Phosphorus and potassium fertilizer recommendations in Brazil and Paraguay: convergences, divergences, and paths towards harmonization

UFRGS
UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

Tales Tiecher
Departamento de Solos
Faculdade de Agronomia
tales.tiecher@ufrgs.br

DEPARTAMENTO DE SOLOS UFRGS

PÓS-GRADUAÇÃO EM CIÊNCIA DO SOLO UFRGS

IRGEB
interdisciplinary research group on environmental biogeochemistry

How it all started?

NC STATE UNIVERSITY

NC STATE UNIVERSITY
Crop & Soil Sciences

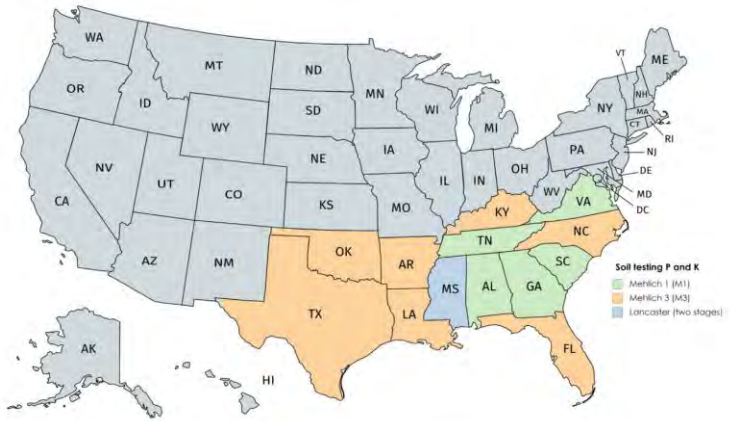
Visiting Scholar
December 2021 - November 2022
Crop and Soil Sciences Department
North Carolina State University

Dr. Luke Gatiboni

How it all started?

FRST

FERTILIZER RECOMMENDATION SUPPORT TOOL



Zhang *et al.* (2021). Variation in soil-test-based phosphorus and potassium rate recommendations across the southern USA. **Soil Sci Soc Am J.** 2021;85:975-88. https://doi.org/10.1002/saj2.20280

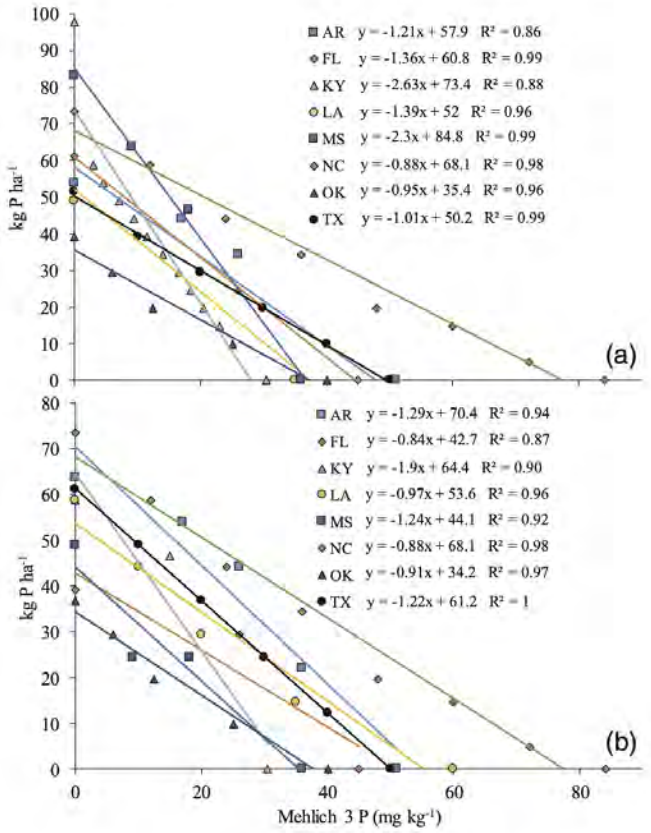


FIGURE 2 Fertilizer P rate recommendations based on Mehlich-3 and Lancaster extractable P (STP) for (a) corn at a yield goal of 10.1 Mg ha^{-1} and (b) warm-season grass hay at a yield goal of 13.5 Mg ha^{-1}

