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Research Article

Applicability of the 'Recommendations for Sustainable Land Use' method for Brazilian tropical soils

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Abstract

The current demand for the preservation of natural resources and biodiversity has led to the need to adjust agricultural activities according to land-use capability. One method, the 'Recommendations for Sustainable Land Use', aims to overcome the limitations of the diverse systems currently available for evaluating agricultural land capability. The aim of this work was to critically analyze the application of this method for tropical soils (Plinthosols and Planosols). The evaluation occurred in two phases: the first with application of the method, and the second analyzing whether the land-use recommendations were appropriate for the edaphic and landscape characteristics. We found that corrections to the methodology are needed to facilitate comprehension by the user. The suitability of classes of Plinthosols and Planosols should be adjusted with the incorporation of indicators associated with the presence of plinthite, and the improvement of indicators related to salinity and sodicity. With these adjustments, the 'Recommendations for Sustainable Land Use' method will be an important tool for the conservation of environmental resources such as soil and water.

Keywords: land use capability, Planosols, Plinthosols.

Resumo

A exigência atual de preservar os recursos naturais e a biodiversidade leva à necessidade de adequar as atividades agrícolas à capacidade de uso do solo. O método de "Recomendação de Uso Sustentável das Terras" tem o objetivo de superar as limitações dos diversos sistemas de avaliação de capacidade de terras agrícolas. O objetivo desse trabalho foi testar e analisar criticamente esse método para solos tropicais (Plintossolos e Planossolos). A avaliação se deu em duas fases: a primeira com a aplicação do método, e a segunda analisando se a recomendações de uso do solo foram adequadas às características edáficas e de paisagem. São necessárias correções na metodologia para facilitar o entendimento do usuário. Deve-se adequar a classe de aptidão dos Plintossolos e Planossolos, mediante a incorporação de indicadores relacionados à presença de plintita e melhoria dos indicadores relacionados à salinidade e sodicidade, respectivamente. Com estes ajustes, o método de "Recomendação de Uso Sustentável das Terras" será uma ferramenta importante para a conservação dos recursos ambientais, tais como, o solo e a água.

Palavras-chave: capacidade de uso da terra, lanossolos, Plintossolos.

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Introduction

In the conservation of biodiversity and other natural resources, a frequently used approach is the reservation of areas of land for either non-use or low–impact uses, such as ecotourism [1] and extractivism [2]. However, Baudron and Giller [3] demonstrated that isolated protected areas correspond to only 5.1% of the earth's surface, leaving countless species outside those sites without protection, and the majority of the terrestrial biodiversity located within anthropogenic systems. Therefore, it is necessary to develop conservation strategies for these areas managed by people.

The most common use of land is for agriculture, which is of extreme importance for food security, but occupies large areas and has a high environmental impact. Pagiola et al. [4] stated that farms may provide several environmental or ecological services, such as regulation of the hydrologic cycle, conservation of biodiversity, and carbon sequestration.

Policies that promote the compensation of farmers for these services are important for integrating the goals of agricultural production, natural resource conservation, and poverty reduction [4, 2]. In countries such as the United States and the United Kingdom, compensation is given to farmers in exchange for their adopting lower impact activities [5].

In this regard, determining the land-use capability or the agricultural suitability of a particular area is a key factor, because soil use and management have a direct effect on water quality and biodiversity. Many systems, using a variety of methods to group soils according to their resistance or vulnerability to degradation caused by a specific agricultural activity over time, are used for the classification of land-use capacity [6].

Similar to taxonomic systems of classification, the agricultural suitability of soils is determined according to specific criteria that vary from country to country. In the USA, the use of classification methods for land-use capability began around 1940 [7]. In Scotland, England, and Wales, a standardized system for agricultural land-use classification, derived from pedological surveys, was published in 1969. In 1978, Scotland started to use its own classification system [6].

In Brazil, the most used method is the "System for the Evaluation of Land Agricultural Capability", which was elaborated in 1978 and adjusted in 1995 [8, 9]. The state of São Paulo has adopted its own distinct methodology [10]. The application of any of these methods is a complex, difficult, and prolonged task, involving interdisciplinary knowledge and a vast amount of data [11]. These characteristics lead to two main difficulties. First, many countries require urgent conservation practices, but do not have detailed soil surveys, and second, the system of interpretation used may be very subjective. Great divergence in land-use classification groups has been observed by different specialists for the same soil profiles [12, 13].

