Characterization, agricultural potential, and perspectives for the management of light soils in Brazil

Guilherme Kangussu Donagemma[(1)], Pedro Luiz de Freitas[(1)], Fabiano de Carvalho Balieiro[(1)], Ademir Fontana[(1)], Silvio Túlio Spera[(2)], José Francisco Lumbreras[(1)], João Herbert Moreira Viana[(3)], José Coelho de Araújo Filho[(4)], Flávia Cristina dos Santos[(3)], Manoel Ricardo de Albuquerque[(3)], Manuel Cláudio Motta Macedo[(5)], Paulo Cesar Teixeira[(1)], André Julio Amaral[(4)], Elisandra Bortolon[(6)] and Leandro Bortolon[(6)]

[(1)]Embrapa Solos, Rua Jardim Botânico, no 1.024, Jardim Botânico, CEP 22460-000 Rio de Janeiro, RJ, Brazil. E-mail: guilherme.donagemma@embrapa.br, pedro.freitas@embrapa.br, fabiano.balieiro@embrapa.br, ademir.fontana@embrapa.br, jose.f.lumbreras@embrapa.br, paulo.c.teixeira@embrapa.br [(2)]Embrapa Agrossilvipastoril, Rodovia dos Pioneiros MT-222, Km 2,5, Zona Rural, CEP 78550-970 Sinop, MT, Brazil. E-mail: silvio.spera@embrapa.br [(3)]Embrapa Milho e Sorgo, Rodovia MG-424, Km 45, CEP 35701-970 Sete Lagoas, MG, Brazil. E-mail: joao.herbert@embrapa.br, flavia.santos@embrapa.br, manoel.ricardo@embrapa.br [(4)]Embrapa Solos, Unidade de Execução de Pesquisas de Recife, Rua Antônio Falcão, no 402, Boa Viagem, CEP 51020-240 Recife, PE, Brazil. E-mail: jose.coelho@embrapa.br, andre.amaral@embrapa.br [(5)]Embrapa Gado de Corte, Avenida Rádio Maia, no 830, Zona Rural, CEP 79106-550 Campo Grande, MS, Brazil. E-mail: manoel.macedo@embrapa.br [(6)]Embrapa Pesca e Aquicultura, Prolongamento Quadra 104 Sul, Avenida LO1, no 34, Conjunto 4, 1º e 2º Pavimentos, Plano Diretor Sul, CEP 77020-020 Palmas, TO, Brazil. E-mail: elisandra.bortolon@embrapa.br, leandro.bortolon@embrapa.br

Abstract – Light soils occupy 8% of the Brazilian territory and are especially expressive in the new and last agricultural frontier in Brazil: the Matopiba region – in the states of Maranhão, Tocantins, Piauí, and Bahia –, where they represent 20% of the area. These soils fit into the textural classes of sand and loamy sand or sandy loam, down to 0.75-m soil depth or deeper, and they are mainly represented by Neossolos Quartzarênicos (Quartzipsamments) and, partly, by Latossolos (Oxisols) and Argissolos (Ultisols). The understanding of soil functioning depends on the establishment of distinguishing criteria for: organic matter dynamics; content and mineralogy of the clay fraction; coarse sand and total sand contents, in relation to those of fine sand; mean diameter of the sand fraction; and water retention capacity. These criteria can contribute for the zoning and for the conservation and fertility management of light soils, as well as for the estimation of their agricultural potential. Integrated production systems, such as crop-livestock and crop-livestock-forestry integration, besides no-tillage with crop rotation, mixed forestry planting with legumes, and the use of green manure and cover crops are relevant for the proper management of these soils. The objective of this review was to characterize light soils and to highlight the main challenges regarding their agricultural potential and their conservation and fertility managements, in face of the expansion and consolidation of the new Brazilian agricultural frontier.

Index terms: agricultural aptitude, fragile soils, management and conservation, Neossolos Quartzarênicos (Quartzipsamments), sandy soils, soil fertility management.

Introduction

Light soils occupy 8% of the Brazilian territory. In the Cerrado biome, 15% are represented by Neossolos Quartzarênicos (Quartzipsamments), while, in the Matopiba region – comprising the states of Maranhão, Tocantins, Piauí, and Bahia –, which is considered the last great agricultural frontier in Brazil, they represent 20% of the territory and consist mainly of Neossolos Quartzarênicos (Quartzipsamments) and, partly, of Latossolos (Oxisols) and Argissolos (Ultisols) (Spera et al., 1999; Santos et al., 2011; Lumbreras et al., 2015).

In the past, light-textured soils were of little relevance in agricultural regions, even when they were present in areas favorable to mechanization, due to management limitations, such as: nutrient deficiency, high susceptibility to erosion and groundwater contamination, and water deficit under rainfed conditions (Ramalho Filho & Beek, 1995). These soils are also more susceptible to degradation and to losses of production capacity, when compared with finer-textured soils in similar environmental conditions.

Currently, Brazilian agriculture is being established on light soils, due to advances in production systems and agricultural practices. However, in order to do this, systems adapted to each region should be taken into consideration, particularly the no-tillage (NT) and integrated production systems, such as the integrated crop-livestock (ICL), integrated crop-livestock-forestry (ICLF), and the agroforestry (AFS) systems (Kluthcouski et al., 2003; Landers et al., 2006; Macedo, 2009; Vilela et al., 2011; Balbino et al., 2012).

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Light soils are, in general, homogenous in terms of susceptibility to degradation, potential for agricultural use, and production capacity; however, they vary significantly regarding their physico-hydraulic and chemical attributes. The following criteria can be used to differentiate between these soils: organic matter dynamics; clay fraction content and mineralogy; coarse sand and total sand contents, in relation to those of fine sand; mean diameter of the sand fraction; and water retention capacity, and, consequently, available water capacity for plants. The establishment of these criteria will enable a more detailed soil classification and a better evaluation of its agricultural potential, as well as the development of more appropriate zonings for land-use planning and the sustainable management of natural resources such as soil, water, and biodiversity.

The objective of this review was to characterize light soils and to highlight the main challenges regarding their agricultural potential and their conservation and fertility managements, in face of the expansion and consolidation of the new Brazilian agricultural frontier.

Characterization of light soils

These soils fit into the textural classes sand and loamy sand or sandy loam, down to 0.75-m soil depth or deeper. As to soil particle distribution, the Brazilian System of Soil Classification (SiBCS) distinguishes, in the first category level, mainly between Neossolos Quartzarênicos, Latossolos, and Argissolos (Santos et al., 2013a).

