emissions.

However, these GHG emissions are far less than those avoided by the improved territorial efficiency that high yields represent. Thus, as [15] points out, without crop intensification in sub-Saharan Africa, increased food production will continue to depend on the clearing of forests and grasslands. According to the author, this has resulted in emissions of at least 1 billion tons of CO_2 per year. To curb this trend, the international community needs to understand that special attention should be given to crop intensification in sub-Saharan Africa, the only region in the world where hunger is the main reason for clearing forests and grasslands. Irrigation and farm automation undoubtedly imply a greater use of fossil energy; but judiciously applied to efficient plant material, the environmental cost could be reduced through improved land efficiency.

In the maize-groundnut cropping system, groundnuts grown in monocropping generated about 1.7 and 3.8 times more greenhouse gases than maize in mono-specific cropping for the whole production and per ton of noble part, respectively. This could indicate that the environmental cost of protein and lipid synthesis is higher than that of carbohydrates. This is not surprising as the mechanisms from photosynthesis to protein and lipid synthesis are more complex than for carbohydrates and therefore require more energy and generate more CO_2.

The mineral fertilizers used immediately increase the NO_3^- content of a soil, which appears when ammonium is nitrified. During the growing season and when the soil is well aerated, nitrification is rapid [16]. Whatever the form or type of fertilizer, large quantities of NO_3^- become available within days of application and are likely to be transformed into N_2O [13]. The emission of nitrous oxide is linked to both the manufacture of nitrogenous fertilizers and their use by the plant. This gas is emitted in small quantities by the soil and has a significant global warming potential ([17] [18]).

5. Conclusion

Agriculture contributes to the emission of greenhouse gases. However, the volume and nature of that emission are influenced by cultivation practices. It appears from this research that crop combinations reduce the amount of greenhouse gases emitted compared to monocropping. These emissions increase as yields increase, but the quantities emitted are very negligible compared to the emissions of these GHGs avoided thanks to the high yields. In fact, agriculture in Benin remains extensive, which means that an increase in production requires an increase in the area cultivated. The consequence is that increasing production to achieve food security leads to greater destruction of vegetation, which releases the carbon dioxide previously sequestered. Crop association, by improving crop yields, avoids or reduces land clearing. This association must be done by reducing competition between plants for light, water and mineral salts. Thus, it contributes to productive agriculture with a minimum of pressure on the environment.

Acknowledgements

This study was carried out as part of my thesis entitled "Intensification of traditional cropping systems and environmental conservation in West Africa: the case of Benin", defended at Université d'Abomey-Calavi (UAC). We express our gratitude to all people who have contributed at various levels to the achievement of this work.

Conflicts of Interest

The authors declare that they have no conflict of interest.

References

[1] Adjahossou, V.N. (2012) Intensification des systèmes de cultures traditionnels et préservation de l'environnement en Afrique de l'Ouest: Le cas du Bénin. Thèse de Doctorat unique, Option Environnement Santé Développement, Université d'Abomey-Calavi, Bénin, 279 p.

[2] Griffon, M. (1999) Développement durable et agriculture: La révolution doublement verte. *Cahiers Agricultures*, **8**, 259-267.

[3] Riedacker, A. (2008) Un peu plus d'énergie fossile pour la sécurité alimentaire, le climat et la biodiversité. Les choix mondiaux entre confiance technologique et préoccupations environnementales. *Liaison Énergie-Francophonie*, **80**, 56-61.

[4] Brundtland, G.H. (1987) Notre avenir à tous. Rapport de la Commission mondiale sur l'environnement et le développement de l'ONU. University Press, Oxford, 349 p.

[5] Adam, S.K. and Boko, M. (1993) Le Bénin. Edicef, Paris, 97 p.

[6] INSAE (2005) Cahier des villages et quartiers de ville département de l'Atlantique. Cotonou, Bénin, 34 p.