Aiming to overcome these difficulties, Wadt [7] proposed the 'Recommendation for Sustainable Land Use' method, adapted from Ramalho Filho and Beek [9]. This method does not require full pedological assessments and increases objectivity in the interpretation of edaphic and environmental data. In addition, it can be used with data acquired in the cultivation sites.

As the 'Recommendation for Sustainable Land Use' methodology proposed by Wadt [7] has not yet been widely tested, the objective of this study was to critically analyze it, using profiles of Plinthosols and Planosols to validate it.

Methods

Four soil profiles were selected from the Soils Exploratory-Recognition Survey (Levantamento Exploratório-Reconhecimento de Solos) of the state of Maranhão, Brazilian Eastern Amazon [14] (Fig. 1). The selection criterion was depth less than 100 cm. Therefore, the profiles included two Plinthosols, one Planosol, and one previously classified as Solonetz-Solodizado, which actually corresponds to the Planosols order in the Brazilian System of Soil Classification [15]. These soil classifications correspond to the Plinthosols and Planosols classes in the international classification system [16].

The identifications of the profiles according to the field survey and Brazilian classification were as follows: *PLINTOSSOLO CONCRECIONÁRIO Álico* - A moderate, medium-textured to very-gravelly/clayey, sub-perennial, dicotiledonea-palmae forest (with babaçu) phase, slightly undulated relief (Plinthosol 1); *PLINTOSSOLO CONCRECIONÁRIO Álico* - A moderate, medium-textured to very gravelly/clayey, sub-deciduous savanna (cerrado)/deciduous forest phase, slightly undulated relief (Plinthosol 2); *PLANOSSOLO Ta EUTRÓFICO não solódico vértico - A* moderate, medium-textured/clayey, deciduous forest/savanna (Cerrado)/Caatinga phase, plane relief (Planosol 1); SOLONETZ-

SOLODIZADO Tb - A moderate, medium-textured/clayey, riparian forest of carnaúba phase plane relief (Planosol 2).

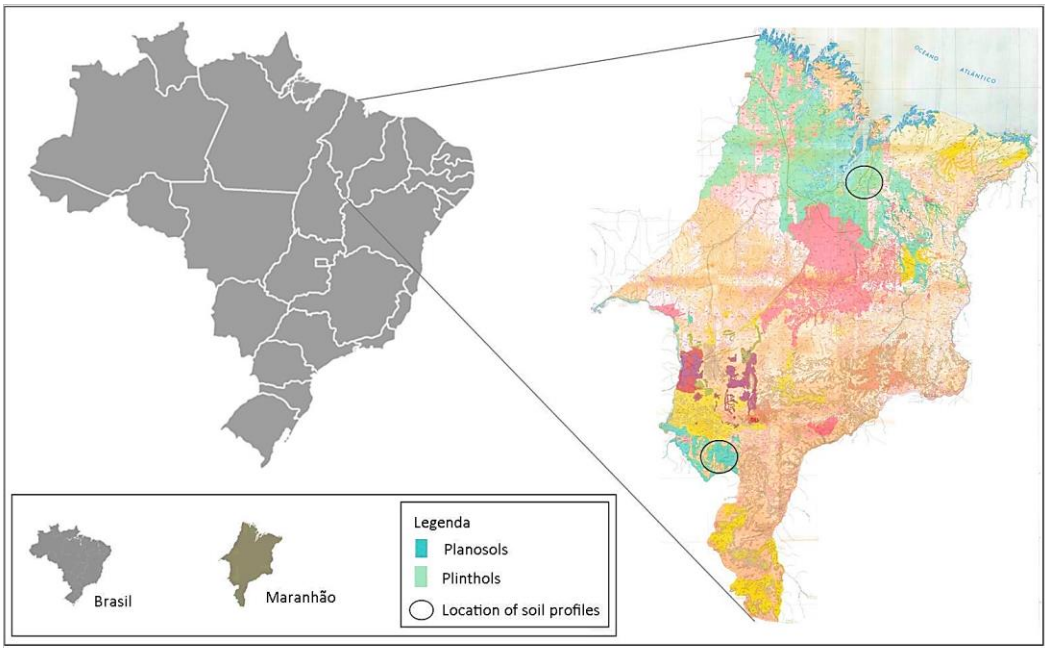

Fig 1. Location of the study areas.