In this context, in the SiBCS, stand out Neossolos Quartzarênicos, which have a sandy texture – textural class sand or sandy loam – in all horizons until a depth of 1.50 m from soil surface or to lithic contact. Other soils with agronomic importance present thick light-textured horizons, such as: psammitic soils, sandy soils with difficulty of water retention, including Latossolos and Neossolos Flúvicos (Fluvic Neosols or Fluvents); "arênicos", soils with sandy texture from the soil surface until at least 50 cm and up to 100 cm-depth; "espessarênicos", soils with sandy texture from the soil surface until a depth of 100 cm or more, including Argissolos, Luvissolos (Aridisols), Planossolos (Alfisols), and Plintissolos (Albaquults); "êndicos", presence of a petroplinthite layer from 40-cm depth; and "espessos", soils with sandy texture from soil surface until the B horizon, which occurs at a depth of 100 cm or more, such as Planossolos.

Light-textured soils are significant in Brazil, and Neossolos Quartzarênicos account for 49.6 million hectares, i.e., 5.82% of the country (Spera et al., 1999; Santos et al., 2011), covering 15% of the Cerrado area. In the region of Matopiba, excluding the areas occupied by protected areas and indigenous lands, Neossolos Quartzarênicos occur in 6.8 million hectares (11.05%), and light-textured Latossolos and Argissolos in 5.8 million hectares (9.45%) (Lumbreras et al., 2015).

Figure 1 shows the geographic occurrence of Neossolos Quartzarênicos, notably in the Cerrado biome and in the Matopiba region. The other light-textured soils are not included, which usually occur in association with Neossolos Quartzarênicos, such as psammitic Latossolos and sandy/medium-textured Argissolos. Table 1 presents the environment for soil formation and the correspondent geology, expressed in the parent material of the light-textured soils distributed in the different environments of the Brazilian territory.

Light soils, usually with sandy texture, are predominately characterized by a weak structure and small granules or single grains, which give great friability to these soils, allowing the use of machinery and equipment. However, these soils are highly susceptible to erosion, due to the low cohesion between soil particles and to aggregate stability (Fidalski, 1997; Vale Junior et al., 2009; Scopel et al., 2012). Important characteristics, such as water retention and permeability, are closely related to soil texture and clay mineralogy. Gibbsitic Latossolos, for example, even with a high clay content, show greater permeability, macroporosity, and aggregate stability than kaolinitic Latossolos (Ferreira et al., 1999).

Therefore, when considering the nature of the fractions that compose the classes with greater participation of sand fractions, it is assumed that, in general, sandy soils have low water retention and high permeability (Or & Wraith, 2002).

The relationship between soil texture and water retention is related to clay content and factors such as packing, and particle shape and orientation in the soil. This is an indicative that the increase in the water retention potential occurs by reducing pore size.

In homogeneous sandy materials, with narrow particle-size distribution, pore size depends on particle size, so that the reduction in the latter leads to a reduction in pore size and to an increase in water retention forces. According to Bybordi (1973), saturated hydraulic conductivity (Ks) values can vary by more than 20 times in comparison with coarse sand (12 mesh, 1.68-mm opening) and fine sand (60 mesh, 0.25-mm opening). Therefore, even in materials consisting exclusively of the sand fraction, changing particle size would already imply in changes in their physico-hydraulic behavior. This reduction would also increase the specific surface area, as well as the contact forces and the solid/liquid interaction on the soil, with effects on water retention and solute flux.

In the case of materials with higher particle-size heterogeneity, the effective pore size can be reduced by the occupation of the empty spaces between larger particles by smaller ones (packaging phenomenon); therefore, the occurrence of certain particle-size distributions that provide soil compaction and minimize