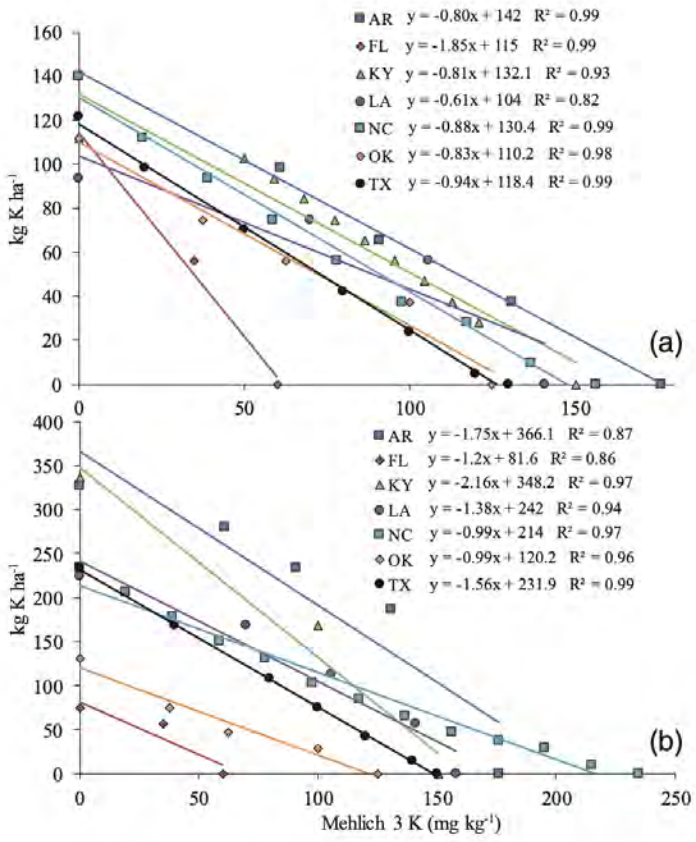


FIGURE 6 Fertilizer K rate recommendations based on Mehlich-3-extractable K (STK) for (a) corn at yield goal of 10.1 Mg ha^{-1} and (b) warm-season grass hay at a yield goal of 13.5 Mg ha^{-1}

Ilhas Malvinas
Argentina
Uruguai
Paraguai
Bolívia
Brasil
Peru
Equador
Colômbia
Suriname
Guiana
Venezuela
África do Sul
Moçambique
Angola
Indonésia
São Tomé e Príncipe
Guiné Equatorial
Etiópia
Guiné-Bissau
Cabo Verde
Índia
Emirados Árabes Unidos
Arábia Saudita
Egito
Irã
China
Rússia
Portugal
Timor-Leste
China
Rússia
OCEANO
ÍNDICO
OCEANO
OCEANO
ATLÂNTICO
PACÍFICO
OCEANO GLACIAL ÁRTICO
LINHA DO EQUADOR
S
E
W
N
0 500 1 000 2 000 km
PROJEÇÃO DE ECKERT III

