EVALUATING THE INFLUENCE OF SOIL AND SOCIOECONOMIC FACTORS ON AGRICULTURAL EFFICIENCY †

[EVALUACIÓN DE LA INFLUENCIA DEL SUELO Y FACTORES SOCIOECONÓMICOS EN LA EFICIENCIA AGRÍCOLA]

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SUMMARY

Background: Given the importance of the agricultural activity for the economic development of the state of Rio de Janeiro, Brazil, in this paper we assess the effect of the environmental parameters related to soils and socioeconomic factors on the performance of the municipalities. **Objective:** To identify factors that influence on agricultural production performance, as well as the directions of such influences (positive or negative). **Methodology:** A two-stage Data Envelopment Analysis (DEA) was chosen for this analysis. The performance scores are computed considering land, labor, and capital (or technology) as inputs, and the value of crops and of livestock production as outputs. **Results:** The average efficiency was 0.5509 and 12 municipalities out of the 89 assessed were 100% efficient. A high level of susceptibility to erosion significantly and negatively influences the efficiency scores. The suitability of land for agriculture and for livestock are positively associated with performance. The presence of family-based farmers favors the agricultural performance of the assessed municipalities. **Implications:** These results may support public policies related to land use and soil governance. **Conclusions:** The proposed two-stage DEA approach was useful to assess the influence of factors related to soils and socioeconomic indicators on the agricultural performance of the municipalities in the state of Rio de Janeiro.

Keywords: performance assessment; soil erosion; land use; land suitability; family farming.

RESUMEN

Antecedentes: Dada la importancia de la actividad agrícola para el desarrollo económico del estado de Río de Janeiro, Brasil, en este artículo evaluamos el efecto de los parámetros ambientales relacionados con los suelos y los factores socioeconómicos en el desempeño de los municipios. **Objetivo:** Identificar los factores influyentes en el desempeño de la producción agrícola, así como las direcciones de dichas influencias (positivas o negativas). **Metodología:** Análisis Envolvente de Datos (DEA) en dos etapas fue elegida para este análisis. Los puntajes de desempeño se calculan considerando la tierra, la mano de obra y el capital (o tecnología) como insumos, y el valor de los cultivos y de la producción ganadera como productos. **Resultados:** La eficiencia promedio fue de 0,5509 y 12 municipios de los 89 evaluados fueron 100% eficientes. Los altos niveles de susceptibilidad a la erosión influyen significativa y negativamente en los puntajes de desempeño. La aptitud de la tierra para la agricultura y la ganadería se asocian positivamente con el desempeño. La presencia de agricultores familiares favorece el desempeño agrícola de los municipios evaluados. **Implicaciones:** Estos resultados pueden apoyar políticas públicas relacionadas con el uso de la tierra y la gobernanza del suelo. **Conclusiones:** El enfoque DEA en dos etapas propuesto fue útil para

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evaluar la influencia de factores relacionados con los suelos y los indicadores socioeconómicos en el desempeño agrícola de los municipios del Estado de Río de Janeiro.
Palabras clave: evaluación del desempeño; erosión del suelo; uso de la tierra; aptitud de la tierra; agricultura familiar.

INTRODUCTION

The agricultural sector is important for generating employment and income and contributes to the economy of the municipalities in the state of Rio de Janeiro, Brazil, especially in the countryside (Emater-Rio, 2021). In order to promote public policies for this sector, it is necessary to understand the factors that influence its performance. Regarding the agricultural activities in the state, cattle ranching (dairy and beef), followed by horticulture and fruit production, stand out and represented 39%, 20% and 12% of the total gross revenue (amounts paid to the producers) in 2020, respectively (Emater-Rio, 2021). Family farming accounts for most of the state's agricultural production, contributing to 68% of the production of beans, 75% of cassava, 67% of corn grain, 55% of rice, and 52% of coffee (IBGE, 2019).

Among the physical and environmental factors that affect the performance of the agricultural activity, soil, relief, and climate are noteworthy (Cong, 2021). Soil is the most common and easy to manage for farmers, as they may adapt it to the productive and profitable development of agricultural activities by reducing its natural limiting factors.