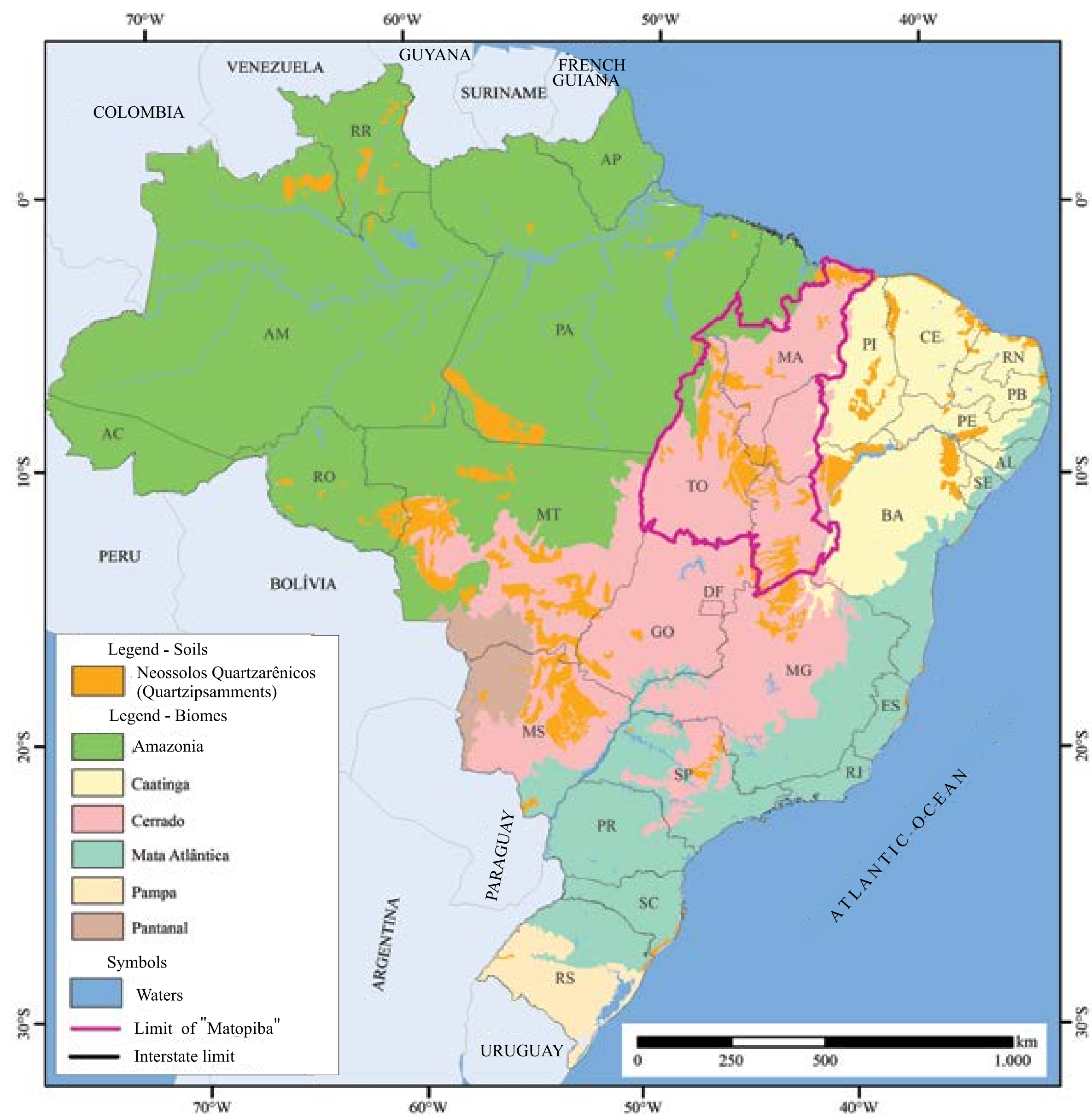

Figure 1. Occurrence of Quartzipsamments in Brazil, especially in the Cerrado region and in the states of Maranhão, Tocantins, Piauí, and Bahia (Matopiba region). Source: Santos et al. (2011).

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its porous space is possible. Riva (2010) observed that a proportion of about 30% of small particles favored packaging. Given these observations, the evaluation of coarse sand content in relation to fine sand (CS/FS), and of total sand in relation to fine sand (TS/FS) can be an indicator of this adjustment behavior and also of water retention. The more heterogeneous the soil is in terms of particle size, the greater is the possibility of readjustment. Values closer to 1.00 in the CS/FS ratio indicate that there is no pronounced predominance of course sand in relation to fine sand. Some examples are given in Table 2, as observed for Latossolo Vermelho (Rhodic Haplustox) in the municipality of Guaraí, in the state of Tocantins, and for Neossolo Quartzarênico in the municipality of Campo Verde, in the state of Mato Grosso.

Besides these criteria regarding the relative content of particles in the soil, the mean diameter of the sand fraction can also aid in identifying the differences between light soils, which would allow a more detailed classification, as well as to differentiate them among and within soil classes.

Table 1. Occurring environments of light soils in Brazil and the geology associated to them.

Occurrence environment	Geology	References
Western Region of the state of Bahia	Sandstones deposits of Urucuia Formation, sandyquartz sediments of Holocene, aeolian sediments of Quartenary, and clay-sandy and sandy materials of the Vazantes Formation.	Levantamento... (1976); Levantamento... (1977); Freitas et al. (2014)
Northwest e North of the state of Minas Gerais	Sandy quartz sediments of Tertiary/Quarternary, and Areado, Urucuia, and Mata da Corda sandstones.	Fundação Centro Tecnológico de Minas Gerais (1981)
Upper Paranaíba River in the state of Minas Gerais	Detrital deposits, Sandstones deposits of Areado and Bauru Formations, "Paraopeba", "Paranoá", "Três Marias" and "Mata da Corda" Formations, and "São Bento" e "Canastra" groups.	Motta et al. (2004)
Northwest Region of the state of Minas Gerais	Sandy quartz sediments of Tertiary/Quaternary, sandystone deposits of "Urucuia" Formation, and "Paraopeba" and "Três Marias" formations.	Levantamento... (1979)
Triângulo Mineiro in the state of Minas Gerais	Sandstone of Bauru group.	Levantamento... (1982)
Campos dos Parecis in the state of Mato Grosso	Sandystone deposits of "Utiariti" and "Salto do Céu" Formations from Parecis Group.	Oliveira (2011); Camargo (2011); IBGE (2012)
Upper Araguaia river in the state of Mato Grosso	Aquidauana groups of "Tubarão" supergroup.	Oliveira (2011); Camargo (2011); IBGE (2012)
Chapada dos Guimarães in the state of Mato Grosso	Marília Formation.	Oliveira (2011); Camargo (2011); IBGE (2012)
Sedimentation Zones of São Francisco and Parnaíba River in the State of Tocantins	Sediments.	IBGE (2007)
Campanha Region of the state of Rio Grande do Sul	Phanerozoic sedimentary basin and "Botucatu", "Guará", "Sanga do Cabral", "Porambóia" and "Rio do Rastro" Formations.	Brasil (1973); Klamt (1994); Streck et al. (2008)
Tabuleiros costeiros Region in "Jatobá-Tucano" sediment basin and Southern Plateau of the state of Maranhão and Western region of the state of Piaui	Granitic Stones.	Silva et al. (1993)
Northwestern and Northern Regions of the State of Paraná	"Caiuá" Sandstone deposits.	Levantamento... (1984); IBGE (1987); Fasolo et al. (1988); Carvalho (1994)
Southwestern Region of the state of Goiás	"Botucatu" and "Pirambóia" Sandstones, and Basalt of "Serra Geral" formation.	Projeto Radambrasil (1981); Guerra (1989); Moraes (2014)
Amazon Biome – states of Acre, Amazonas, Pará, Rondônia, Roraima, Mato Grosso, and Tocantins	Several Sandstone deposits, sandyquartz sediments of Tertiary/Quarternary.	IBGE (2012)
Center-Weasthern, Northwestern, and Western Regions of the state of São Paulo	"Botucatu", Cauiá" and "Bauru" Sandstones deposits.	Moniz & Carvalho (1973); Salomão (1994; Oliveira et al. (1999)
State of Mato Grosso do Sul	"Cauiá"; "Bauru"; "Botucatu"; e "Aquidauana" Sandstone deposits.	Brasil (1971); Theodorovicz & Theodorovicz (2010)

One of the major practical implications of soil texture is related to its relationship with water retention. River & Shipp (1972), working with light soils of the classes corresponding to Chernossolos (Molisols) and Neossolos Quartzarênicos, found that the amount of water available varies significantly, according to the contents of very fine sand and silt, from 6 to 600 kPa. Costa et al. (2013) reported, for Neossolos Quartzarênicos in the state of Santa Catarina, fine sand content of 681–783 g kg^{-1}. Fidalski et al. (2013), studying the relationship of sand fractions with water retention in soils of the Paranavaí and Caiuá formations in the state of Paraná, observed: lower water retention; coarser texture in the order of 681 g kg^{-1} of coarse sand; and larger pores in the order of 546 g kg^{-1} of coarse sand, in the soils of the Caiuá sandstone. Field capacity values were also recorded: 0.14 m^3 m^{-3} for the Caiuá sandstone and 0.22 m^3 m^{-3} for the Paranavaí sandstone, regardless of land use and soil depth, which implies in a lower risk of water deficiency and productivity loss for the latter.

