Global Environmental Change 63 (2020) 102075

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

The effect of Cuban agroecology in mitigating the metabolic rift: A quantitative approach to Latin American food production

Mauricio Betancourt*

University of Oregon, Department of Sociology

ARTICLE INFO

Keywords:
Metabolic rift
agroecology
industrial agriculture
decoupling
Cuba

ABSTRACT

The historical development of capitalism created what Karl Marx called a rift in the social metabolism with nature, whereby soil nutrients were systematically siphoned into cities where they were discarded as waste and thus did not return to the land. An alternative mode of food production known as agroecology was developed by different scientists and activists partly to transcend this contradiction. Drawing on data from the United Nations and the World Bank, this work analyzes whether agroecology has contributed to mitigate the metabolic rift in agriculture in Cuba, the country where this approach to food production, adopted after the dissolution of the Soviet Union in 1991, is more widely developed. By means of a panel model, both an internal comparison through time within Cuba and a cross-national comparison of Cuba with the rest of Latin America and the Caribbean (LAC), were developed to determine whether the post-Soviet transition to agroecology in Cuba successfully decoupled industrial agricultural practices from productivity in comparison to other countries in LAC. Decoupling is understood as the removal of the positive correlation between fertilizer use and yield. Synthetic fertilizer use is utilized as an indicator of industrialized agriculture, and productivity of maize and beans as a proxy measure of soil improvement. The model shows a reversal of the fertilizer use and productivity positive correlation in Cuba, where crop productivity has increased while the use of inputs has diminished, which suggests that agroecology has indeed mitigated the metabolic rift produced by industrialized agriculture.

1. Introduction

As research over the last three decades has shown, an important component of Karl Marx's critique of political economy was his analysis of ecological perturbations provoked by the capitalist system (Saitō 2017; Burkett 2014; Foster et al. 2010; Foster 2000; Foster 1999; Vaillancourt 1992). This aspect of Marx's work was based on the critique of alienation (*i.e.*estrangement) of human beings from the rest of nature. Marx utilized the concept of metabolism (*Stoffwechsel*) to refer to the material exchange within and between society and the environment and explained that, in capitalism, an “irreparable rift” in the human “metabolic interaction” with nature was produced as a consequence of the division between town and country. This was due to the systematic loss of soil nutrients that were siphoned into cities in the form of food or fiber, where they were discarded as waste and thus did not return to the land (Foster et al. 2010; Marx 2010: 637; Wittman 2009). Hence, although at one pole this logic of production allowed for an increase in food output by continually revolutionizing the means available to and organization of agricultural labor, at the opposite pole it caused a rift in the social metabolism with nature.

Since the 1970s, an alternative mode of food production was independently developed by different scientists and activists largely as a response to socioecological effects of the metabolic rift in agriculture. This approach is known as agroecology and considers the field and farm as ecosystems to be managed using practices learned from natural systems. It pays primary attention to restoring soil quality by increasing soil organic matter, reducing tillage, using polycropping, and improving nutrient cycling through use of cover crops and other techniques while attaining people's nutritional needs (Wezel et al. 2009). Agroecological farming has similarities to regenerative and organic farming, but stresses social issues and indigenous knowledge (Sevilla-Guzmán and Woodgate, 1997: 93–94). Agroecological approaches are practiced in hundreds of places, mainly within Africa, Asia, and Latin America, as well as encouraged by a variety of organizations such as Brazil's Landless Workers Movement (MST) or the international peasant movement La Vía Campesina. However, agroecology has been developed to a greater extent in Cuba through a countrywide movement that is supported by the state (Rosset et al. 2011: 171,186; Funes et al. 2009:

Through agroecology, Cuba has achieved a tenfold increase in maize and beans yield

* Corresponding author: 1291 University of Oregon, 614 PLC. Eugene, Oregon 97403, USA
E-mail address: mbetanco@uoregon.edu.

https://doi.org/10.1016/j.gloenvcha.2020.102075
Received 12 June 2019; Received in revised form 27 October 2019; Accepted 30 March 2020

4). Agroecology was gradually adopted in this country as a consequence of the dissolution of the Soviet Union in late 1991, from which Cuba imported most of its agricultural inputs (Rosset and Benjamin 1994: 3). The aim of this work is to establish whether the transition to agroecology in Cuba has contributed to mitigating the metabolic rift in agriculture. To do so, I will determine the relationship between industrial agricultural practices and productivity in Cuba relative to the rest of Latin America and the Caribbean (LAC) from 1961 to 1991, and ascertain whether the post-Soviet transition to agroecology in Cuba successfully decoupled (*i.e.* dissociated) these practices from productivity in comparison to all other countries in the study, which would point to metabolic restoration (*cf.* Bai and Dent 2007).

Shedding light on agroecology's potential capability to mend the metabolic rift is essential in the face of arguably the most serious ecological crisis in the planet's anthropogenic history (Steffen et al. 2011; Zalasiewicz et al. 2011; Foster et al. 2010; Rockström et al. 2009). Agriculture, forestry, and other land use together are among the human activities that most contribute to climate change, generating about 24 percent of the world's greenhouse gas emissions (IPCC 2014: 47). However, if properly managed the soil can absorb large amounts of carbon (C). C sequestration has the potential to offset 5 to 15% (~0.4-0.7 Gt Ceq yr^{-1}) of the yearly global fossil-fuel emissions (Smith 2016: 1319; Lal 2004: 1626). In addition to climate change, due to industrialized agriculture's intensive practices, the nitrogen (N) and phosphorus (P) biogeochemical cycles have been disrupted well beyond the earth system's stability boundary (Steffen et al. 2015). According to Steffen *et al.* (2015), the global value of industrial and intentional biological fixation of N is ~150 Tg yr^{-1}, when it should not exceed a rate of about 62 Tg yr^{-1} to stay within a “safe operating space” for humanity. Because of the Haber-Bosch process, through which most of the world's synthetic fertilizer is produced, in the last 200 years the N cycle has undergone more alterations than in the last 2.5 billion years (Macfarlane 2016; Vitousek 1997). This process has been so impactful and pervasive that is referred to as the “detonator of the population explosion” (Smil 1999). Moreover, nitrogen fertilizer production is very energy intensive (usually using natural gas), requiring high temperatures and pressure to convert atmospheric molecular nitrogen (N_2) into forms that plants can use.

Likewise, the global phosphorus flow rate from freshwater ecosystems into the ocean is ~22 Tg yr^{-1}, twice the amount of the safe value, and the regional P flow from fertilizers to erodible soils is ~14 Tg yr^{-1}, 2.26 times greater than it should be (Steffen et al. 2015). The estimated rate of global erosion of soils currently exceeds its production rate by about 23 billion tons per year. At this rate, the planet soils will be exhausted in little more than one hundred years (Montgomery 2012).

At the same time, 16 million km^2 (a portion equivalent to the size of all of South America) of the planet's landmass have been deforested for agricultural use, and 30 million km^2 (an extension corresponding to the total area of Africa) have been turned into land for grazing (IE 2009). Industrialized agriculture has also contributed, directly or indirectly and especially through habitat loss, to the global extinction of around 25,000 species in the last 250 years, a rate comparable to that of the five massive extinctions of life on the planet. The excessive use of agricultural pesticides and synthetic fertilizers is probably also contributing to the massive loss of insects (Sánchez-Bayo and Wyckhuys 2019). Hence, the ongoing global annihilation event has been accurately and alarmingly called “the sixth extinction” (Ceballos et al. 2017; Urban 2015; Kolbert 2014; Leakey and Lewin 1995). As researchers from University of Minnesota's Institute on the Environment (IE 2009) rightly state, “there is nothing we do that transforms the world more than agriculture, and there's nothing we do that is more crucial to our survival.” This work seeks to contribute to the development of holistic responses to such conundrum by examining an alternative nature-society relationship in general, and some of agroecology's socioecological effects in particular.

The resolution of the ecological crisis does not concern the natural sciences exclusively, since it is a product of the socioeconomic organization embedded within the natural environment. Therefore, the ecological crisis requires a socioeconomic solution, firmly based on natural science's findings (Angus 2016). Marx's theory of metabolic rift, as developed by John Bellamy Foster (1999), has proved a powerful approach for analyzing specific environmental and social degradation instances under capitalism, such as the human alteration of the carbon cycle and the climate (Clark and York 2005), the nitrogen cycle (Mancus 2007), ecological imperialism and the guano/nitrates trade in Peru and Chile (Clark and Foster 2009), livestock agribusiness (Gunderson 2011), urban agriculture (McClintock 2010), environmental justice (Weston 2014), and the undermining of the oceanic ecosystems (Longo et al. 2015; Clausen and Clark 2005).

On the other hand, a vast amount of research has studied agroecology's capability to produce healthy and sufficient food through ecologically sustainable methods that conserve and restore soil quality, building up and maintaining sufficient nutrients and fertility for crops (Rosset and Altieri 2017; Perfecto et al. 2009; Gliessman 2007; Altieri 2002). Important work has been done in this regard in relation to Cuba (Bolliat et al. 2012; Rosset et al. 2011; Wright 2011; Machín Sosa et al. 2010; Simón et al. 2010; Funes et al. 2002; Rosset and Benjamin 1994; Levins 1990). Moreover, some case studies of specific plots in Cuba where agroecological techniques are used have demonstrated that soil fertility has indeed increased relative to pre-agroecological levels (Funes-Monzote 2009: 134; Treto and García 2002: 185; Treto et al. 2001).