Soils, however, vary in the landscape (Chicota *et al.*, 2006), and have different potentials for agricultural production and productivity (Resende *et al.*, 2014; Gallo *et al.*, 2018). Soils contribute to ecosystem services that, in turn, contribute to the United Nations Sustainable Development Goals (SDGs). Relevant soil ecosystem services are biomass production (SDG 2 – zero hunger), providing clean water (SDG 6), climate mitigation by carbon capture and reduction of greenhouse gas emissions (SDG 13 – climate action), and biodiversity preservation (SDG 15 – life on land) (Bonfante *et al*., 2020). Their proper use and management, according to the land use suitability, is one of the best strategies to avoid or to mitigate their degradation, which is a growing problem on a global scale (Lal, 2015, Montanarella *et al.*, 2015, Vattuone *et al.*, 2018).

A methodology to assess agricultural land suitability was adjusted to Brazilian conditions by Ramalho Filho and Beek (1995), considering five soil limiting factors: fertility deficiency, water deficiency, water excess or oxygen deficiency, a barrier to mechanization, and susceptibility to erosion. The latter concerns the wear and tear that soil surface may suffer when subjected to any use (Ramalho Filho and Beek, 1995), which leads to soil erosion, considered one of the main types of land degradation (Montanarella *et al.*, 2015, Bednář and Šarapatka, 2018, Poesen, 2018, FAO, 2019).

Agricultural land suitability has been analyzed on national (Carvalho Filho *et al.*, 2021) and on state (Carvalho Filho *et al.*, 2003, Delarmelinda *et al.*, 2011, Silva *et al.*, 2013, Almeida *et al.*, 2019) levels, in order to guide the planning of rural areas and the implementation of public policies aimed at the sustainable use, occupation, and conservation of the soil.

The susceptibility of soils to water erosion, on the other hand, is an appropriate criterion both for the assessment of the potential environmental degradation of a given area and for the selection for strategic intervention purposes in public programs and policies dedicated to sustainable rural development. Soil erosion is considered the primary cause of other problems that lead to environmental degradation (Ananda and Herath, 2003, Montanarella *et al.*, 2015, Poesen, 2018, Borrelli *et al.*, 2020), including water quality deterioration (Issaka and Ashraf, 2017), generating low productivity (Montanarella *et al.*, 2016) and impoverishment of rural areas (Wambua and Kithiia, 2014, Gomiero, 2016), especially in the global southern hemisphere (Poesen, 2018). It has been frequently used as a criterion for prioritizing areas for the implementation of statewide micro watershed programs in Brazil, as is the case of São Paulo (CATI, 2000).

Beyond variables concerning environmental aspects, such as agricultural land suitability and susceptibility of soils to water erosion, other factors may influence the performance of agricultural production. According to Souza *et al.* (2020, 2022), one should also consider socioeconomic attributes closely related to market imperfections. Market imperfections impose restrictions to production and to the adoption of technology, specially for small-scale productions. Thus, credit and technical assistance are important issues in reducing market asymmetries, providing equal opportunities in the market for small and large-scale farms. Given this context, our hypothesis is that environmental parameters related to soils and socioeconomic factors influence the agricultural performance in the state of Rio de Janeiro. To validate such statement, we structured Data Envelopment Analysis (DEA) models to estimate the efficiency (or performance) of the municipalities, following the perspective of an agricultural production function. We then evaluated the potential effect of covariates on performance, namely: soil susceptibility to water erosion, agricultural land use suitability, and socioeconomic variables (presence of family farming, presence of technical assistance, and presence of funding). Therefore, our objective is to identify the factors that influence agricultural production performance, as well as the directions of such influences (positive or negative), by means of an analytical framework based on the so-called two-stage DEA procedure (DEA followed by regression models).

It is important to cite that the quantitative framework used in our paper is widely used in the literature in the agriculture context. Liu *et al.* (2013) and Emrouznejad and Yang (2018) identified agricultural evaluation as one of the top five application areas in DEA. Also, Liu *et al*. (2016) and Emrouznejad and Yang (2018) identified the two-stage DEA models as one of the top areas of recent studies in DEA. Liu *et al*. (2013) point to the study of two-stage DEA as one of the three main paths followed by applications in agriculture. This set of information shows the relevance of the type of study presented here, and the need to invest in research that focuses both on the application of DEA models to real cases of national agriculture and cattle ranching, and in the proposition of models that allow us to identify the determinants of efficiency in order to enhance the sector's performance and support the formulation of public policies.

DEA models are not the only option for modeling production frontiers. Stochastic Frontier Analysis (SFA) models are an alternative (Coelli *et al.*, 2005). However, we chose DEA models because some characteristics of the DEA approach, such as not imposing restrictive assumptions about the frontier (technology), except for the convexity assumption, not requiring assumptions about the statistical distribution of efficiency scores, in addition to the possibility of incorporating multiple inputs and multiple outputs. Another favorable feature that we can cite is the flexibility and benevolence in the choice of weights of inputs and outputs that will compose the ratio of weighted sums that define the efficiency score. This allows us to identify specializations and achieve the maximum possible efficiency score, given the sample under evaluation.

