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Adapting the land agricultural suitability assessment scheme for drylands edaphoclimatic conditions

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ABSTRACT: The rational exploitation of the land requires planning its agricultural use, which can be supported by the agricultural land suitability (ALS) assessment. The scheme to assess ALS proposed by Food Agricultural Organization (FAO) has been adopted in Brazil based on guiding charts for subtropical, humid tropical and semi-arid tropical climate. However, the guiding chart used for the semi-arid region has dramatically limited the ALS in drylands on which rainfed agriculture has been practiced. In this study, an adequation for the ALS assessment regarding the edaphoclimatic conditions of semi-arid region was proposed to improve the representation of agricultural areas and to allow a better planning of soil conservation practices. The ALS of the south region of Ceará State (Brazil) was assessed according to the FAO scheme and its initial adaptation to the Brazilian conditions; subsequently, this assessment was obtained by two adequations. Adequation I disregarded the limiting factor of water availability, while adequation II, besides disregarding the factor of water availability, established new limits for the classes of effective soil depth. The adequations resulted in an increase of 177.19 % in the areas with regular suitability for crops to the detriment of areas with restricted suitability for crops and areas with suitability only for pasture or grazing lands. The adequations increased the agricultural suitability in 41.26 % of the area of the mapping units, and 16.77 % of them were due to the modifications related to the effective soil depth, while the other 26.35 % were due to the changes related to water availability. The results related to water availability were equivalent to those observed through the dynamic analysis of land-use and cover associated with the rainfall, which demonstrated an increase in the areas for rainfed agriculture and a reduction in fallow and pasture areas in the years with rainfall within the climatic normality. The areas considered suitable for crop production with the adequation of the scheme may be included in soil conservation programs.

Keywords: technical land classification, rock fragments, effective soil depth, water deficit.

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INTRODUCTION

A crucial point in achieving the sustainable development goals proposed by the United Nations is the caution in using natural resources for food production. For this, it is necessary to plan the use of land using the evaluation of agricultural suitability as a tool to increase production, promote ecological conservation and protect biodiversity (Paula and Oscar, 2012; Akpoti et al., 2019; Binte-Mostafiz et al., 2021).

The methods for assessing agricultural land suitability (ALS) derive from schemes proposed by the Soil Conservation Service of the United States Department of Agriculture (Klingebiel and Montgomery, 1961) and by the Food Agricultural Organization (FAO, 1976). The scheme proposed by FAO assumes water availability as a limiting factor and has been considered a good method because it is simple, objective, and for allowing the automation of the procedure and incorporation of geographic information system (GIS) tools, remote sensing and machine learning, hence being among the modern methods for assessing ALS (FAO, 2007; Mendas and Delali, 2012; Akpoti et al., 2019; Taghizadeh-Mehrjardi et al., 2020).

In Brazil, an adaptation of the FAO scheme regarding guiding charts for regions of subtropical, humid tropical, and semi-arid tropical climate is used (FAO, 1976; Ramalho Filho and Beek, 1995; Wadt, 2013). However, the guiding chart for the semi-arid climate results in severe limitations of land-use, marginalizing areas that in practice are being used for rainfed agriculture. Thus, knowledge of pre-existing agricultural use should be considered to indicate ALS in a given region (Liu et al., 2008; Yi and Wang, 2013; Worqlul et al., 2017).

Climatic factors that most limit ALS assessment by the methods currently adopted in drylands are rainfall and temperature. Instead of rainfall, some studies have considered the extent of the rainy season and how rainfall compromises some phenological stages of specific crops (Akpoti et al., 2019; Taghizadeh-Mehrjardi et al., 2020). This may be a good strategy to avoid underestimating areas that have the potential for agricultural use in regions such as the Brazilian semi-arid region, where rainfall ranges from 513 to 1,299 mm yr^{-1}, values considered high when compared to other drylands (Sathler, 2021).

Another limiting edaphic factor in drylands is the effective soil depth, due to its influence on root growth, agricultural mechanization practices, and its magnitude in erosion processes (Akpoti et al., 2019). In addition, it is necessary to consider that the effective depth also influences water accumulation in the root growth zone (Bandyopadhyay et al., 2009).

Regarding soil classes found in the Brazilian semi-arid region, such as *Argissolos*, *Luvissolos*, and *Planossolos* (Santos et al., 2018), corresponding to Acrisols, Luvisols, and Planosols (WRB/FAO) respectively, 10.5 % of them have a shallow subsurface B horizon with higher clay content in comparison with the surface one. It helps to store water in the soil during dry days that can occur in the rainy season, improving the conditions for plant development (Cunha et al., 2010).

In the Brazilian semi-arid region, in the rainy season, with low use of mechanization, in the soil strips with greater effective depth and with higher water retention due to the presence of a more clayey subsurface horizon, farmers have cultivated land considered unsuitable by the adaptation of the scheme proposed by FAO. Production in these areas can intensify land degradation processes because when considered unsuitable by the technical classification system, they are not included in the use planning for adopting appropriate conservation practices.

The hypothesis raised is that adequate water availability and effective soil depth as limiting factors will increase the areas classified as suitable for agriculture in a semi-arid region, improving the representation in accordance with land-use and cover observed by satellite images and agricultural production of the region. In view of the above, this study aimed to propose an adaptation for the ALS scheme to the edaphoclimatic conditions of the semi-arid region.