The methodology of 'Recommendations for Sustainable Land Use' is part of a proposal called, "*Payments for Farm Environmental Services*" [7], created to promote environmental policies based on compensation to farmers who reach specific levels of sustainability in their production areas. The method takes into account the environmental, socio-economic, and cultural dimensions of the farm. However, it is possible to use only the first dimension of the methodology, which focuses on soil and landscape indicators.

The soil and landscape indicators included effective soil depth; soil texture class; sodium adsorption ratio; electrical conductivity; clay activity; cation exchange capacity; sum of basic cations; remaining phosphorus; percent of base saturation; soil aluminum saturation; soil carbon; available soil water (Appendix 1); annual water inputs; dry season; slope; erodibility; degree of soil oxygenation; and mechanization constraints (Table 1). The remaining phosphorus content, which was absent in the original soil survey data, was presumed to use a value of P < 5 mg kg^{-1}, for a soil class texture with more than 35% clay.

To address the three soil layers (0–25, 26–60, and 60–100) proposed by Wadt [7], the weighted average of the indicators was used from the pedological description data [14]. Based on the tables [7], which were used as identification keys, decisions were made regarding the quality of land-use classes for each limiting factor: fertility deficiency, water deficiency, oxygen deficiency, susceptibility to erosion, and constraints to mechanization (Appendix 2).

Table 1. Landscape indicators for the recommendation for sustainable land use of Plinthosols and Planosols

Soil profile	AWI mm year^{-1}	DS month year^{-1}	SLP %	EDL t h MJ^{-1} mm^{-1}	SOx	MC
Plinthosol 1	1600-1800	4	3 a 4	0,45	3	0
Plinthosol 2	1200	5	4 a 5	0,44	3	0
Planosol 1	1200	5	0-3	0,41	3	0
Planosol 2	1600-1800	4	0-3	0,44	3	0

AWI: annual water inputs; DS: dry season; SLP: slope; EDL: erodibility; SOx: degree of soil oxygenation; MC: mechanization constraints. Adapted from Jacomine et al. [14].

Quality classes are defined as follows: capital letters indicate good quality; lowercase letters, moderate quality; lowercase letters within parenthesis, restricted; and the word *inapt*, unsuitable. The quality class is provided in the tables [7] from left to right, according to the type of land-use (intensity group): annual crops, perennial crops, agroforestry systems, pastures, planted forest, and native forest. Thus, letters go from a-f following the format mentioned above (Appendix 3).

Therefore, for each technological level, the quality class is assigned to each intensity group. The technological levels represent three different production systems. Technological level 1 consists of all production systems that are largely independent of external farm inputs and utilize internal resources to the maximum. Technological level 2 refers to production systems that demand medium to high intensity of external inputs, but do not depend on the large-scale application of resources. Technological level 3 is similar to level 2, but depends on the large-scale application of resources [7].

The assessment of the methodology was performed in two steps: 1) during application by evaluating whether the information given to the user about indicators, limitation factors, and recommended land-uses was sufficient and understandable for the method; and 2) after obtaining the results, analysis of whether the recommendation for land-use was adequate for the edaphic and landscape characteristics of the profile under evaluation.

Results

The application phase of the 'Recommendations for Sustainable Land Use' methodology [7] was found to be practical and effective. However, some factors limited the applicability of its results. The interpretation phase showed some inconsistency. The profiles Plinthosol 1 and Plinthosol 2 had an effective depth of 74 and 70 cm, respectively; and the Planosol 1 and Planosol 2 only 50 cm.

Interpretation of indicators resulted in inconsistent denominations for the abbreviations of limitation levels, which should be the following: N - *Null Limitation*, M - *Medium Limitation*, S - *Strong Limitation*, and V - *Very Strong Limitation*; which were shown as N, M, F, and MF [7] (Appendix 3), probably corresponding to abbreviations in Portuguese: “nulo” (null), “médio” (medium), “forte” (strong), and “muito forte” (very strong).

The methodology [7] also results in digitation mismatching in the identification of the frequent and unsuitable land-use classes in some of the tables (Appendix 3), in which the letters should follow the pattern from a-f.

There was no other limitation in applying the method regarding the two Plinthosols (1 and 2). As for the Planosols (1 and 2), the system did not clearly address situations such as an effective depth lower than 100 cm and there was some limitation in working with only two layers of soil, particularly for the Planosols, which had only 50 cm of effective depth.