MATERIALS AND METHODS

The state of Rio de Janeiro is located in the Tropical Zone of the Southeast Region of Brazil between 20°44′-23°22′S and 40°57′-44°53′W (Figure 1) (Ribeiro *et al.*, 2018b). The state comprises an area of 43,781.6 km² (IBGE, 2021), with different soil types, geology, climates, and vegetation in Atlantic Forest biome (Lumbreras *et al*., 2003). Among the predominant soils, the Latossolos (Ferralsols), Argissolos (Acrisols) and Cambissolos (Cambisols) stand out (Carvalho Filho *et al.*, 2003, Santos *et al.*, 2018, IUSS, 2022). In general, these soils have low natural fertility, with Argissolos and Cambissolos predominantly located in rugged relief and are susceptible to erosion processes (Carvalho Filho *et al.*, 2003). Therefore, the state has heterogeneous ecosystems, with lagoons, mangroves, swamps, wetlands, sandbank vegetation, forests, and grassland areas. According to the Köppen System, the climate of the state varies as Aw, Am, Af, BSh, Cfa, Cfb, Cwb, and Cwa (Ribeiro *et al.*, 2018a), with the annual rainfall index reaches 3000 mm in the centre of the state, where the mountainous region is located, which is followed by the southern region (Green Coast Region), where values of 2000 mm are reached. On the other hand, the northern region of the state is the driest, with annual rainfalls of approximately 870 mm (André *et al*., 2008, Ribeiro *et al*., 2018b). The annual mean temperature is 24°C; the minimum temperature is recorded in the dry season (14°C), and the maximum temperature occurs in the rainy season (40°C) (Miguel *et al.*, 2014).

We structured DEA models (Cooper *et al*., 2011) to estimate the agricultural performance of the state municipalities. This type of mathematical programming model calculates the efficiency of production units, called Decision Making Units (DMUs), optimizing the ratio between the weighted sum of outputs and the weighted sum of inputs. Each DMU defines the weights for each variable (input or output) in the most benevolent way, as long as these weights applied to the other DMUs do not generate a ratio greater than 1. It is also possible to project each inefficient DMU on the efficiency frontier, allowing the identification of benchmarks and target values. These conditions are formalized in the linear programming models presented in Eq. 1 and Eq. 2 (see Cooper *et al.*, 2011, for further details).

We assumed a variable returns to scale (VRS) hypothesis. By determining a convex frontier, the VRS model allows DMUs that operate with low input values to have increasing returns to scale and those that operate with higher values to have decreasing returns to scale. The use of the VRS hypothesis is justified by the understanding that the constant returns (CRS) assumption is difficult to verify in this case study. In addition, the municipalities have different production scales, which suggests a better adequacy of the VRS frontier. We also assumed that the search for efficiency will be done by increasing production, keeping the inputs unaltered (output-oriented DEA model).

In Eq. 1, the so-called envelope formulation, h_o is the efficiency score of the DMU o under evaluation; x_{ik}

and y_{jk} are the inputs i, i=1...r, and the outputs j, j=1...s, of the DMU k, k=1...n; x_{io} and y_{jo} are the inputs i and the outputs j of the DMU o; λ_k is the contribution of DMU k to the target of DMU o (DMUs with non-zero λ_k are the benchmarks of DMU o). In Eq. 2, known as the multipliers formulation, and the dual problem of Eq. 1, v_i and u_j are the weights assigned to inputs and outputs, respectively; v_* is a dual variable associated with the restriction $\Sigma_k\lambda_k$=1 (convexity restriction) and may be interpreted as a scale factor (the DMU operates under decreasing returns to scale when positive, increasing returns to scale when negative, and constant returns to scale when zero). We used the SIAD software (Angulo Meza *et al.*, 2005) to compute the DEA efficiency scores.

$$\begin{aligned} &\text{Max} \quad h_o \\ &\text{st} \\ &x_{io} - \sum_k x_{ik}\lambda_k \geq 0, \forall i \\ &-h_o y_{jo} + \sum_k y_{jk}\lambda_k \geq 0, \forall j \\ &\sum_k \lambda_k = 1,\ \lambda_k \geq 0, \forall k \end{aligned} \qquad \text{(Eq. 1)}$$

$$\begin{aligned} &\text{Min} \quad h_o = \sum_i v_i x_{io} - v_* \\ &\text{st} \\ &\sum_j u_j y_{jo} = 1 \\ &-\sum_i v_i x_{ik} + \sum_j u_j y_{jk} - v_* \leq 0, \forall k \\ &u_j \geq 0, v_i \geq 0, \forall j,i,\ v_* \in \Re \end{aligned} \qquad \text{(Eq. 2)}$$

