Empirical approach to arable land and livestock using co-integration and causality techniques with panel data

Micaela Calderon[1], Marcelo León[2] and Sergio Núñez[1]

[1]Universidad Tecnológica Empresarial de Guayaquil, Guayaquil, Ecuador
[2]Universidad Nacional de Loja, Loja, Ecuador

Abstract

The availability of food and the right to food is linked to the concept of food security, poverty and development of nations; and, therefore, to a focus on agricultural production and availability of land suitable for cultivation. In this context, the main objective of this research is to evaluate the effect of livestock production on the availability of arable land in Latin American and Caribbean countries, between 1961-2017, using cointegration and causality techniques to propose policies that contribute to a smaller decrease in arable land. For the development of the research, control variables were added: population growth, average temperature variation and fertilizer use. Statistical information was collected from the World Bank (2020) and the Food and Agriculture Organization of the United Nations (2020) databases. The main results show a statistically positive relationship and the existence of a long-run equilibrium relationship between the variables used in the model. The results indicate that a 1% increase in head of cattle is related to an increase of 0.04 hectares in arable land. On the other hand, it was found that the main causes of variations in arable land are livestock and fertilizer use. Policy implications suggest some measures to ensure the availability of arable land considering the role of livestock and fertilizer use.

Keywords

Arable land, Livestock, Food security, Population growth, Development

1. Introduction

Currently, there is widespread concern regarding the decline of arable land in the world. According to data from the World Bank (2020) the amount of arable land per capita in the world has decreased from 0.36 ha in 1961 to 0.18 ha in 2017. Modern agriculture has been successful in increasing food production, as food production has even outpaced population growth [1]. However, the number of hungry people continues to rise, reaching 821 million in 2017, 1 in 9 of the world's population. United Nations Children's Fund UNICEF, 99.7% of the food that humans need to survive comes from the land; therefore, productive land and soils are vitally important to our lives and economies.

ICAIW 2021: Workshops at the Fourth International Conference on Applied Informatics 2021, October 28–30, 2021, Buenos Aires, Argentina
mica.sol92@hotmail.com (M. Calderon); mleon@uteg.edu.ec (M. León); sejunuso@hotmail.com (S. Núñez)
0000-0003-2626-8921 (M. Calderon); 0000-0001-6303-6615 (M. León); 0000-0001-8804-3088 (S. Núñez)

In regions that base their economies on agriculture, such as Latin America and the Caribbean (LAC), the agriculture sector contributes significantly to economic growth, representing more than 5% of GDP in approximately 20 countries. Given that the poor are concentrated in rural areas, it also contributes significantly to the reduction of poverty and hunger, and contributes substantially to employment, accounting for between 10% and 15% of total employment. Thus, the availability of land suitable for cultivation is of fundamental importance as it becomes a means to overcome malnutrition and hunger, and also a source of income for rural people.

The availability of food and the right to food is linked to the concept of food security and, therefore, to a focus on agricultural production and availability of arable land [2]. Therefore, in order for people to have permanent access to food both physically and economically, it requires the capacity and resources to produce or obtain all the food needed for the household and its members [3]. The supply of food is not the main issue, the key is whether people can buy enough food to be able to enjoy an adequate diet, which translates into a lack of access. Lack of access to food can be economic, due to high levels of poverty, high food prices, lack of credit; and physical, due to poor road and market infrastructure [4].

On the other hand, there is evidence of an increase in the production of beef cattle worldwide, as; it went from 27,684,560 tons in 1961 to 67,353,900 tons in 2018. The evolution of the livestock sector in Latin America and the Caribbean, maintains a rapid pace of growth that is more the result of increased inventories than the adoption of technologies to increase yields. According to Graziano et al., [5] in recent decades there has been a significant increase in the global demand for animal products; it is estimated that by 2050 there will be an increase of up to 70%. However, Latin America and the Caribbean has responded favorably to this trend, becoming the main global exporter of beef and poultry meat; thus, exports of beef meat recorded an increase of 7%, equivalent to $737 million additional in 2020, compared to 2019.

This paper focuses mainly on what Malthus [6] said, admitting the possibility that the eating patterns of the upper class could cause an increase in the land devoted to livestock and, therefore, a decrease in the available food. This is where the importance of the research topic lies; it seeks to examine the relationship between the availability of arable land and livestock. It is important to emphasize that the literature on the subject is scarce; therefore, this research contributes as new knowledge to the existing scientific field with respect to the analysis of the variations of arable land caused by cattle production, population growth, average temperature variation and the use of fertilizers in 21 countries that make up the Latin America and the Caribbean region; 15 belonging to the Latin America sector and six to the Caribbean. Therefore, the main contribution of this study is based on the econometric strategy: second generation cointegration techniques, which control for the presence of cross-sectional dependence between countries and are more effective in assessing the effects of long-run determinants of arable land.