However, so far just a handful of studies have, to a greater or lesser extent, explicitly linked metabolic rift theory and agroecology either generally or in relation to Cuba (Clausen and Longo 2015; Weston 2014:173–5; Wittman 2009; Clausen 2007). In this study, Cuban agroecology is examined under the lens of metabolic rift theory by analyzing this country's progressive removal of the positive association between industrial inputs and yield. As will be shown below, this would point to improved soil quality attained through an alternative approach to food production, and thus to moving towards the socioecological restoration of the human metabolism with nature in the realm of agriculture. Moreover, although succinctly describing some of Cuba's agroecological developments, Clausen and Longo (2015) and Clausen (2007) have just highlighted the *potential* of agroecology for “healing” the metabolic rift. No study so far has assessed whether agroecology in Cuba has in fact mitigated this rift. What is more, given that metabolic rift theory emphasizes the qualitative aspects of environmental impacts (Foster et al. 2010: 509), no research has undertaken a quantitative approach to somehow measure the degree to which this rupture extends or has been restored. Lastly, no work has carried out a longitudinal, cross-national comparison of Cuban and LAC agriculture using data that covers more than half a century. By means of a panel model, which consists of the analysis of repeated observations of the same variables over time, this study intends to address all of these gaps.

1.1. *Agroecology in Cuba*

After the disintegration of the Soviet Union in December, 1991, Cuba's economic condition deteriorated dramatically. Along with several other measures, the Cuban government carried out a complete restructuration of the country's agricultural production. Prior to 1991, according to Rosset and Benjamin (1994: 3), Cuba depended on the socialist bloc for trading petroleum, industrial equipment, and agricultural inputs such as pesticides, fertilizers, and foodstuffs (around 57% of the total calories consumed by the population). However, after the dissolution of the USSR, Cuba's GDP fell by 34.8% and food production collapsed. For instance, vegetable production fell by 65% from 1988 to 1994, bean production decreased 77%, and root and tuber crop production dropped by 42% (Rosset et al. 2011: 181). Moreover, Cuba lost 85% of its trade relations and 70% of its imports, and thus was unable to introduce enough food, petroleum, machinery, and other agricultural inputs as before 1991 (*Ibid.*: 166). Overall food consumption dropped 34% (from 2,908 calories in the 1980s to 1,863 calories a day in 1993) (Kost in Reardon et al. 2010: 914) and the people's diets deteriorated significantly.

Cuba was surprisingly able to overcome this acute crisis known as the "Special Period" [in Time of Peace], despite the strengthening of U.S. economic sanctions exercised through the Cuban Democracy (1992) and Helms-Burton (1996) Acts. Drastic changes were carried out by the Cubans in order to rearrange the country's economy, particularly in the peasant sector (Rosset et al. 2011: 166). As ecologist Richard Levins (2002: 279) argues, "[t]he ecological transformation of Cuban agriculture since the early 1990s is overwhelmingly complex, including changes in agrotechnology, land tenure and use, social organization of production and research, educational programs, and financial structures."

However, this "revolution within a revolution" (Nelson et al. 2009) was not an improvised emergency reaction to the Special Period, but a strategy that had its roots in the transformation of the Cuban society and its scientific institutions since the Revolution of 1959 (Lewontin and Levins 2007: 343). The Cubans had been turning their attention to the problems of the agricultural sector and to alternative food production methods several years before the dissolution of the USSR (Bolliat et al. 2012; Deere 1993), and thus some of the conditions to produce such a swift transition were already present in the country. Otherwise, this shift would have simply been impossible. Moreover, despite the promptness of this transformation, it gradually progressed from an input substitution stage (*e.g.* relying on biofertilizer, poultry manure, or worm humus instead of manufactured fertilizer) earlier in the Special Period, to a more thoroughly agroecological phase (exhibiting intercropping, the integration of crops and livestock, diversification, recycling of nutrients, etc.) (Rosset et al., 2011).

Concerning land management, state farms that had been created by the Agrarian Reform Laws of 1959 and 1963 were turned into smaller Basic Units of Cooperative Production (UBPCs) and handed in rent-free perpetuity (usufruct) to farmers in 1993, to motivate them to achieve the greatest production at the lowest possible costs (Pérez and Echevarría 2002) and to "establish a more direct relationship between agricultural workers and production" (Castro 1996). In this same year, Decree 179 was passed to regulate the protection, use, and conservation of soils (Gardi et al. 2015: 133). Additionally, the cooperatives of the National Association of Small Farmers (ANAP), a federation formed in 1961 for farmers with less than 67 hectares of land (Puerta and Alvarez 1993), developed a *campesino–to–campesino* agroecology movement (Rosset et al. 2011), presently constituted by 331,974 members, through which more than 65% of the country's food is produced, in only 25% of the land (Funes et al. 2009: 4).

Cuba not only recovered, but showed the best performance in all of LAC with a 4.2% annual per capita food production growth from 1996 to 2005 (Rosset et al. 2011: 168). In the 1996-7 season, this country recorded its then highest-ever production levels for 10 of the 13 basic food articles in the national diet (Rosset 2000: 210). By 2007, the production of vegetables "rebounded to 145 percent over 1988 levels, despite using 72 percent fewer agricultural chemicals than in 1988," beans production rose 351% over 1988 levels, using 55% less agrochemicals, and roots and tubers production increased to 145% of 1988 levels, with 85% fewer chemical inputs (Rosset et al. 2011: 181). At the same time, undernourishment –which had dropped after 1959 and abruptly rose to affect 19.9% of the population around 1992-94– decreased once again, in just five years, to values lower than 5% –as those in any high-income country– and in fact has been kept below 2.5% since 2014 (FAO 2017: 81).

Last but not least, Cuba has also developed an important urban agriculture (UA) program, managed through agroecological practices across a variety of city systems such as organoponics, intensive gardens, and parcel plots (Koont 2011; Wright 2011: 81-92; Altieri et al. 1999). Nationally, more than 1.5 million tons of vegetables are produced by 383,000 urban farms, supplying at least 70% of all the fresh vegetables in Havana, Santa Clara, and other cities, and contributing about 5 per cent of Cuba's total production (Funes et al. 2009: 5; Wright 2011: 83, 91). According to Funes *et al.* (2009: 5), "[n]o other country in the world has achieved this level of success with a form of agriculture that reduces food miles, energy use, and effectively closes local production and consumption cycles." Hence, it is likely that UA has also contributed to metabolic restoration by decreasing the siphoning of soil nutrients into urban centers and softening the antagonism between the countryside and cities. Thus, an exhaustive study assessing metabolic rift mitigation in Cuba should integrate rural, peri-urban, and urban agroecology, along with waste management procedures (*cf.* Companioni et al. 2002: 234).

2. Data and Methods

The data for this work was obtained from three public sources available online: The Food and Agriculture Organization of the United Nations (FAOSTAT), the World Bank Open Data (WB), and the World Bank's Climate Change Knowledge Portal (CCKP). Seven datasets were downloaded from these organizations' websites as Microsoft Excel files and were later cleaned, edited, and merged using the open source software *R*. Through these procedures a final dataset comprised of ten variables was obtained (see supplementary material). This dataset includes information for 22 countries in Latin America and the Caribbean from 1961 to 2015, excluding Bahamas, French Guiana, Guyana, Puerto Rico, Suriname, and the Lesser Antilles, given the very high amount of missing values for these nations. A limitation that arises from utilizing this data is that, because these organizations collect official statistics from each country, establishing their overall accuracy is not possible. As for the Cuban case, some authors have referred to data scarcity during the 1990s, and questioned their reliability during 1995-97 (Mesa-Lago 1998).

The dependent variable in this study is the natural logarithm of the yield (in t ha^{-1}) of either maize, beans, or both crops, which, when taken together with synthetic fertilizer usage, can be considered a proxy indicator of soil improvement (*i.e.* of agricultural metabolic restoration) (Magdoff and Van Es 2009). This variable was logarithmized to attenuate the skewness of the data produced by a handful of outlying values (*e.g.* Chile's). Secondly, these crops were chosen because of their important production levels in LAC, a result of their prevalence in the region's diets (Nuss and Tanumihardjo 2010; Bermudez and Tucker 2003).[1] The ideal variable to measure soil improvement would have been soil organic carbon (and/or nutrient) content (Gardi et al. 2015: 139). However, such data does not exist at the country and yearly levels. Hence, drawing on research which suggests that soil degradation and improvement are commonly inferred from long-term trends of productivity, when other factors (climate, soil, terrain, and land use) are accounted for (Magdoff and Van Es 2009; Bai and Dent 2007) the imperfect but reliable yield (of maize, beans, or both crops) variable was used as the optimal option available.

The independent variables that were used are: agricultural land (*i.e.* the country's percentage of share of land in agriculture), tractor use (per 100 km^2 of arable land), average rainfall (mm per year), average annual temperature (°C), and synthetic fertilizer use (nitrogenous, potash, and phosphate fertilizers, including mineral fertilizers and excluding animal and plant manures, in kg per hectare of arable land). The latter variable had to be calculated utilizing data both from FAOSTAT and the World

---

[1] An alternative analysis was carried out utilizing the yield of all aggregated crops that FAOSTAT collects and reports (cereals, citrus, grain, fiber, fruit, pulses, roots, tree-nuts, and vegetables), both for each of these categories and for their sum. The results run in the same direction as when using the yield of maize and beans (see supplementary material).