To obtain some of the indicators, such as the sum of basic cations and available soil water in the soil profile, it is necessary to calculate the contribution of the three soil layers by assigning different weights to each layer. In this case, although it was not explicit in the methodology, zero thickness was used for the layer, resulting in a zero value for the contribution to the nutrient stock or water availability in the profile.

Another restraint in the interpretation was found for the sodium adsorption ratio and the electrical conductivity of the soil, as the methodology did not indicate at what depth this indicator should be analyzed. Therefore, we focused on the layer with the greatest content.

Table 4.4 [7] was used to make decisions regarding susceptibility to soil erosion. The first row tested whether the declivity of the area was greater than 3%. If it was not, we proceeded to the fourth row, where the statement to be tested was whether declivity was greater than 8%. If declivity was not greater than 3%, it meant that there were problems with this identification key (Appendix 2).

The two profiles of Plinthosol (1 and 2) presented the same land-use recommendation (Table 2). The greater restriction for technological level 1 was fertility deficiency, and for levels 2 and 3, oxygen deficiency. Technological level 1 was classified in the restrictive quality class for annual and perennial crops; moderate class for agroforest systems, pastures, and planted forests; and good class for native forests. For technological level 2, the quality class was restrictive for annual crops; moderate for perennial crops and agroforest systems; and good for pastures, planted forest, and native forest. For level 3, there was no restrictive quality class. The class was moderate for annual crops, perennial crops, and agroforest systems, and good for the remaining land-uses.

The recommendations for Planosols were more restrictive than for the Plinthosols. The Planosol 1 (Table 2) was most limited in technological levels 1 and 3 by fertility deficiency and, in level 2, by oxygen deficiency (Appendices 2 and 3). In level 1, this soil was considered unsuitable for agricultural use, having good quality classes only for native forest. In levels 2 and 3, the soils were classified as unsuitable for the use of annual and perennial crops and agroforest systems; it was restricted to pasture and planted forest, and differed only in the use of native forest. In level 2, it had moderate quality, and in level 3, it showed good quality.

Table 2. Recommendations for sustainable land use according to the intensity group and technological level of the farmer

Technological level	AC	CP	AFS	G	FP	NF
Plinthosol 1						
	-----------------------------Quality class------------------------					
1	(a)	(b)	c	d	e	F
2	(a)	b	c	E	E	F
3	a	b	c	D	E	F
Plinthosol 2						
1	(a)	(b)	c	d	e	F
2	(a)	b	c	E	E	F
3	a	b	c	D	E	F
Planosol 1						
1	inapt	inapt	inapt	inapt	inapt	F
2	inapt	inapt	inapt	(d)	(e)	f
3	inapt	inapt	inapt	(d)	(e)	F
Planosol 2						
1	inapt	inapt	inapt	(d)	(e)	f
2	inapt	Inapt	inapt	(d)	(e)	f
3	inapt	Inapt	inapt	d	e	f

Quality class – good: capital letters; moderate: lowercase letters; restricted: lowercase letters and brackets; and inapt.

Technological level – 1: maximum utilization of internal resources; 2: not dependent on large-scale application of external resources; 3: dependent on large-scale application of external resources.

Intensity group – AC: annual crops; PC: perennial crops; AFS: agroforestry; G: grassland; FP: forestry plantation; NF: natural forestry.

Discussion

From a methodological and scientific point of view, the problems encountered in the 'Recommendations for Sustainable Land Use' method have a wider relevance and should be corrected. The sodium adsorption ratio is an example. Delarmelinda et al. [13] applied the value in the upper layer (0-25 cm). However, in our study, we considered the layer in which the greatest content occurred, on the basis that presence of salinity is more relevant than depth where it occurs (if we consider a depth limit of up to 100 cm). Even with this restriction the interpretation of the indicators was adequate to infer the land-use limitation level according to each factor (fertility deficiency, water deficiency, oxygen deficiency, susceptibility to erosion, and constraints to mechanization) and the technological levels evaluated.

With regard to the Plinthosols the main limitation factor was the soil fertility deficiency, determined by the low sum of basic cations and high exchangeable aluminum saturation (43.8% for 0–25 cm, and 72.43% for 26–60 cm). As in level 1, a low influence of external inputs was assumed, and there are few annual or perennial crops viable for cultivation in this level, since the organic fertilization techniques may not be effective to overcome the high content of exchangeable aluminum [17].