The existing literature is quite scarce regarding the variables used in this research. However, it has been possible to gather information from the few studies found on the subject in question. Studies such as Alexander et al., [7] who find a negative relationship between cattle production and arable land. While, Rabés et al., [8]; Chai et al., [9] and He et al., [10] find that cattle ranching implies a greater grabbing of arable land. Another group of studies point out that future food supply is constrained by the excessive use of arable land primarily intended to produce feed for livestock [11] and [12]. Also, the literature assumes that climate change and excessive fertilizer use have both positive and negative implications on land availability and crop yields. Finally, there is evidence that unsustainable practices in the agriculture sector end up aggravating the latent problems on climate change [13] and [14].

The results of this research contribute to fill the empirical gap regarding the analysis of arable land use from the perspective of livestock farming. It could be evidenced that cattle production has a statistically positive relationship with arable land; as well as a negative relationship between temperature variation, fertilizer use and arable land. In the same way, it is proved that the dependent variable and the control variables present an equilibrium in the long term. In terms of causality, it was found that the main causes of variations in the availability of arable land are livestock and fertilizer use.

2. Literature review

The theory underpinning the present research is that of Malthus [6] who admits the possibility that the eating patterns of the upper class could cause an increase in land devoted to livestock, and thus a decrease in available food, implying that the increased demand for meat is reflected in an increase in livestock stocks, and this in turn leads to less land being devoted to growing food for humans. However, it must be considered that there are other additional factors that can determine variations in arable land. In this sense, this section is divided into four groups that are written according to the explanatory variables used: cattle production, population growth, climate change and fertilizer use.

In the first group are studies such as Alexander et al., [7] which by using panel data taken from FAO; and a decomposition analysis, mention that the improvement of people's income implies a diet with the highest amount of animal products, which may cause a further reduction of land used for agriculture. Also, a Greenpeace report (2019) points out that industrial livestock farming is causing land grabbing, with more than two thirds of arable land already devoted to growing food for livestock, while food production for people is losing ground. Along the same lines, Yawson [15] through an estimation of future food balances and with the use of FAO data determines that it is necessary to substantially increase the area of land currently allocated to barley to meet the projected demand for feed use in the future, since the results indicate that productivity gains must be complemented by increasing the harvested area. Likewise, Rodrigues et al., [11] used a classification approach based on Landsat satellite image objects, whereby they mention that future land use is determined by agro-pastoral expansion. Similarly, Soltani et al., [12] concludes that the future food supply and efficiency of the country is at stake, due to overexploitation of water and land resources, mainly for livestock expansion, deforestation and mining. FAO indicate that the main driver of land use change is the livestock sector, as large tracts of land are converted to pasture or animal feed crops, with serious implications for agriculture and food systems; as one of the main challenges is to produce more with less.

In contrast, Rabès et al., [8] who through an analysis of covariance estimated the effect of four food diets on three environmental indicators; found that, food systems constitute a burden on the environment and resource use; with animal-based foods representing the highest land occupation and GHG emissions. For their part, Chai et al., [9] through a systematic review of 34 studies indicate that reducing meat consumption can placate the impact of the meat industry on the environment, and He et al., [10] indicate that eating habits imply a greater demand for arable land, destined to produce livestock food.

The second group, relating population growth to arable land, used unique panel data for rural households containing information on soil quality and show that population pressure reduces soil quality and also induces agricultural intensification. Used unique panel data for rural households containing information on soil quality and show that population pressure reduces soil quality and also induces agricultural intensification. Likewise, Prabhakar [16] mentions that the rapidly growing population and its needs are one of the main drivers of land use change. In the third group, relating climate change and arable land, are Huang et al., [17] who, using a RUSLE model, estimated the spatio-temporal variations in the rate of soil loss and followed by a scenario design to decouple the effects of climate and land use changes, found that changes in climate cause soil losses, but this is compensated by reforestation. Huang et al., [17] mentions that crop yields are more sensitive to increased rainfall and temperature variability; thus, they indicate that to ensure food security under a changing climate, best management practices that improve soil structure and nutrient retention should be adopted. Severe soil losses has become a very important environmental problem and is strongly affected by climate change and land use [18]. On the other hand, the impact generated by temperature on land and crops, has much to do with the area and type of crop [19]; in some cases in the long term significantly increases production; but also reduces the efficiency of soils [20]. Likewise, Shakhawat et al., [21], using a Ricardian model conducted a cross-sectional regression analysis by which they established that as temperature increases, a reduction in the value of agricultural land is projected. Similarly, Hossain et al., [22]; Arshad et al., [23] find that climate change is causing land degradation by decreasing its value, agricultural productivity and income. In fact, by 2030, climate change will exacerbate extreme poverty problems through impacts on agriculture and food security.

Regarding arable land as a driver of climate change, Yang et al., [24] and Bell et al., [25] indicate that abandoned land helps to combat climate change as it undergoes a natural recovery of vegetation and soil carbon; and helps to remove carbon dioxide from the atmosphere. Mekonnen et al., [13] found that improved soil and water conservation practices positively influence soil physico-chemical properties, which in turn leads to reduced pollutant emissions and improved soil quality as natural sinks. According to Silveira et al., [26] greenhouse gas emissions are directly associated with climate change problems. Part of these emissions are caused by agriculture, by the burning of fossil fuels such as coal, natural gas and oil used as a source of energy for the performance of agricultural machinery. On the other hand, Del Buono [27] indicates that soil salinity due to the excessive use of fertilizers is one of the most problematic causes that will increase anthropogenic climate change. Likewise, Shakoor et al., [14] points out that croplands due to their large area and management practices emit harmful emissions to the environment, which end up aggravating the problems of climate change.