[7] Atidegla, C.S., Sintondji, L.O., Hounkpe, J. and Kpadonou, E. (2017) Effets du labour mécanisé successif sur le statut nutritif du sol et le rendement du riz pluvial dans la commune d'Abomey Calavi (Sud Bénin). *European Scientific Journal*, **13**, 341-357.

[8] GIEC. (2006) Lignes directrices pour les inventaires nationaux de gaz à effet de

serre. Chapitre 11: Émissions de N_2O des sols gérés, et émissions de CO_2 dues au chaulage et à l'application d'urée, 60 pages.

[9] Migliore, S. (2007) Bilans Environnementaux de la luzerne déshydratée, du soja, du colza et du blé: Comparaisons, avec le soja, de diverses combinaisons de cultures comprenant de la luzerne déshydratée et du colza ou du blé. Mémoire de Master 2 Professionnel BIO-GEO, Espace et Milieu Paris 7 réalisé à l'INRA Unité MONA Ivry, 131 p.

[10] Bamière, L., De Cara, S., Lénaïc Pardon, L., Pellerin, S., Samson, E. and Dupraz, P. (2014) Agriculture et changement climatique. *Notes et Études Socio-Économiques*, **38**, 53-71.

[11] Viard, A., Henault, C., Rochette, P., Kuikman, P., Flenet, F. and Cellier, P. (2013) Le protoxyde d'azote (N_2O), puissant gaz à effet de serre émis par les sols agricoles: Méthodes d'inventaire et leviers de reduction. *Oilseeds and Fats*, *Crops and Lipids*, **20**, 108-118.

[12] Rochette, P., van Bochove, E., Prévost, D., Angers, D., Côté, A.D. and Bertrand, N. (2000) Soil Carbon and Nitrogen Dynamics Following Application of Pig Slurry for the 19th Consecutive Year: II. N_2O Fluxes and Mineral Nitrogen. *Soil Science Society of America Journal*, **64**, 1396-1403. https://doi.org/10.2136/sssaj2000.6441396x

[13] Chantigny, M. (2001) Émissions de protoxyde d'azote (N_2O) En agriculture, contribution des Amendements organiques, des Fertilisants minéraux et du labour. In: Ordre des Agronomes du Québec, *Changements climatiques*: *Comprendre pour mieux agir*, 65è Congrès de l'ordres des agronomes du Québec publié au Québec, 1-8.

[14] Lessard, R., Rochette, P., Gregorich, E.G., Pattey, E. and Desjardins, R.L. (1996) Nitrous Oxide Fluxes from Manure-Amended Soil under Maize. *Journal of Environmental Quality*, **25**, 1371-1377. https://doi.org/10.2134/jeq1996.00472425002500060029x

[15] Riedacker, A. (2004) Changements Climatiques et forêts. Editions Silva et Riat, Paris, 231 p.

[16] Nicolardot, B., Mary, B., Houot, S. and Recous, S. (1997) La dynamique de l'azote dans les sols cultivés. In: Lemaire, G. and Nicoladot, B., Eds., *Maîtrise de l'azote dans les agrosystèmes*, INRA-Editions, Paris, 336 p.

[17] Labreuche, J., Lellahi, A., Malaval, C. and Germon, J.C. (2011) Impact des techniques culturales sans labour (TCSL) sur le bilan énergétique et le bilan des gaz à effet de serre des systèmes de culture. *Cahiers Agricultures*, **20**, 204-215. https://doi.org/10.1684/agr.2011.0492

[18] Schellenberg, D.L., Alsina, M.M., Muhammad, S., Stockert, C.M., Wolff, M.W., Sanden, B.L., Brown, P.H. and Smart, D.R. (2012) Yield-Scaled Global Warming Potential from N_2O Emissions and CH_4 Oxidation for Almond (*Prunus dulcis*) Irrigated with Nitrogen Fertilizers on Arid Land. *Agriculture*, *Ecosystems & Environment*, **155**, 7-15. https://doi.org/10.1016/j.agee.2012.03.008