In levels 2 and 3, soil fertility is less limiting because, with the use of limestone, the aluminum toxicity can be neutralized or reduced [18]. In these levels, mineral fertilizers are used for increased crop production. In this case, oxygen deficiency would be a greater limitation, and soil use would be limited to crops adapted to low-oxygen conditions, or requiring the use of soil drainage techniques. Such techniques also apply to agricultural mechanization.

Because Wadt [7] did not consider the taxonomic classification of the soil, his methods result in greater objectivity and greater ease of application, making it possible for any agricultural technician to use. However, as oxygen deficiency was the main factor limiting land-use with the Plinthosols, with increasing levels of technology and the use of drainage in these soils, there is a risk of changing the soil suborder from Concretionary to Petric, increasing its restriction to root development and its susceptibility to erosion, and decreasing its water storage capacity. Sano et al. [19] reported this concern with regard to Plinthosols, mainly in the cultivation of irrigated rice.

Surveys of Agricultural Land Capability based on the systems proposed by Ramalho Filho et al. [8] and Ramalho Filho & Beek [9], have classified Plinthosols as being unsuitable for any type of farming, and therefore destined for flora and fauna conservation. This is due to mechanization possibilities being highly limited (due to steep slopes in some areas), low effective depth, or oxygen deficiency [20]. Thus, they are frequently more suitable for pasture cultivation or conservative uses [19].

The 'Recommendations for Sustainable Soil Use' method could be improved through the inclusion of indicators regarding the presence of plinthite and petroplinthite. Such indicators should include its quantity and position in the profile. These are characteristics distinguished in the field, and they could make the limiting factor of oxygen deficiency more restrictive.

The main indicator related to fertility deficiency of the Planosol 1 was the high electrical conductivity, 68 dS m^{-1}, an indicator of the soil salinity. The minimum value for a soil to be considered saline is 4 dS m^{-1} [15]. This is a difficult edaphic characteristic to manage and is not usually economically viable, even with high levels of technology, mainly due to restricted soil depth.

The main method in the literature for salinity correction is the movement of excess soluble salts via leaching and organic amendments [21, 22]. Gypsum is recommended to reduce sodicity [21], but this reclaiming method is limited by low soil drainage. When applying these technologies, special attention should be focused on drainage of the leaching water and the inadequate proportion of basic cation from soil, which occurs with excessive leaching of potassium and increases in calcium availability [21-24]. Thus, if fertility deficiency was the most restrictive factor for technological level 3, the same applies, in this case, for the other technological levels. The recommendation for land-use should be from moderate to restrictive for native forest, and unsuitable for the remaining land-use catagories.

Planosol 2 (Table 2) had oxygen deficiency as the greatest limiting factor in each of the three technological levels. In levels 1 and 2, the soil was considered unsuitable for the cultivation of annual and perennial crops and agroforest systems, with restricted quality for pasture and planted forest, and moderate quality for native forest. Level 3 differed only in the use of pastures and planted pastures, which were of moderate quality instead of restricted quality.

The levels of salinity and sodicity in Planosol 2 were not high enough to impact greatly on land-use, unlike oxygen deficiency. Use of a quality class which defines land as restricted for pasture and planted forest in technological levels 1 and 2, and moderate for the same cultivations in level 3, is a recommendation consistent with land-use in these soils.

According to the Brazilian System for Soil Classification [15], the Planosols order is comprised of mineral soils that are imperfectly drained, with a superficial horizon or eluvial sub-superficial of sand texture, which contrasts strongly with the illuvial B horizon immediately subjacent which has a greater clay content. They have slow or very slow permeability, sometimes constituting a pan horizon, responsible for the formation of overlapping water-holding layers (suspended) of periodical existence and with variable presence throughout the year.

These characteristics frequently result in oxygen deficiency in Planosols and, during floods, they may lead to hypoxic or anoxic conditions around the root systems of plants due to the diffusion of oxygen in the aqueous environment [25]. A high risk of anoxic conditions was reported in Planosols in Rio Grande do Sul, Brazil [26]. However, some crops, such as rice, are adapted to low-oxygen conditions and temporary flooding.

Dias-Filho & Carvalho [27] reported that *Brachiaria brizantha* is intolerant to flooding, *B. decumbens* is moderately tolerant, and *B. humidicola* is tolerant. They also emphasized that management practices should be careful not to worsen the soil properties through compaction, since that increases its susceptibility to flooding and oxygen deficiency. Among the cultivars *B. brizantha,* Marandu is the least tolerant and Piatã, B163, and B166 have intermediate tolerance [28].