MATERIALS AND METHODS

Characterization of the studied area

The study was carried out in the South Mesoregion of the Ceará State (Brazil), which is composed of 25 municipalities and occupies approximately 14,892.13 km^2 (IBGE, 2016), corresponding to 1.54 % of the total area of the Brazilian semi-arid region (Figure 1). According to the climatic classification system of Köppen-Geiger, the predominant climate of the region is BShw', defined as Hot Semi-Arid Tropical, characterized by the irregularity of rainfall, water deficit and high evaporation. Rainfall in the South Mesoregion of Ceará varies from 600 to 1,127 mm yr^{-1} (Funceme, 2012).

The geology is marked by the predominance of the rocky basement belonging to the crystalline domain. However, there is also the occurrence of sedimentary formations from the Mesozoic in the South and alluvial deposits from the Holocene in the valleys. The relief is characterized by four geomorphological units: Plateau, Fluvial Plains, Sertaneja Depression and Crystalline Residual Massifs (Funceme, 2012). The climatic conditions associated with the geomorphological aspects result in the predominance of intermittent water courses and in the occurrence of various soil classes, particularly *Argissolos* (Acrisols), *Latossolos* (Ferralsols) and *Neossolos Litólicos* (Leptosols), which represent approximately 79 % of the total area of the mesoregion (Funceme, 2012).

Agricultural land suitability (ALS) assessment

ALS was simultaneously determined using the FAO scheme initially adapted for the Brazilian conditions (Ramalho Filho and Beek, 1995), and through the methods I and II (Figure 2), both adapted from the initial one. In this study, regardless of the method used

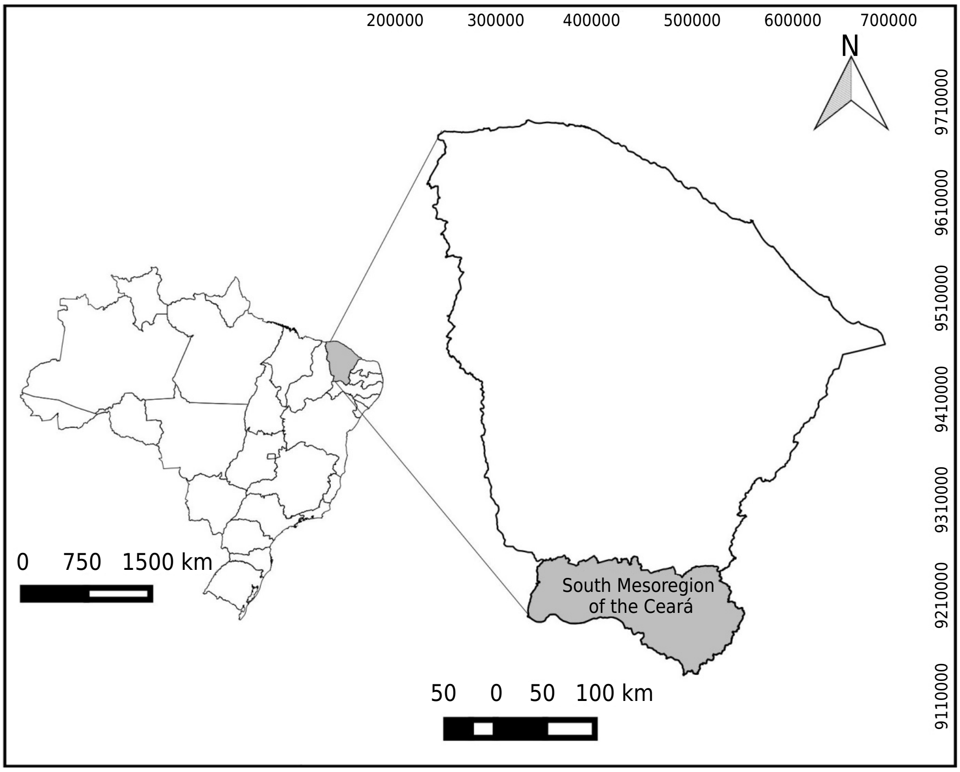

Figure 1. South Mesoregion of the Ceará.