Bank, given that the WB only has fertilizer use data from 2002 to 2015. On the other hand, the FAO has data on arable land (in hectares) and synthetic fertilizer use (in metric tons) from 1961 to 2002. Thus, the FAO fertilizer use data was converted to kilograms, and then divided by the FAO arable land values. Subsequently, all the missing values in the WB's fertilizer use column (*i.e.* 1961-2001) were substituted by the new obtained values. For the year 2002, there were two possible values: the already existing ones in the WB dataset, and the ones calculated using the FAO data. For all countries (with the exception of Belize) both values were very similar. Given that the WB values had been already published, these were the ones that were used for fertilizer use (kg ha^{-1}) for the year 2002. Also, due to the complexity of Cuba's agricultural transformation and intrinsic and practical limitations of the data, there are other socioeconomic variables concerning land tenure and use (*e.g.* the disbanding of state farms into smaller, more efficient systems) as well as market incentives for overproduction, that may have influenced crop productivity and were not measured.

To assess the effect of Cuban agroecology on the mitigation of the metabolic rift, a longitudinal study was carried out by means of a difference-in-difference-in-difference (DDD) ordinary least squares (OLS) panel model. The general equation for the model is:

$$\begin{aligned} y_{it} \;=\; & \alpha_i + \beta(x_{it}) + \gamma(t \geq 1995) + \delta(x_{it})(t \geq 1995) + \zeta(x_{it})(C_i) \\ & + \eta(t \geq 1995)(C_i) + \theta(x_{it})(t \geq 1995)(C_i) + \lambda(w_{it}) \\ & + \mu(z_{it}) + \nu(m_{it})(n_{it}) \end{aligned}$$

where y_{it} is the measure of agricultural productivity (*i.e.* soil improvement), α_i controls for countries' fixed effects, β gives an overall measure of the relationship between industrial agricultural practices and productivity (which is expected to be positive), x_{it} is a measure of synthetic fertilizer use, γ gives the average change in yield in the post-transition period for all countries except Cuba, and $(t \geq 1995)$ is a dummy variable for the transition year. The year 1995 was used instead of 1991 or '92 in order to avoid lagged effects caused by the initial crisis of the first three years after the demise of the USSR. In addition, 1994 was the most critical year of the Special Period, when the economy bottomed out, there was a critical shortage of inputs, and the country operated at one third of its industrial capacity (Wright 2011: 69; Machín Sosa et al. 2010: 13). Some models (not shown) were developed by adjusting this year all the way from 1991 to 1999, and the obtained results ran in the same direction as when using 1995.

There is then a sequence of two-way and three-way interactions among these variables, where δ indicates how much fertilizer use and yield were decoupled in the "control group" (*i.e.* all countries in the study except Cuba) in the post-Soviet stage, ζ specifies how different was the relationship between industrial agricultural practices and yield in Cuba relative to the control group from 1961-1995, and C_i is a dummy variable for Cuba. η, which is expected to be positive, gives the average change in yield in the post-transition period for Cuba above and beyond the general γ effect, and θ, which is expected to be negative, is the key diff-in-diff-in-diff estimator that indicates how much fertilizer use and yield were decoupled in the post-Soviet period for Cuba in comparison to the control group. Additionally, λ is a measure of the relationship between agricultural land and yield (which is negative in general), w_{it} controls for countries' agricultural areas, μ estimates the association of tractor use and yield (which is positive), z_{it} controls for countries' tractor use in agriculture, ν estimates the interaction between rainfall and temperature (a proxy control for the weather), and m_{it} and n_{it} control for rainfall and temperature, respectively. Finally, the *R* package *panelAR* was utilized to account for autoregressive AR(1)-type autocorrelation and panel heteroscedasticity. AR(1) autocorrelation is addressed through a Paris-Weinstein feasible generalized least squares (FGLS) regression model with panel-corrected standard errors (PCSE).

The aim of this DDD panel model is twofold: on the one hand it estimates the relationship between industrial agricultural practices and yield in Cuba relative to the rest of Latin America and the Caribbean from 1961 to 1991, and on the other hand it evaluates whether the post-Soviet transition to agroecology in Cuba decoupled these practices from yield in comparison to everywhere else. The detachment of industrial agricultural practices and productivity is the central rationale underlying this panel model. Synthetic fertilizer use is generally associated with an increase in crop productivity (Mózner et al. 2012; Evenson and Gollin 2003, this study). In Cuba, after 1991, industrial agricultural practices have been substituted to a great extent by an agroecological nationwide movement, and food productivity has increased, contrary to what would be expected according to industrialized agriculture's logic of production. This increase in yield per hectare, minimizing fertilizer use, occurs because agroecological techniques (*e.g.* compost, cover crops, intercropping, rotation) are explicitly aimed at avoiding soil erosion and degradation, and preserve and increase organic matter and nutrients *in situ*, through more labor-intensive practices than those of industrial agriculture. Contrary to industrialized agriculture, which focuses on nourishing plants in order to enhance their growth, agroecology nourishes the soil, which in turn nurtures the plants.

A DDD model was developed because it can simultaneously address the positive correlation between industrial agriculture and yield, and also the hypothesized, smaller or even negative correlation between these two variables in Cuba after the post-Soviet shift to agroecology. The exogenous source of variation in this model is the dissolution of the Soviet Union (1991), and it counterfactually assumes that, had the USSR not disintegrated, the relationship between industrial agriculture and yield in Cuba would have run in the same direction both for the "treatment" (Cuba) and "control group."

3. Results

Fig. 1 shows the natural logarithm of synthetic fertilizer use (kg ha^{-1}) in five Latin American countries –Argentina, Brazil, Mexico, Costa Rica, and Cuba– from 1961 to 2015. The first three countries were chosen because their agricultural production is mostly guided by agro-industrial policies and practices, and due to their importance regarding LAC food production. Costa Rica was selected given that, during the last half century, it is the country that has utilized the most synthetic fertilizer per area in LAC, on average. From 1961 to 1991, the average synthetic fertilizer consumption in Cuba was 155.47 ± 44.6 kg ha^{-1}. From 1992 to 2015, this value decreased significantly and averaged 43.81 ± 16.5 kg ha^{-1} (a 71.82% reduction). Conversely, the average value of fertilizer use in the rest of LAC from 1961 to 1991 was 56.87 ± 65.03 kg ha^{-1}, which *increased* to 149.50 ± 173.45 kg ha^{-1} from 1992 to 2015. This represents a 162.88% increase in fertilizer use in the control group. The standard deviations of the values in the control group are so high because fertilizer consumption has varied enormously across countries (*e.g.* with Costa Rica and Bolivia averaging about 697.2 and 5.2 kg ha^{-1}, respectively, from 1992 to 2015). Nonetheless, these numbers show that fertilizer use has increased overall in LAC. The only countries in the study where fertilizer use has decreased relative to pre-1991 levels are Cuba and Jamaica.

When analyzing synthetic fertilizer use through an OLS regression including every LAC country except Cuba, the model (not shown) predicts that fertilizer use increased by about 4.5% per year since 1961. For instance, in Argentina this increment was of 7.24%, on average (although starting from a very low application rates); in Brazil, the growth in fertilizer use has been of 4.85% per year, on average; in Costa Rica, of 4.13%; and, in Mexico, of 2.73%, on average. Conversely, if analyzing Cuba's fertilizer use through time by means of two OLS models, one from 1961 to 1991 (the industrial agriculture period), and one from 1992 to 2015 (the agroecological period), the former shows that fertilizer use increased by about 1.41%, and the latter that there has been a 1.22% yearly *decrease* in fertilizer use, on average.

Fig. 2 shows the *ln* of the combined yield of maize and beans (t ha^{-1}) in the same five Latin American countries in the sample from

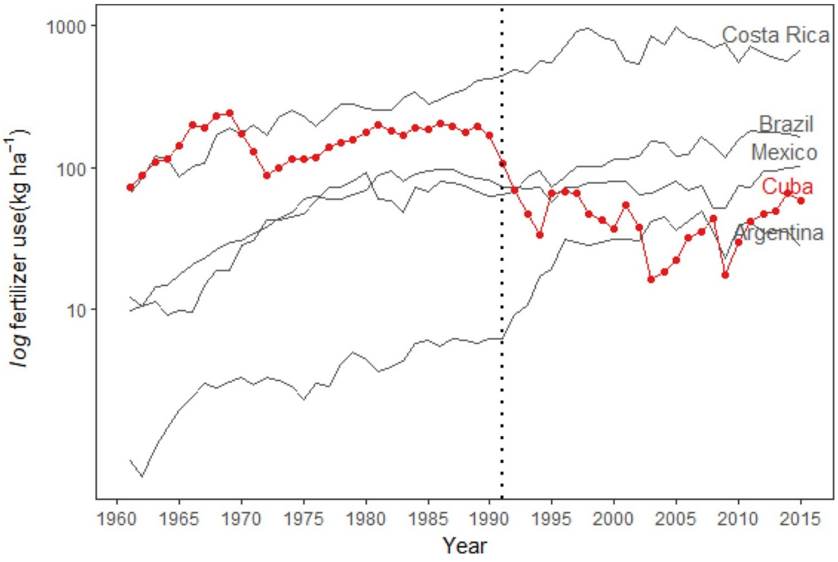

Fig. 1. Natural logarithm of synthetic fertilizer use in selected Latin American countries from 1961 to 2015. The vertical, dotted line represents 1991, the year of the dissolution of the USSR.

