# PERFORMANCE AND PRODUCTIVE DIVERSITY OF AGRICULTURE IN MOUNTAIN ENVIRONMENTS †

# [RENDIMIENTO Y DIVERSIDAD PRODUCTIVA DE LA AGRICULTURA EN ENTORNOS DE MONTAÑA]

**Elton de Oliveira[1]*, Adriana Maria de Aquino[2], Renato Linhares de Assis[2], João Carlos Correia Baptista Soares de Mello[3] and Lidia Angulo Meza[3]**

*[1] Departamento de Engenharia Agrícola e Meio Ambiente. Escola de Engenharia. Universidade Federal Fluminense - UFF. Rua Passo da Pátria, 156 - Bloco D, sala 235 – São Domingos, 24210-240 - Niterói, RJ - Brasil. E-mail: oliveruff2@gmail.com*
*[2] EMBRAPA Agrobiologia, Núcleo de Pesquisa e Treinamento para Agricultores. Avenida Alberto Braune, 223 – Centro, 28613-001 – Nova Friburgo, RJ - Brasil. E-mail: adriana.aquino@embrapa.br, renato.assis@embrapa.br*
*[3] Departamento de Engenharia de Produção. Escola de Engenharia. Universidade Federal Fluminense - UFF. Rua Passo da Pátria, 156 – São Domingos, 24210-240 - Niterói, RJ - Brasil. E-mail: joaocsmello@gmail.com, lidia.angulo.meza@gmail.com*
**Corresponding author*

## SUMMARY

**Background:** The mountainous regions of the state of Rio de Janeiro, due to the way they were colonized, their land structures, and their technical, cultural and climatic conditions, offer unique conditions, not only for the formation of unique environments and characteristic products, but also for the development productive diversity that can provide greater efficiency and agricultural stability. **Objective:** This study aims to evaluate the performance of the agricultural sector of eighty-five municipalities in the state of Rio de Janeiro, with regard to three productive variables: cultivated area in hectares, number of different crops produced, and total revenue in Brazilian Reais, for the calendar year 2015. **Methodology:** Data Envelopment Analysis (DEA) was chosen for this analysis, because it allows the computation from these input (cultivated area) and output (number of crops and revenue) variables of an efficiency index for each municipality. **Results:** A dispersion plot of efficiency against the altitude of the administrative seat of the municipalities revealed that 68.23 % of the municipalities lay in the two quadrants corresponding to low altitude, low efficiency and high altitude, high efficiency, indicating a positive correlation of efficiency with altitude. Of the twelve efficient municipalities, eleven practice agriculture in mountain environments, at altitudes ranging from 355 to 871 m. **Implications.** Of the twelve efficient municipalities, eleven practice agriculture in mountain environments at altitudes ranging from 355 to 871 m. **Conclusions:** These results support the supposition that greater agrobiodiversity, as found in the mountainous regions of the state of Rio de Janeiro, contributes to greater agricultural efficiency.
**Keywords:** agrobiodiversity; data envelopment analysis; efficiency; productive strategies.

## RESUMEN

**Contexto:** Las montañas del estado de Rio de Janeiro, a través de la forma en que fue colonizada, su estructura de propiedad de la tierra y sus condiciones técnicas, culturales y climáticas, ofrecen condiciones singulares, no solo para la formación de productos únicos y característicos, pero también para el desarrollo de una diversidad productiva que pueda fomentar una mayor eficiencia y estabilidad agrícola. **Objetivo:** Este estudio evalúa el desempeño del sector agrícola de ochenta y cinco municipios en el estado de Río de Janeiro, con respecto a tres variables productivas: área cultivada en hectáreas, número de cultivos diferentes producidos e ingresos totales en reales brasileños, para el año calendario 2015. **Metodología:** Análisis de Envolvente de Datos (DEA) fue elegida para este análisis, ya que permite el cálculo de estas variables de entrada (área cultivada) y salida (número de cultivos e ingresos) de un índice de eficiencia para cada municipio. **Resultados:** Un diagrama de dispersión de eficiencia contra la altitud de la sede administrativa de los municipios reveló que el 68.23% de los municipios se encuentran en los dos cuadrantes correspondientes a baja altitud, baja eficiencia y alta altitud, alta eficiencia, lo que indica una correlación positiva de la eficiencia con la altitud. De los doce municipios eficientes, once practican la agricultura en entornos de montaña, en altitudes que van desde 355 a 871 m. **Implicaciones.** De los doce municipios eficientes, once practican la agricultura en entorno de montaña, en altitudes que van desde 355 a 871 m. **Conclusiones:** Estos resultados apoyan la suposición de que una mayor agrobiodiversidad, como se encuentra en las regiones montañosas del estado de Rio de Janeiro, contribuye a una mayor eficiencia agrícola.
**Palabras clave**: agrobiodiversidad; análisis envolvente de datos; eficiencia; estrategias productivas.

---

† *Submitted August 3, 2020 – Accepted September 29, 2020.* This work is licensed under a CC-BY 4.0 International License.
ISSN: 1870-0462.

## INTRODUCTION

In the calendar year 2015, agricultural production in the state of Rio de Janeiro generated revenues of R$ 1.83 billion, from a cultivated area of 146.4 thousand hectares (EMATER-RIO, 2015). Sixty-seven distinct crops were produced across a total of eighty-five agriculturally active municipalities. Examining crop diversity, the municipality (Duas Barras) with the greatest produced thirty three different agricultural crops. According to Schneider (2010, p. 89), the creation of mechanisms and strategies which lead to diversification of labour and income is the means to stimulating system resilience in the face of the vulnerabilities of the environment within which productive agriculture is conducted. Extending this reasoning, the greater the diversification of a productive unit, be it an agricultural establishment, region or territory, the greater its chances and indeed opportunities for stability when confronted by the crises which are inherent to the agribusiness sector. As suggested by the preceding arguments, the scope for and advantages of the introduction of productive diversity into the agricultural sector are considerable. An overarching concept within the application of productive diversity to the farming sector is agrobiodiversity, which may be defined as the assemblage of the types and components of biodiversity which are conserved, manipulated, and utilized by farmers (Nodari and Guerra, 2015, MMA, 2017). The strategic importance of the management of agrobiodiversity for local and traditional communities has been recognized by EMBRAPA, who in 2008 produced a book (EMBRAPA, 2008) addressing the attainment of sustainable agriculture through public support of family farming. One of the central themes emerging from this detailed reflection was the impacts of the legal system on the diversity of plants and crops cultivated, and the resulting agricultural ecosystems.

The Brazilian National Program for the Conservation of Agrobiodiversity performs evaluations and monitoring of agroecology in Brazil. In their 2011 bulletin (PNA, 2011), the PNA highlighted that agroecological systems are environmentally and socially more sustainable and more efficient in their use of energy. However, the PNA go on to point out that the great difficulty is the lack of governmentally supported programs at the state level to support the dissemination and implementation of the agroecological mode of agricultural production. Assis *et al.* (2016) in the Bulletin of the Brazilian Society for Soil Science (SBSC) enumerate and highlight among the driving precepts of agroecology: crop diversification, the minimum possible dependence on external supplies, together with the conservation of natural resources. They demonstrate how an agroecosystem cannot de dissociated from its sociocultural, economic, technical, and ecological components. From this brief review, it is clear that in farming activities, the principle bodies, which promote and stimulate public policy and research, recognize the importance of the management of agrobiodiversity.