Silva et al. (2006) analyzed differences in the soil-water retention curve in Neossolos Quartzarênicos compared with Latossolos in the Cerrado region, and found a higher water content in soils with two times more clay or associated with the presence of fine sand. Ribeiro et al. (2007) obtained different hydraulic conductivity values of 11.99 and 42.1 cm h^{-1}, respectively, for a psammitic Latossolo Vermelho-Amarelo (Typic Haplustox), with 21.4% very fine sand, and for a Neossolo Quartzarênico, with 7.9% very fine sand.

It was also observed that the more heterogeneous the soils are regarding particle size, the greater will be their susceptibility to surface sealing and compaction. For example, larger contents of fine sand (27%) and very fine sand (36%) in the 0.0–0.2-m layer of Neossolos Quartzarênicos, in the state of Rio Grande do Sul, favor the formation of surface sealing (Scopel et al., 2012). Moreover, some light soils, particularly with medium texture and predominantly kaolinite clay fraction, have a higher cohesion than other oxidic ones, consequently showing hard to extremely hard consistency when dry and friability when wet (Fontana et al., 2016), a behavior similar to that found in the "Barreiras" sediment formation (Moreau, 2001; Lima et al., 2006; Giarola et al., 2009).

Soil density in sandy soils ranges from 1.4 to 1.9 g cm^{-3}, which reflects the high occurrence of packaging in sandy materials; in this case, the value of 1.85 g cm^{-3} is a critical rate for the development of roots (Skopp, 2002). However, these values do not necessarily indicate limitation for root development, since these soils are generally friable when moist.

Abraham et al. (1998) reported a greater soil penetration resistance with the increase of fine sand

Table 2. Variation in the contents of coarse and fine sand, and in their relations, in Oxisol with medium texture and in Quartzipsamments of producing regions of grain, fibers, and eucalyptus (*Eucalyptus* spp.).

Municipality, state	Soil	Horizon and depth	Coarse sand	Fine sand	Coarse sand/ fine sand	Total sand/ fine sand
		(cm)	(g kg^{-1})			
Chapada gaúcha, MG	LVA	A_1 (0–10)	358–620	215–519	0.60–2.81	1.60–3.71
Chapada gaúcha, MG	LVA	Bw_2 (101–146)	232–517	235–523	0.47–2.11	1.47–2.66
Chapada gaúcha, MG	RQ	A_1 (0–9)	326–380	549–625	0.56–0.59	1.52–1.69
Chapada gaúcha, MG	RQ	C_2 (108–150)	301–443	489–631	0.48–0.91	1.29–1.91
Guaraí, TO	LV	A_1 (0–10)	437–473	394–439	1.00–1.20	2.0–2.20
Guaraí, TO	LV	Bw_2 (113–160)	338–358	418–442	0.76–0.86	1.72–1.86
Guaraí, TO	RQ	A_1 (0–10)	364–705	202–555	0.57–3.49	1.66–2.55
Guaraí, TO	RQ	C_2 (117–156)	303–705	128–555	0.56–6.38	1.56–7.38
Campo Verde, MT	LV	A_1 (0–13)	289–605	308–615	0.47–1.96	1.47–2.96
Campo Verde, MT	LV	Bw_2 (128–161)	262–578	333–606	0.43–1.74	1.43–2.74
Campo Verde, MT	RQ	A_1 (0–18)	416–579	925–948	0.82–1.66	1.82–2.66
Campo Verde, MT	RQ	C_2 (115–147)	452–493	400–458	0.99–1.21	1.99–2.21

LVA, Latossolo Vermelho-Amarelo (Typic Haplustox); RQ, Neossolo Quartzarênico (Quartzipsamments); and LV, Latossolo Vermelho (Rhodic Haplustox). Coarse sand, particle diameter of 2,00–0,21 mm; fine sand, particle diameter of 0,21–0,053 mm; and total sand, paticle diameter of 2,00–0,053 mm.

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content and of particle-form heterogeneity, which enables a more compact arrangement of the particles. This occurs because, in some cases, the soil is friable when wet, but hard when dry.

The chemical characterization of Neossolos Quartzarênicos and medium-textured Latossolos, considered here as light soils, is shown in Table 3, in which a wide variation was observed in the following attributes: organic carbon, exchangeable aluminum, cation exchange capacity (CEC), and pH. In addition, low levels of assimilable P, available K^+, and exchangeable Ca^{2+} and Mg^{2+} are reported, which limit soil chemistry. However, the lower buffering capacity of these soils, both for pH and available P can be considered an advantage for its agricultural use when compared with clayey and very clayey soils, which have high P adsorption capacity (Novais et al., 2007) and require a greater amount of lime to correct soil acidity.

Agricultural potential of light soils

Areas with light soils have been currently incorporated into the production process of grains, fibers, energy materials, sugarcane (*Saccharum officinarum* L.), forestry, and cultivated pastures. The agricultural potential of these soils, according to Ramalho Filho & Beek (1995), is regular, restricted, or unsuitable for annual and perennial nonirrigated crops, in appropriate conditions of drainage, climate, and relief under undeveloped (intermediate technological level) and developed (high technological level) management.

Light soils, when mechanized and receiving the application of fertilizers and other agricultural inputs, have provided high yields of soybean [*Glycine max* (L.) Merr.], corn (*Zea mays* L.), and cotton (*Gossypium hirsutum* L.), among other crops, besides making management operations easier (Santos et al., 2008). However, even though they are favorable to mechanization, these soils show limitations regarding fertility, which are related to nutrient storage and to soil pH, for example, as well as susceptibility to erosion and low water retention capacity, which are conditions for agricultural capability in rainfed conditions (Ramalho Filho & Beek, 1995).

With the evolution of Brazilian agriculture, new models of production have been introduced, which incorporate principles of conservation agriculture, such as NT, ICL system, ICLF system, and AFS, which enable sustainable land use and allow for the efficient use of available local resources (Kluthcouski et al., 2003; Landers et al., 2006; Macedo, 2009; Vilela et al., 2011; Balbino et al., 2012).

Table 3. Chemical attributes of medium textured Oxisol and of Quartzipsamments under natural vegetation (Cerrado) in producing regions of grain, fiber, and pasture[(1)].