1961 to 2015. From 1961 to 1991, the average combined yield of maize and beans in Cuba was 1.37 ± 0.16 metric tons per hectare. From 1992 to 2015, this value increased to 2.74 ± 1.04 t ha^{-1} (a 100.31% increase), on average. Note that the latter value has been pulled down by the considerably lower 2009 and 2010 yields, which were due to the back-to-back devastating effects of hurricanes Gustav, Ike, and Paloma on August 30, September 8, and November 8, of 2008, respectively. For instance, referring to Hurricane Ike's effect on Cuban agriculture, a report issued by the National Hurricane Center of the National Oceanic and Atmospheric Administration of the U.S. reads: “Banana, coffee, yucca, and corn crops sustained serious damage across the country, and about 4,000 metric tons of foodstuffs were lost due to damage to storage facilities” (Berg 2014: 9).

If analyzing these trends by means of OLS regressions (not shown), it can be seen that the passage of a year in the control group is associated with a 1.58% increase in the yield of maize and beans, on average. For example, in Argentina, this increase is of 2.26%, on average; in Brazil, it is also 2.26% per year, on average; in Costa Rica, 1.1%, on average; and, in Mexico, 2.06%, on average. In Cuba, the overall value of increase in productivity is 2.1%, on average. However, if just analyzing the yield trend from 1961 to 1991, the model shows that the passage of one year is associated with a 0.23% increase, on average. On the other hand, when analyzing the period from 1992 to 2015, the passage of a year is associated with a 5.09% average increase in the yield of maize and beans, *i.e.* a tenfold increase in productivity relative to the pre-transition period, brought about by utilizing 71.82% less synthetic fertilizer, on average (see Fig. 1).

What is more, these results actually underestimate the total productivity achieved by means of agroecology in Cuba, given that only the yields of maize and beans are accounted for. The logic underlying industrialized agriculture is the intensive, large-scale production of monocultures. In contrast, agroecology is based on small-scale production of polycultures. Thus, as stated by Funes *et al.* (2009: 4), “small farms are much more productive than large farms if total output is considered rather than yield from a single crop.” Instead of measuring the quantity of a single crop per area, productivity should comprise the *total output* of a plot, including intercropping and livestock-crop rotations (Warwick 1999). According to Rosset *et al.* (2011: 188),

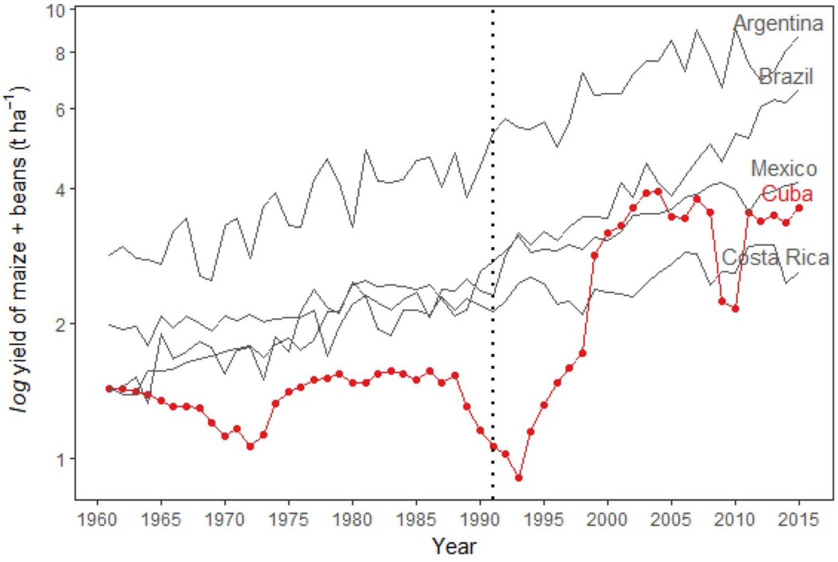

Fig. 2. Natural logarithm of the combined yield of maize and beans in selected Latin American countries from 1961 to 2015. The vertical, dotted line represents 1991, the year of the dissolution of the USSR.

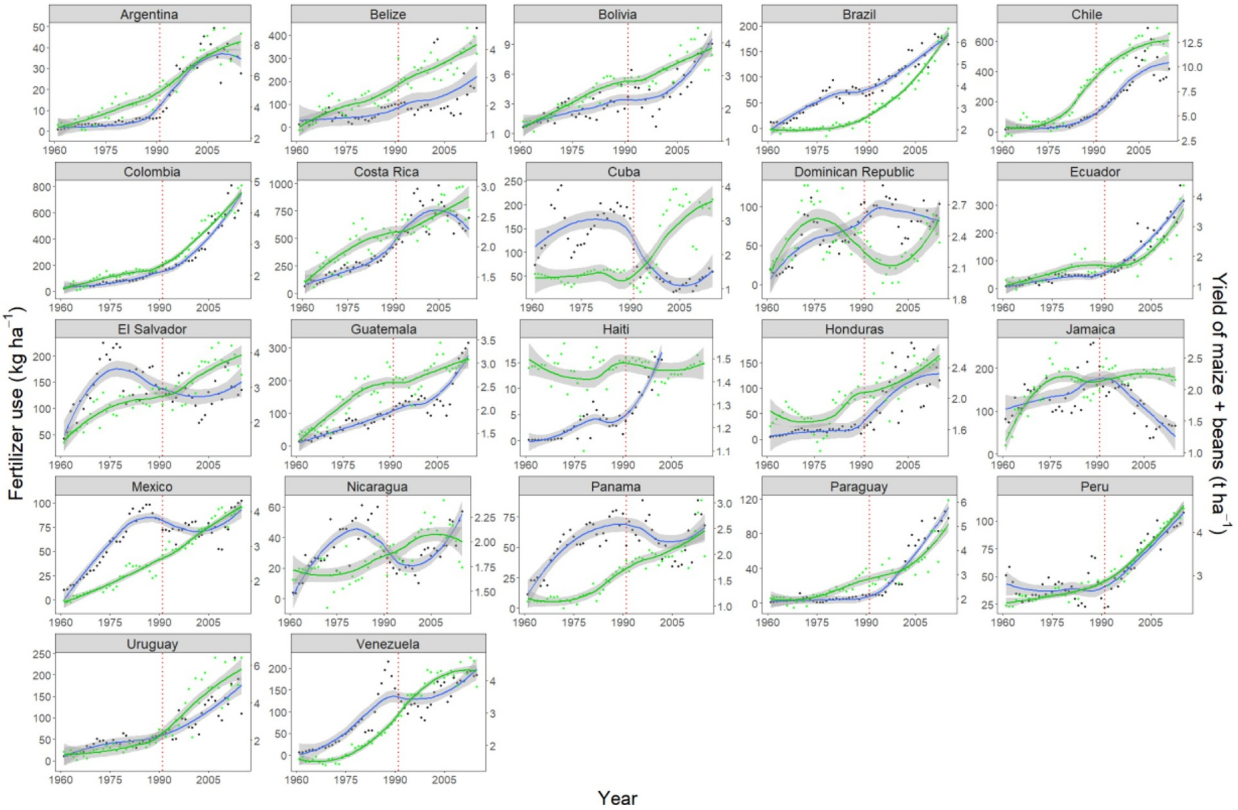

Fig. 3. Synthetic fertilizer use (in blue) and combined yield of maize and beans (in green) as a function of time in LAC, before and after the dissolution of the USSR (red, dotted line). The smoothed lines were generated using the LOESS method.

agroecology is more productive per unit area, and also per unit labor and investment (as well as more resilient to climate change and economic and political shocks) than large-scale monocultures.

Fig. 3 shows the use of synthetic fertilizer (in blue) and the combined yield of maize and beans (in green) in all countries in the study before and after the dissolution of the USSR. It can be seen that, for the most part, yield increased to a greater or lesser degree in each country as fertilizer use augmented. Most countries in the study have kept relying on the agro-industrial approach to food production, seeking to increase their yields by utilizing ever more synthetic fertilizer. Even though in some countries (Costa Rica, El Salvador, Jamaica) higher productivity has been occasionally attained when synthetic fertilizer consumption has diminished or remained constant, only in Cuba has productivity unequivocally increased to unprecedented levels (*e.g.* ~4 t ha $^{-1}$ in 2004) while less chemical fertilizer (~18.5 kg ha^{-1}) has been applied. This trend suggests that fertilizer use and yield were decoupled in Cuba as a consequence of the development of agroecology in this country. No other country in the study exhibits a similar behavior, where yield has been maximized at the same time that fertilizer use has been minimized. The mitigation of the metabolic rift in agriculture in Cuba can be inferred from these trends.