The state of Rio de Janeiro is an advantageous region within which to study the influence of diversity on agricultural efficiency, because of the range of landscapes and lifestyles. It is important to recognize that there are mountainous regions with the State of Rio de Janeiro, as described by López Netto *et al*. (2017), which fully conform with the topographical definitions of mountains propounded by Kapos *et al.* (2000), and to the definition of region or environment from Leff (2001). In the case of the state of Rio Janeiro, the Kapos *et al*. (2000) and Leff (2001) definitions identify the mountainous regions as areas having altitudes varying from 300 to 1,500 m, where there are human communities. These communities have their own lifestyles, set by the natural environment of their surroundings, as well as being expressions and with activities that in general reflect their history and development over time. Their presence and activities highlight the anthropocentric component of the previous definitions, in which human beings are an essential agent within the whole. It may therefore be presumed that the mountainous Região Serrana of the state of Rio de Janeiro, through the form in which it was colonized, its structure of land-ownership, and its technical, cultural, and climatic conditions, offers singular conditions, not only for the formation of unique and characteristic products, but also for the development of a productive diversity that could foster greater agricultural efficiency and stability.

A review performed by Emrouznejad and Yang (2017) shows an exponential increase over the last forty years (1978-2017) in the number of publications on DEA, addressing both theoretical advances and the applications of DEA to an ever-increasing number of areas in which the quantification and improvement of efficiency are sought. Examining the fields to which the methodologies of DEA are being applied, for the years 2015 and 2016, the largest proportion of the DEA papers published in academic journals addressed agriculture. A further example of the use DEA to examine the response of agricultural efficiency to external variables can be found in the work of Toma *et al.* (2015), who performed a comparison of agricultural performance between different environments and geographical locations. However, few studies with DEA address productive diversity in the evaluation of efficiency in agriculture.

In the vision of Conway (1987), a sustainable agroecosystem is to be understood as the combined search for: productivity, obtaining the maximum quantity of products or energy, or production value per unit of supplies and resources consumed during the production; stability, constant productivity despite climatic fluctuations; sustainability, the ability of the system to maintain productivity when subjected to normal environmental fluctuations; resilience, the capacity of the system to react in the shortest possible time to a given disturbance; and invulnerability, the lack of vulnerability of the system to disturbances, such as environmental stresses or a fall in the price of a product, that reduce product diversity. Balbino *et al*. (2011) have taken these desired agroecosystem properties, and argued that the agroecosystems of the twenty-first century should be capable, at the same time, of maximizing the quantity of high quality agricultural products and conserving the resources of the system. Sustainable rural development depends on the formulation of an agenda that contemplates and addresses an array of challenges including: the conservation of the biodiversity and of the environmental services; the reduction of pollution and environmental contamination of human origin; the conservation and improvement of the quality of the soil and of the water; the integrated management of pest insects, diseases, and weeds; the raising of the value afforded to traditional systems of resource management; the reduction of the anthropogenic pressure for the occupation and use of fragile ecosystems and environments; and the adaptation to the new demands of the market.

In the present study, we have analysed the agricultural performance of the municipalities (DMUs) of the state of Rio de Janeiro by estimating their efficiency with DEA, and followed this with an examination of the influence of the altitude of the seat of the municipality, a variable external to the DEA, on the efficiency. As previously discussed, mountainous regions have greater agrobiodiversity, so that through an exploration of the distribution of efficiency in relation to altitude, to confirm the assumption that the agrobiodiversity of these mountain environments provides greater efficiency in agriculture.

## MATERIALS AND METHODS

The data on production (the input and output variables), utilized in the current analysis, were extracted from the report on the Systematic Monitoring of Agricultural Production (ASPA) for the State of Rio de Janeiro, which details Agricultural Activity by Geographical Location (SISTEMA AGROGEO) and is produced by the Technical Assistance and Rural Extension Company of the State of Rio de Janeiro (EMATER-RIO/CPLAN/NIDOC). In the case of the calendar year 2015 (EMATER-RIO, 2015), the report presented data for eighty-five municipalities of the state, which were agriculturally productive, out of the total of ninety-two which comprise the state of Rio de Janeiro. The remaining seven municipalities were absent from the report and not considered further, since they presented no agricultural production in 2015. The State of Rio de Janeiro is divided into eight governmental regions. The Brazilian names for these eight regions are the Região Metropolitana, the Região do Médio Vale do Paraíba, the Região Centro-Sul Fluminense, the Região Serrana, the Região das Baixadas Litorâneas, the Região Norte Fluminense, the Região Noroeste Fluminense, and the Região da Costa Verde. Rio de Janeiro (RJ) is a Brazilian state located in the southeastern region of the country, making borders with the states of Espírito Santo, to the north; Minas Gerais, to the northwest; and São Paulo, to the southwest. Its entire east coast is bathed by the Atlantic Ocean, its capital is the city of Rio de Janeiro.

Of the variables available from the EMTER-RIO (2015) report, three were chosen as the components of the Data Envelopment Analysis of the efficiency of each of the municipalities: cultivated area (input), total number of crops (output 1), and total revenue (output 2). The other variables and pieces of quantitative information contained in the EMATER-RIO (2015) report are potentially useful in understanding, explaining, and justifying the behaviour, strategies, and productive characteristics adopted by the municipalities (DMUs). Consideration of this supplementary, but comments on highly valuable information will be deferred until after the analysis of the efficiencies of the municipalities and will be incorporated into the discussion of the results.

Data Envelopment Analysis (DEA) utilizes the concept of efficiency to establish a comparative analysis and ranking between productive units or between Decision Making Units (DMUs), which together form a defined set. DEA could be defined as a mathematical tool for the measurement of efficiency. Central and important features of the DEA methodology are that it is characterized by the non-utilization of inferential statistics, of measures of central tendency, or of parametric approximations. DEA is a method for performance evaluation and benchmarking against best practice, and the returned efficiency for a DMU is not a function of the production of the DMU (Cook *et al*., 2014). The results from a DEA are invariant with regard to the scale of each of the inputs and outputs. Therefore, each variable is included in the model with its original scale and unit of measurement; there are no transformations for the uniformization of scale (Cooper *et al*., 2007).

Efficiency can conceptually be defined as the ratio of a weighted sum of outputs to a weighted sum of inputs. The evaluation and hence comparison of the efficiencies of the $n$ DMUs in a set can be constructed as a fractional programming problem (FPP). The solution of the fractional program is difficult. Through some simple manipulations, the FPP can be transformed to a linear programming problem (LPP), the solution to which requires the maximization or minimization of a linear function subject to linear constraints. The advantage of transforming from the original FPP to the LPP is the availability of simple and efficient algorithms for solving LPPs.