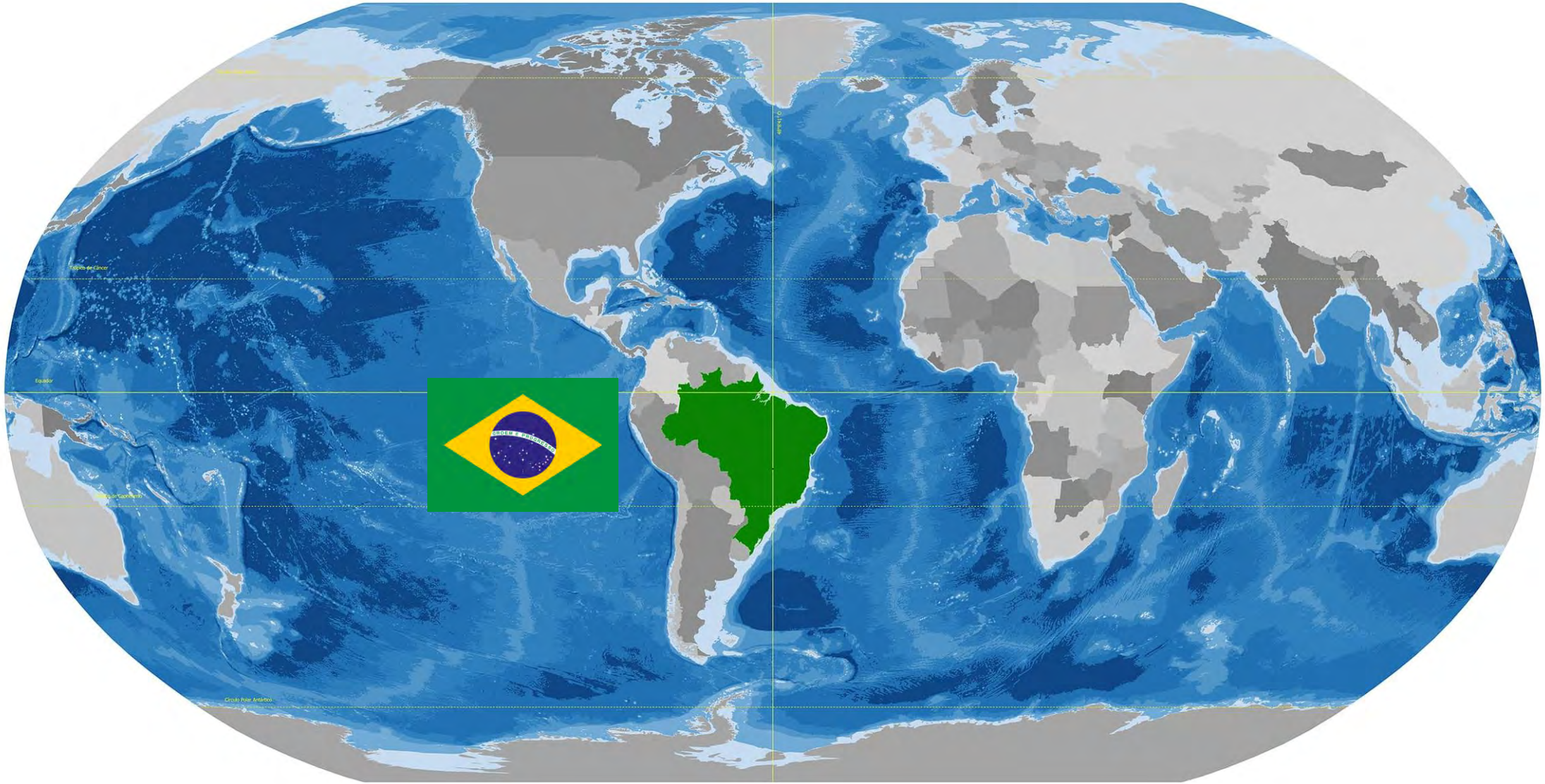
Fontes:
1. ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE. ArcGIS Data and Maps. Redlands: ESRI, 2022.
2. COMISSÃO INTERMINISTERIAL PARA OS RECURSOS DO MAR (Brasil). Plano de levantamento da plataforma continental brasileira. 2018.