Finally, the fourth group contains studies that relate fertilizer use to arable land, for example, Hao et al., [28], conducting a field experiment in a moderate acid soil to quantify soil acidification rates in response to fertilization with different types of fertilizers revealed that soil acidification is induced by nitrogen fertilizers. Soil acidification causes changes in soil properties, hard soils and susceptibility to pests; thus, the amount of chemical fertilizer applied to agricultural land has resulted in nutrient losses from soils, which reduces water and nutrient holding capacity and thus crop yields. Likewise, Zhang et al., [29] used a combination of scenario analysis and an agricultural survey of 1500 farmers across China to explore the impacts of replacing fertilizer with manure, and determined that there is a need for a transparent manure exchange market, with advisors on manure use, accurate information on composition and price. Chai et al., [9] investigated 12 types of biomass resources and calculated their nitrogen pools, where they found that organic fertilizers have enormous potential to replace chemical fertilizers, mitigating threats to the environment and human health.

Similarly, Habtemariam et al., [30] through a trade-off analysis for multidimensional impact assessment model determines that the adoption of fertilizer and rainwater harvesting, reduces the percentage of food insecure people and improves the yield and income of many farmers. However, Adnan et al., [31] however, mentions that these resources alone do not generate significant changes in terms of reducing poverty and food insecurity. In addition, Toledo [32] indicates that the lack of knowledge about soil management has led farmers to use methods based on the excessive use of fertilizers, which generates a better productive response of crops and at the same time deterioration of productive soils.

3. Data and methodology

3.1. Data

The data used in this research were obtained from FAO and World Bank statistical sources. The dependent variable used was the amount of arable land per capita in hectares, which measures

Table 1
Description of variables and data sources

Variable and notation	Unit of measure	Source of data	Description
Arable land per capita (tcp)	Hectares	World Bank	These are those on which crops are grown that occupy the land for extended periods of time. This category includes land with flowering shrubs, fruit trees and nut trees, but excludes land on which timber trees are grown.
Heads of cattle (lcgv)	Stocks	FAO	Number of head of live cattle, animals that are used for the production of meat and milk.
Temperature variation (vt)	Degrees Celsius	FAO	Change in average surface temperature with respect to a reference climatology. These average temperature variations are expressed in degrees Celsius.
Population growth (cpob)	Growth rate	World Bank	The annual population growth rate is the mid-year population growth from year t-1 to year t, expressed as a percentage. All residents are counted regardless of their legal status or citizenship.
Fertilizer use (lfn)	Kilogram	FAO	They are those to which nitrogen or compounds derived from it are incorporated, they are used to promote plant growth and improve their cellular structure. They cause water and atmospheric pollution.

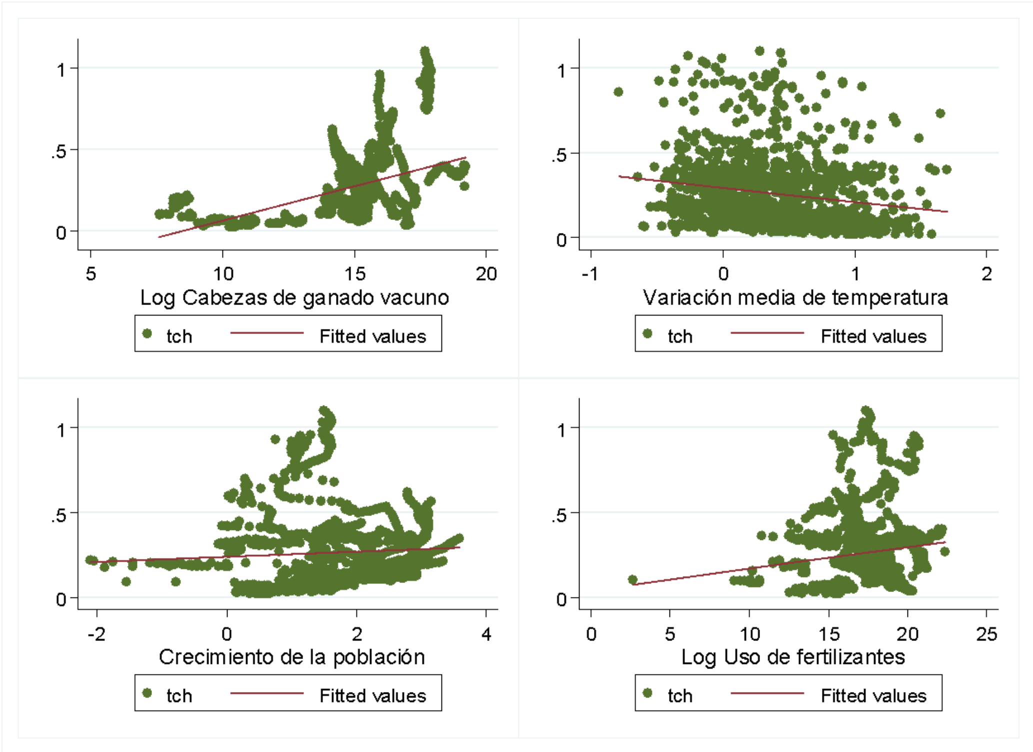

Figure 1: Correlation between head of cattle, mean temperature variation, population growth, fertilizer use and arable land per capita.