Solution of the $n$ LPPs reveals a subset of DMUs which are fully efficient, in the sense that for these DMUs it is not possible to improve any input or output without worsening some other input or output. These DMUs correspond to the Pareto-Koopmans definition of full efficiency. The outcome of the identification of the set of fully efficient DMUs for an activity is the generation of an efficient production frontier. The fully efficient DMUs lie along the frontier, while all of the inefficient DMUs fall to one side of the efficient production frontier, each by a distance that provides an index of efficiency of the DMU. Efficiency indices can vary from 1 (fully efficient, on the production frontier) down to a very small, positive number (highly inefficient, far from the production frontier) (Cooper *et al*., 2007).

There are numerous approaches to DEA to be found in the literature. For the present study, the classic BCC approach (named after its creators: R. D. Banker, A. Charnes, and W. W. Cooper) to the construction and use of the efficient production frontier was chosen. The motive for this choice was the recognition that an increase in the input by a factor $s$ might not lead to an increase in the outputs by the same factor (constant returns-to-scale, CRS). The BCC approach constructs a piecewise efficient production frontier, which accommodates variable returns-to-scale (VRS) (Banker *et al*., 1984). The objective of the analysis conducted in the present study was the maximization of the outputs of the municipalities (number of different crops, and total revenue from the crops), while maintaining the input (cultivated area in the municipality) constant. An output-oriented DEA of the municipalities following the BCC (variable returns-to-scale, VRS) approach was accordingly conducted. Details of this methodology can be found in Cooper *et al.* (2007). The central linear programming problem for an individual DMU $o$ of the set of $n$ ($n = 85$ for the present study) is the dual (multiplier) form associated with the BCC linear program for the efficiency of DMU $o$. Expressed in algebraic notation (Cooper *et al.*, 2007) present the programs in vector-matrix form; the program to be solved for DMU $o$ is:

$$\min h_o = \sum_{i=1}^{p} v_i\, x_{io} + v_* \qquad (1)$$

where the minimization is with respect to $v_i$ ($i = 1\ to\ p$), $u_j$ ($j = 1\ to\ q$), and $v_*$, subject to the following constraints:

$$\sum_{j=1}^{q} u_j\, y_{jo} = 1 \qquad (2)$$

$$\sum_{j=1}^{q} u_j\, y_{jk} - \sum_{i=1}^{p} v_i\, x_{ik} - v_* \leq 0, \forall k$$
$$u_j \geq 0, \forall j$$
$$v_i \geq 0, \forall i$$
$$v_* \in \mathrm{R}$$

where:

$h_o$ efficiency of DMU $o$;
$x_{io}$ input to DMU $o$;
$y_{jo}$ outputs from DMU $o$;
$v_i$ weight calculated by the BCC approach for input $i$;
$u_j$ weight calculated by the BCC approach for output $j$;
$v_*$ a scale factor.

**The DMUs and their variables in the VRS DEA**

In the present study, the set of productive units, that is the Decision Making Units (DMUs) considered in the DEA, comprised the 85 municipalities of the state of Rio de Janeiro, which reported agricultural production during the calendar year 2015. The Data Envelopment Analysis made possible the evaluation of the performance of each of these municipalities (DMUs) in relation to the others. Three variables, one input and two outputs, were considered. The input variable for a municipality was the area of land cultivated in the municipality, and was the sum of the areas occupied with all the crops produced in the municipality during the calendar year 2015. The output variable, number of different crops produced, was used to quantify the agrobiodiversity of the municipality. This integer can provide only a limited view of the agrobiodiversity in the agricultural production in a municipality. However, given the limited data available, this quantifier of the different types of crops managed in a municipality was selected as the number which could best reflect the degree of agrobiodiversity of each DMU. The second output variable was the revenue in Brazilian Reais generated by the municipality through sales of the crops produced within the municipality. This was calculated as the amount (weight, kg) of each crop produced multiplied by its value (R\$ $kg^{-1}$) in the local market, summed over all the crops produced in the municipality. Having collected the input and output variables for each of the 85 municipalities, the software package SIAD (*Sistema Integrado de Apoio à Decisão*), named ISYSD (Integrated System for Decision Support) in English (Angulo Meza *et al*., 2005) was employed to perform the Data Envelopment Analysis of the results according to the BCC, variable returns-to-scale approach.

**The variable altitude – external to the DEA**

Since this study is focussed upon a macroanalysis of the mountainous regions of the state of Rio de Janeiro, the decision was made to assign a unique altitude to each municipality, corresponding to the altitude of the seat of the municipality (IBGE, 2017).

This altitude was utilized as the base parameter to define whether parts of the municipality were mountainous. These altitude data were used as an external variable in the examination of the results from the DEA of the municipalities. The altitude cannot be controlled by the DMU, but it could affect or interfere with the productive processes of the DMU. The altitude was accordingly not included as one of the variables (input) in the DEA, which contains only variables that can be managed by a DMU. However, the efficiency indices for the municipalities generated by the DEA were examined alongside their altitudes to see if any relationships became apparent. A dispersion plot of efficiency against altitude was constructed, and inspected to see if the distribution of the efficiencies of the set, comprising all 85 of the productive municipalities, was linked to their respective altitudes.

## RESULTS AND DISCUSSION

The application of the one input and two outputs DEA analysis, with BCC variable returns-to-scale, of the agricultural production of the 85 municipalities identified thirteen DMUs with efficiency indices equal to one, the criterion to be classified as efficient. However, it is an inherent property of the BCC approach (Cooper *et al*., 2007), that the DMU with the least value of a determined input will always be efficient, and this DMU is accordingly called efficient by default. Of the 85 municipalities considered in the present study, the municipality of Comendador Levy Gasparian, located in the Região Centro-Sul Fluminense, had the smallest value for the single input, with an area under cultivation of only 6 ha. Thus, Comendador Levy Gasparian was identified as efficient by default, leaving twelve DMUs as actually efficient.

Table 1 contains a list of 21 of the 85 municipalities, ordered by revenue. The list contains the 17 municipalities with efficiency indices of 0.900 or greater (including the default DMU, Comendador Levy Gasparian), the two with the lowest efficiencies (Varre-Sai and Paracambi), and the two with the largest areas under cultivation (input; Campos dos Goytacazes and São Francisco de Itabapoana.

Sumidouro in the Região Serrana was not only efficient, but also occupied fourth position by revenue, producing 31 different crops (Table 1). On these criteria, in the calendar year 2015, it may be argued that this municipality chose an optimized distribution of the cultivated area over the crops. Considered in relation to the full set of 85 analysed DMUs, Sumidouro succeeded in finding the best combination of revenue with diversity.

Duas Barras is another efficient municipality located in the Região Serrana (Table 1). More detailed data (EMATER-RIO, 2015) on the agricultural production in Duas Barras revealed that the crop making the largest contribution to the revenue was tomato (18.85 %), which occupied 4.70 % of the total cultivated area. The crop raised on the largest fraction of the cultivated area was maize (16.85 %), which accounted for 1.14 % of the total revenue. Sugarcane produced for animal forage was the second most important crop in terms of area (9.71 %) and contribution to the total revenue (8.88 %). Duas Barras was the municipality producing the largest number of different crops (33). However, the total revenue per cultivated area (27,083.68 R\$ $ha^{-1}$) was considerably lower than for Sumidouro (42,120.61 R\$ $ha^{-1}$), and the distribution of the cultivated area over the different crops was less even (kurtosis = 7.34) than for Sumidouro (kurtosis = -0.02).