Municipal data came from the 2017 Brazilian agricultural census, available in IBGE (2019). The variables used to estimate the efficiency scores were defined as follows:

- “land” – given by the sum of areas cultivated with permanent and temporary crops, flower crops, planted forests, agroforestry systems, forestry, natural and planted pastures, represented by agripec and measured in hectares (agripec; hectares);

- “labor” (labor) – defined as expenses with salaries paid (vsp; thousand BRL);

- “capital or technology” (v15; thousand BRL) – included expenses with leasing land, contracting services, fertilizers and correctives, seeds and seedlings, purchase of animals, pesticides, medicines for animals, salt, feed, and other supplements, production transportation, electricity, purchase of machinery and vehicles, fuel and lubricants, new permanent crops and forestry, pasture formation, other expenses; and

- “production value” (vbp; thousand BRL) – sum of the livestock production value (vpan; thousand BRL) and of the crop production value (vpv; thousand BRL).

The DEA model had, therefore, three inputs (proxies for land, labor, and capital dimensions) and two outputs (proxies for crop and livestock productions). In theory, this model allows municipalities that are specialized in one of these types of production to be efficient. It also allows those municipalities that have a well combined production to be efficient. This approach is similar to that used by Gomes *et al.* (2009) when evaluating land use efficiency of rural producers. The modeling of production functions for Brazilian agriculture using recent census data can be seen in Souza *et al.* (2020, 2022).

Variable selection in DEA is a main concern. This step is made prior to the implementation of the DEA analysis and the efficiency scores are conditioned by the choice of inputs and outputs, either based on their definition or their quantity. According to Dyson *et al.* (2001), this set should consider four assumptions: it covers the full range of resources used; all activity levels are captured; all units use the same set of factors; if required, environmental variation should be captured and assessed. Although this is not the case here, the number of inputs and outputs selected may be a pitfall, as a large number of variables in relation to the number of DMUs can decrease the discrimination power of DEA models (ties for efficient units). In this regard, there are some “rules of thumb” in the literature that suggest the relation between the number of observations and the number of variables (Banker *et al.*, 1989; Cook *et al.*, 2014). As discussed by Peyrache *et al.* (2020), variable selection is still an unresolved issue in the DEA literature, as it is strongly dependent on the experience of the researchers and on the interpretation of the efficiency scores. In our study, we considered all these issues, and the choice of the variables was based on the traditional interpretation of production functions in agriculture, i.e., the output (revenue, production etc.,) is derived from land, labor, and capital. It is important to mention that the environmental variation cited by Dyson *et al.* (2001) was assessed here in the second stage, by the regression fit. In such case, the choice of the covariates was based on the researchers’ multidisciplinary expertise and on data availability, guided by the hypothesis made.

Ninety-one (91) of the 92 municipalities in the state of Rio de Janeiro were included in the data sources obtained from the 2017 agricultural census (IBGE, 2019), with the exception of Nilópolis. Of these 91, we disregarded two, Arraial do Cabo and São João de Meriti, as they presented null values for the agricultural production variables. Thus, we considered a set of 89 DMUs in the efficiency evaluation.

The DEA efficiency scores were grouped into quartiles and the ESRI's ArcGIS 10.5.1 software (Environmental Systems Research Institute, 2017) was used to represent their spatial distribution.

In addition to calculating an efficiency or performance measure, we identified the variables that affect performance via a two-stage DEA approach (Simar and Wilson, 2011). We opted for the fractional regression fit, as proposed by Ramalho *et al.* (2010) for DEA models. For the municipal district *j*, fractional regression assumes $E\left(\hat{\theta}_n\left(x_j, y_j \middle| z_j\right)\right) = G\left(\delta' z_j\right)$, where *G*(.) is a non-linear function with values in (0,1], θ is the DEA score in (0,1], *x* is the inputs vector, *y* is the outputs vector, *z* is the covariates vector and δ is the parameters vector. The recommendation is to use a distribution function to model *G*(.). We may estimate the model by non-linear least squares or quasi-maximum likelihood. Here we used the Probit model to fit the conditional mean, as it showed a better log-likelihood value when compared to the potential competing models (Logit and heteroskedastic Probit models).