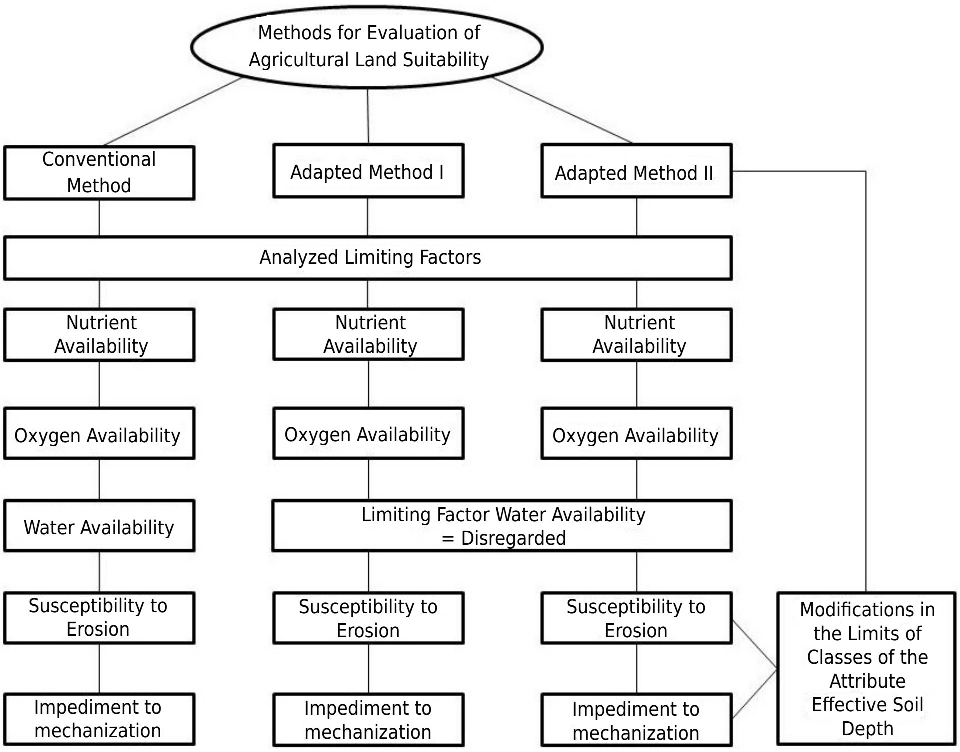

Figure 2. Methods flow chart adopted for evaluating the agricultural aptitude of the lands in the South Mesoregion of the Ceará, in Brazil.

to determine the agricultural suitability of the lands, only the technological management levels B and C were considered for the crops.

Five limiting biophysical factors were considered: nutrient availability (N), water availability (W), oxygen availability (O), impediment to mechanization (M), and susceptibility to erosion (SE). For the estimation of these limiting factors and consequent determination of agricultural suitability of the lands, the technical report of Funceme (2012) was consulted to obtain the analytical data (physical, chemical and mineralogical) and morphological data of 93 soil profiles representative of the mapping units (MUs) that compose the Survey of Medium Intensity Recognition of the Soils of the South Mesoregion of the Ceará State on the scale 1:100,000 (Figure 3).

Due to the mapping scale, the MUs usually comprise associations of soils formed by two or more representative soil classes (IBGE, 2007). These classes may have different physical, chemical and mineralogical properties and, consequently, different agricultural suitability. For this reason, three rules were established to symbolize the agricultural suitability of these MUs, namely:

1. Simple MU: the symbol corresponded to the respective suitability, as exemplified in the mapping unit LA1 (Table 1);

2. Composite MU with soil classes of similar suitabilities: the symbol corresponded to classes whose summed areas represented at least 70 % of the total MU area, as exemplified in the units PVA1 and LA3 (Table 1);

3. Composite MU not included in rule No. 2: the composite symbol was used as in PV12 (Table 1).

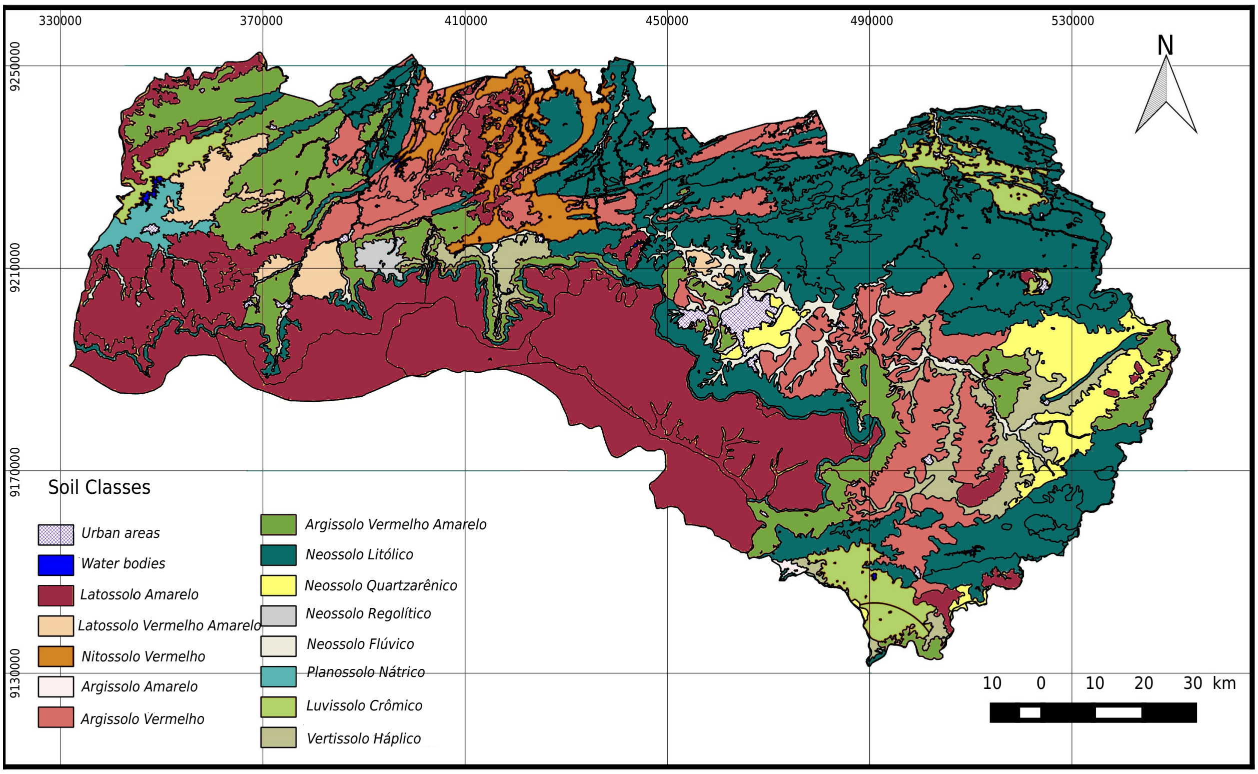

Figure 3. Mapping units of the Soils of the South Mesoregion of the Ceará. *Latossolo Amarelo* (Ferralsols), *Latossolo Vermelho Amarelo* (Ferralsols), *Nitossolo Vermelho* (Nitisols), *Argissolo Amarelo* (Acrisols), *Argissolo Vermelho* (Acrisols), *Neossolo Litólico* (Leptosols), Neossolo *Quaertzarênico* (Leptosols), *Neossolo Regolítico* (Leptosols), *Neossolo Flúvico* (Leptosols), Neossolo Flúvico (Leptosols), *Planossolo Nátrico* (Solonetz), *Luvissolo Crômico* (Luvisols Chromic), *Vertissolo Háplico* (Vertisols).