Petrópolis, another efficient municipality in the Região Serrana (Table 1), achieved a total crop revenue per area of R\$ 34,009.53 $ha^{-1}$ in the calendar year 2015. The principal crops were parsley (11.56 % of total revenue, highest; 5.82 % by cultivated area, seventh), followed by kale (9.48 % of revenue, second; 3.42 % by area, eleventh). Lettuce was produced across 12.94 % of the total cultivated area (highest), and was responsible for 8.55 % of the total revenue (fourth). Second in order of cultivated area was chayote (7.97 %; 7.06 % of revenue, sixth), followed by gilo (6.91 %; 6.95 % of revenue, seventh), cackrey (6.47 %; 2.49 % of revenue, fourteenth), green bean (6.29 %; 6.29 % of revenue, fifth), zucchini (6.25 %; 2.92 % of revenue, eleventh), parsley (5.82 %), broccoli (5.51 %; 6.66 % of revenue, eighth). A further 16 crops were raised over the remaining 41.82 % of the total cultivated area and were responsible for 44.62 % of the total revenue. These detailed figures on the proportion of the cultivated area assigned to each of the 24 crops produced in Petrópolis, and their respective contributions to the total revenue demonstrate a good balance, which gave the municipality an efficient performance.

Nova Friburgo, also in the Região Serrana, had 47.04 % of its cultivated area divided between broccoli (22.52 %; 14.24 % of revenue) and cauliflower (24.52 %; 20.67 % of revenue). The third most important crop by cultivated area was tomato (13.06 %; 32.68 % of revenue); the remaining 39.89 % of the cultivated area was used for the raising of 22 other crops. In the calendar year 2015, the revenue per unit area was 48,961.52 RS $ha^{-1}$. This production strategy, with broccoli and cauliflower as the principal crops by area, made Nova Friburgo efficient.

Paty do Alferes and Vassouras, both in the Região Centro-Sul Fluminense, were efficient, and presented the highest values for revenue per unit area for the state of Rio de Janeiro: 89,136.34 and 85,789.22 R\$ $ha^{-1}$, respectively. In both cases, the crop making the largest contribution to the total revenue was tomato (85.03 % for Paty do Alferes and 71.68 % for Vassouras). Paty do Alferes produced 13 other crops in addition to tomato, and Vassouras 14 other crops (Table 1). Tomato as a crop is vertical, in the sense that individual tomato plants can reach a height of 2 m, and tomato fruits are produced through the full height of the plants, from the ground to the top. Thus productivity per unit area is high (mean of 66.16 t ha$^{-1}$ over the 38 municipalities producing tomato, surpassed only by chayote (77.20 t ha$^{-1}$ over the 11 municipalities producing this crop); 87.67 t ha$^{-1}$ for Paty do Alferes and 82.54 t ha$^{-1}$ for Vassouras). In addition, the market price for tomato is relatively high (mean of 1.73 R$ kg$^{-1}$ over the 38 tomato-producing municipalities; 1.48 R$ kg$^{-1}$ for Paty do Alferes and 1.81 R$ kg$^{-1}$ for Vassouras). Overall the raising of tomatoes offers excellent revenue per unit area (mean of 114,629.86 R$ ha$^{-1}$ over the 38 tomato-producing municipalities, surpassed only by strawberry (234,825.79 R$ ha$^{-1}$, Nova Friburgo); 129,754.38 R$ ha$^{-1}$ for Paty do Alferes and 149,399.35 R$ ha$^{-1}$ for Vassouras). These values for tomato may be compared against leafy or low crops, such as lettuce (25.35 t ha$^{-1}$, 1.21 R$ kg$^{-1}$, and 30,722.65 R$ ha$^{-1}$; means over the 32 lettuce-producing municipalities) and parsley (32.92 t ha$^{-1}$, 2.10 R$ kg$^{-1}$, and 69,232.89 R$ ha$^{-1}$; means over the 11 parsley-producing municipalities).

Teresópolis sits at the top of Table 1 because this municipality, located in the Região Serrana, had the highest value for revenue from crops of all the municipalities of the state of Rio de Janeiro. It is efficient, and of the municipalities located in mountainous regions had the highest area under cultivation. The agricultural production of Teresópolis is concentrated on leafy crops, which require greater spacing between the plants, and have a lower market value per unit weight, so that for the calendar year 2015, the revenue per unit area was 36,428.53 R$ ha$^{-1}$ (sixteenth of the full set of 85 municipalities). Other features of Teresópolis were the production of 22 different crops, with 66.08 % of the cultivated area being planted with lettuce, which was responsible for 57.22 % of the total revenue. The second crop by area was mandarin orange, occupying 6.24 % of the cultivated area and making

**Table 1. List of the 21 highlighted municipalities (DMUs), together with their values for the input variable and the two output variables used in the calculation from the full set of 85 DMUs of their efficiency indices. The DMUs are listed in order of decreasing revenue, and the altitudes of the seat of each of the municipalities are also given.**

| Municipality (DMU) | Variables | | | | |
|---|---|---|---|---|---|
| | Input | Output | | External Altitude / m | Efficiency |
| | $x_1$ Cultivated area / ha | $y_1$ Number of crops | $y_2$ Revenue / R$ | | |
| Teresópolis | 7,302.10 | 22 | 266,004,770.40 | 871 | 1.000 |
| São Francisco de Itabapoana | 29,399.20 | 12 | 193,472,379.00 | 8 | 0.727 |
| Nova Friburgo | 2,334.60 | 25 | 114,305,567.70 | 846 | 1.000 |
| Sumidouro | 1,557.79 | 31 | 65,615,069.10 | 355 | 1.000 |
| Campos dos Goytacazes | 30,873.00 | 11 | 64,629,940.00 | 13 | 0.405 |
| Duas Barras | 1,441.95 | 33 | 39,053,311.00 | 530 | 1.000 |
| Varre-Sai | 5,639.00 | 3 | 38,205,300.00 | 680 | 0.178 |
| Paty do Alferes | 404.90 | 14 | 36,091,304.00 | 610 | 1.000 |
| Vassouras | 276.51 | 15 | 23,721,577.00 | 434 | 1.000 |
| Petrópolis | 386.28 | 24 | 13,137,202.00 | 809 | 1.000 |
| Iguaba Grande | 298.25 | 18 | 12,861,866.00 | 18 | 0.909 |
| Paracambi | 1,135.20 | 5 | 5,839,310.00 | 50 | 0.166 |
| Rio Claro | 592.75 | 28 | 4,618,349.40 | 446 | 1.000 |
| Armação dos Búzios | 80.80 | 15 | 2,944,671.00 | 3 | 1.000 |
| Barra Mansa | 120.96 | 16 | 2,324,089.50 | 381 | 0.989 |
| Rio das Flores | 50.60 | 12 | 2,152,094.00 | 525 | 0.926 |
| Macaé | 398.39 | 20 | 1,682,466.20 | 2 | 1.000 |
| Resende | 185.85 | 18 | 1,598,779.00 | 407 | 1.000 |
| Carmo | 77.11 | 13 | 1,260,825.90 | 347 | 0.923 |
| Miguel Pereira | 6.50 | 11 | 114,709.00 | 618 | 1.000 |
| Comendador Levy Gasparian | 6.00 | 2 | 63,961.10 | 315 | 1.000 |
| Total for state | 146,359.64 | 67 | 1,826,307,110.90 | | - |
| Maximum (any of the 85 DMUs) | 30,873.00 (Campos dos Goytacazes) | 33 (Duas Barras) | 266,004,770.40 (Teresópolis) | 871 (Teresópolis) | 1.000 (various) |
| Minimum (any of the 85 DMUs) | 6.00 (Comendador Levy Gasparian) | 2 | 63,961.10 | | 0.166 (Paracambi) |