We assessed this second stage in two steps: the first considering only the environmental covariates, and then adding the covariates of socioeconomic nature. In the first group of covariates, those related to soil characterization and evaluation, we selected: soil susceptibility to water erosion (Ferraz *et al.*, 2021) and land use suitability (Carvalho Filho *et al.*, 2021); spatial-based information from the Pronasolos Data Portal (https://geoportal.cprm.gov.br/pronasolos/). The covariates of socioeconomic nature are related to the presence of family farming, technical assistance, and financing, whose source is the 2017 agricultural census (IBGE, 2019).

While the criteria for the selection of environmental variables were the availability of information on a cartographic scale compatible with that required for its evaluation at the state level, as well as the relevance of the two, traditionally used in the country for the implementation of programs and public policies related to sustainable rural development, those related to socioeconomic nature were based on their presumed influence on agricultural production and their use in similar studies (Souza *et al.*, 2020, 2022). Socioeconomic variables are derived from the correspondent binary variables (yes/no) of the 2017 Brazilian agricultural census. Thus, the covariates were defined as follows (measured on a logarithmic scale):

- ps1 = percentage of area with very low susceptibility to water erosion;

- ps2 = percentage of area with low susceptibility to water erosion;

- ps3 = percentage of area with moderate susceptibility to water erosion;

- ps4 = percentage of area with high susceptibility to water erosion;

- ps5 = percentage of area with very high susceptibility to water erosion;

- paplav = percentage of area suitable for farming, which includes land with regular or restricted suitability for farming, regardless of management level;

- pappast = percentage of area suitable for pasture, which includes lands with regular or restricted suitability for pasture and farming, without considering management level;
- pappoutra = percentage of area unsuitable for farming and pasture, which includes land with restricted suitability for forestry, without considering management level, and land unsuitable for farming, pasture or forestry;

- paf = percentage of rural establishments that declared to be family farming;

- pat = percentage of rural establishments that received technical assistance;

- pfin = percentage of rural establishments that obtained credit or financing.

The aforementioned percentages of area were obtained considering the area occupied by each class in relation to the total area of each municipality. The percentages of rural establishments were measured by the ratio between the number of rural establishments that presented such characteristic and the total number of rural establishments in each municipality. In this regard, it is important to mention that for the agricultural census the definition of family farming follows the Brazilian legislation, i.e., farms that develop economic activities in rural areas and meet basic requirements, such as an area no greater than four fiscal modules, family labor is predominant in the farm's economic activities, and the biggest part of the family income comes from the farm's economic activities.

We should mention that we tested alternative models, such as the use of a single output (sum of livestock and crop production values, vpan and vpv) and with two inputs (sum of variables related to labor and capital/technology, v15 and vsp). In addition to these, we also tested separate models for crop and livestock productions. The choice for the model described here is due to the fact that it presented the highest correlation between observed and predicted values in the regression fit, as well as the highest average efficiency. In addition, the rank correlation of the efficiency scores for the competitive agricultural production models was around 90%, which may indicate the robustness of the structured models. The separate agricultural and livestock production models did not show divergent, nor more informative results than the agricultural production model and, therefore, were disregarded.

RESULTS

In Figure 1 we spatially represented the DEA efficiency scores. We identified the municipalities by performance classes, with each class representing one-third – upper, intermediate, or lower – of the range of performance values. According to this model, 12 municipalities of the 89 evaluated are efficient, i.e., 12 municipalities have an efficiency score equal to 1. The average efficiency is 0.5509, minimum value 0.2114, 1st quartile 0.3848, median 0.4826, 3rd quartile 0.6735.

Considering the entire set of observations and the weights calculated by the DEA model (Eq. 2), the order of importance assigned by the model to the inputs weights was labor, capital and land (the average of the weights was 52%, 32% and 16%, respectively). On the outputs' side, the importance is almost the same for crop and for livestock production values (49% and 51%, respectively).

In Table 1 we show the results for the fractional regression fit, considering both soil and socioeconomic covariates. The percentage of area with moderate, high, and very high susceptibility to erosion (lps3, lps4, pls5) have a statistically significant negative effect on the agricultural efficiency scores. The percentages of areas suitable for farming (paplav) and pasture (pappast) showed a positive and a statistically significant effect on the regression (marginal for pasture). The covariate related to the presence of family farming is positive and significant.