Table 1. Soil physicochemical characterization and land suitability before the adequation

Mapping unit	Soil classes of the mapping unit	Suitability	Legend
LA1	LA *Distrófico típico* (100 %)	2bc	2bc
PVA1	PVA *Distrofico típico* (40 %) + LVA *Distrofico típico* (30 %) + LA *Distrófico típico* (30 %)	2bc/3(bc)/2bc	2bc
LA3	LA *Distófico típico* (60 %) + LA *Distrofico plíntico* (40 %)	2bc/2bc	2bc
PV12	PV *Distrófico latossólico* (50 %) + RL *Eutrófico fragmentário* (25 %) + NV *Eutrófico típico* (25 %)	4P/6/5n	4P/6/5n

Classification according to the and Brazilian Soil Classification System (SIBCS) and World Reference Base for Soil Resources/Food and Agriculture Organization (WRB/FAO) in parentheses: LA: *Latossolo Amarelo* (Ferralsols); PVA: *Argissolo Vermelho Amarelo* (Acrisols); RL: *Neossolo Litólico* (Leptosols); NV: *Nitossolo Vermelho* (Nitisols); 2bc: lands with regular aptitude at the technological management levels B and C; 3(bc): lands with restricted aptitude at the technological management levels B and C; 4P: lands with good aptitude for planted pasture; 5n: lands with regular aptitude for natural pasture; and 6: lands unsuitable for agricultural use.

Initial method adapted from FAO scheme

The classification was made according to the scheme of the FAO/Brazilian system (Ramalho Filho and Beek, 1995) described in Wadt (2013), in which the suitability is determined through a comparative study between the degrees of limitation observed in the properties of the soils and environment (N, W, O, M and SE) and the degrees of limitation attributed in a guiding chart to the semi-arid climate (Table 2). The degrees of limitation, or degrees of deviation (Δ), are higher than or equal to zero and expressed in increasing order, according to the severity of the limitation, as follows: 0 – Null; 1 – Light; 2 – Medium; 3 – Strong and 4 – Very strong.

Table 2. Guiding chart for the semi-arid region

Agricultural aptitude			Degrees of limitation of agricultural conditions of the lands for the management levels A, B and C															Recommended utilization
Group	Subgroup	Class	Fertility deficiency			Water deficiency			Water excess			Susceptibility to erosion			Impediment to mechanization			
			A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	
1	1BC	High		0a	0a		1/2	1/2		1a	0/1a		0/1a	0a		1/2	0	Crops
2	2bc	Moderate		1a	1b		2	2		1/2a	1b		1a	0/1b		2	1	
3	3(bc)	Marginal		1/2a	1/2b		2/3	2/3		2a	2b		2a	1/2b		2/3	2	
4	4P	High		2a			2			3			2/3a			2		Planted pasture
	4p	Moderate		2/3a			2/3			2/3			3a			2/3		
	4(p)	Marginal		3a			3			2/3			3/4			3		
5	5S	High		2/3a			2			1a			3a			2/3		Silviculture
	5s	Moderate		3a			2/3			1a			3a			3		
	5(s)	Marginal		4			3			1/2a			3/4			3		
	5N	High	2/3			3			3			3			3			Natural Pasture
	5n	Moderate	3			3/4			3/4			3			4			
	5(n)	Marginal	4			4			4			3			4			
6	6	Not suitable																Flora and fauna preservation

Source: Adapted from Ramalho Filho and Beek (1995). 0: Null; 1: Light; 2: Medium; 3: Strong; and 4: Very strong. a:improvement viable with simple practices and low use of capital; b:improvement viable with intensive, more sophisticated practices and considerable capital investment, but economically rewarding. 1BC: lands with good suitability for crops at management levels B and C; 2bc: lands with regular suitability for crops at management levels B and C; 3(bc): lands with restricted suitability for crops at the management levels B and C; 4P, 4p and 4(p): lands with good, regular and restricted suitability for planted pasture, respectively; 5S, 5s and 5(s): lands with good, regular and restricted suitability for silviculture, respectively; 5N, 5n, 5(n): lands with good, regular and restricted suitability for natural pasture, respectively.

The analysis of the water availability limitation was made using rainfall data from historical series (1974 to 2015) of 25 observation posts of Funceme (2016) distributed over the studied area. The deviation degree of water as a limiting factor was determined according to the occurrence of rainfall. Zones with mean annual rainfall below 700 mm received strong degree of limitation (3). The medium degree of limitation (2) was attributed to regions with mean rainfall above 850 mm, while areas with historical rainfall between 700 and 850 mm received an intermediate degree of limitation (2/3), between medium and strong (Ramalho Filho and Beek, 1995; Resende et al., 2007).