a contribution of 2.85 % to the total revenue. The remaining 20 crops were produced from only 27.68 % of the total cultivated area, yet contributed 39.94 % of the revenue for the calendar year 2015. The strategy of relying heavily on a single crop of relatively low productivity per unit area, lettuce, limits the production of crops offering greater productivity per unit area and higher market value. However, lettuce is a non-seasonal crop, which can be produced throughout the entire year.

Miguel Pereira, an efficient municipality in the Região Centro-Sul Fluminense, had the second smallest area under cultivation (6.5 ha, Table 1). This municipality produced 11 different crops, and due to the small area, had the highest crop diversity per unit area (1.69 $ha^{-1}$) of the full set of 85 municipalities.

There were two efficient municipalities in the Região do Médio Vale do Paraíba. They were Rio Claro, which produced 28 different crops, with a crop diversity per unit area of 0.0472 $ha^{-1}$, and Resende, which produced 18 different crops, from one of the smaller cultivated areas (185.85 ha) of any of the 85 municipalities. For Resende the crop diversity per unit area was 0.0968 $ha^{-1}$, just over double that of Rio Claro.

São Francisco de Itabapoana (the largest producer of pineapple in the state of Rio de Janeiro, 166,250.00 t, 92.31 %) and Campos dos Goytacazes occupied the second and fifth positions, respectively, in the list of municipalities ordered by total revenue. Both are located in the Região Norte Fluminense and were the municipalities with the largest areas under cultivation. However, they produced a relatively small number of different crops (Table 1), with 73.13 % and 98.10 %, respectively, of their cultivated area given over to sugarcane, a strategy which evidently leads to low efficiency indices.

Paracambi and Varre-Sai, which occupied the forty-sixth and fifteenth positions, respectively, in the list of municipalities ordered by total revenue, had the worst efficiencies, and produced only five and three different crops, respectively (Table 1). Varre-Sai attained its higher position in the revenue order because of the better market prices commanded by its two main crops (coffee, 5.28 R$ $kg^{-1}$; and beans, 3.00 R$ $kg^{-1}$), which together are responsible for 99.59 % of its revenue. In contrast, the two crops from which Paracambi derived the bulk (84.67 %) of its revenue, banana and okra, had market prices of only 0.95 R$ $kg^{-1}$ and 1.92 R$ $kg^{-1}$, respectively. The municipality of Varre-Sai was the largest producer of coffee in the state of Rio de Janeiro (7010 t, 39.32 % of the total for the state), and generated the most revenue from coffee production (R$ 37,012,800.00). The key parameter that makes Varre-Sai such a centre for coffee production are that it is the municipality with the highest altitude (680 m) in the Região Noroeste Fluminense.

Mutyasira *et al*. (2018) show a positive association between DMU acreage size and sustainability. However, in the present study, the same is not true of productive efficiency. The consensus in these two studies is that productive diversity can strengthen both the efficiency and sustainability of this activity. The result of both contributes to evaluate and classify different agricultural producing regions, facilitating the intervention and directing of actions and policies for monitoring and increasing agriculture.

Therefore, it is observed that the way of managing the productive diversity, by the DMUs observed in this study, whether by rotation, by the consortium or by the sequence of different crops, promotes interactions that can provide a better use of the cultivated area throughout the year. and, also, greater productivity. Allowing the producer greater revenue, compared to DMUs with less crop diversity. Thus, providing a better result per hectare cultivated throughout the year.

**Distribution of the efficiency indices as a function of altitude**

Figure 1 shows the distribution of the efficiencies of the eighty-five municipalities as a function of the altitude of their respective seats. The figure is divided into quadrants by a vertical line at the mean altitude of the full set of eighty five municipalities (226 m), and a horizontal line at the mean efficiency of the full set of municipalities (0.6324) The quadrants are numbered clockwise, with Quadrant I corresponding to the highest efficiencies and altitudes (Figure 1), as well as used in the work of K. Wang *et al*. (2012).

Means, standard deviations, minima, and maxima of the efficiencies and altitudes of the DMUs contained in each of the quadrants, and the global values over the full set of 85 municipalities are given in Table 2. Inspection of Figure 1 indicates that the highest frequency of efficient municipalities occurred at the highest altitudes. In the dispersion diagram, there are more municipalities in quadrants Q I and Q III (58, 68.2 %)) than in quadrants Q II and Q IV, which is indicative of a positive correlation between efficiency and altitude.

Quadrant I contains the municipalities with higher altitudes (>= 226 m) and higher efficiencies (>= 0.6324), of which there were 23. The mean efficiency of these 23 municipalities was 0.8869 (Table 2). Ten of the twelve efficient municipalities fall in Quadrant I.