DISCUSSION

Among the municipalities with high performance, we note that five of them are among the largest agricultural producers in the state (Campos dos Goytacazes, São Francisco de Itabapoana, Teresópolis, São José do Vale do Rio Preto and Nova Friburgo). Another three municipalities have above average production, although they are not among the largest producers (Sumidouro, São João da Barra, and Japeri). The municipalities Belford Roxo, Mesquita and Niterói, also showed high performance, although their production areas are very small in the context of the state. This observation highlights the DEA characteristic, i.e., identifying observations that produce most with lower values of inputs.

The municipality of Barra do Piraí, the most referenced benchmark (taken as benchmark for the 77 inefficient municipalities), stands out in the state for the production of poultry. In the recent years, this municipality showed permanent and temporary crops productivity and livestock production growth. The wages in the agricultural sector were also increased. Other important characteristics refers to the logistics for production, as roads, proximity to the market, and the presence of processing industries for the agro sector.

Another important benchmark is Japeri. It was considered a benchmark for 62 of the 77 inefficient municipalities. Japeri has an agricultural origin and only 30% of its total area is considered urban area, according to the Brazilian Institute of Geography and Statistics – IBGE. It is crossed by railroad lines and is close to the main access route to the capital and to the Rio-São Paulo axis, becoming a logistical point of interest for various activities in the region. The agricultural activity in the municipality remains intense, although this business characteristic is of concern.

The structure of the weights suggests that land may be the detrimental input. In the DEA context, this means that it would be possible to produce more with the same amount of land. This would imply in adopting land use intensification technologies, if possible. Regarding the outputs, the weights results showed that the state of Rio de Janeiro has a good balance between crops and livestock productions.

While the analysis of DEA efficiency scores can be done per municipality, the analysis of the determinants of efficiency (regression fit) must be interpreted globally, for the whole sample of municipalities. In other words, this approach is unable to identify the contextual factors that affect the individual efficiencies or establish relationships between the efficiency score of a specific municipality and each covariate.