Adapted methods

In the adapted method I, the limiting factor of water availability was disregarded, but the others were analyzed as in the initial method, including the number of analyzed soil profiles. In the adapted method II, besides disregarding the limiting factor of water availability, new limits were incorporated into the classes of effective soil depth (Table 3), considering the depths commonly found in the soils of the region. The effective soil depth, besides directly influencing the factors impediment to mechanization and susceptibility to erosion, also influences the limiting factors of water and oxygen availability in the soil. However, the present study established modifications related only to the limiting factors of susceptibility to erosion and restriction to agricultural mechanization. The modifications aiming to attenuate the restrictions imposed by the edaphic conditions of the semi-arid region changed the determination of the limiting factors' susceptibility to erosion and impediment to mechanization (Table 3).

Table 3. Factors and criteria adopted to estimate the agricultural aptitude by the different methods tested

Criteria	Conventional					Adaptation I					Adaptation II				
	Degree of limitation					Degree of limitation					Degree of limitation				
	Null	Light	Medium	Strong	Very strong	Null	Light	Medium	Strong	Very strong	Null	Light	Medium	Strong	Very strong
Chemical soil fertility															
SB (cmol$_c$ kg^{-1})	>6	3-6	<3	-	-	No modifications					No modifications				
EC (dS m^{-1})	-	<4	4-8	8-15	>15										
ESP (%)	-	<6	6-15	>15	-										
Water availability															
Rainfall	>1000	>1000	700-1000	500-700	<500	Disregarded					Disregarded				
Dry season	0-2	3-5	4-6	7-9	>9										
Availability of oxygen															
Drainage	Good	Moderate	Imperfect	Poor	Very Poor	No modifications					No modifications				
Erosion risk															
Slope (%)	0-3	3-8	8-13	13-20	>20	No modifications					No modifications				
Soil depth (m)	>1.50	1.00-1.50	0.50-1.00	0.25-0.50	<0.25						>100	60-100	40-60	20-40	<20
Impediments to mechanization															
Slope (%)	0-3	3-8	8-20	20-45	>45	No modifications					No modifications				
Soil depth (m)	>1.50	1.00-1.50	0.50-1.00	0.25-00.50	<0.25						>100	60-100	40-60	20-40	<20
Coarse fragments (%)	0.0	0.1-15	15-50	50-75	>75						No modifications				

The other limiting factors comprising the initial method were not altered (Figure 2). Lastly, a comparison was made between the products obtained by the different methods (Initially adapted, Adapted I and Adapted II), to measure, in percentage terms, how much the modifications increased the ALS of the semi-arid lands.

Assessment of land-use, land cover, and agricultural production

The survey on land-use and cover in the studied area was performed through the supervised classification of satellite images, using the Gaussian Maximum Likelihood (Maxver) algorithm with a threshold equal to 5 %. The procedure used images from the TM/Landsat 5 and OLI/Landsat 8 sensors corresponding to the orbits/points 216/065 and 217/065. A time series contemplating the years 2007, 2009, 2011, 2013 and 2015 represented the evolution of the different land-uses and covers over time. The following classes of land-use and cover were defined: dense forest, sparse forest, rainfed agriculture and fallow areas.

Data on the agricultural production of the studied region were obtained from the Brazilian Institute of Geography and Statistics (IBGE, 2016). The data on planted area, harvested area and yield of the main temporary crops cultivated in the region between the years corresponding to the time series (from 2007 to 2015) were used for comparison between the behavior of the production and yield of these crops as a function of the annual rainfall.

RESULTS

The soils of the studied region do not have good suitability for the most intensive use for crops, regardless of the adopted method and technological management level (Table 4). The influence of the limiting factor of water availability was observed in the initial method. With the removal of the limiting factor water (adapted method I), there was an increment of 177.19 % in the areas with regular suitability for crops (identified as 2bc) compared to the method adapted initially (Table 4). This increment occurred to the detriment of the areas with restricted suitability for crops - identified as 3(bc), and restricted for planted pasture – identified as 4(p), which showed reductions of 72.73 and 26.01 %, respectively.

In the spatial distribution of the suitability classes for the same tested method and variability of the classifications between methods, agricultural suitability increased in the Southwest portion of the studied region (Figures 4a and 4b). For this region, lands previously classified by the initial method with restricted suitability for crops or restricted suitability for pasture, showed regular suitability for crops when classified by the adapted method I.

Agricultural suitability increased between the Central and Northwest portions of the studied region (Figures 4b and 4c). Thus, lands previously classified with suitability only for pasture or grazing by the adapted method I, changed to regular or restricted suitability for crops when classified by the adapted method II. When agricultural suitability was evaluated through the adapted method II, which, besides disregarding the limiting factor water, established new limits of effective soil depth, there was an increment of the areas from the 2b(c) suitability subgroup, areas with restricted suitability for crops – 3(bc) - and areas with good suitability for planted pasture – 4P – to the detriment of areas with regular and restricted suitability for pasture - 4p and 4(p), respectively - and of the areas with regular suitability for grazing lands (5n).

The evaluation through the adapted method I resulted in an increase in the agricultural suitability of 26.35 % of the areas of the MUs previously limited by the factor of water availability. The evaluation through the adapted method II resulted in an increase of 16.77 % in the area of the MUs previously limited by the attributes stoniness and effective soil depth.