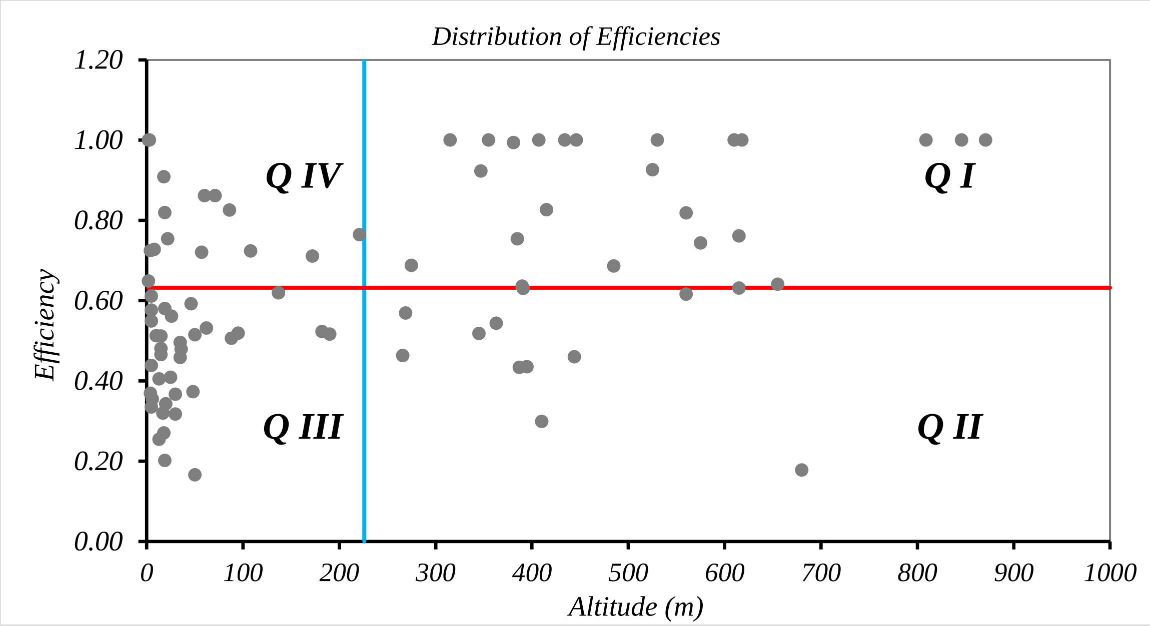


**Figure 1** Dispersion diagram of the efficiency indices of the 85 municipalities in relation to their altitudes.

The software package *QGIS* (version 3.4 'Madeira') used geographical information systems (GIS) in a digital elevation model (DEM) with a resolution of 90 m and UTM projection (WGS 1984) in the GEOTIFF format (16 bits) (EMBRAPA, 2019) to produce the relief map of the state of Rio de Janeiro presented in Figure 2. The position of the state of Rio de Janeiro within the map of Brazil is seen in the detail on the right corner.

The Região Serrana contained five efficient municipalities, with altitudes that varied between 355 and 871 m. In the Região Centro-Sul Fluminense, there were three efficient municipalities, with altitudes between 434 and 618 m, and the default DMU Comendador Levy Gasparian at 315 m. There were no efficient municipalities in the Região Noroeste Fluminense. The Região das Baixadas Litorâneas had just one efficient municipality, Armação dos Búzios, with an altitude of only 3 m. In the Região Norte Fluminense, the low-lying municipality of Macaé (altitude: 2 m) was the only efficient municipality. With the exception of Armação dos Búzios and Macaé in the Região Norte Fluminense, the other ten efficient municipalities had altitudes that ranged from 355 to 871 m.

The regions of the state of Rio de Janeiro which contained the greatest numbers of efficient municipalities were the Região Serrana (5), the Região Centro-Sul Fluminense (3), and the Região do Médio Vale Paraíba (2), which are the higher altitude regions of the state with a preponderance of mountainous areas. This result emphasizes the importance of crop production from these regions to the agriculture of the state. Just as found by Salgado Junior *et al*. (2014) in their work on sugar mill efficiency, variables associated with geographical location, in the present case altitude, have an impact on the efficiency of the agriculture. Looking more deeply into the production data for the efficient municipalities, it becomes apparent that following the strategy emphasized by Nodari and Guerra (2015), in which productive diversity is promoted as the means to increasing agricultural efficiency, is indeed the basis of the most efficient DMUs.

**Table 2 Analysis of the distribution of the efficiency and altitude values between the four quadrants (Q I to Q IV, defined in Figure** 1**), and comparative global values over the full set of 85 municipalities.**

| Quadrant | Number DMUs | Efficiency | | | | Altitude | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Dev. | Min. | Max. | Mean | Std. Dev. | Min. | Max. |
| I | 23 | 0.8869 | 0.1383 | 0.6362 | 1.0000 | 515 | 167 | 275 | 871 |
| II | 12 | 0.4814 | 0.1370 | 0.1775 | 0.6315 | 427 | 129 | 266 | 680 |
| III | 35 | 0.4437 | 0.1180 | 0.1659 | 0.6191 | 39 | 47 | 4 | 190 |
| IV | 15 | 0.8034 | 0.1061 | 0.6486 | 1.0000 | 57 | 67 | 2 | 221 |
| GLOBAL | 85 | **0.6324** | 0.2367 | 0.1659 | 1.0000 | **226** | 244 | 2 | 871 |

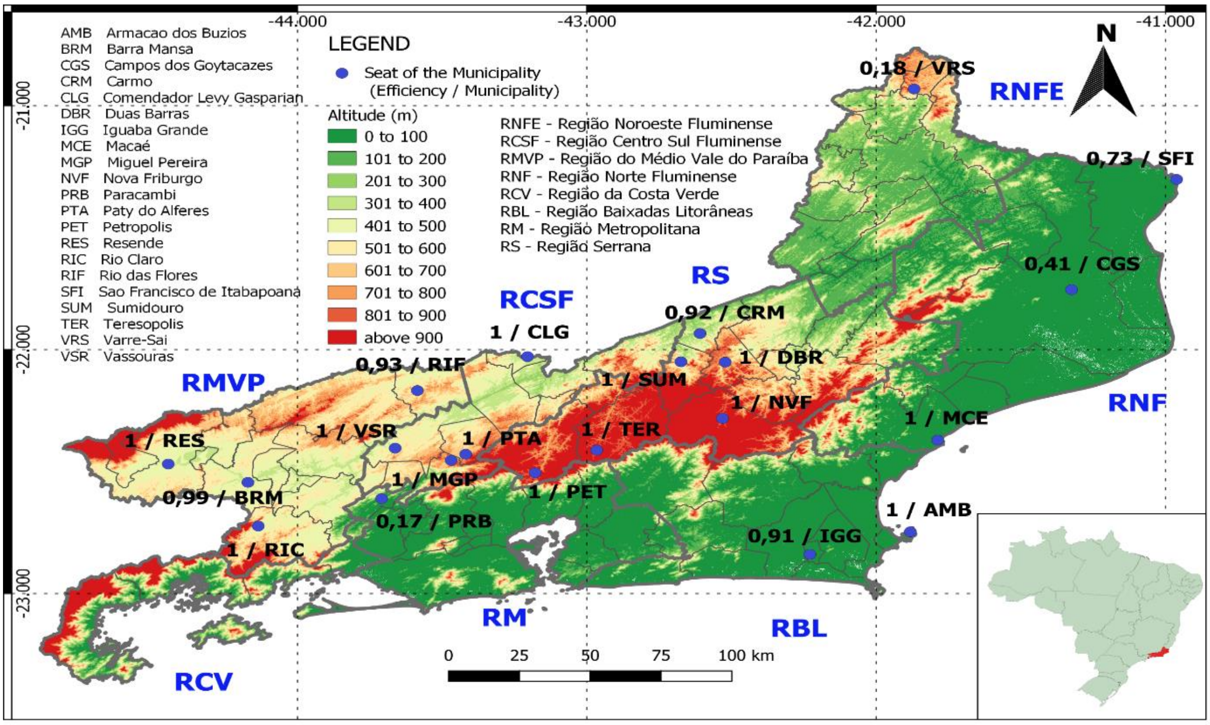


**Figure 2** Relief map of the state of Rio de Janeiro, showing the eight regions, the locations of the administrative seats, and the efficiencies of the 21 municipalities of Table 1. Source: author.