Table 1 shows the difference-in-difference-in-difference (DDD) panel models predicting the effect of fertilizer use –while controlling for tractor use, agricultural land, rainfall, and temperature– on the yield of maize, beans, and both crops combined, both in Cuba and cross-nationally, relative to the expected values had the Cuban post-Soviet transition to agroecology not occurred. The results thrown by these models are coherent with what Fig. 3 displays. First, the models predict that a one kg per hectare increase in synthetic fertilizer consumption (β) is associated with a statistically significant 0.3%, 0.1%, and 0.2% raise in the yield of maize, beans, and both crops, respectively. Secondly, η, the coefficient of the interaction term of the two dummy variables, ($t \geq 1995$) x Cuba, shows a statistically significant increase in average

Table 1
OLS diff-in-diff-in-diff regressions estimating the relationship between industrial agriculture practices and yield in Cuba relative to the rest of LAC from 1961 to 1995, and assessing if the post-Soviet transition to agroecology in Cuba decoupled these practices from yield in comparison to the control group.

	log (maize)	*log* (beans)	*log* (maize + beans)
Fertilizer use (β)	0.003***	0.001**	0.002***
	(0.000)	(0.000)	(0.000)
Time (≥1995) (γ)	0.278***	0.071	0.207***
	(0.060)	(0.049)	(0.051)
Cuba	-1.193***	-0.963***	-1.116***
	(0.307)	(0.250)	(0.255)
Agricultural land (λ)	0.004	0.001	0.003
	(0.004)	(0.003)	(0.003)
Tractor use (μ)	0.002***	-0.000	0.001**
	(0.001)	(0.000)	(0.000)
Rainfall	0.005	0.000	0.003
	(0.004)	(0.002)	(0.003)
Temperature	0.010	-0.011	0.003
	(0.029)	(0.019)	(0.023)
Fertilizer use x Time (≥1995) (δ)	-0.001**	0.000	-0.001*
	(0.000)	(0.000)	(0.000)
Fertilizer use x Cuba (ζ)	-0.002**	-0.002	-0.002**
	(0.001)	(0.001)	(0.001)
Time (≥1995) x Cuba (η)	0.562**	1.513***	0.758***
	(0.205)	(0.275)	(0.198)
Rainfall x Temperature (ν)	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)
Fertilizer use (≥1995) x Time x Cuba (θ)	-0.007*	-0.018***	-0.009**
	(0.003)	(0.004)	(0.003)
Constant	9.702***	9.361***	10.239***
	(0.515)	(0.328)	(0.406)
R-squared	0.947	0.952	0.971
n	758.000	758.000	758.000

***p <0.001, **p<0.01, *p<0.05

yield after 1995 in Cuba for the three models, of 56.2%; 151.3%, and 75.8%, respectively. This outcome is coherent with the results shown in Fig. 2, and those presented in works like Rosset *et al.* (2011). This increase goes above and beyond the γ effect for the control group, where maize yields after 1995 have averaged an increase of 27.8%, beans have averaged a non-statistically significant 7.1% growth, and both crops combined have averaged a 20.7% increase. Additionally, the δ (*i.e.* the coefficient of the interaction between fertilizer use and the dummy variable for time) of models one and three shows a small, negative, statistically significant change in the relationship between fertilizer use and yield, on average, across all countries except Cuba from 1995 onwards. This serves as the counterfactual for what would have been expected to happen in Cuban agriculture in the absence of their agroecological transformation.

On the other hand, θ, the coefficient of the three-way interaction, expresses how different this change was in actuality for Cuba compared to the counterfactual. In general, the counterfactual suggests a slightly weaker relationship between fertilizer use and yield of maize and/or beans for all countries except Cuba after 1995 (-0.1% for maize, 0% for beans, and -0.1% for both maize and beans), but a much bigger, statistically significant decline of -0.8% ((-0.001-0.007)x100), -1.8%, and -1%, respectively and on average, for Cuba. In other words, this shows that, while controlling for tractor use, agricultural land, rainfall, and temperature, fertilizer use and yield were decoupled to a greater extent in Cuba than anywhere else in Latin America and the Caribbean. All these results may be indicative of metabolic restoration associated with agroecology in Cuba, as more food is produced with less synthetic fertilizer, suggesting that the soil nutrient rift is much smaller than it was during the industrialized agriculture epoch. However, given the longitudinal, cross-national scale of this study, it is important to note that neither the actual return of nutrients to the countryside, nor the reduction in chemical fertilizer consumption due to processes unrelated to agroecological practices are being measured. This would require a smaller-scale analysis that lies beyond the scope of the paper.

Finally, the increase in the yield of maize and beans per area that minimizes the use of synthetic fertilizer in Cuba has been accompanied by an absolute increase in the total production of these crops, from an average value of about 0.1 million tons from 1961 to 1991, to 0.36 million t (a 248% increase) from 1992 to 2015. This increase has occurred as the agricultural land area in Cuba decreased. Fig. 4 shows how land use has changed as a function of time both in LAC and within Cuba. Using data only from 1990 onwards (given that there is no forest land data available for earlier years), an OLS regression model (not shown) predicts that agricultural land, defined by FAOSTAT as the "[l]and used for cultivation of crops and animal husbandry" in a country, has increased in LAC (excluding Cuba) at a yearly rate of 0.14%, on average. On the other hand, from 1990 on, forest land (*i.e.* primary forest, other naturally regenerated forest, and planted forest) in LAC (excluding Cuba) has *decreased* at a 0.32% yearly rate, on average. Once again, there is a lot of variation within these averages, with countries like Paraguay increasing their agricultural land while decreasing their forest land importantly; Honduras, Guatemala, and Nicaragua reducing their forest land abruptly; and Costa Rica, Jamaica, and Guatemala decreasing their agricultural surface. Only Costa Rica, Cuba, and Dominican Republic exhibit a diminution of their agricultural land while increasing their forest areas.

Agricultural land in Cuba has been shrinking since 1991 at a 0.16% yearly rate, on average (it grew at a 1.19% mean rate from 1961 to 1990), and forest land has been *expanding* at a 1.89% yearly rate, on average, since 1991 (*cf.* FAO 2015: 10). So, as stated by Rosset and Benjamin (1994: 64) trees "cover more of the island now than in 1959 – something few countries in the world can boast." This points to another intertwined topic that lies outside the scope of this paper, concerned with how agroecology appears to be not only a more sustainable way of food production in terms of mitigating the metabolic rift, but also pertaining deforestation, climate change, and biodiversity loss (*cf.* Altieri et al. 2015; Perfecto and Vandermeer 2010; Perfecto et al. 2009).

4. Conclusions

The aim of this work was to establish whether agroecology in Cuba has contributed to mitigate the metabolic rift in agriculture, by means of determining the relationship between industrial agricultural practices and productivity in this country relative to the rest of LAC from 1961 to 1991, and then establishing if the post-Soviet transition to agroecology in Cuba decoupled fertilizer use from productivity in comparison to all other countries in the study. The fact that the yield of maize and beans (although, as shown in the supplementary material this result also holds when utilizing the total yield of all crops grown) has been maximized in Cuba while synthetic fertilizer use has considerably diminished, accounting for rainfall, temperature, land use, and tractor use, points to metabolic restoration, as soil nutrients and organic matter are not depleted, but are preserved within the land. Because of the complexity of Cuba's ecological transformation and data limitations, some socioeconomic variables concerning land use and overproduction incentives that may have influenced crop productivity were not included in the model. Additionally, given the cross-national scale of the analysis, it was not possible to quantify, but only infer, the flow of nutrients from urban centers back to the soil. An exhaustive study of metabolic rift mitigation in Cuba should in some way incorporate such socioeconomic variables, and integrate them into a multiscale analysis of rural, peri-urban, and urban agroecology.

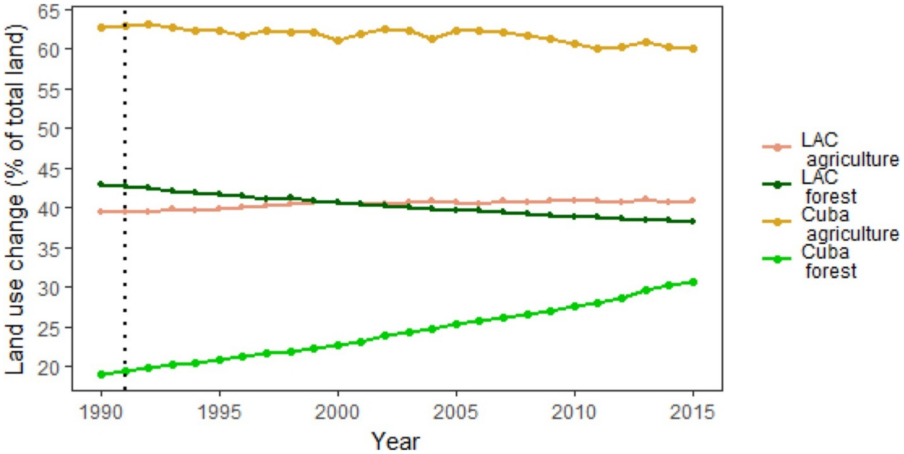

Fig. 4. Average agricultural and forest land use change in LAC and Cuba from 1990 to 2015. LAC values do not include Cuba's. The vertical, dotted line represents 1991, the year of the dissolution of the USSR.