Table 4. Classes of agricultural suitability of the lands and respective percentages of the area obtained by the different methods

Group	Subgroup	Suitability Conventional	Suitability Adapted I	Suitability Adapted II
		%		
1	1BC	0.00	0.00	0.00
2	2bc	11.40	31.60	31.60
	2b(c)	5.20	6.30	7.50
3	3(bc)	23.10	6.30	8.30
4	4P	0.60	0.60	2.80
	4p	2.10	2.10	0.00
	4(p)	17.30	12.80	11.10
5	5n	7.00	7.00	6.40
6	6	33.30	33.30	32.30

1BC: lands with a good suitability for crops at management levels B and C; 2bc: lands with a regular suitability for crops at management levels B and C; 2b(c): lands with a regular suitability for crops at the management level B and restricted at the management level C; 3(bc): lands with a restricted suitability for crops at the management levels B and C; 4P: lands with a good suitability for planted pasture; 4p: lands with a regular suitability for planted pasture; 4(p): lands with a restricted suitability for planted pasture; and 5n: lands with a regular suitability for natural pasture.

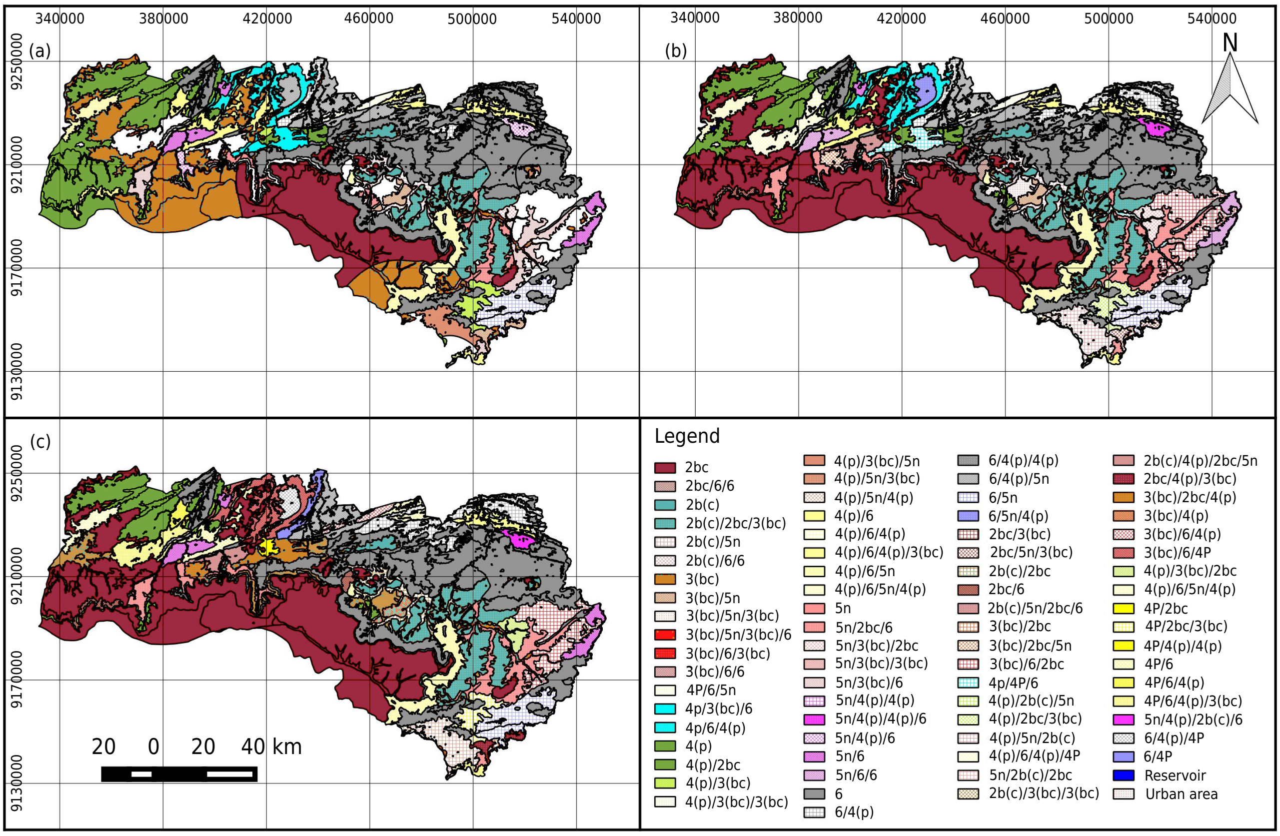

Figure 4. Agricultural suitability maps of the lands by Methods conventional (a); Adapted I (b) and Adapted II (c).

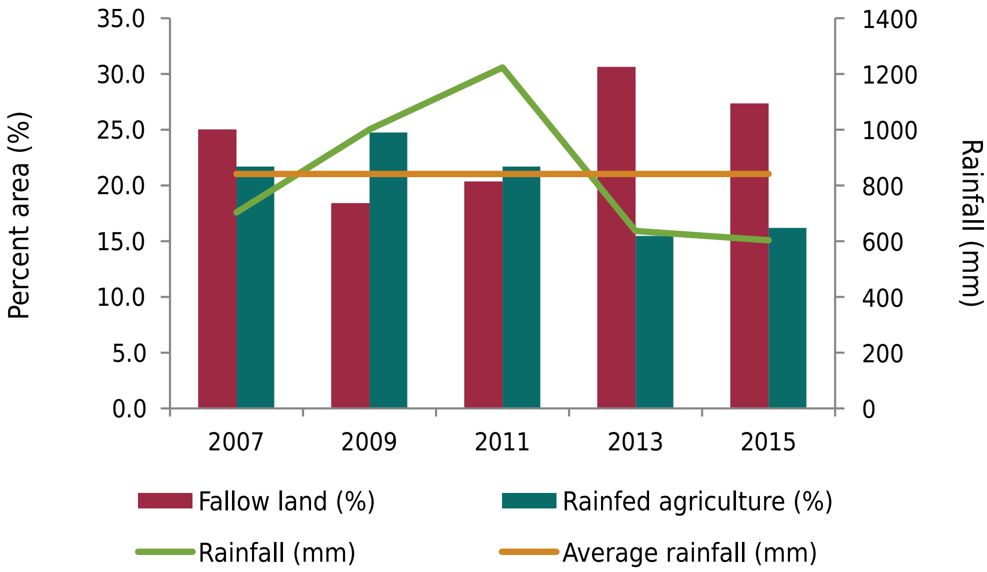

Figure 5. Temporal variation of rainfall as a function of land-use and occupation.