the availability of arable land for each person, and the independent variable was the number of heads of cattle in units, which measures the presence of livestock in the region. Subsequently, three control variables were added, as they were considered important for the estimation and, above all, to make the model more robust: climate change, fertilizer use and population growth. Due to the limited availability of data, only 21 countries that make up the Latin American and Caribbean region could be covered; 15 belonging to the Latin American sector and six to the Caribbean. In addition, fertilizer use and head of cattle are transformed into logarithms, while mean temperature variation, arable land per capita and population growth are worked in their original unit of measurement. Table 1 details the variables used in the econometric models.

In Figure 1 , the correlations between the variables cattle head, population growth, temperature variation, fertilizer use and arable land per capita show a positive and significant correlation, which suggests that these variables play a very important role in the availability of arable land in Latin American and Caribbean countries. However, mean temperature variation shows a negative correlation with arable land; and, population growth a slight inclination towards a positive correlation.

Subsequently, Table 2 presents the descriptive statistics of the dependent and independent variable including the control variables, where it is observed that the data panel is balanced because it consists of a total of 1197 observations, which in general involves 21 countries in a

Table 2
Descriptive statistics

Variable		Mean	Thirst. Dev	Min	Max	Observations
Arable land per capita	overall	0,263	0,213	0.018	1,101	N=1197
	between		0,202	0.039	0,896	n= 21
	within		0,079	0,052	0,662	T= 57
Log Heads of cattle	overall	14,709	2,489	7,600	19,200	N=1197
	between		2,533	8,429	18,684	n= 21
	within		0,288	13,759	15,386	T= 57
Population growth	overall	1,641	0,938	-2,099	3,588	N=1197
	between		0,752	0,029	2,687	n= 21
	within		0,584	-2,150	3,081	T= 57
Average temperature variatio	overall	0,393	0,447	-0,785	1,697	N=1197
	between		0,095	0,177	0,551	n= 21
	within		0,437	-0,713	1,649	T= 57
Log Fertilizer us	overall	17,259	2,285	2,625	22,367	N=1197
	between		2,094	11,818	20,525	n= 21
	within		1,020	8,065	20,599	T= 57

period of time of 57 years. In addition, the mean, standard deviation, maximum and minimum values and the number of observations are shown. The variation between countries is larger than within countries, both for arable land per capita, cattle head, population growth and fertilizer use. In contrast, the mean variation in temperature is greater within countries than between countries, hence there is greater variability within countries. In conclusion, the variation of the variables is mostly explained by the standard deviation between countries. It should be emphasized that the maximum value of the average temperature variation indicates that the temperature increase has been maintained at less than 2°C as proposed in the Paris Agreement approved in 2015, as its value is 1.7°C, although this raises concern as it is a value very close to the objective set out in the Paris Agreement.

3.2. Methodology

In order to evaluate the effect of livestock on arable land, a panel data analysis was carried out using cointegration techniques for 21 countries in Latin America and the Caribbean, during the period 1961-2017. The econometric strategy used was carried out according to the specific objectives [33]; therefore, the research had several stages that are explained below. Firstly, a baseline regression is based on the theoretical contribution of Malthus [6] which indicates that the feeding patterns of the upper class could cause an increase in the land dedicated to livestock; and, therefore, a decrease in the available food. Therefore, the present relationship is formalized in Equation (1):

$$tcp_{it} = \beta_0 + \beta_1 lcgv_{it} + \varepsilon_{it} \tag{1}$$

In order to determine what other variables affect the availability of arable land in Latin American and Caribbean countries, the estimation of a Generalized Least Squares (GLS) model is presented [34], which prior to its estimation it is very necessary to apply diagnostic tests such as multicollinearity, autocorrelation and heteroscedasticity [35]. The model includes control variables such as: population growth, average temperature variation and fertilizer use, whose estimation is presented in Equation (2):

$$tcp_{it} = \beta_0 + \beta_1 lcgv_{it} + \beta_2 cpob_{it} + \beta_1 vt_{it} + \beta_1 lfn_{it} + \varepsilon_{it} \tag{2}$$

In Equation (1) and (2) tcp representing arable land per capita; lcgv representing the logarithm of cattle production; cpob which represents population growth; vt indicates the average temperature variation; lfn is the logarithm of fertilizer use; for the countries in the period $i = 1, 2, 3, ..., 21$ in the period $t = 1961, 1962, ..., 2017$ and, finally, the ε_{it} it is the error term.