This study suggests that the metabolic rift has been mitigated in Cuba by means of agroecology (both rural and urban) not only in its narrower sense of stopping the systematic exhaustion of soil nutrients to supply cities, but also in its wider nuance concerning the reconcilement of associated producers with the land. As mentioned above, the UBPCs were explicitly created to, among other things, establish a closer link between agricultural workers and production. This reconcilement is coherent with what, according to Rosset et al. (2011: 165), van der Ploeg has called re-peasantization. During the Cuban transition to agroecology, the return of people to the countryside and their incorporation or reincorporation to agriculture was promoted by state policies (Machín Sosa et al. 2010: 32). Government programs sought to create housing and services within rural areas, in order to encourage urban dwellers to work on farms for periods ranging from two weeks to two years (Warwick 1999). In fact, the only new housing built by the Cuban state during the Special Period was in agricultural communities close to state farms (Rosset and Benjamin 1994: 68). Through Decree-Law 259 (2008), this "urban exodus," as described by Boillat *et al.* (2012: 604), was further encouraged through land usufruct rights for about 100,000 new farmers in more than one million hectares. All this is coherent with Marx and Engels's view that the "…gradual abolition of the distinction between town and country, by a more equable distribution of population over the country" (1968: 40) should be sought in socialism.

The mending of the antagonism between town and country in Cuba is also partly due to the fact that agroecology is more labor-intensive than industrialized agriculture (Altieri and Toledo 2011). Although labor-intensive systems are not necessarily desired, beyond them lies a knowledge-intensive agriculture that seeks to design self-operating systems, where horizontal exchanges of knowledge, seeds, and tools among peasants and farms play a central role (Lewontin and Levins 2007: 359; Altieri and Toledo 2011). Additionally, agroecological, small-scale farms usually rely on family labor, which is more committed to the success of the farm, while large farms use relatively "alienated hired labor" (Warwick 1999). Further research –both quantitative and qualitative– concerning the nature of non-estranged, agroecological labor, and its relation to agroecology's role in restoring the lost productivity of degraded soils, is needed to thoroughly understand how the science, practice, and movement of agroecology (Wezel et al., 2009) contributes to mending the agricultural metabolic rift in particular, and the general rift in the human metabolism with the rest of nature.

Furthermore, future investigations could extend the scope of this work by including countries beyond LAC in the metabolic rift comparison. A particularly interesting study could compare and contrast Cuba's agricultural transformations with those that occurred in ex-Soviet and Eastern Europe countries (*e.g.* farm restructuring, land reforms, general reduction in fertilizer use and yields) and asses their respective environmental impacts (*cf.* Lerman 2008; Lerman et al. 2003; Turnock 1996). On the other hand, studies could be carried out at scales smaller than the national one so more detailed data (*e.g.* soil carbon content) can be analyzed under this lens. Lastly, some alternative ways to measure if agroecology has mitigated the rift, based on energy use in agriculture, pesticide use, agricultural greenhouse gas emissions, value added or energy expended in processing, transporting, and exchanging of agricultural commodities, national or local food exports-imports-distribution ratio, in-farm and off-farm agricultural work, and/or farm input-output ratios could be utilized.

So far, a transition as the Cuban shift to agroecology has not been observed anywhere else on the planet on a large scale (Bolliat et al. 2012: 606). Following Clausen and Longo *et al.* (2015: 17) and Weston (2014: 189), it is essential to note that the success of Cuban agroecology is not due solely to the application of alternative agricultural technology, but to a profound countrywide social transformation of production, distribution, exchange, and consumption. In the same vein Orlando Lugo, former president of the ANAP –a pivotal institution in the development of Cuban agroecology–, stated: "We have the conviction that for this [progress] there has been a major conditioning factor: the Revolution, which gave us and guaranteed the possession of the land, which developed us academically, technically, and socially; which instilled in us the values of collectivism, cooperation, and solidarity" (in Machín Sosa et al. 2010: 6). Similarly, Jorrín and Agustín (2015), Director of the Cuban Soil Institute and President of the Cuban Society of Science observed that "the Cuban peasantry is currently in a very favorable situation, especially because the country has understood that sovereignty is also food sovereignty." What is more, the World Wildlife Fund's (WWF) *Sustainability Index Report* (2006: 19) cited Cuba as the only "sustainable country" on Earth. "No region," –states this document– "nor the world as a whole, met both criteria for sustainable development [Human Development Index > 0.8 and ecological footprint < 1.8 ha/person]. Cuba alone did, based on the data it reports to the United Nations." It should be noted, however, that this condition is not only a consequence of Cuba's agricultural transformations, but is also due to external socioeconomic factors such as the USSR's dissolution and the U.S. trade sanctions, which have importantly reduced Cuban production and consumption. In this sense, Cuba's sustainability is also a product of necessity, and not entirely an autonomous choice. Future research could study the possibility and characteristics of the development of agroecology in other political and economic settings.

While many peasants shifted to agroecology by necessity, after having developed it, some have become committed stewards of this movement, which makes it less likely that Cuba would convert back to industrialized agriculture should national or international political-economic circumstances change (Nelson et al. 2009: 240). As Richard Lewontin and Levins stated (2007: 361), one of the tasks of the agroecological movement was to convert these "ecologists by necessity" into "ecologists by conviction."

As much as has been done in Cuba through agroecology (both rural and urban) to mitigate the rift in the cycling of soil elements, one of the largest rifts –human waste (sewage) and its nutrients not being returned to the land– remains an issue in this country and almost everywhere else. The large quantity of nutrients that humans excrete, and that concerned Marx so (1993: 195), are still pumped into local water sources, either treated first and sludge-handled separately and buried, or just as is. Handling sewage (or the concentrated sludge) is very problematic, especially in countries lacking financial resources, since it contains contaminants (*e.g.* pharmaceutical, industrial, and household chemicals) and human pathogens, and due to the high costs involved in building processing and transport facilities for its management (Magdoff, personal communication). Further research could study how the stream of human waste could be cleaned up, and how the mitigation of this rift could be linked to agroecology through the creation of infrastructure to process the waste and to transport at least the solid materials back to the soils.

Although Cuba still faces many challenges within and without the realm of agriculture, and has a long way to go to solve many agricultural issues (*e.g.* soil salinization, certain import's dependency, climate change adaptation), and in spite of disagreements between some Cuban policy makers with an industrial agriculture mindset and agroecologists (Altieri and Funes-Monzote 2012), what this country has achieved with so little external input resources, and in spite of the economic, commercial, and financial U.S. embargo, is remarkable. Its agroecological movement could be emulated in different places, adjusted to the specific socioecological circumstances of the site in question. As stated by Rosset and Benjamin (1994: 82), "[t]he Cuban experiment is the largest attempt at conversion from conventional agriculture to organic…farming in human history. We must watch alertly for the lessons we can learn from Cuban successes as well as from Cuban errors." Likewise, as expressed by prominent agroecologists Funes, Altieri, and Rosset, "surely the USA" –and indeed the rest of the world– "could learn much from Cuba regarding how to achieve a more energy efficient, sustainable, socially just and resilient agriculture" (2009: 6). In today's world, it is hard to imagine a more manifest example of an attempt to mend the metabolic rift than that which is taking place through agroecology in a small island in the Caribbean.

Funding Sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

I would like to thank John Bellamy Foster, Richard York, Aaron Gullickson, Fred Magdoff, Adriana Uscanga, and two anonymous reviewers for their thoughtful insights into this work. I am solely responsible for any remaining errors or omissions in the article. I would also like to thank the Mexican National Council of Science and Technology (CONACyT) for its financial support through a Ph.D. scholarship.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2020.102075.

References

Altieri, Miguel A., Companioni, Nelso, Cañizares, Kristina, Murphy, Catherine, Rosset, Peter, Bourque, Martin, Nicholls, Clara I., 1999. The greening of the “barrios”: Urban agriculture for food security in Cuba. Agriculture and Human Values 16 (2), 131–140. https://doi.org/10.1023/A:1007545304561.

Altieri, Miguel A., 2002. Agroecology: The Science of Natural Resource Management for Poor Farmers in Marginal Environments. Agriculture, Ecosystems & Environment 93 (1-3), 1–24. https://doi.org/10.1016/S0167-8809(02)00085-3.

Altieri, Miguel A., Funes-Monzote, Fernando R., 2012. The Paradox of Cuban Agriculture. Monthly Review 63 (8), 23. https://doi.org/10.14452/MR-063-08-2012-01_3.

Altieri, Miguel A., Toledo, Victor Manuel, 2011. The Agroecological Revolution in Latin America: Rescuing Nature, Ensuring Food Sovereignty and Empowering Peasants. Journal of Peasant Studies 38 (3), 587–612. https://doi.org/10.1080/03066150.2011.582947.

Altieri, Miguel A., Nicholls, Clara I., Henao, Alejandro, Lana, Marcos A., 2015. Agroecology and the Design of Climate Change-Resilient Farming Systems. Agronomy for Sustainable Development 35 (3), 869–890. https://doi.org/10.1007/s13593-015-0285-2.

Angus, Ian, 2016. Facing the Anthropocene: Fossil Capitalism and the Crisis of the Earth System. Monthly Review Press, New York.

Bai, Z G, and D L Dent. 2007. “Land Degradation and Improvement in Cuba 1. Identification by Remote Sensing.” Report 2007/04, ISRIC World Soil Information. Wageningen.

Berg, R., 2014. Tropical Cyclone Report. Hurricane Ike (AL092008), 1-14 September 2018. National Hurricane Center of the National Oceanic; Atmospheric Administration of the U.S. https://www.nhc.noaa.gov/data/tcr/AL092008_Ike.pdf.