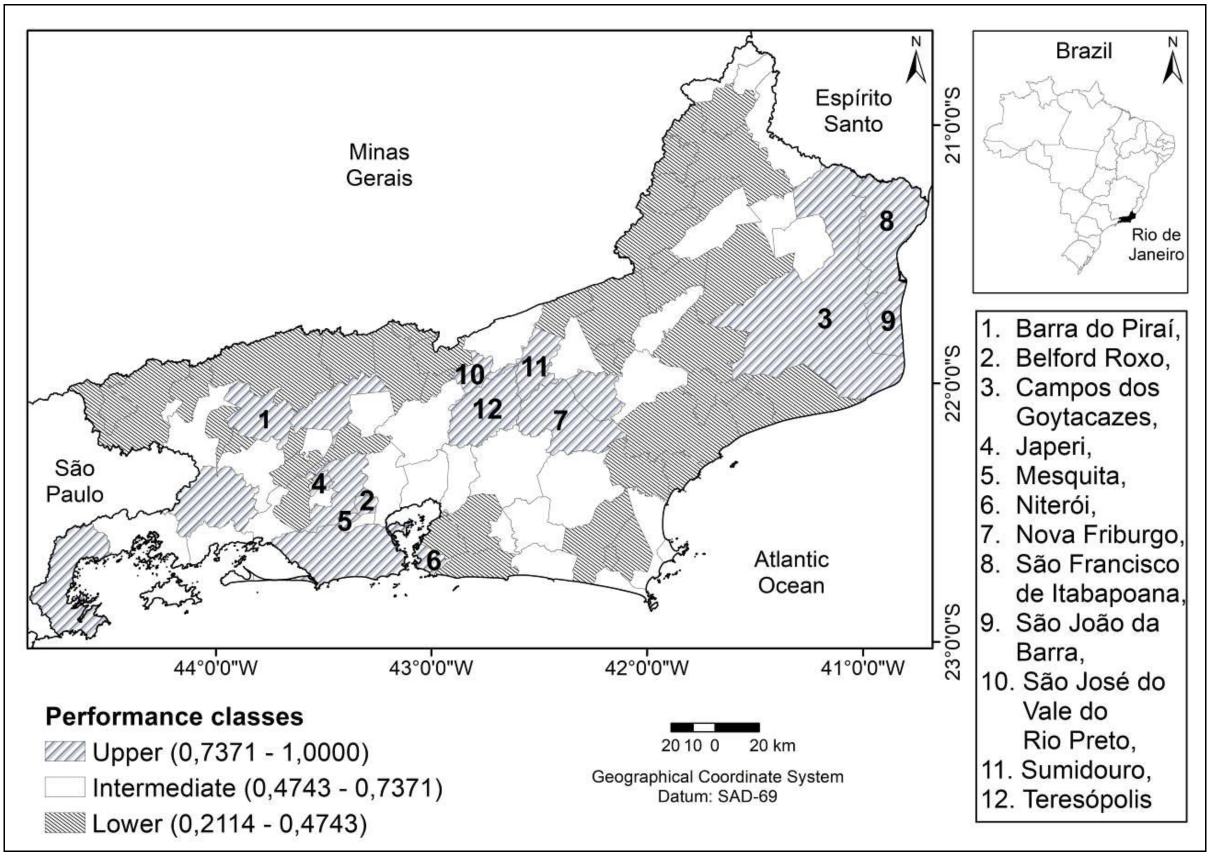

Figure 1. Spatial distribution of the agricultural performance scores in the state of Rio de Janeiro. Source: authors.

Table 1. Fractional regression fit. Bold font refers to the statistically significant covariates.

Covariates	Coefficient	Standard deviation	z	P>|z|	95% confidence interval	
lpaf	**1.130**	**0.383**	**2.95**	**0.003**	**0.380**	**1.880**
lpat	-0.159	0.155	-1.02	0.306	-0.464	0.145
lpfin	-0.096	0.089	-1.09	0.278	-0.270	0.078
lps1	-0.068	0.095	-0.72	0.471	-0.254	0.117
lps2	-0.123	0.189	-0.65	0.514	-0.493	0.247
lps3	**-1.109**	**0.265**	**-4.19**	**0.000**	**-1.628**	**-0.590**
lps4	**-0.273**	**0.086**	**-3.19**	**0.001**	**-0.441**	**-0.105**
lps5	**-0.630**	**0.177**	**-3.56**	**0.000**	**-0.977**	**-0.283**
lpaplav	**0.216**	**0.070**	**3.08**	**0.002**	**0.079**	**0.353**
lpappast	0.390	0.218	1.79	0.073	-0.036	0.817
lpapoutra	-0.073	0.090	-0.81	0.417	-0.250	0.103
constant	0.442	2.136	0.21	0.836	-3.745	4.630

lpaf = log of the percentage of rural establishments that declared to be family farming; lpat = log of the percentage of rural establishments that received technical assistance; lpfin = log of the percentage of rural establishments that obtained credit or financing; lps1 = log of the percentage of area with very low susceptibility to water erosion; lps2 = log of the percentage of area with low susceptibility to water erosion; lps3 = log of the percentage of area with moderate susceptibility to water erosion; lps4 = log of the percentage of area with high susceptibility to water erosion; lps5 = log of the percentage of area with very high susceptibility to water erosion; lpaplav = log of the percentage of area suitable for farming; lpappast = log of the percentage of area suitable for pasture; lpappoutra = log of the percentage of area unsuitable for farming and pasture.

In general terms, the results shown in table 1 indicate the influence of soil conditions on the performance of the agricultural activity, such as soil erosive potential and agricultural land suitability. Thus, the municipalities that had soils less susceptible to erosion and with the best agricultural land suitability had the higher efficiency scores (for instance, Belford Roxo, Campos dos Goytacazes, Japeri, Mesquita, Niterói, Nova Friburgo, São Francisco de Itabapoana, São João da Barra; see Figure 1).

Although the classes of susceptibility to water erosion only provide an alert of the higher or lower capacity of the soils of being subjected to erosive processes, these results may suggest the deleterious effect of these processes on agricultural productivity. They are considered the primary cause of other problems that lead to lower productivity and to impoverishment in rural areas (Wambua and Kithiia, 2014). Indeed, soil erosion by water, wind, and land preparation is now considered the greatest threat to the health of soils and to their ecosystem services in many regions of the world (FAO, 2019). In agricultural areas, soil erosion reduces its infiltration ability, water availability and drainage, and the rooting depth of plants (Lal, 2017), inducing losses of water, soil, organic matter, fertilizers, and soil nutrients (Dechen *et al.*, 2015). Soil particles displaced from eroded sites may cause sedimentation and pollution of surface waters, blockage of water courses, and damage to infrastructure (Lal, 2017). Such damages may mean financial losses, with a substantial impact on farmers' expenses and net income (Dechen *et al.*, 2015).