Municipality, state	Soil	Horizon and depth (cm)	pH in water	Al^{3+}	$Ca^{2+} + Mg^{2+}$	K^+	Available P	Organic C	CEC
					($cmol_c$ kg^{-1})		(mg kg^{-1})	(g kg^{-1})	($cmol_c$ kg^{-1})
Chapada gaúcha, MG	LVA	A_1 (0–10)	4.4–4.9	0.2–0.7	0.1–0.6	0.02–0.04	≤1	4.4–9.8	4.0–5.6
Chapada gaúcha, MG	LVA	Bw_2 (101–146)	4.3–5.2	0.0–0.2	0.1–0.5	≤0.01	≤1	0.9–1.6	0.9–2.2
Chapada gaúcha, MG	RQ	A_1 (0–9)	4.5–4.9	0.5–1.0	0.1–0.3	0.03–0.04	1–2	5.7–11.8	5.2–6.2
Chapada gaúcha, MG	RQ	C_2 (108–150)	5.0–5.3	0.1–2.0	0.1–0.3	0.01–0.06	≤1	0.7–1.1	0.9–2.0
Guaraí, TO	LV	A_1 (0–10)	4.2–4.8	0.6–0.9	0.5–0.6	0.02–0.04	≤1	5.9–10.4	4.3–6.5
Guaraí, TO	LV	Bw_2 (113–160)	5.3–5.4	0.1–0.3	0.03–0.06	≤0.01	≤1	1.3–1.3	1.6–4.2
Guaraí, TO	RQ	A_1 (0–10)	4.0–4.9	0.1–0.6	0.1–0.6	0.01–0.02	1–2	1.7–8.0	0.9–3.9
Guaraí, TO	RQ	C_2 (117–156)	4.6–5.7	0.0–0.1	0.1–0.4	0.01–0.01	≤1	0.1–1.2	0.3–1.2
Campo Verde, MT	LV	A_1 (0–13)	4.2–5.2	0.4–0.7	0.1–0.6	0.02–0.07	1–2	5.8–12.1	3.7–8.1
Campo Verde, MT	LV	Bw_2 (128–161)	4.9–5.5	0.0–0.1	≤0.1	≤0.01	≤1	1.1–1.3	1.1–1.9
Campo Verde, MT	RQ	A_1 (0–18)	4.1–4.5	0.4–0.6	≤0.1	0.01–0.03	≤1	2.9–7.1	2.1–3.9
Campo Verde, MT	RQ	C_2 (115–147)	5.0–5.1	0.1–0.1	≤0.1	0.0	≤1	0.9–1.0	0.9–1.1

LVA, Latossolo Vermelho-Amarelo (Typic Haplustox); RQ, Neossolo Quartzarênico (Quartzipsamments); LV, Latossolo Vermelho Vermelho (Rhodic Haplustox); and CEC, soil cation exchange capacity.

For more specific and detailed assessments of the agricultural potential of light soils in their occurring sites, the following should be considered: climate, i.e., rainfall distribution and volume; texture, which includes the absolute value of fractions and the relationships between the components of the sand fraction; clay mineralogy; organic matter dynamics; production systems; and characteristics of the crops.

Use and management of light soils

Some examples of the use and sustainable management of light soils are: cultivated pastures, planted forest, sugarcane, and grain and fiber production.

Cultivated pastures

Of the 180 million hectares of pastures in Brazil, 120 million are cultivated (IBGE, 2007). In addition, pastures with certain stages of degradation are present in all regions of the country, including agricultural frontier areas (Dias-Filho, 2014).

However, it should be noted that, in light soils, pastures are fundamental to control erosion, since they improve the levels of organic matter affected by root turnover and promote mycorrhizal associations that favor soil structure stabilization. Mixed systems, such as ICL and ICLF – characterized by the diversification and rotation of agricultural activities, and also by the succession and intercropping of forage grasses with grains, fibers, and forest species –, can be used to recover and reform pastures with different stages of degradation (Vilela et al., 2011).

The adoption of ICL and ICLF systems has provided benefits for the maintenance of soil quality and C sequestration (Carvalho et al., 2010; Salton et al., 2011); however, more studies are still needed on the behavior of light soils cultivated with pastures.

Embrapa has proposed variations of mixed crop-livestock systems, such as the “Barreirão” (Kluthcouski et al., 1991), “Santa Fé” (Kluthcouski & Aidar, 2003), “Santa Brígida” (Oliveira et al., 2010), and “São Mateus” (Salton et al., 2013) systems, and also develops systems that include forestry activities (Balbino et al., 2011). Many areas in Brazil, with medium-textured soils, have potential to benefit from these or similar systems.

It was observed, for example, that the ICL system with rotational grazing by cattle, in a sandy/medium-textured Argissolo (Ultisol), in the state of Rio Grande do Sul, maintains soil quality and is a sustainable system for light soils (Lanzanova et al., 2007).

The adoption of the ICL system in a psammitic Latossolo Amarelo (Xanthic Haplustox), in the municipality of Correntina, in the west of the state of Bahia, did not affect soil physical quality, with the adoption of “safrinha de boi” – pasture areas, in consortium with summer crops, that are used for livestock during the dry season (winter), when forage deficit normally occurs, in which cattle is kept between harvests (Marchão et al., 2009). This system also increased the profit in the area, in comparison with that obtained when it was just used with grains. In this case, the ICL system is a sustainable and economical form of grain production in the region, which can promote better nutrient use and lower fertilizer costs, since nutrient release via straw meets most of the plant demands for nutrients and protects soil against erosion (Santos et al., 2014).

In the Alegrete region, in the state of Rio Grande do Sul, the silvopasture system with eucalyptus (*Eucalyptus* spp.) and sheep, in light soils, improved soil quality, when compared with soils cultivated with pasture, and also increased profitability and sustainability in comparison with conventional livestock (Flores et al., 2010). Sales et al. (2010), evaluating the ICL system, grain crops under no-tillage, and pastures in the Cerrado, in a Neossolo Quartzarênico in Mineiros, in the state of Goiás, highlighted the importance of maintaining soil cover to avoid erosion and maintain soil quality.

The use of *Urochloa ruziziensis* (R.Germ. & CMEvrard) Morrone & Zuloaga (Syn. *Brachiaria ruziziensis*) increased significantly in the Cerrado region, especially under NT and integrated systems (ICL, ICLF, and integrated livestock-forest) for corn production in consortium (Vilela et al., 2011). This has prompted the interest of farmers in also using this grass as forage (Vilela et al., 2011). The use of grasses, particularly brachiaria, has been key for the sustainability of grain and fiber production systems, as well as for the sustainability of agriculture in light soils, particularly in Neossolos Quartzarênicos and psammitic Latossolos in areas where rainfall and its distribution are not limiting factors for cultivation under rainfed conditions.