Although the Planosols show some physical impairments to the development of roots for plants with deep root systems (such as trees), it is believed that its physical aspects do not interfere in a significant way [25]. The greatest limitation is oxygen deficiency. In this context, the selection of tree species is also important. Costa et al. [26] observed that Planasols, mainly found in wetland areas, limit the development of eucalyptus, particularly in the initial phase of crop development due to a lack of oxygen caused by restricted drainage.

Since there are plant species adapted to hypoxic conditions, the limitations of the Planosols are mainly its salinity and sodicity characteristics (which limit fertility). They require adjustment in order to provide adequate recommendations. The degree of oxygen deficiency is related to the profile position in the landscape [26]. As Wadt's methodology [7] predicts the location in the landscape as an indicator of oxygen deficiency, this is a good limiting factor and it generates adequate recommendations.

With adjustments, the 'Recommendation for Sustainable Land Use' method is an important tool for the conservation of environmental resources. The Plinthosols and Planosols are important soils in tropical regions, particularly in the Amazon region, where they are often related to hydromorphic environments. They have a relevant relationship with the conservation of water and the biota of the ecosystem.

Implications for conservation

Soil conservation is closely related to water quality and the conservation of biodiversity. Because the 'Recommendations for Sustainable Land Use' method does not require detailed pedological surveys, it can be applied in areas that lack large-scale soil characterizations, and should therefore be widely tested. The system has the advantages of being simple, objective, and easy to interpret, but it requires validation. This can be achieved by testing the method in different areas and, as a result, adjusting the criteria or including new properties.

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Appendix 1. Soil indicators for the recommendation for sustainable land use of Plinthosols and Planosols

Soil profile	Depth	STC	Clay	Silty	Sand	SAR	EC	CA	CEC	SBC	RP	PBS	SAS	SC	ASW
Plinthosol 1	0-25	loam	20,2	46,0	33,8	-	-	42,1	8,3	2,3	<5,0	27,0	43,8	1,7	137,8
Plinthosol 1	25-60	loam	26,7	42,0	31,3	-	-	24,9	6,5	0,9	<5,0	14,7	72,4	0,9	192,5
Plinthosol 1	60-74	loam	31,0	42,0	27,0	-	-	19,0	5,9	0,8	<5,0	14,0	0,8	0,6	80,9
Plinthosol 2	0-25	loam	24,0	43,0	33,0	-	-	18,3	4,4	1,0	<5,0	23,0	57,0	0,9	135,9
Plinthosol 2	25-60	loam	24,0	43,0	33,0	-	-	18,3	4,4	1,0	<5,0	23,0	57,0	0,9	190,3
Plinthosol 2	60-70	loam	24,0	43,0	33,0	-	-	18,3	4,4	1,0	<5,0	23,0	57,0	0,9	54,4
Planosol 1	0-25	loam	23,0	26,0	51,0	0,07	-	102,6	23,6	19,9	<5,0	84,0	0,0	1,3	101,8
Planosol 1	25-50	clayey	49,0	22,0	29,0	0,08	68,0	72,9	35,7	35,3	>5,0	99,0	0,0	0,3	154,2
Planosol 2	0-25	loam	11,0	19,4	69,6	1,77	-	36,7	4,0	1,0	>5,0	25,0	40,6	0,6	321,2
Planosol 2	25-50	clayey	38,2	17,8	44,0	6,08	1,60	17, 5	6,1	5,7	<5,0	85,6	8,6	0,3	292,2

DEPTH: effective soil depth (cm); STC: soil texture class; SAR: sodium adsorption ratio (dS $m^{-1)}$; EC: electrical conductivity ($cmol_c$ kg^{-1}); CA: clay activity ($cmol_c$ kg^{-1}); CEC: cation exchange capacity ($cmol_c$ kg^{-1}); SBC: sum of basic cations ($cmol_c$ kg^{-1}); RP: remaining phosphorus mg kg^{-1}; PBS percent of base saturation (%) ; SAS ; soil aluminum saturation (%) ; SC soil carbol (%) ; ASW Available soil water (cm). Adapted from Jacomine et al. [14].