Bermudez, Odilia I., Tucker, Katherine L., 2003. Trends in Dietary Patterns of Latin American Populations. Cadernos de Saúde Pública 19 (suppl 1), S87–S99. https://doi.org/10.1590/S0102-311X2003000700010.

Boillat, Sébastien, Gerber, Julien-François, Funes-Monzote, Fernando R., 2012. What Economic Democracy for Degrowth? Some Comments on the Contribution of Socialist Models and Cuban Agroecology. Futures 44 (6), 600–607. https://doi.org/10.1016/j.futures.2012.03.021.

Burkett, Paul, 2014. Marx and Nature: A Red and Green Perspective. Haymarket Books, Canada.

Castro, Fidel, 1996. Discurso pronunciado por el Comandante en Jefe Fidel Castro Ruz, Primer Secretario del Comité Central del Partido Comunista de Cuba y Presidente de los Consejos de Estado y de Ministros, en el Acto Central por el 35 aniversario de la ANAP y el 37 de la promulgación de la Ley de Reforma Agraria, efectuado en la plaza “Camilo Cienfuegos. de Ciego de Ávila, el 17 de mayo de 1996, ‘año del centenario de la caída en combate de Antonio Maceo’.

Ceballos, Gerardo, Ehrlich, Paul R., Dirzo, Rodolfo, 2017. Biological Annihilation via the Ongoing Sixth Mass Extinction Signaled by Vertebrate Population Losses and Declines. Proceedings of the National Academy of Sciences 114 (30), E6089–E6096. https://doi.org/10.1073/pnas.1704949114.

Clark, Brett, Foster, John Bellamy, 2009. Ecological Imperialism and the Global Metabolic Rift: Unequal Exchange and the Guano/Nitrates Trade. International Journal of Comparative Sociology 50 (3-4), 311–334. https://doi.org/10.1177/0020715209105144.

Clark, Brett, York, Richard, 2005. Carbon Metabolism: Global Capitalism, Climate Change, and the Biospheric Rift. Theory and Society 34 (4), 391–428. https://doi.org/10.1007/s11186-005-1993-4.

Clausen, Rebecca, 2007. Healing the Rift: Metabolic Restoration in Cuban Agriculture. Monthly Review 59 (1), 14.

Clausen, Rebecca, Clark, Brett, 2005. The Metabolic Rift and Marine Ecology: An Analysis of the Ocean Crisis Within Capitalist Production. Organization & Environment 18 (4), 422–444. https://doi.org/10.1177/1086026605281187.

Clausen, Brett Clark, Longo, Stefano B., 2015. Metabolic Rifts and Restoration: Agricultural Crises and the Potential of Cuba's Organic, Socialist Approach to Food Production. World Review of Political Economy 6 (1), 4. https://doi.org/10.13169/worlrevipoliecon.6.1.0004.

Companioni, Nelso, Hernández, Yanet Ojeda, Páez, Egidio, Murphy, Catherine, 2002. The Growth of Urban Agriculture. In: Funes, Fernando, García, Luis, Bourque, Martín, Rosset, Peter M. (Eds.), Sustainable Agriculture and Resistance: Transforming Food Production in Cuba. Food First Books, Oakland, CA, pp. 220–236.

Deere, Carmen Diana, 1993. Cuba's National Food Program and Its Prospects for Food Security. Agriculture and Human Values 10 (3), 35–51. https://doi.org/10.1007/BF02217839.

Evenson, R.E., Gollin, D., 2003. Assessing the Impact of the Green Revolution, 1960 to 2000. Science 300 (5620), 758–762. https://doi.org/10.1126/science.1078710.

FAO, 2015. Global Forest Resources Assessment 2015. FAO. http://www.fao.org/3/a-i4808e.pdf.

FAO, 2017. Building Resilience for Food and Food Security. The State of Food Security and Nutrition in the World 2017. Rome: FAO.

Foster, John Bellamy, 1999. Marx's Theory of Metabolic Rift: Classical Foundations for Environmental Sociology. American Journal of Sociology 105 (2), 40.

Foster, John Bellamy, 2000. Marx's Ecology: Materialism and Nature. Monthly Review Press, New York.

Foster, John Bellamy, Clark, Brett, York, Richard, 2010. The Ecological Rift: Capitalism's War on the Earth. Monthly Review Press, New York.

Funes, F., M.A. Altieri, and P. Rosset. 2009. “The Avery Diet: The Hudson Institute's Misinformation Campaign Against Cuban Agriculture.”.

Funes, Fernando, García, Luis, Bourque, Martín, Pérez, Nilda, Rosset, Peter Michael, 2002. Sustainable Agriculture and Resistance: Transforming Food Production in Cuba. Food First Books, Oakland, CA.

Funes-Monzote, Fernando R., 2009. Agricultura Con Futuro: La Alternativa Agroecológica Para Cuba. Estación experimental Indio Hatuey, Matanzas.

Gardi, Ciro, Angelini, M., Barceló, S., Comerma, J., Cruz Gaistardo, C., Encina Rojas, A., Jones, A., Krasilnikov, P., Mendonça Santos Brefin, M.L., Montanarella, L., Muñiz Ugarte, O., Schad, P., Vara Rodríguez, M.I., Vargas, R., Ravina da Silva, M. (Eds.), 2015. Soil Atlas of Latin America and the Caribbean. European Comission Publications Office of the European Union, L-2995, Luxembourg.

Gliessman, Stephen R., 2007. Agroecology: The Ecology of Sustainable Food Systems, 2nd ed. CRC Press, Boca Raton.

Gómez Jorrín, Luis Agustín. 2015. “Encuentro de Intercambio y Trabajo En Agroecología. Zaachila, Oaxaca, Mexico.”.

Gunderson, Ryan, 2011. The Metabolic Rifts of Livestock Agribusiness. Organization & Environment 24 (4), 404–422. https://doi.org/10.1177/1086026611424764.

Institute on the Environment [Institute on the Environment, University of Minnesota]. 2009, December 9. *Big Question: Feast or Famine?* [Video File]. Retrieved June 10, 2019 fromhttp://environment.umn.edu/discovery/gli/videos/.

Edited by Core Writing TeamIPCC, 2014. In: Pachauri, R.K., Meyer, L.A. (Eds.), Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland Edited by Core Writing Team.

Kolbert, Elizabeth, 2014. The Sixth Extinction: An Unnatural History. Henry Holt & Company, New York.

Koont, Sinan, 2011. Sustainable Urban Agriculture in Cuba. University Press of Florida, Gainsville, FL.

Lal, R., 2004. Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science 304 (5677), 1623–1627. https://doi.org/10.1126/science.1097396.

Leakey, Richard, Lewin, Roger, 1995. The Sixth Extinction. Patterns of Life and the Future of Humankind. Anchor Books, New York, N.Y., U.S.A.

Lerman, Zvi, Kislev, Yoav, Biton, David, Kriss, Alon, 2003. Agricultural Output and Productivity in the Former Soviet Republics. Economic Development and Cultural Change 51 (4), 999–1018. https://doi.org/10.1086/376884.

Lerman, Zvi, 2008. Agricultural recovery in the former Soviet Union: an overview of 15 years of land reform and farm restructuring. Post-Communist Economies 20 (4), 391–412. https://doi.org/10.1080/14631370802444526.

Levins, Richard, 1990. The Struggle for Ecological Agriculture in Cuba. Capitalism Nature Socialism 1 (5), 121–141. https://doi.org/10.1080/10455759009358419.

Levins, Richard, 2002. The Unique Pathway of Cuban Development. In: Funes, Fernando, García, Luis, Bourque, Martín, Pérez, Nilda, Rosset, Peter M. (Eds.), Sustainable Agriculture and Resistance: Transforming Food Production in Cuba. Food First Books, Oakland, CA, pp. 276–280 edited by.

Lewontin, Richard C., Levins, Richard, 2007. Biology Under the Influence: Dialectical Essays on Ecology, Agriculture, and Health. Monthly Review Press, New York.

Longo, Stefano, Clausen, Rebecca, Clark, Brett, 2015. The Tragedy of the Commodity: Oceans, Fisheries, and Aquaculture. Rutgers University Press, New Brunswick, New Jersey.

Macfarlane, R.2016. “Generation Anthropocene: How Humans Have Altered the Planet for Ever.” The Guardian.http://www.theguardian.com/books/2016/apr/01/generation-anthropocene-altered-planet-for-ever.

Sosa, Machín, Braulio, Jaime, Adilén María Roque, Lozano, Dana Rocío Ávila, Rosset, Peter Michael, 2010. In: Vedado, Ciudad de La Habana (Ed.), 2nd ed. Asociación Nacional de Agricultores Pequeños y La Vía Campesina, Cuba.

Magdoff, Fred, Es, Harold Van, 2009. Building Soils for Better Crops: Sustainable Soil Management, 3rd ed. Handbook Series, bk. 10SARE, Beltsville, MD.

Mancus, Philip, 2007. Nitrogen Fertilizer Dependency and Its Contradictions: A Theoretical Exploration of Social-Ecological Metabolism. Rural Sociology 72 (2), 269–288. https://doi.org/10.1526/003601107781170008.

Marx, Karl, 1993. Capital: A Critique of Political Economy III Middlesex, England Penguin Classics (Book 3)Harmondsworth: Penguin.

Marx, Karl, 2010. Capital: A Critique of Political Economy. Madison Park, United States.