The state of Rio de Janeiro has many areas of rugged relief, which favor erosion processes, often associated with soils that are naturally very susceptible to water erosion, such as Cambisols and Argisols, due to their intrinsic attributes (Carvalho Filho *et al.*, 2003). Lumbreras *et al.* (2003), when carrying out the agroecological zoning of the state, found that areas subjected to mechanization (slopes of less than 15%), suitable for agricultural activities, represent about 21% of the total area of the state. Of these, 8% are located in lowlands, exhibiting drainage restriction and flood risk, while the remaining areas are located in highlands, subject to erosive processes. Therefore, the findings that suggest the association between the soil's susceptibility to water erosion and the performance of the agricultural activity in the state of Rio de Janeiro may be either due to the environmental conditions of the state, which favor erosive processes in many areas, or due to the harmful role of erosion in environmental, economic, and agricultural production sustainability.

Regarding the influence on the performance of the factors concerning land suitability, the results mean that municipalities with the best land suitability for crops and for livestock in the state are those that perform best (e.g., Barra do Piraí, Campos dos Goytacazes, Japeri, Niterói, São Francisco de Itabapoana, São José do Vale do Rio Preto, Sumidouro, Teresópolis; see Figure 1).

The effect of susceptibility to erosion and of land suitability on the agricultural performance points out to the need to invest in appropriate technologies for areas that are more susceptible to erosion and less suitable for production, with adjustments to their use, aiming at increasing agricultural efficiency.

Among the socioeconomic nature covariables, only the percentage of rural establishments declared to be family farming was statistically significant. Similar results were obtained in a recent study based on a sample of rural establishments interviewed by the 2017 agricultural census (about 265 thousand observations) and with the adjustment of a stochastic production function. In such study, the authors found negative signs for the coefficients of technical assistance and financing, and the non-significance of the former (Souza *et al.*, 2020).

The positive and significant association between family-base farming and performance can be explained by the diversity and consequent agricultural production performance that can be noticed in places where a large set of this category of farmers is concentrated (Rensburg and Mulugeta, 2016, Mutyasira *et al.*, 2018, Acevedo-Osorio *et al.*, 2020). This is because family farming can promote the best use of space, benefit from intercropping, crop rotation, and integration with livestock, and ensure that the farmer can optimize and stabilize his/her income throughout the year (López Netto *et al.*, 2017, Oliveira *et al.*, 2021, Grisel and Assis, 2020).

The methodological framework here proposed may support actions regarding soil use and management, especially those that contribute to land use planning by focusing on the improvement of agricultural performance. In this sense, it is important to mention that the recommendations derived from the DEA results are applicable only to the set under evaluation, as DEA models compute a relative measure of efficiency and construct an empirical efficiency frontier based on the sample of observations and on the set of variables selected by the experts. The results will potentially change by changing any of these sets and by modifying the underlying assumptions regarding frontier convexity, returns to scale or model orientation. The choice of both the variables to be used to compute the performance or efficiency scores and the covariates is case-specific. Thus, the results presented here may not be extrapolated, while they meet the literature and the experts' expectations.

As any quantitative approach, the models we considered have limitations and pitfalls. DEA modeling have some advantageous features, as the ability to handle multiple inputs and outputs; the efficiency frontier is empirical and not based on a pre-specified functional form; variables can be measured in different scales; the possibility of identifying benchmarks and sources of inefficiency. Some drawbacks are the sensitiveness of the results to the inputs and outputs selected, as well as to the set of DMUs under analysis; the number of efficient units may increase as the number of variables increases; weights/multipliers may not be unique; measurement errors may affect results, the use of statistical hypothesis tests is not straightforward. Regarding the second-stage regression model, the fit can be modified by assuming different distribution functions or by using conditional measures of efficiency. However, we understand that the key point of such approaches is to provide a basis for dialogue between the decision makers to support complex decisions. Although models are used to understand or to cope with reality, they are a simplified version of this reality and should be used with care.

CONCLUSIONS

The proposed two-stage DEA approach was useful to assess the influence of factors related to soils and socioeconomic indicators on the agricultural performance of the municipalities in the state of Rio de Janeiro. The positive influential factors were land suitability and the presence of family farming. High levels of susceptibility to water erosion showed negative influence on the efficiency scores.

The influence of the factors related to susceptibility to erosion and to land suitability on the agricultural performance of the state demonstrates the importance of including these land characteristics for the definition of public policies that seek to promote the sustainable development in rural areas.

The presence of family-based farmers also favors the agricultural performance of the assessed municipalities, showing the relevance of these results to support public policies related to land use and soil governance.

The discussions presented here may be seen as subsidies for the understanding of the performance determinants, in order to potentially promote decision making in the state agricultural sector.

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