Consecutively, to avoid biased and inconsistent results we test for cross-sectional dependence using the Pesaran diagnostic test. (2015) which are recommended for balanced and unbalanced panels. This Pesaran CD_{NT} of the Pesaran test (2015) has the following expression, described in Equation (3):

$$CD_{NT} = \sqrt{\frac{2}{N(N-1)}} \left[\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \sqrt{T} \widehat{\rho}_{ij} \right] N(0,1) \tag{3}$$

Where, N denotes the number of cross sections (countries), T indicates the period and $\widehat{\rho}_{ij}$ shows the correlation by ordered pairs corresponding to the cross sections in each period, as described in equation (4):

$$\widehat{\rho}_{ij} = T^{-1} \sum_{i=1}^{T} \varepsilon_{it} \varepsilon_{jt} \tag{4}$$

Where, ε_{it} y ε_{jt} denotes the scaled residuals of the specific Ordinary Least Squares (OLS) regressions for each cross section (countries). $i = 1, 2, 3, ..., N$.

Therefore, for the panel with presence of cross-sectional dependence we estimate the second generation unit root tests that are more robust and reliable in this case, for which we estimate the CADF and CIPS* tests proposed by Pesaran (2007). Therefore, the first known cross-sectional augmented Dickey-Fuller (CADF) test is specified in equation (5):

$$Y_i = \alpha_i + \beta_i Y_{i,t-1} + \omega_0 \widehat{Y}_{t-1} + \varphi_i \Delta \widehat{Y}_t + \varepsilon_{it} \tag{5}$$

Where, $Y_i = \alpha_i + \beta_i Y_{i,t-1} + \omega_0 \widehat{Y}_{t-1} + \varphi_i \Delta \widehat{Y}_t + \varepsilon_{it}$ is regression error.

As for, the second test is calculated from the average of the individual ADF statistics augmented in the cross section (CADF) is called CIPS* which analyzes the unit root properties of the whole panel as shown in equation (6):

$$CIPS^* = \frac{1}{N} \sum_{i=1}^{N} CADF_i \tag{6}$$

Where, $CADF_i$ denotes the cross-sectional augmented Dickey-Fuller statistic for i which represents each cross-sectional unit.

In the presence of cross-sectional dependence, the Westerlund error correction test is applied to verify the long-run relationship between the variables. Is applied to verify the long-run relationship between the variables. The test allows us to conclude whether cointegration exists for individual panels as well as for the whole panel as a whole, considering that the variables analysed are stationary. Equation (7) expresses the error correction that defines the speed of correction towards equilibrium:

$$\Delta y_{i,t} = \delta \dot{d}_t + \varepsilon_i (y_{i,t-1} - \beta_i \dot{x}_{i,t-1}) + \sum_{j=1}^{p_i} \varphi_{i,j} y_{i,t-1} + \sum_{j=q_i}^{p} \varphi_{i,j} y_{i,t-1} + \varepsilon_{it} \tag{7}$$

Where, $t = 1, 2, 3, .., T; i = 1, 2, 3, ..., N$ y d_t express the deterministic components; $+\varepsilon_i$ represents the constant term; p_i y q_i denote the orders and advancement of each of the countries.

The Westerlund [36] test yields four statistics where G_τ y G_α indicate that at least one cross section is cointegrated and the statistics P_τ y P_α statistics show that the whole panel is cointegrated, to evaluate the null hypothesis of no cointegration as shown in equations (8-11):

$$G_\tau = \frac{1}{N} \sum_{i=1}^{N} \frac{\varepsilon_i}{Se\left(\widehat{\varepsilon}_i\right)} \tag{8}$$

$$G_\alpha = \frac{1}{N} \sum_{i=1}^{N} \frac{T_i}{\dot{\varepsilon}_i} \tag{9}$$

$$P_\tau = \frac{\widehat{\varepsilon}_i}{Se\left(\widehat{\varepsilon}_i\right)} \tag{10}$$

$$P_\alpha = T\widehat{\varepsilon} \tag{11}$$

Finally, it was necessary to apply the Granger-type causality tests developed by Dumitrescu and Hurlin [37] to check whether the results of a variable serve to predict another variable; that is, whether these have a unidirectional or bidirectional behavior. More generally, if the behavior of A causes the behavior of B in Granger's sense, the relationship is said to be unidirectional. If, on the other hand, the behavior of B predicts the behavior of A, a bidirectional relationship is said to exist. The formal representation is presented in Equation (12):

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_i^k y_{i,t-k} + \sum_{k=1}^{K} \beta_i^k X_{i,t-k} + \mu_{i,t} \tag{12}$$

Where, α_i the intersection of the slope; k shows the lag orders in all units assuming the panel is balanced; $\gamma_{i(k)}$ is the autoregressive parameter, $\beta_{i(k)}$ indicates the regression coefficient differing between cross sections.

4. Discussion of results

Prior to the estimation of the GLS model, the existence of multicollinearity, heteroscedasticity, autocorrelation was determined, the results of which ruled out multicollinearity; and, corroborated the presence of autocorrelation and heteroscedasticity. Consequently, the results of the GLS model estimation are presented in Table 3, which indicate that the cattle head variable shows a statistically significant and positive relationship with arable land; including the control variables. That is, a 1% increase in cattle head is associated with a 0.04 hectare increase in arable land. The variables mean temperature variation and fertilizer use also show significance and a negative relationship with arable land, i.e., a 1°C increase in temperature causes a 0.004 ha decrease in arable land area. Similarly, a 1% increase in fertilizer use decreases arable land by 0.012 hectares.