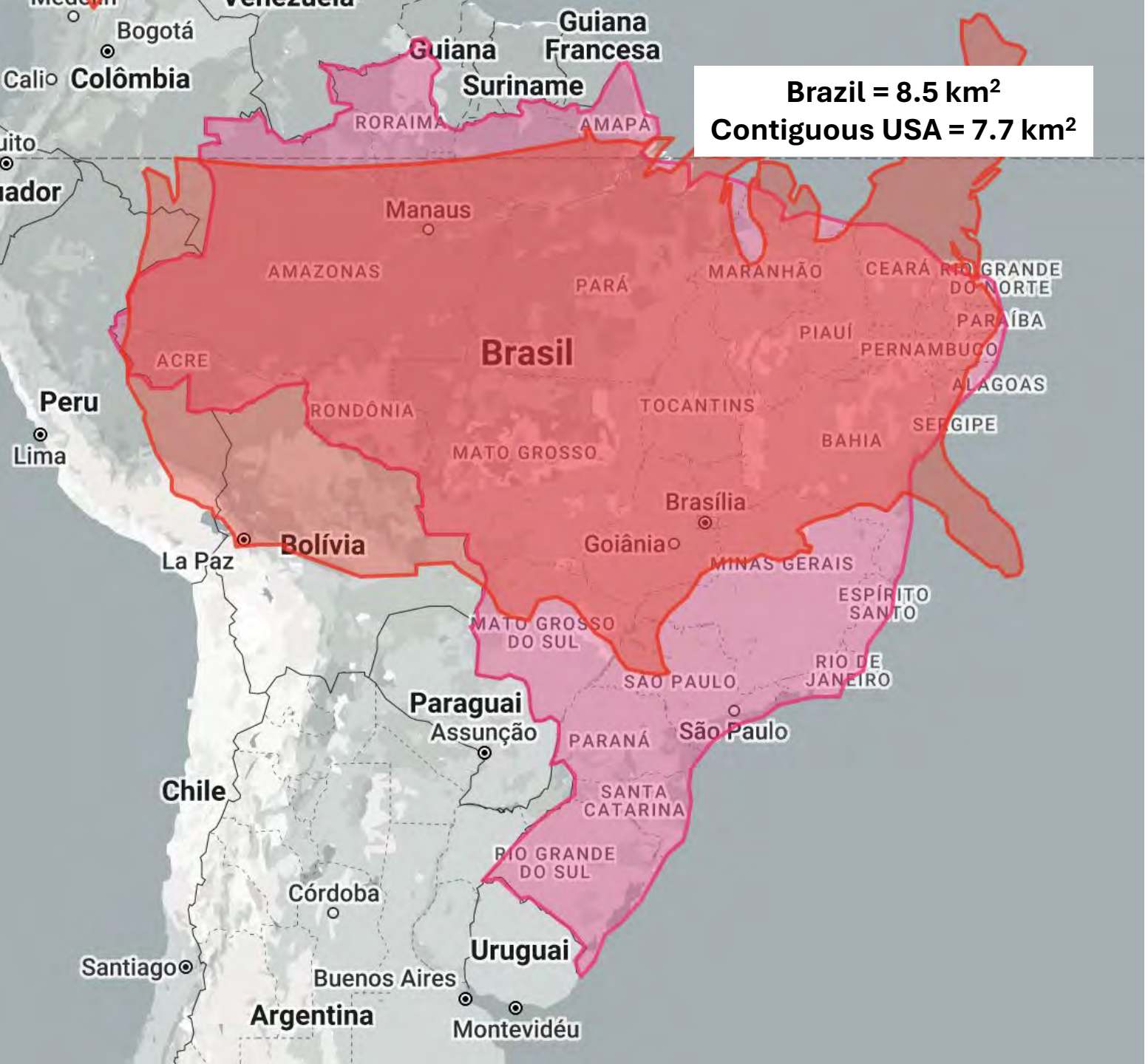
Notas:
1 - Este mapa não reflete fronteiras em disputa.
2 - * = Território não autônomo.
3 - O Brasil está com a presidência pro tempore do BRICS em 2025.
4 - O Brasil estará com a presidência pro tempore da REES - Reunião Especializada de Estatística do Mercosul a partir de julho de 2025.

Rio de Janeiro - capital dos BRICS
Belém - capital da COP30
Ceará - Estado sede do Triple Fórum Internacional da Governança do Sul Global - 11 a 13 de junho de 2025