Marx, Karl, Engels, Friedrich, 1968. In: Sweezy, Paul M., Huberman, Leo (Eds.), Monthly Review Press, New York Edited by.

McClintock, Nathan, 2010. Why Farm the City?: Theorizing Urban Agriculture Through a Lens of Metabolic Rift. Cambridge Journal of Regions Economy and Society 3 (2), 191–207. https://doi.org/10.1093/cjres/rsq005.

Mesa-Lago, Carmelo, 1998. Assessing Economic and Social Performance in the Cuban Transition of the 1990s. World Development 26 (5), 857–876. https://doi.org/10.1016/S0305-750X(98)00020-5.

Montgomery, D.R., 2012. Dirt: The Erosion of Civilization, Second. University of California Press, Berkeley.

Mózner, Zsófia, Tabi, Andrea, Csutora, Mária, 2012. Modifying the Yield Factor Based on More Efficient Use of Fertilizer—The Environmental Impacts of Intensive and Extensive Agricultural Practices. Ecological Indicators 16 (May), 58–66. https://doi.org/10.1016/j.ecolind.2011.06.034.

Nelson, Erin, Scott, Steffanie, Cukier, Judie, Galán, Ángel Leyva, 2009. Institutionalizing Agroecology: Successes and Challenges in Cuba. Agriculture and Human Values 26 (3), 233–243. https://doi.org/10.1007/s10460-008-9156-7.

Nuss, Emily T., Tanumihardjo, Sherry A., 2010. Maize: A Paramount Staple Crop in the Context of Global Nutrition. Comprehensive Reviews in Food Science and Food Safety 9 (4), 417–436. https://doi.org/10.1111/j.1541-4337.2010.00117.x.

Perfecto, I., Vandermeer, J., 2010. The Agroecological Matrix as Alternative to the Land-Sparing/Agriculture Intensification Model. Proceedings of the National Academy of Sciences 107 (13), 5786–5791. https://doi.org/10.1073/pnas.0905455107.

Perfecto, Ivette, Vandermeer, John H., Wright, Angus Lindsay, 2009. Nature's Matrix: Linking Agriculture, Conservation and Food Sovereignty. Earthscan, London; Sterling, VA.

Pérez, Niurka, Echevarría, Dayma, 2002. Case Studies: The Mixed Experiences of Two New Cooperatives. In: Funes, Fernando, García, Luis, Bourque, Martín, Pérez, Nilda, Rosset, Peter M. (Eds.), Sustainable Agriculture and Resistance: Transforming Food Production in Cuba. Food First Books, Oakland, CA edited by.

Puerta, Ricardo A., Alvarez, José, 1993. Organisation and Performance of Cuban Agriculture at Different Levels of State Intervention. Gainseville, Food Resource Economics Department, Institute of Food; Agricultural Sciences, University of Florida.

Rockström, Johan, Steffen, Will, Noone, Kevin, Persson, Åsa, Chapin III, F.Stuart, Lambin, Eric, Lenton, Timothy M., Scheffer, Marten, Folke, Carl, Schellnhuber, Hans Joachim, Nykvist, Björn, de Wit, Cynthia A., Hughes, Terry, van der Leeuw, Sander, Rodhe, Henning, Sörlin, Sverker, Snyder, Peter K., Costanza, Robert, Svedin, Uno, Falkenmark, Malin, Karlberg, Louise, Corell, Robert W., Fabry, Victoria J., Hansen, James, Walker, Brian, Liverman, Diana, Richardson, Katherine, Crutzen, Paul, Foley, Jonathan, 2009. Planetary Boundaries: Exploring the Safe Operating Space for Humanity. Ecology and Society 14 (2). https://doi.org/10.5751/ES-03180-140232.

Rosset, Peter, 2000. Cuba: A Successful Case Study of Sustainable Agriculture. In: Magdoff, Fred, Foster, John Bellamy, Buttel, Frederick H. (Eds.), Hungry for Profit: The Agribusiness Threat to Farmers, Food, and the Environment. Monthly Review Press, Canada, pp. 203–213 edited by.

Rosset, Peter Michael, Sosa, Braulio Machín, Jaime, Adilén María Roque, Lozano, Dana Rocío Ávila, 2011. The Campesino to Campesino Agroecology Movement of ANAP in Cuba: Social Process Methodology in the Construction of Sustainable Peasant Agriculture and Food Sovereignty. Journal of Peasant Studies 38 (1), 161–191. https://doi.org/10.1080/03066150.2010.538584.

Rosset, Peter, Altieri, Miguel A., 2017. Agroecology: Science and Politics. Fernwood Publishing; Practical Action Publishing, Black Point, Nova Scotia: Warwickshire, UK Agrarian Change and Peasant Studies Series 7.

Rosset, Peter, Benjamin, Medea (Eds.), 1994. The Greening of the Revolution: Cuba's Experiment with Organic Agriculture. Ocean, Melbourne, Vic., Australia.

Saitō, Kōhei, 2017. Karl Marx's Ecosocialism: Capitalism, Nature, and the Unfinished Critique of Political Economy. Monthly Review Press, New York.

Sánchez-Bayo, Francisco, Wyckhuys, Kris A.G., 2019. Worldwide Decline of the Entomofauna: A Review of Its Drivers. Biological Conservation 232 (April), 8–27. https://doi.org/10.1016/j.biocon.2019.01.020.

Sevilla-Guzmán, Eduardo, Woodgate, Graham, 1997. ‘Sustainable Rural Development’: From Industrial Agriculture to Agroecology. In: Redclift, M.R., Woodgate, Graham (Eds.), The International Handbook of Environmental Sociology, 1st ed. Edward Elgar, Cheltenham, UK; Northampton, MA, USA, pp. 83–100 edited by.

Reardon, Simón, Alberto, Juan, Pérez, Reinaldo Alemán, 2010. Agroecology and the Development of Indicators of Food Sovereignty in Cuban Food Systems. Journal of Sustainable Agriculture 34 (8), 907–922. https://doi.org/10.1080/10440046.2010.519205.

Smil, Vaclav, 1999. Detonator of the Population Explosion. Nature 400 (6743), 415. https://doi.org/10.1038/22672.

Smith, Pete, 2016. Soil Carbon Sequestration and Biochar as Negative Emission Technologies. Global Change Biology 22 (3), 1315–1324. https://doi.org/10.1111/gcb.13178.

Steffen, W., Grinevald, J., Crutzen, P., McNeill, J., 2011. The Anthropocene: Conceptual and Historical Perspectives. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 369, 842–867. https://doi.org/10.1098/rsta.2010.0327. (1938).

Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., 2015. Planetary Boundaries: Guiding Human Development on a Changing Planet. Science 347 (6223), 1259855. https://doi.org/10.1126/science.1259855.

Treto, Eolia, García, Margarita, 2002. Advances in Organic Soil Management. In: Funes, Fernando, García, Luis, Bourque, Martín, Rosset, Peter M. (Eds.), Sustainable Agriculture and Resistance: Transforming Food Production in Cuba. Food First Books, Oakland, CA, pp. 164–189 edited by.

Treto, Eolia, García, Margarita, Viera, Rafael Martínez, Febles, José M., 2001. Avances en el manejo de los suelos y la nutrición orgánica. Transformando El Campo Cubano. Avances de La Agricultura Sostenible. Asociación Cubana de Técnicos Agrícolas y Forestales, La Habana, pp. 167-190.

Turnock, David, 1996. Agriculture in Eastern Europe: Communism, the transition and the future. GeoJournal 38 (2), 137–149. https://doi.org/10.1007/BF00186661.

Urban, M.C., 2015. Accelerating Extinction Risk from Climate Change. Science 348 (6234), 571–573. https://doi.org/10.1126/science.aaa4984.

Vaillancourt, Jean-Guy, 1992. Marxism and Ecology: More Benedictine Than Franciscan. Capitalism Nature Socialism 3 (1), 19–35. https://doi.org/10.1080/10455759209358471.

Vitousek, P.M., 1997. Human Domination of Earth's Ecosystems. Science 277 (5325), 494–499. https://doi.org/10.1126/science.277.5325.494.

Warwick, Hugh, 1999. Cuba's Organic Revolution. Ecologist 29 (December), 457–460.

Weston, Del, 2014. The Political Economy of Global Warming: The Terminal Crisis. Routledge, Abingdon, Oxon.

Wezel, A., Bellon, S., Doré, T., Francis, C., Vallod, D., David, C., 2009. Agroecology as a Science, a Movement and a Practice. A Review. Agronomy for Sustainable Development 29 (4), 503–515. https://doi.org/10.1051/agro/2009004.

Wittman, Hannah, 2009. Reworking the Metabolic Rift: La Vía Campesina, Agrarian Citizenship, and Food Sovereignty. The Journal of Peasant Studies 36 (4), 805–826. https://doi.org/10.1080/03066150903353991.

World Wildlife Fund. 2006. “Living Planet Report.” assets.panda.org/downloads/living_planet_report.pdf.

Wright, Julia Emma, 2011. Sustainable Agriculture and Food Security in an Era of Oil Scarcity: Lessons from Cuba. Earthscan Publishing, London, New York.

Zalasiewicz, J., Williams, M., Haywood, A., Ellis, M., 2011. The Anthropocene: A New Epoch of Geological Time? Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 369, 835–841. https://doi.org/10.1098/rsta.2010.0339. (1938).