The positive relationship between livestock and arable land would not be favorable, since this increase would be destined to livestock breeding and production, but not to feeding human beings, which would endanger the food security of the inhabitants of the Latin American and Caribbean region, worsening the scenarios of hunger and malnutrition. Likewise, this increase in the use of arable land due to livestock farming indicates the lack of productivity and performance of the livestock sector in the region, which implies higher costs for each unit produced. These results do not support the contribution of Malthus [6] who points out that the feeding patterns of the upper class would lead to an increase in land devoted to livestock and, therefore, a decrease in the food available to the poorest. Likewise, Alexander et al., [7] also note that a diet involving more animal products can lead to a further reduction in land devoted to agriculture. Similarly, a Greenpeace report report points out that industrial livestock farming is causing land grabbing, mostly for livestock feed, while food production for people is losing ground.

On the contrary, He et al., [10] agrees with the present results; since, these authors indicate that food habits and urbanization imply a greater demand for arable land, mainly destined to produce food of animal origin. Similarly, Rabès et al., [8] mentions that food systems constitute a burden for the environment and the use of resources; being food of animal origin the ones that represent a greater occupation of land and emission of GHG. Therefore, Chai et al., [9] indicates that reduction of meat consumption can placate the impact of the meat industry on the environment.

Climate variability, when associated with events such as heavy rains, floods and droughts, are factors that affect the production and distribution of crops, as these often lead to crop losses and high costs. These losses also imply a reduction in income for the people who mostly live in rural areas and depend mainly on agriculture, which can worsen the situation of poverty and affect economic growth, since the agricultural sector contributes significantly to the total production of the countries that make up the region. The present results are supported by Huang et al., [17] and Huang et al., [38] who mention that increased rainfall and temperature variability cause soil losses and soil sensitivity, but that this effect can be compensated by reforestation; therefore, they indicate that to ensure food security under a changing climate, best management practices that improve soil structure and nutrient retention should be adopted. Severe soil losses have become a very important environmental problem and it is strongly affected by climate change and land use [18].

Table 3
Estimation of the GLS model including control variables

	Basic Model	**Model with control variables**
lcgv	0.00537* (2.19)	0.0443*** (25.94)
cpob		-0.00543 (-1.38)
vt		-0.00434* (-2.37)
lfn		-0.0117*** (-8.79)
Constant	0.0637 (1.88)	-0.217*** (-11.08)
Observations Adjusted R2	1197	1197

Note: * significance at 5%, **significance at 10%, ***significance at 1%.)

The use of fertilizers has its advantages and disadvantages. On the one hand, they increase crop yields, thus allowing to feed the growing population; but, on the other hand, their excessive use causes soil degradation, since their chemical composition causes damage to the soil, which with excessive and prolonged use ends up worsening the health of the soil. In addition to this, fertilizers are groundwater polluters that then end up being sources of irrigation for crops, whose situation affects the normal growth of plants; and at the same time, contamination of food, which translates into serious health problems for humans. These findings are similar to those found by Hao et al., [28], who demonstrated that soil acidification is induced by nitrogen fertilizers. Soil acidification causes changes in soil properties, hard soils and susceptibility to pests; thus, the amount of chemical fertilizer applied to agricultural land has caused nutrient losses from soils, which reduces the water and nutrient holding capacity and thus crop yields. On the other hand, Zhang et al., [29] indicate that organic fertilizers have enormous potential to replace chemical fertilizers, thus mitigating threats to the environment and human health.

Prior to estimating the long-term relationships, we applied the cross-sectional dependence tests proposed by Pesaran which uses the correlation coefficients between the series of each of the countries. Therefore, Table 4 reports the results of the cross-sectional dependence test (CD); and, given that the p-value is less than 0.001, the null hypothesis of no cross-sectional dependence between countries is strongly rejected and it is concluded that the variables present cross-sectional dependence between countries at a significance level of 0.1%.

Since there is the presence of transversal dependence within the model, it is pertinent to apply the second generation unit root tests, in order to verify the stationarity of the panel data series, and the same happens with the long term estimations. In this sense, the CADF tests and the CIPS of Pesaran which are more robust and reliable in the presence of cross-sectional dependence. Table 5 shows the results obtained from the unit root tests in levels (constant and

Table 4
Tests of cross-sectional dependence

Test Pesaran (2015)		
Variables	**CD**	**p-value**
Arable land per capita	104.021***	0.000
Log Heads of cattle	109.364***	0.000
Population growth	92.356***	0.000
Average temperature variation	90.863***	0.000
Log Fertilizer use	109.072***	0.000