For the land-use as a function of the rainfall observed in the satellite images, the exploitation of the areas with agricultural crops under rainfed conditions increased in the years that the rainfall occurred within the climatic normality (Figure 5).

Data on agricultural production of the studied region, referring to the yield of the main temporary crops cultivated between the years 2007 and 2015 (IBGE, 2016), indicate that the factor water availability ceased to be limiting in the years in which the annual rainfall reached or exceeded the historical mean of the region (Figure 6).

In general, the *Latossolos* (Ferralsols) showed regular suitability for crops – 2bc -, and the main limiting factor is the natural fertility of the soils in this class. However, there were exceptions in patches of soils located in the Southwestern portion of the mesoregion when evaluated through the initial method (Figure 4a), whose water deficit became the main limiting factor.

Argissolos (Acrisols) prevailed in the mapping units that exhibited an increase in agricultural suitability when evaluated through the adapted method II. There was a change in the classification of the lands in mapping units associated with the *Luvisssolos Crômicos* (Luvisols) and *Planossolos Nátricos* (Solonetz). However, not all mapping units constituted by *Argissolos*, *Luvissolos Crômicos* or *Planossolos Nátricos* showed a change in the suitability due to the application of the adapted method II. Such increase in agricultural suitability was limited to soils with an effective depth greater than 0.60 m, maximum stoniness of 15 % and terrain slope not higher than 13 % (moderately undulating relief).

In some MUs constituted by *Argissolos* (Acrisols) under conditions of more rugged relief (slope higher than 13 %), the agricultural suitability increased when classified by the adapted method II. In the case of MUs in which the predominant soil class was *Neossolos Litólicos* (Leptosols), the changes made in the method did not alter the ALS.

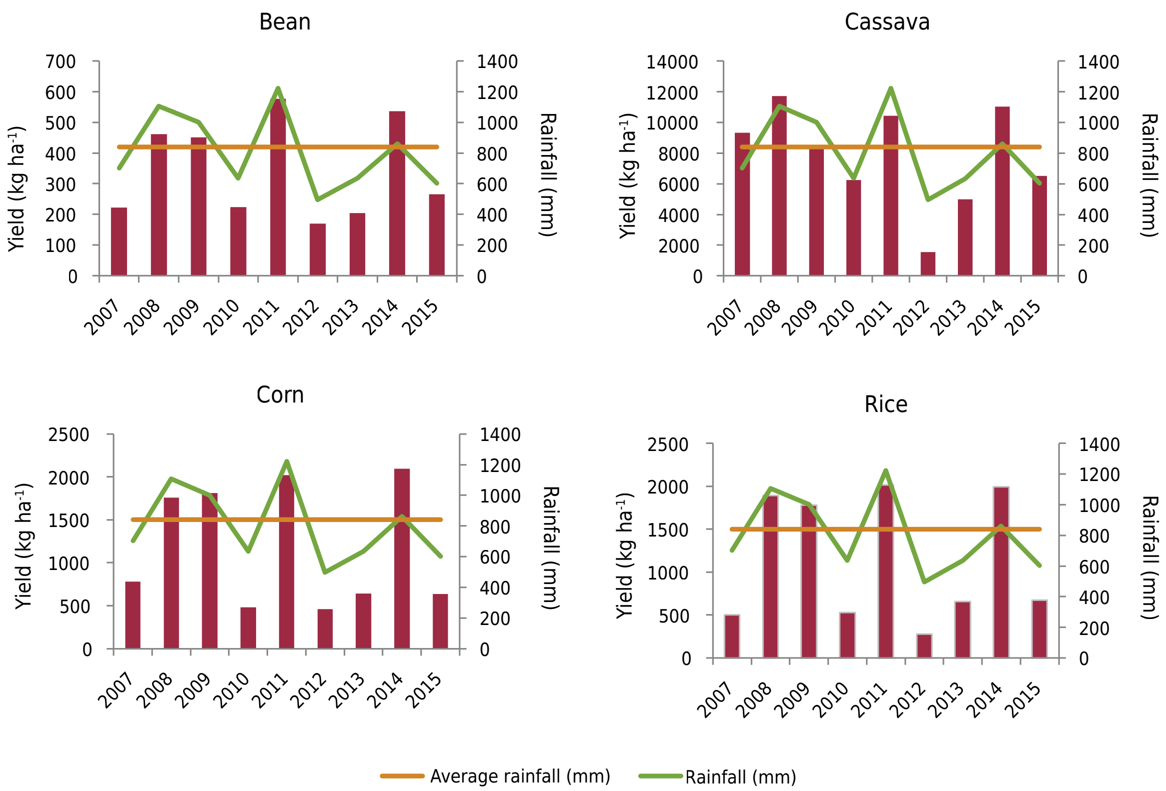

Figure 6. Temporal variation of crops cultivated as a function of rainfall.