Appendix 2. Decision rules for Fertility Deficiency, Water Deficiency, Oxygen Deficiency, Erosion Susceptibility, and Impediments to Mechanization

	Fertility deficiency			Water deficiency			Oxygen deficiency			Erosion susceptibility			Impediments to mechanization		
Step	Decision	If true	If false	Decision	If true	If false	Decision	If true	If false	Decision	If true	If false	Decision	If true	If false
1	EC > 15	#1: f_V	Step 2	Floodplain Area	Step 2	Step 6	Floodplain Area	Step 2	Step 6	Slope > 3	Step 2	Step 4	Slope > 3	Step 5	Step 2
2	EC > 8	#2: f_S	Step 3	AWI > 1000	N	Step 3	SOx = 3	#22: o_V	Step 3	EDL ≤ 0.2	Step 3	#28: e_L	MC < 1	Step 4	Step 3
3	SAR > 15	#2: f_S	Step 4	AWI > 500	Step 4	Step 5	SOx = 2	#23: o_S	Step 4	SOx < 3	N	#28: e_L	MC < 2	#33: m_L	#32: m_M
4	EC > 4	#3: f_M	Step 5	SWA > 75	#14: w_L	#15: w_M	SOx = 1	#24: o_M	Step 5	Slope > 8	Step 7	Step 5	SOx < 2	Step 5	#32: m_M

5	SAR > 6	#3: f_M	Step 6	AWI >250	#13: w_S	#12: w_V	Middle texture = "very clay" or Middle CA > 27 or Bottom CA > 27	#24: o_M	#25: o_L	EDL ≤ 0.2	Step 6	#29: e_M	Upper texture very clayey or clayey and upper CA > 27	#33: m_L	N
6	Upper Texture and middle Texture = “Sandy"	#4: f_Sn	Step 7	AWI > 250	Step 7	#16: w_V	Slope > 3	Step 11	Step 7	SOx < 3	#28: e_L	#29: e_M	Solpe > 8	Step 9	Step 7
7	SBC ≤ 1.5	Step 8	Step 9	AWI > 500	Step 9	Step 8	SOx = 3	#23: o_S	Step 8	Slope > 20	Step 9	Step 8	MC < 1	#34: m_L	Step 8
8	Middle SAS ≥ 30	#5: f_Ma	#4: f_Sn	SWA > 75	#17: w_S	#16: w_V	SOx = 2	#24: o_M	Step 9	SOx < 2	#29: e_M	#30: e_S	MC < 2	#35: m_M	#36: m_S
9	SBC ≤ 3.0	Step 10	Step 12	AWI > 1000	Step 14	Step 10	SOx = 1	#25: o_L	Step 10	Slope > 45	#31: e_V	#30: e_S	Solpe > 20	Step 12	Step 10
10	Eutrophic in upper and middle layer	#7: f_Sn	Step 11	Dry Season > 6	Step 11	Step 12	Middle CA > 27 or Bottom CA > 27	#25: o_L	N				MC < 1	#35: m_M	Step 11
11	Middle SAS > 30	#5: f_Ma	#6: f_Sa	SWA > 40	#17: w_S	#16: w_V	SOx = 1	#26: o_M	Step 12				MC < 2	#36: m_S	#37: m_V

12	SBC ≤ 6.0	Step 13	Step 15	Dry Season > 6	#17: w_S	Step 13	SOx = 0	#27: o_L	N	Slope > 45	#37: m_V	Step 13
13	Middle SAS > 30	#8: f_Ma	Step14	Dry Season > 3	#18: w_M	#19: w_L				MC < 1	#38: m_S	#37: m_V
14	Eutrophic in upper and middle layer	#9: f_Ma	#10: f_La	AWI > 1500	Step 17	Step 15						
15	Middle CA < 27	Step 16	Step18	Dry Season > 1	#20: w_M	Step 16						
16	Eutrophic in upper and middle layer	N	Step 17	Dry Season > 0	#21: w_L	N						
17	Middle SAS > 30	#8: f_Ma	#10: f_La	AWI > 2000	Step 20	Step 18						
18	Middle RP < 5	#11: f_Ln	Step 19	Dry Season > 1	#21: w_L	Step 19						
19	DEPTH < 51	#11: f_Ln	N	Middle CA > 27	#21: w_L	N						

20	Dry Season > 1	#21: w_L	N

Adapted from Tables 4.1-4.5 [7].