Planted forests

The most planted forest species in Brazil is Eucalyptus spp., which occupies about 5 million hectares (Anuário..., 2013), most of which are light soils.

Since water availability has been identified as a determining factor for the growth of eucalyptus in Brazil (Reis et al., 1985; Stape et al., 2004; Souza et al., 2006; Balieiro et al., 2008a; Stape et al., 2010), high yields can be expected in light soils in areas with favorable rainfall incidence and distribution. Stape et al. (2004) observed that in the state of Bahia, the high rates of the efficient use of soil (2–35% clay) cultivated with eucalyptus are associated with regions that have low deficit of air vapor saturation and water stress.

Other species have gained prominence in regions with light soils. In the state of Mato Grosso, for example, Shimizu et al. (2007) reported that teak (*Tectona grandis* L.f.) and rubber tree [*Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg. are among the most planted in the state, where they represent 33 and 31% of the planted forest area, respectively. According to the authors, eucalyptus – *Eucalyptus urophylla* S.T.Blake, *E. camaldulensis* Dehnh., *E. grandis* W.Hill, *E. pellita* F.Muell., *Corymbia* (ex-*Eucalyptus*) *citriodora* (Hook.) K.D.Hill & L.A.S.Johnson, and the hybrids urograndis (*E. urophylla* x *E. grandis*) and urocam (*E. urophylla* x *E. camaldulensis*) – and rubber tree are the most planted tree species on Neossolos Quartzarênicos. In the studied light soils, eucalyptus wood production ranged from 7 to 22 m^3 ha^{-1}, while, in the more clayey ones, it ranged from 13 to 26 m^3 ha^{-1}. In the municipality of Campo Verde, in the state of Mato Grosso, light soils cultivated with the species Corymbia citriodora, considered tolerant to water stress, without soil fertilization and lime, did not allow wood yield values greater than 20 m^3 ha^{-1}.

The sustainability of planted forests in light soils can be increased by the management of crop residues or by the establishment of mixed plantings, which favor interactions such as biological N_2 fixation, nutrient cycling, or changes in C allocation. Biomass production of eucalyptus and soil quality are directly related to the residue mass left after harvest (Chaer & Totola, 2007; Laclau et al., 2010). Similarly, mixed systems (with the inclusion of species associated with diazotrophic bacteria) are able to increase the net biomass production of forest sites and, at the same time, enhance the ecological interactions between species (Forrester et al., 2006; Coelho et al., 2007; Balieiro et al., 2008b; Laclau et al., 2008; Rachid et al., 2015); however, the selection of species and the arrangement of production systems must be well planned.

Mixed eucalyptus plantations in sandy and medium-textured soils, with N_2-fixing leguminous trees, such as *Acacia mangium* Willd., have favored the supply of N (especially nitrate), the indices of soil microbial diversity and evenness, soil C stocks, and wood production (Balieiro et al., 2008b; Rachid et al., 2013, 2015; Santos et al., 2016). These benefits are possibly related to the biological N_2 fixation provided by *A. mangium*. Recently, Paula (2015) reported these same benefits in a medium-textured Latossolo in the state of São Paulo.

Regarding fertilization, eucalyptus plantations usually have low response to high doses, when compared with water availability in light soils, with sand content between 91 and 94%; however, in fertilized sites, the response is 48% higher than in non-fertilized ones (Silva et al., 2013). These authors also pointed out that the split application of N and K represents additional gains in productivity and minimizes losses by nutrient leaching.

Sugarcane

The expansion of sugarcane crops in the Midwestern and Southern regions of Brazil has been affected by the incorporation of light soils, once occupied with pastures or with annual or perennial crops (Manzatto et al., 2009; Gauder et al., 2011), in the production process. In these regions, due to the favorable relief, planting and harvesting are mechanized; however, the equipment formed by the harvest machine and the infield wagon traffics five times more than the conventional system with burning and manual harvest (Roque et al., 2010), which causes compaction and losses of soil physical quality (Luca et al., 2008). The adoption of conservation systems, with no-tillage and the absence of burning crop residues, improves the physico-hydraulic soil conditions, which, together with climate and the genetic potential of the crop, determine the crop's productivity and longevity (Carvalho et al., 2012).

Nutrient losses by leaching in sugarcane fields have been studied in Brazil, mainly in the state of São Paulo. Among the factors that determine leaching losses, can be mentioned: crop stage, fertilizer doses and solubility, and rainfall distribution in the region (Oliveira et al., 2001; Cantarella et al., 2007; Ghiberto et al., 2011). Table 4 shows nitrite, nitrate, and ammonium drainage and losses in a sugarcane crop in the municipality of Pirassununga, in the state of São Paulo, in a sandy clay loam Latossolo, with mean sand content of 680 g kg^{-1} in the 0 to 1-m layer. Nitrogen losses in light soils were not significant, due to the fertilizer applied to the crop; however, a low N use rate was observed.

According to Vitti (2003) and Cantarella et al. (2007), a considerable amount of the N applied remains on the soil and has a potential residual effect for the next regrowth, which can also be lost by leaching. It was found that the N sources commonly used in the crop – urea, nitrate, ammonium sulfate, and solutions such as uran and aqua ammonia – have a high solubility. Therefore, further studies are needed on these soils to improve the agronomic efficiency of N for sugarcane crops, especially regarding N fertilizer doses, sources, and ways of application.

Recently, Ucker et al. (2015) found an increase in P contents, with depth, when sugarcane crops were compared with areas under native vegetation; this behavior was more noticeable in a Neossolo Quartzarênico than in a medium-textured Latossolo Vermelho-Amarelo (Typic Haplustox). Although several factors can control P dynamics in these soils, the management of fertilizers, other inputs, and organic matter should increase plant nutrient use efficiency, avoiding losses on soil surface or in depth.

Planting annual crops, such as soybean, peanut (*Arachis hypogaea* L.), sunflower (*Helianthus annuus* L.), corn, or sunn hemp (*Crotalaria juncea* L.), when renewing sugarcane crops, has been shown to be an opportunity to improve soil structural and chemical quality, with increases in water retention and infiltration in the soil (Duarte Junior & Coelho, 2008; Smith et al., 2012). However, more studies are also needed on light soils under climatic variations in order to increase the phytotechnical effects of those crops on the soil and on sugarcane crops.