Note: t denotes significance * p < 0.05, ** p < 0.01, *** p < 0.001

Table 5
Results of unit root tests on levels and second differences

CADF Test Statistics					
	Levels		Second differences		
Variables	**Constant**	**Constant and trend**	**Constant**	**Constant and trend**	**Order**
Arable land per capita	-1.873	-2.191	-3.782***	-4.139 ***	I (1)
Log Heads of cattle	-1.998	-2.440	-3.748 ***	-3.729 ***	I (1)
Population growth	-1.401	-1.557	-4.877 ***	-5.430 ***	I (1)
Average temperature variation	-3.727***	-3.599***	-5.989 ***	-6.119***	I (1)
Log Fertilizer use	-2.286 *	-2.860***	-5.680 ***	-5.793***	I (1)
CIPS Test Statistics					
Arable land per capita	-1.823	-2.237	-4.817***	-5.368***	I (1)
Log Heads of cattle	-1.893	-2.236	-5.783***	-5.733***	I (1)
Population growth	-1.469	-1.626	-3.176***	-3.595 ***	I (1)
Average temperature variation	-5.680***	-5.941***	-6.190***	-6.420***	I (1)
Log Fertilizer use	-2.992 ***	-3.783 ***	-6.190***	-6.420***	I (1)

Note: t denotes significance * p < 0.05, ** p < 0.01, *** p < 0.001

constant-trend), in which it is observed that three series of five are non-stationary at level I (0). Therefore, the first difference was performed to all variables to become stationary (constant and constant-trend), determining that the series have an order of integration I (1) at a significance level of 0.1%.

Once the order of integration of the variables is determined, we estimate the long-run equilibrium relationship between the variables included in the model [39]. Considering that the model presents transversal dependence, we apply the cointegration test developed by Westerlund [36]. In order to interpret the results, it should be kept in mind that the statistics Gt and Ga, test the alternative hypothesis that at least one unit is cointegrated, while Pt and Pa test the alternative hypothesis that the panel is cointegrated [40]. The results for all the four statistics that this test yields determine that there is cointegration between the variables; since the p-values are less than 0.05, the results of which are shown in Table 6. Consequently, a long-term relationship between the variables included in the model implies keeping in mind that the availability of arable land is compromised in the future by variations in the number of cattle, population growth, temperature variation and fertilizer use, which generates food,

Table 6
Results of Westerlun's cointegration test

Statistic	Value	Z-value	VP-value
Gt	-3,147***	-3,366	0,000
Ga	-14,567***	-0,963	0,006
Pt	-14,178**	-4,000	0,029
Pa	-17,480***	-4,941	0,000

Note: t denotes significance * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

poverty and development problems for future generations.

Having clear that land is a limited resource, it is worrying the excessive use of it, as it can reach the day when there is no more land to produce. Therefore, we should be concerned about the available resources in the future, in the scenario that over time the demand for land increases, and its use is not only to produce food, but for all kinds of activities that mostly generate environmental damage and decrease of productive soils; in itself, over time the extent of land will not disappear but if the amount of land suitable for cultivation will be reduced, due to the decrease of nutrients and fertility necessary for food production needed by humans, not only for their physical survival but also: economic and social. These results are validated by the contribution of Yawson [15] who mentions that it is necessary to substantially increase the area of land currently allocated to barley to meet the projected demand for feed use in the future, since the results indicate that productivity gains must be complemented by increasing the harvested area. Likewise, Rodrigues et al., [11] determines that future land use is determined by agro-pastoral expansion. For their part, Soltani et al., [12] in Iran concludes that the future food supply and efficiency of the country is at stake, due to the overexploitation of water resources and land, mainly for the expansion of the livestock sector, deforestation and mining.

The long-run relationship between arable land and control variables is supported by Mugizi et al., [41] who show that population pressure reduces soil quality and induces agricultural intensification. This suggests that, although farmers are trying to mitigate the negative effects of population, the rate of soil degradation is outpacing the rate of intensification. Likewise, Prabhakar [16] mentions that the rapidly growing population and its needs are one of the main drivers of land use change. On the other hand, the impact of temperature on land and crops has a lot to do with the area and the type of crop; in some cases in the long term it significantly increases production, but also reduces soil efficiency [20]. Likewise, Shakhawat et al., [21]; Hossain et al., [22]; Arshad et al., [23] find that climate change is causing land degradation by decreasing its value, agricultural productivity and income. In fact, by 2030, climate change will exacerbate extreme poverty problems through impacts on agriculture and food security. Regarding the relationship with fertilizer use, those who agree with our findings are Fontana et al., [42] who find that the proper use of fertilizers and the implementation of cover crops lead in the long term to improved soil properties and higher soil yields.

Finally, in order to estimate causal relationships, the Granger causality test developed by Dumitrescu and Hurlin [37] was used. In this context, it is established that the fact that two variables are correlated with each other does not necessarily imply causality, i.e. the fact that

Table 7
Dumitrescu and Hurlin's causality results

Address	W-bar	Z-bar	P-value	Conclusion
tch - lcgv	2,7994	5,8307	0,0000	Causality
lcgv - tch	3,1447	6,9497	0,0000	Causality
tch - cpob	10.1204	29.5535	0,0841	Non-causality
cpob - tch	1.7385	2.3930	0.0746	Non-causality
tch - vt	16.3029	49.5871	0,0000	Causality
vt - tch	0.6681	-1.0753	0.2822	Non-causality
tch - lfn	5.7041	15.2431	0,0000	Causality
lfn - tch	3.6789	8.6806	0,0000	Causality

Note. Adapted from FAO (2020) and World Bank (2020).

one variable correlates to another does not imply that this is the cause of the alterations in the values of another. The results of the test show that there is a bidirectional causal relationship between arable land and cattle production, and also between arable land and fertilizer use. That is, variations in arable land cause variations in cattle production and variations in cattle production cause variations in arable land, and the same is true for fertilizer. Similarly, arable land shows unidirectional causality with mean temperature variation. The results are shown in Table 7.