Appendix 3. Framework for quality classes inside each intensity group and technological level in relation to each limiting factor

	Quality classes																	
Limiting factor	Technological level 1						Technological level 2						Technological level 3					
	AC	CP	AFS	G	FP	NF	AC	CP	AFS	G	FP	NF	AC	CP	AFS	G	FP	NF
f_N	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
f_Ln	a	b	c	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
f_La	(a)	(b)	c	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
f_Mn	(a)	(b)	c	d	e	F	A	B	C	D	E	F	A	B	C	D	E	F
f_Ma	(a)	(b)	c	d	e	F	a	b	c	D	E	F	A	B	C	D	E	F
f_Ms	inapt	inapt	(c)	d	e	F	(a)	(b)	(c)	D	E	F	(a)	(b)	(c)	D	E	F
f_Fn	inapt	inapt	(c)	d	e	F	a	b	c	d	e	F	A	B	C	D	E	F
f_Fa	inapt	inapt	(c)	d	e	F	(a)	(b)	(c)	D	E	F	A	b	c	D	E	F
f_Fs	inapt	inapt	inapt	(d)	(e)	F	inapt	inapt	inapt	d	e	F	inapt	inapt	inapt	d	e	F
f_MFn	inapt	inapt	inapt	(d)	(e)	F	(a)	(b)	(c)	(d)	(e)	F	a	b	c	D	E	F
f_MFa	inapt	inapt	inapt	(d)	(e)	F	(a)	(b)	(c)	d	e	F	a	(b)	(c)	d	e	F
f_MFs	inapt	inapt	inapt	inapt	inapt	F	inapt	inapt	inapt	(d)	(e)	F	inapt	inapt	inapt	(d)	(e)	F
w_N	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
w_Ld	A	b	c	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
w_Lp	a	b	c	D	E	F	a	b	c	D	E	F	A	B	C	D	E	F
w_Md	a	(b)	(c)	d	e	F	a	b	c	d	e	F	A	b	c	d	e	F
w_Mp	(a)	(b)	(c)	(d)	(e)	F	a	(b)	(c)	d	e	F	a	(b)	(c)	d	E	F
w_F	(a)	inapt	inapt	(d)	(e)	f	(a)	(b)	(c)	(d)	(e)	f	(a)	(b)	(c)	(d)	(e)	f
w_MF	inapt	inapt	inapt	inapt	inapt	f	inapt	inapt	inapt	inapt	(e)	f	inapt	inapt	inapt	inapt	(e)	(f)
o_N	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
o_L	a	b	c	D	E	F	a	b	c	E	E	F	a	b	c	D	E	F

o_M	a	b	c	D	E	F	(a)	b	c	E	E	F	a	b	c	D	E	F
o_F	inapt	inapt	(c)	d	e	F	(a)	(b)	(c)	d	e	F	(a)	(b)	(c)	d	e	F
o_MF	inapt	inapt	inapt	(d)	(e)	f	inapt	inapt	inapt	(d)	(e)	f	(a)	(b)	(c)	d	e	F
e_N	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
e_L	a	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
e_M	(a)	b	c	d	E	F	a	b	c	D	E	F	a	b	b	D	E	F
e_F	(a)	(b)	c	d	e	F	(a)	b	c	d	E	F	(a)	b	b	c	E	F
e_MF	inapt	(b)	(c)	(d)	e	F	inapt	(b)	(c)	(d)	e	F	inapt	(b)	(b)	(c)	e	F
m_N	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
m_L	A	B	C	D	E	F	A	B	C	D	E	F	a	B	C	D	E	F
m_M	A	B	C	D	E	F	b	B	C	D	E	F	(a)	b	c	D	E	F
m_F	a	d	g	j	E	F	b	e	h	D	E	F	(a)	(b)	(c)	d	e	f
m_MF	(a)	(d)	(g)	(j)	m	F	inapt	(e)	(h)	k	n	q	inapt	inapt	inapt	(d)	(e)	(f)

Quality classes – good: capital letters; moderate: lowercase letters; restricted: lowercase letters and brackets; and inapt.
Limiting factor – f: fertility deficiency; w: water deficiency; o: oxygen deciciency; e: erosion susceptibility; m: impediments to mechanization. Technological level – 1: maximum utilization of internal resources; 2: not dependent on large-scale application of external resources; 3: dependent on large-scale application of external resources.
Intensity group – AC: annual crops; PC: perennial crops; AFS: agroforestry; G: grassland; FP: forestry plantation; NF: natural forestry.
Adapted from Tables 4.6-4.10 [7].