Considering the contributions of biological N2 fixation to the sugarcane crop (Urquiaga et al., 1992; Boddey et al., 2003), as well as the positive effects of the inoculation of endophytic bacteria on this crop's growth (Schultz et al., 2014), it can be concluded that the energy balance of this crop has potential to be further increased in these soils (Macedo et al., 2008).

Not burning crop residues and maintaining them on soil surface should ensure soil protection against high soil temperature, keeping soil moisture and organic matter at favorable levels for microbial aggregation and activity.

Table 4. Precipitation, drained water, and nitrogen flux at different periods in the sugarcane culture (*Saccharum officinarum*)[(1)].

Period	Precipitation	Drainage	Lixiviated N (kg ha^{-1})				
	(mm)		N total	N-NO_2^-	N-NO_3^-	N-N-NH_4^+	^{15}N fertilizante
8/24–11/30	191	0.1 (0.7)	0.0 (0.0)	0.000	0.014	0.001	0.004
12/1–12/14	61	-0.1 (0.0)	0.0 (0.0)	0.000	-0.006	-0.001	-0.002
12/15–1/8	326	-22.3 (11.4)	-0.4 (0.4)	-0.010	-0.226	-0.155	-0.043
1/9–1/31	19	0.9 (1.1)	0.0 (0.0)	0.000	-0.001	-0.006	0.000
2/1–2/20	297	-49.4 (32.4)	-0.6 (0.3)	-0.087	-0.162	-0.354	-0.010
2/21–3/18	92	-4.1 (1.1)	0.0 (0.0)	-0.005	-0.007	-0.035	-0.001
3/19–3/29	131	-9.6 (12.2)	-0.1 (0.0)	-0.011	-0.023	-0.028	-0.001
3/30–5/31	58	-4.7 (2.0)	0.0 (0.0)	-0.010	-0.011	-0.027	-0.001
Total	1.175	-91.0 (60.9)	-1.1 (0.7)	-0.123	-0.422	-0.605	-0.054

[(1)]The number shown in each period represents the average of four replications with their respective standard deviations (in parentheses), while the number shown in the line with the total values, refers to the sum of each period and their respective standard deviations, in which positive numbers indicate water and nitrogen gains, and negative indicate loss down to 90-cm depth. 120 kg ha^{-1} N, 120 K_2O, and P_2O_5, besides 2 Mg ha^{-1} of dolomitic limestone, were used in the experiment. Source: Ghiberto et al. (2011).

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Grains and fibers

Grain production has been expanding in light soils, especially in the Midwestern and Southeastern regions of Brazil, as well as in the west of the state of Bahia. In this last region, many changes occurred in land use from 1985 to 2000. According to Batistella & Valladares (2009), in 1985, modern farms – mostly large farms, irrigated or not, producing soybean, cotton, corn, and bean (*Phaseolus vulgaris* L.), characterized by intensive use of technology and fertilizers, with high productivity – occupied 631,175 ha. The area with these farms, however, reached 1,605,762 ha in 2000. The irrigated farms in the region grew from 17,554 to 109,883 ha, in the same period. Similarly, traditional properties – with traditional management practices, family labor, small farms, and more dispersed distribution – exceeded 1,000,000 ha in the region, although its growth was not as intense as that of the irrigated farms (28 vs. 526%).

Another region with a significant presence of light soils that underwent significant changes in the physical environment is the Matopiba region, which refers to an area of about 73 million hectares, covering the entire state of Tocantins and part of other states, such as Maranhão, Piauí, and Bahia (Lumbreras et al., 2015). In the last decade, the region has been affected by agricultural expansion, which has been related to the expansion of transport infrastructure, logistics, and energy, enabling the emergence of expansion units in the agricultural frontier. In 2010, the region produced 2.3 million tons of grains, whereas, for 2015, a harvest of 10 million is estimated (Lumbreras et al., 2015).

Many of these lands are composed by light soils, whose price at the time these agricultural frontiers were opened allowed the expansion of conventional livestock, previously characterized by the low investment in production technology (Carvalho, 2006). A high investment, however, has been made in crops planted on light soils, since their productivity levels can be as high as those of heavier soils with a clayey texture. Santos et al. (2008), using data from 28 commercial soybean stands in the states of Mato Grosso and Mato Grosso do Sul, recorded an average crop yield of 3,090 kg ha^{-1} grains, with values up to 4,200 kg ha^{-1}. The soil texture of these plots showed variable clay content of 30 to 150 g kg^{-1}.

In the municipality of Campo Verde, in the state of Mato Grosso, high soybean and corn yields were observed in light soils (Dias et al., 2010), except during the dry periods or under nematode attack (Table 5). However, farmers in the region reported corn yields in the second harvest ranging from 5,110 to 6,000 kg ha^{-1} in these soils, less than the 8,400 kg ha^{-1} obtained in more clayey soils.

According to Galbieri et al. (2014), in the state of Mato Grosso, cotton yield does not differ between clayey and medium-textured soils.

Silva et al. (1994) evaluated soybean crops, cultivated from 1 to 5 years on Neossolos Quartzarênicos and medium- and clayey-textured Latossolos Vermelho-Amarelos, in order to understand the relationship between organic matter and CEC. The authors found that the decrease in organic matter was associated with the decline of CEC, at pH 7.0, and with cultivation time. In addition, Neossolos (Entisols) showed a wider range of decrease of 2.38 $cmol_c$ kg^{-1}, corresponding to a decrease of 61% in the initial value of CEC, while, in Latossolos, the reduction was of 1.52 $cmol_c$ kg^{-1}, corresponding to 29% CEC.

Therefore, the buffering capacity and the resilience of light soils depend on the adopted management in the

Table 5. Soybean (*Glycine max*) and corn (*Zea mays*) production in light textured soils in the 2012/2013 and 2013/2014 crop seasons, in Campo Verde, MT, Brazil.

Soil class[(1)]	Crop season	Yield	Observations
RQ	2012/2013	1,050 kg ha^{-1} soybean	Drought and nematode
RQ	2013/2014	2,880 kg ha^{-1} soybean	Without drought
RQ	2013/2014	3,480 kg ha^{-1} soybean	Without drought
LV psammitic	2013/2014	1,370 to 3,300 kg ha^{-1} soybean	The lower yields were due to the occurrence of 18-day drought during the grain filling stage
LV psammitic	2013/2014	3,480 kg ha^{-1} soybean 7,320 kg ha^{-1} corn	Without drought

[(1)]RQ, Neossolo Quartzarênico (Quartzipsamments); and LV, Latossolo Vermelho Vermelho (Rhodic Haplustox).

production system. It is necessary to preserve or even to increase the levels of soil organic matter, through the constant supply of biomass, minimum soil disturbance, balanced use of external inputs, and increase in the diversity of the production systems.