Specifically, it is determined that the main causes of variations in the availability of arable land are livestock and fertilizer use, which can be said to generate distortions in both the extent and degradation of land. On the one hand, livestock farming implies greater land use and at the same time the sector emits emissions such as methane that are absorbed by the soil, since the soil is a natural sink for emissions. These studies are find that the main driver of land use change is the livestock sector, as large tracts of land are converted to pasture or feed crops. Between 1960 and 2011, animal food production has been responsible globally for 65% of land use change and the expansion of cultivated land. Similarly, FAO mentions that increasing livestock production has implications for agriculture and food systems; as one of the main challenges is to produce more with less, while preserving and improving farmers' livelihoods.

Fertilizer use on its part, as well as helps to improve soil yield and productivity; it equally emits pollutant gases such as nitrous oxide, which in conjunction with methane are harmful to the environment and human health. These findings are similar to those found by Habtemariam et al., [30] and Adnan et al., [31] who mention that the adoption of fertilizers and rainwater harvesting reduces the percentage of food insecure people and improves the yields and incomes of many farmers. However, these resources alone do not generate significant changes in terms of reducing poverty and food insecurity. In addition, Toledo [32] indicates that the lack of knowledge about soil management has led farmers to use methods based on the excessive use of fertilizers, which generates a better productive response of crops and at the same time deterioration of productive soils.

Finally, a very important result within causality is that the availability of arable land is the cause of the average temperature variation; whose relationship is explained by the emissions that are thrown by the agricultural sector at the time of producing and distributing food; because, these cause alterations in temperature. The production of land involves the use of chemicals that release gases into the air and penetrate the soil, which act as natural carbon sinks, which alters the climate system by increasing the amount of gases that are responsible for heat retention on the planet, and thus aggravates the problems of climate change that are evident today. Thus, our results are similar to the studies of Yang et al., [24] and Bell et al., [25] who state that abandoned lands help to combat climate change as they experience a natural recovery of vegetation and soil carbon; and help to remove carbon dioxide from the atmosphere. Similarly, Mekonnen et al., [13] finds that improved soil and water conservation practices positively influence soil physico-chemical properties, which in turn leads to reduced pollutant emissions and improved soil quality as a natural sink.

According to Silveira et al., [26] greenhouse gas emissions are directly associated with climate change problems. Part of these emissions are caused by agriculture, by the burning of fossil fuels such as coal, natural gas and oil used as a source of energy for the performance of agricultural machinery. On the other hand, Del Buono [27] indicates that soil salinity due to the excessive use of fertilizers is one of the most problematic causes that will increase anthropogenic climate change. Likewise, Shakoor et al., [14] points out that croplands due to their large area and management practices emit harmful emissions to the environment, which end up aggravating the problems of climate change. Finally, it is important to note that the discussion of causality was not precisely conducted with studies using the same methodology.

5. Conclusions

The results of the present investigation do not fulfill the first hypothesis raised for the analysis of the availability of arable land, seen from a Malthusian point of view; since, the results indicate that the production of bovine cattle is increasing the arable land. Therefore, it is important to emphasize that the increase of arable land is not destined precisely to feed the population, but to the production of fodder, legumes and pastures for food and livestock breeding, which leads to a smaller amount of land for the cultivation of food for human beings. These results contribute to think that people include in their diet mostly meat, whose production generates serious and irreversible environmental problems compared to crop production.

The cointegration tests applied to the model allowed us to appreciate that the variables have a short and long term equilibrium relationship. Concretely, these relationships imply concern for present and future generations and incite to propose and implement policies urgently, to counteract the problems of food security and poverty that are seen to come to the lack of land to cultivate. It should be considered that, not only are variations in arable lands evident in extension, but also in the form of degradation and loss of fertility, which would be the result of the abuse of chemicals and the excessive and unsustainable use of soils when cultivating food. These findings allow for the acceptance of the second hypothesis raised above.

Bidirectional causality was found between cropland and livestock and fertilizer use. Likewise, arable land is a cause of climate change. Livestock and fertilizer use, being polluting gas emitting activities, generate a feedback effect, since their operation causes variations in extension and degradation of arable land, which, in turn, generates impacts again on livestock and fertilizer use, since it will be necessary to apply more fertilizers or extend the land for livestock. Climate change, which is also related to GHG emissions, is affected by agriculture, due to unsustainable agricultural practices. In this sense, the results allow us to accept the third hypothesis.

In general, it is found that the rapid growth of the livestock sector is mostly attributed to the increase in livestock stocks, but not to the improvement in productivity, which implies greater land use. On the other hand, the evident reduction in arable land is not primarily due to cattle production, but to fertilizer use and climate change; therefore, further research is needed on the determinants of this reduction. The short and long term relationship between the variables are results that should draw the attention of governments to act immediately to reduce as much as possible the reduction of arable land, which is the fundamental basis of the economies of Latin America and the Caribbean.

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