Oliveira (2019) has reviewed the development of agriculture in the state of Rio de Janeiro over the last two hundred years, and demonstrated that it has been shaped by the environmental diversity of the state, peoples, plant types, strategies, policies, and economic cycles. It is through the combination of these factors that the state has been moulded into its current configuration. Agrobiodiversity stands out as a characteristic of the state's agriculture, which has become consolidated as part of the heritage of the state, and evolved as part of its historical trajectory. Thus, the arrival of Swiss and later German settlers onto the lands of the mountainous regions of Rio de Janeiro, already inhabited by indians and the descendants of Afro-Brazilian slaves who had escaped from slave plantations, and disputed by Brazilians of Portuguese descent and Portuguese settlers set the scene for a complex game of justifications, interests, dreams, expectations, promises, and results. This was the start of a process of hybridization, which would come to form the genetic and cultural diversity as the territory was constructed. Although the transformation was at times tumultuous, including the relations between the growing number of inhabitants and the indigenous plants, birds, and animals, it gave origin to the robust vitality of the heritage of this region. It is this heritage that Alimonda (2006) relates and describes as empowering the capacity present to put creatively into operation a transformative action, rooted in the linkages derived from a legacy with the past.

The highest average efficiencies are those of the municipalities constituting quadrants I and IV (Table 2). However, the good performance for quadrant IV was significantly influenced by the efficiencies of Armação dos Búzios and Macaé. In Figure 1, the points for these two municipalities are superimposed, for both have an efficiency of one, and the altitudes of their seats are almost identical, 3 and 2 m, respectively. The BCC-computed efficiencies of one for these two municipalities are due to certain highly specific characteristics.

Examining first Armação dos Búzios, this municipality produced 15 different crops from a cultivated area of 80.8 ha, one of the smaller areas in the full set of 85 municipalities (17 municipalities operated with smaller cultivated areas), and achieved a revenue of almost three million Brazilian Reais in the calendar year 2015. The revenue per unit area was 36,443.95 R$ $ha^{-1}$, appearing in fifteenth place, and was similar to that of Teresópolis (36,428.53 R$ $ha^{-1}$). Manioc, banana, kale, rocket, and spinach together were responsible for 85.31 % of the revenue, and occupied 87 % of the cultivated area. The revenue per unit area was raised by the higher local market prices for these products in comparison to other municipalities, which guaranteed the classification of the performance of Armação dos Búzios as efficient (Table 1). Its relatively limited agricultural production benefitted from a market supply chain which generated higher unit prices, due to the intense activity in the municipality, which is an important and established tourist resort.

Macaé appeared in sixty-fifth position in the list of municipalities by revenue, but produced 20 different crops, so that its productive diversity was one of the highest in the Região Norte Fluminense. The principal crops were maize and beans. Although the seat of the municipality is on the coast (Figure 2) and has an altitude of only 2 m, the municipality extends inland into the mountainous regions of the interior of the state. An examination of altimetric data for the municipality shows that while some of the coastal parts have an altitude of zero, in the mountainous interior the altitude reaches as high as 1,400 m. Given this topography, it is a distortion to assign an altitude of 2 m to this municipality, and to use this as the basis for the assessment of all of its agricultural areas. Within the municipality of Macaé, the agricultural practices of mountainous regions are prominent. This can be seen by making a comparison with the efficient municipality of Nova Friburgo (846 m), with which the municipality of Macaé shares a border. It is the mountainous regions of the interior of the municipality of Macaé which enable this DMU to produce such a wide diversity of crops, and be classified as efficient.

Therefore, the trend presented in this work can also be seen in the works by Oliveira *et al.* (2019) and Sambuichi *et al*. (2014), who highlight productive diversity as a promoter of development in agriculture. Omer *et al.* (2010), also, identified a positive relationship between agrobiodiversity (BRASIL, 2017) and agricultural productivity. Rensburg and Mulugeta (2016) found that biodiversity plays a beneficial role in supporting rural producers' profitability.

As in the present study, in the work of Toma *et al.* (2015), a comparison was also made of the performance of agriculture in different environments and geographic locations. The results obtained, as discussed in Toma *et al*. (2015), can contribute to assess and classify the different agricultural producing regions, facilitating intervention, defining strategies and directing actions and policies for monitoring and increasing agriculture, especially in these mountainous regions, where greater restrictions exist for the use and land occupation. Acevedo-Osorio *et al*. (2020) recommend the promotion of agrobiodiversity in public policies for national food security and sovereignty including its conservation as a criterion in land planning plans.

## CONCLUSION

The incorporation of productive diversity, in the form of the number of different crops, into a DEA computation of the agricultural efficiency of municipalities in the state of Rio de Janeiro, has identified that the best performance is found for municipalities in the mountainous regions of the state. Of the twelve municipalities identified as efficient, eleven practiced agriculture in these regions. In other words, the greatest proportion of the efficient municipalities identified in the present study are located in mountainous regions. A positive correlation between agricultural efficiency and the altitude of the cultivated areas was also observed. Taken together, these two results emphasize the importance of agriculture in mountainous regions for crop production in the state of Rio de Janeiro.

**Acknowledgments**
Federal Fluminense University (UFF); Federal Rural University of Rio de Janeiro (UFRRJ); Brazilian Agricultural Research Company (EMBRAPA), Higher Education Personnel Improvement Coordination (CAPES); and National Council for Scientific and Technological Development (CNPq) – Brazil; are thanked for their support of the research presented in this paper.

**Conflict of interests**. The authors state that there are no conflicts of interest in this article.

**Financing source**. This study was not funded. The authors did not receive funding.

**Bioethics committee authorization**. Does not apply.

**Data availability**. Data are available upon request with the corresponding author.

## REFERENCES

Acevedo-Osorio, A., Przychodzka, S.O. and Pinilla, J.E.O. 2020. Aportes de la agrobiodiversidad a la sustentabilidad de la agricultura familiar en colombia. Tropical and Subtropical Agroecosystems 23: 1-18. file:///C:/Users/olive/Downloads/2992-14054-2-PB.pdf

Alimonda, H. 2006. Una herencia en Manaos (anotaciones sobre história ambiental, ecología política y agroecología en una perspectiva latinoamericana). Horizontes Antropológicos 1: 237-255. DOI: 10.1590/S0104-71832006000100012

Angulo Meza, L., Biondi Neto, L., Soares de Mello, J.C.C.B., Gomes, E.G. 2005. ISYDS - Integrated System for Decision Support (SIAD-Sistema Integrado de Apoio à Decisão): a software package for data envelopment analysis model. Pesquisa Operacional 25: 493-503. DOI: 10.1590/S0101-74382005000300011

Angulo-Meza, L., González-Araya, M., Iriarte, A., Rebolledo-Leiva, R., Soares de Mello, J.C.C.B. 2019. A multiobjective DEA model to assess the eco-efficiency of agricultural practices within the CF+DEA method. Computers and Electronics in Agriculture 161: 151–161. DOI: 10.1016/j.compag.2018.05.037

Assis, R.L., Araújo, J.S.P., Anjos, L.H.C., Aquino, A.M. 2016. Agroecologia, produção orgânica e agricultura urbana no Rio de Janeiro. Boletim informativo da Sociedade Brasileira de Ciência do Solo 42: 32-35. URL: https://www.sbcs.org.br/wp-content/uploads/2017/02/Boletim-dezembro-web.pdf

Balbino, L. C., Barcellos, A. O., Stone, L. F. 2011. Marco referencial: integração lavoura-pecuária-floresta. EMBRAPA, Brasília- DF. URL: https://www.alice.cnptia.embrapa.br/bitstream/doc/923530/1/balbino01.pdf

Banker, R.D., Charnes, A., Cooper, W.W. 1984. Some Models for estimating Technical Scale Inefficiencies in Data Envelopment Analysis. Management Science 30: 1078-1092. DOI: 10.1287/mnsc.30.9.1078

BRASIL, MMA – Ministério do Meio Ambiente. 2017. Agrobiodiversidade. http://www.mma.gov.br/biodiversidade/conservacao-e-promocao-do-uso-da-diversidade-genetica/agrobiodiversidade.