Integrated production systems, especially ICL, have been successfully employed in different farms producing grains and fibers, using forage grasses as soil cover crops under NT, where the animal component is an interesting alternative during the off-season (Vilela et al., 2008).

Fertility management of light soils

Liming in light soils is beneficial because it neutralizes toxic aluminum, by raising soil pH, and provides calcium and magnesium to the plants. However, its dosage should be carefully recommended, since this technique can promote the mineralization of organic matter, the reduction of micronutrient availability, and the increase in clay dispersion.

A common practice adopted by technicians and farmers that work with light soils is the application of lime rates above 6 Mg ha^{-1}, which can reach more than 10 Mg ha^{-1}. The reason for this, according to the farmers, is that if the rate of 2 Mg ha^{-1} recommended by the manuals on fertilizer use is applied (Raij et al., 1996; Ribeiro et al., 1999), crop productivity will be low; therefore, they suggest the use of higher doses, especially when the goal is to prepare the soil for crops with higher input demand, such as cotton. This point of view can be explained by the low reactivity of lime in these soils, due to the low aluminum content and buffering capacity of the soil, as well as to the possible losses of cations with depth, by leaching. In this sense, there are still few studies on liming on light soils, considering the intense and growing incorporation of these soils into the production process.

Lima (1993) showed the need to apply higher doses of lime on light soils than those recommended in the manuals, which are calculated based on Al neutralization, increases in Ca and Mg contents, and by the base saturation method. Freitas et al. (2004) reported the risk of clay dispersion with the use of high doses of lime in a conventional management system in light soils, in the west of the state of Bahia. Ferreira & Carvalho (2005), working with lime and fertilization of cotton in soils of the states of Bahia and Góias, also found clay dispersion caused by liming.

Regarding the use of agricultural gypsum, Maria et al. (1993) reported greater losses of Ca^{2+}, Mg^{2+}, and K^{+} in a medium-textured soil than in a clayey one. Ramos et al. (2006), studying the effect of lime and soil conditioners on a Neossolo Quartzarênico, found that agricultural gypsum increases the availability of calcium in all depths.

Regarding the management of phosphate fertilizer, the low P adsorption in sandy soils should be highlighted (Novais et al., 2007). This is an advantage when compared with more clayey soils, considering the limitation of this nutrient in tropical and weathered soils. Bedin et al. (2003) analyzed soybean production with different phosphate fertilizers, on different soil textures. According to these authors, a Neossolo Quartzarênico and medium-textured Latossolo Vermelho-Amarelo had higher phosphate values in the soil solution than a clayey Latossolo Vermelho-Amarelo. Moreover, the increase in soil P buffer capacity, in the sequence Neossolo Quartzarênico<medium-textured Latossolo Vermelho-Amarelo<clayey Latossolo Vermelho-Amarelo, restricted absorption and contributed to a more efficient nutrient use, which leveled the effects of the different P sources evaluated on soybean growth and yield.

Losses of nutrients, such as N and K, in light soils can contaminate groundwater, as observed in column experiments with medium-textured Latossolos (Donagemma et al., 2008; Werle et al., 2008) and in a field experiment with a Neossolo Regolítico (Usthorthent) (Galvão et al., 2008). Therefore, these nutrients should be managed with caution, adopting good soil conservation practices, such as soil cover and crop rotation.

The transport of these nutrients in the soil, in the west of the state of Bahia, is characterized by the intensive use of potassium fertilizers. In this environment, it is common to find available P contents above 50 mg dm^{-3}, at depths greater than 1.8 m, with little possibility of recovery by the crops in the predominant production systems in the region. In a long-term study, conducted between 2006–2013 (Toniêto et al., 2010; Polidoro & Teixeira, 2013), in soybean/corn rotation, the application of the recommended potassium dose on soil surface – by throwing, before or not sowing – was evaluated as a replacement of the dose applied in the planting furrow. It was found that KCl application on grain crops could be changed to throwing of the entire dose, before planting. With this management practice, the agronomic and economic efficiency of KCl was significantly increased, particularly for corn. This work also showed that K leaching was practically null, since the content in the 0.40–0.60-m layer was almost identical to that of the control treatment without K application. Therefore, unlike what has been reported in the literature, which recommends the split application of K, this study showed that the application of the total dose can be done while planting, without significant losses by leaching. It should also be noted that rainfall in the region is not well distributed and its volume is less than the usual one for the Cerrado, which reduces the potential for leaching.

Challenges for the characterization, the evaluation of the agricultural potential, and the Management of light soils

Although the behavior of light soils is considered homogeneous regarding susceptibility to degradation and agricultural productivity, there is a lack of information on the criteria that can distinguish their chemical and physico-hydraulic properties. Among the main challenges are:

1. The lack of criteria for a more detailed classification of these soils by the Brazilian System of Soil Classification, including: organic matter dynamics; content and mineralogy of the clay fraction; coarse sand and total sand contents, in relation to those of fine sand; mean diameter of the sand fraction; and water retention capacity and, consequently, available water capacity to the plants.
2. The establishment of researches on fertility management, lime application and dosage, agricultural gypsum, and fertilizers, as well as the adoption of programs supported by these studies, considering the crop and soil and climate variations.
3. The implementation of production systems, consisting of new arrangements and combinations of species, that should be tested and encouraged due to the benefits related to productivity and improvements in soil quality.
4. The stimulation of transfer and technology use programs, related to the management of light soils, including: mixed plantings with leguminous trees over the monoculture of forest species; cover crops for grain and fiber production to reform sugarcane crops; succession of grasses and forage legumes associated with grain production, in the second crop, and in crop-livestock and crop-livestock-forest integration; use of forage grasses, particularly brachiaria in rotation with or in succession to grain and fiber crops.
5. The development of new genetic materials, more tolerant to water stress and high temperatures, as a strategy for the agricultural use of these soils, on a global climate change scenario.
6. The development of genetic materials with low water and nutrient demands, as well as high resistance to pests and diseases, in order to provide low water, fertilizer, and pesticide inputs, which would prevent the contamination of surface and subsurface water resources.
7. The study of mechanical and vegetative practices to improve soil quality and control erosion, considering the use of heavy equipment and the occurrence of concentrated rainfall, which can accelerate the degradation process of these soils.

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