DISCUSSION

The absence of good suitability for crops in semi-arid regions has also been observed by other authors using the ALS (Araújo et al., 2013) and FAO Framework for Land Evaluation (Jafarzadeh and Abbasi, 2006; Bagherzadeh and Daneshvar, 2014). Boix and Zinck (2008) attributed to water deficit and risk of extreme climatic conditions the absence of lands with good suitability for crops in some semi-arid regions of the Chaco Plain in Argentina. However, in the present study, the lack of good suitability for crops occurred even when water was excluded as a limiting parameter, which means that the soils of the evaluated semi-arid region have other limitations to land-use.

The adapted method II promoted the expansion of the agricultural suitability of the lands for the Ultisols in the studied region. Such improvement is consistent, mostly because it shows fewer limitations regarding their physical properties but will have chemical limitations inherent to the more weathered soils; besides constraints imposed by the climatic condition of the semi-arid region (Figure 3), the same behavior was observed for *Latossolos* (Ferralsols). This increase was only possible because the soils of these MUs showed effective depth greater than 1.00 m and an absence of stoniness. These results highlight the importance of modifications in the limits of the effective soil depth classes to increase the agricultural suitability of lands in the Brazilian semi-arid region and the importance of using the proper evaluation method.

The increase in agricultural exploitation of areas in the years with greater intensity of rainfall supports the proposal of disregarding the limiting factor of water availability for evaluating the agricultural suitability of the lands in the semi-arid region. It is understandable that this limiting factor has been adopted because water deficit has been considered the main limitation to the yield of agricultural crops in the semi-arid region (Kosgei et al., 2007; Rockström et al., 2007). However, there are strategies of soil moisture conservation that benefit crop yield in these environments (Austin et al., 1998).

The adoption of conservation cropping systems improved, in the long run, the conservation of water in the soil and resulted in increase of yield in semi-arid agrosystems of the Mediterranean (Morell et al., 2011). In addition, the importance of strategies of coexistence with the semi-arid region has been highlighted, so the cultivation under rainfed conditions in the semi-arid region needs to be associated with practices that increase moisture contents in the soil profile and reduce the effects of climate irregularity (Brito et al., 2012).

Adopting management practices that result in greater water availability to the root system can improve food safety in semi-arid environments (Araya and Stroosnijder, 2010). Furthermore, maintaining water in the soil is an important element for adapting annual crops to water deficit (Gao and Lynch, 2016). Hence, conservation practices such as soil cover (Ampofo, 2006; Souza et al., 2011; Shen et al., 2012), contour cultivation associated with rock barriers (Santos et al., 2010), and no-tillage farming (Verhulst et al., 2011) aim at the efficient use of water without compromising crop yield (Bodner et al., 2015).

The survey on land-use and cover, presented in figure 5, confirmed the wide exploitation of the semi-arid region by agricultural activities under the rainfed regime, despite the natural limitations of some predominant soil classes and the limitations imposed by the water availability to the rainfed agriculture practiced in this semi-arid region.

Data on agricultural production in 2007 and 2015 corroborate the idea that the edaphic limitations of some soil classes predominant in the Brazilian semi-arid region are not impediments to their agricultural exploitation and do not compromise the yield of the exploited agricultural crops. In the years in which the rainfall showed a positive deviation relative to the historical mean of the region, there was a significant increase in the yield of these crops, even those cultivated for subsistence with low investment in external inputs (Moura et al., 2016).

Neossolos Litólicos (Leptosols) had no change in agricultural suitability even with the changes made in the ALS. This fact can be explained by the shallow depth of these soils, limited to 0.50 m (Santos et al., 2013), and by the presence of stoniness and rockiness, besides the conditions of rugged relief where *Neossolos Litólicos* (Leptosols) usually prevail (Ozsoy and Aksoy, 2011).

Our results demonstrate that the modifications made in the ALS allowed the inclusion of lands previously marginalized by the current classification system, without necessarily favoring the degradation process of these areas, since this inclusion was only possible for certain soil classes that had effective depth greater than 0.60 m, maximum stoniness of 15 % and, generally, terrain slope not higher than 13 %. Terrains with a slope of less than 13 % do not have major problems when cultivated using conservation practices, such as: minimum tillage, contour farming, rock barriers, mulching, green fertilization, among others (Ramalho Filho and Beek, 1995).

Additionally, the adoption of the conservation practices mentioned in the previous paragraph reduces runoff and soil losses through erosion (Jórdan et al., 2010; Montenegro et al., 2013), improves soil physical quality (Mulamba and Lal, 2008), increases water availability in the soil (Bescansa et al., 2006; Santos et al., 2010; Verhulst et al., 2011) and improve the efficiency in the use of rainwater, resulting in yield gains in years with rainfall below the average (Araya and Stroosnijder, 2010).

CONCLUSIONS

Modifications established in the agricultural land suitability (ALS) related to the limiting factor water availability confirm that water deficit is the main limitation for the agricultural suitability of the lands in the studied region. The modifications in the ALS regarding the attribute effective soil depth increased agricultural suitability of the lands, especially in the class of *Argissolos* (Acrisols), thus confirming the established hypotheses.

The increase in the agricultural suitability of mapping units previously limited mainly by the attribute effective soil depth does not mean, necessarily, increase in the risks of degradation, because soils that are shallow and generally occur in areas of rugged relief (e.g., *Neossolos Litólicos*/Leptosols) remained unsuitable for agricultural use.

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