BRASIL, PNA – Programa Nacional de Conservação da Agrobiodiversidade. 2011. Boletim de avaliação e monitoramento. URL: http://terradedireitos.org.br/wp-content/uploads/2011/04/Programa-Nacional-de-Conserva%C3%A7%C3%A3o-da-Agrobiodiversidade-INTERNET-1.pdf

Conway, G. R. 1987. The properties of agroecosystems. Agricultural Systems 24: 95-117. DOI: 10.1016/0308-521X(87)90056-4

Cook, W.D., Tone, K., Zhu, J. 2014. Data envelopment analysis: Prior to choosing a model. Omega 44: 1–4. DOI: 10.1016/j.omega.2013.09.004

Cooper, W.W., Seiford, L.M., Tone, K. 2007. Data Envelopment Analysis – A comprehensive text with models, applications, references and DEA-solver software. Springer, New York, USA.

[dataset] EMATER-RIO - Empresa de Assistência Técnica e Extenção Rural do Estado do Rio de Janeiro. 2015. Relatório de Acompanhamento Sistemático da Produção Agrícola – ASPA. URL: http://www.emater.rj.gov.br/tecnica.asp. (accessed 10 December 2016).

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. 2008. A agrobiodiversidade com enfoque agroecológico implicações conceituais e jurídicas. URL: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/139665/1/machado-01.pdf.

[dataset] EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. 2019. Monitoramento por Satélite. URL: https://www.cnpm.embrapa.br/projetos/relevobr/download/. (accessed 4 July 2019).

Emrouznejad, A. and Yang, G-L. 2017. A survey and analysis of the first 40 years of scholarly literature in DEA: 1978-2016. Socio-Economic Planning Sciences 61: 4-8. DOI: 10.1016/j.seps.2017.01.008

[dataset] IBGE – Instituto Brasileiro de Geografia e Estatística. 2013. Altitude e coordenadas geográficas das sedes municipais, segundo as Regiões de Governo e municípios do Estado do Rio de Janeiro. URL: arquivos.proderj.rj.gov.br/.../anuario.../Anuario2013/.../Tab_01.04_13.xls. (accessed 4 April 2017).

Kapos, V., Rhind, J., Edwards, M.; Price, M. F., Ravilious, C. 2000. Defining mountains by topography only. In: Millenium Ecosystem Assessment. Ecosystems and human wellbeing: Mountain Systems. Washington, DC: Island Press and World Resources Institute, 2005. https://www.millenniumassessment.org/documents/document.293.aspx.pdf.

Ke Wang, Yi-Ming Wei, Xian Zhang. 2012. A comparative analysis of China's regional energy and emission performance: Which is the better way to deal with undesirable outputs? Energy Policy 46: 574–584. DOI: 10.1016/j.enpol.2012.04.038

Leff, E. 2001. Saber ambiental: sustentabilidade, racionalidade, complexidade, poder. Vozes. Petrópolis. Brasil. http://dx.doi.org/10.1590/S1414-753X2002000100010.

López Netto, A., Assis, R.L., Aquino, A.M. 2017. Ações Públicas para o Desenvolvimento Rural Sustentável dos Ambientes de Montanha Brasileiros. Desenvolvimento em Questão 15: 141-170. DOI: 10.21527/2237-6453.2017.39.141-170

Mutyasira, V., Hoag, D., Pendell, D., Manning, D.T., Berhe, M. 2018. Assessing the relative sustainability of smallholder farming systems in Ethiopian highlands. Agricultural Systems 167: 83–91. DOI: 10.1016/j.agsy.2018.08.006

Nodari, R.O., Guerra, M.P. 2015. A agroecologia: estratégias de pesquisa e valores. Estudos Avançados 29: 183-207. DOI: 10.1590/S0103-40142015000100010

Oliveira, E. 2019. Eficiência produtiva da agricultura fluminense em ambientes de montanha. Doctoral thesis. Universidade Federal Rural do Rio de Janeiro, PPGCTIA. URL: file:///C:/Users/Elton/Downloads/(DO-2019)%20Elton%20Oliveira.pdf

Oliveira, E., Aquino, A. M., Assis, R. L., Soares de Mello, J.C.C.B. 2019. Horticultores agroecológicos em ambientes de montanha do município de Teresópolis, Rio de Janeiro. Revista Verde de Agroecologia e Desenvolvimento Sustentável 14(2): 273-280. DOI: 10.18378/rvads.v14i2.6107

Omer, A., Pascual, U., Russell, N. 2010. A theoretical model of agrobiodiversity as a supporting service for sustainable agricultural intensification. Ecological Economics 69(10): 1926-1933. DOI: 10.1016/j.ecolecon.2010.04.025

Rensburg, T. M., Mulugeta, E. 2016. Profit efficiency and habitat biodiversity: The case of upland livestock farmers in Ireland. Land Use Policy 54: 200-211. DOI: 10.1016/j.landusepol.2016.01.015

Salgado Junior, A.P., Carlucci, F.V., Novi, J.C. 2014. Aplicação da análise envoltória de dados (AED) na avaliação da eficiência operacional relativa entre usinas de cana-de-açúcar no território brasileiro. Engenharia Agrícola 34: 826-843. http://www.scielo.br/pdf/eagri/v34n5/03.pdf

Sambuichi, R.H.R., Galindo, E.P., Oliveira, M.A.C., Pereira, R.M. 2014. A diversificação produtiva como forma de viabilizar o desenvolvimento sustentável da agricultura familiar no brasil. In: Brasil em desenvolvimento 2014: estado, planejamento e políticas públicas. Brasília – Ipea 2(3): 61-84

Schneider, S. 2010. Reflexões sobre diversidade e diversificação. Ruris 04: 85-131. http://www.ufrgs.br/pgdr/publicacoes/producaotextual/sergio-schneider/schneider-s-reflexoes-sobre-diversidade-e-diversificacao-agricultura-formas-familiares-e-desenvolvimento-rural-ruris-v-4-n-1-p-85-131-marco-2010

Toma, E., Dobre, C., Dona, I., Cofas, E. 2015. DEA applicability in assessment of agriculture efficiency on areas with similar geographically patterns. Agriculture and Agricultural Science Procedia 06: 704-711. DOI: 10.1016/j.aaspro.2015.08.127