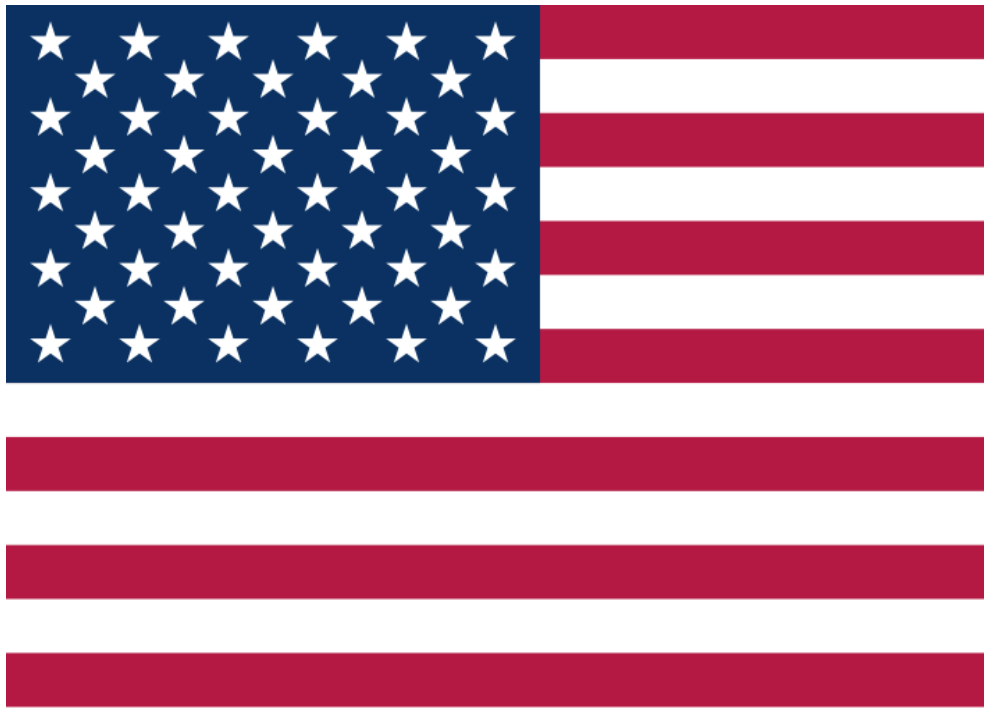
País-membro
BRICS
CPLP - Comunidade dos Países de Língua Portuguesa
Mercosul - Mercado Comum do Sul
OTCA - Organização do Tratado de Cooperação Amazônica
BRICS / CPLP / Mercosul / OTCA

A more familiar way to see the globe...




Brazil = 8.5 km²
Contiguous USA = 7.7 km²
Bogotá
Colômbia
Guiana
Guiana Francesa
Suriname
RORAIMA
AMAPÁ
Manaus
AMAZONAS
PARÁ
MARANHÃO
CEARÁ
RIO GRANDE DO NORTE
PARAÍBA
PIAUÍ
PERNAMBUCO
ALAGOAS
SERGIPE
BAHIA
Brasil
ACRE
RONDÔNIA
TOCANTINS
MATO GROSSO
Peru
Lima
Brasília
Goiânia
Bolívia
La Paz
MINAS GERAIS
ESPÍRITO SANTO
MATO GROSSO DO SUL
RIO DE JANEIRO
SÃO PAULO
São Paulo
Paraguai
Assunção
PARANÁ
Chile
SANTA CATARINA
RIO GRANDE DO SUL
Córdoba
Uruguai
Santiago
Buenos Aires
Argentina
Montevidéu


ORDEM E PROGRESSO



Ways to divide Brazil: by states

26 states + Federal District

1. Acre (AC)
2. Alagoas (AL)
3. Amapá (AP)
4. Amazonas (AM)
5. Bahia (BA)
6. Ceará (CE)
7. Distrito Federal (DF)
8. Espírito Santo (ES)
9. Goiás (GO)
10. Maranhão (MA)
11. Mato Grosso (MT)
12. Mato Grosso do Sul (MS)
13. Minas Gerais (MG)
14. Pará (PA)
15. Paraíba (PB)
16. Paraná (PR)
17. Pernambuco (PE)
18. Piauí (PI)
19. Rio de Janeiro (RJ)
20. Rio Grande do Norte (RN)
21. Rio Grande do Sul (RS)
22. Rondônia (RO)
23. Roraima (RR)
24. Santa Catarina (SC)
25. São Paulo (SP)
26. Sergipe (SE)
27. Tocantins (TO)

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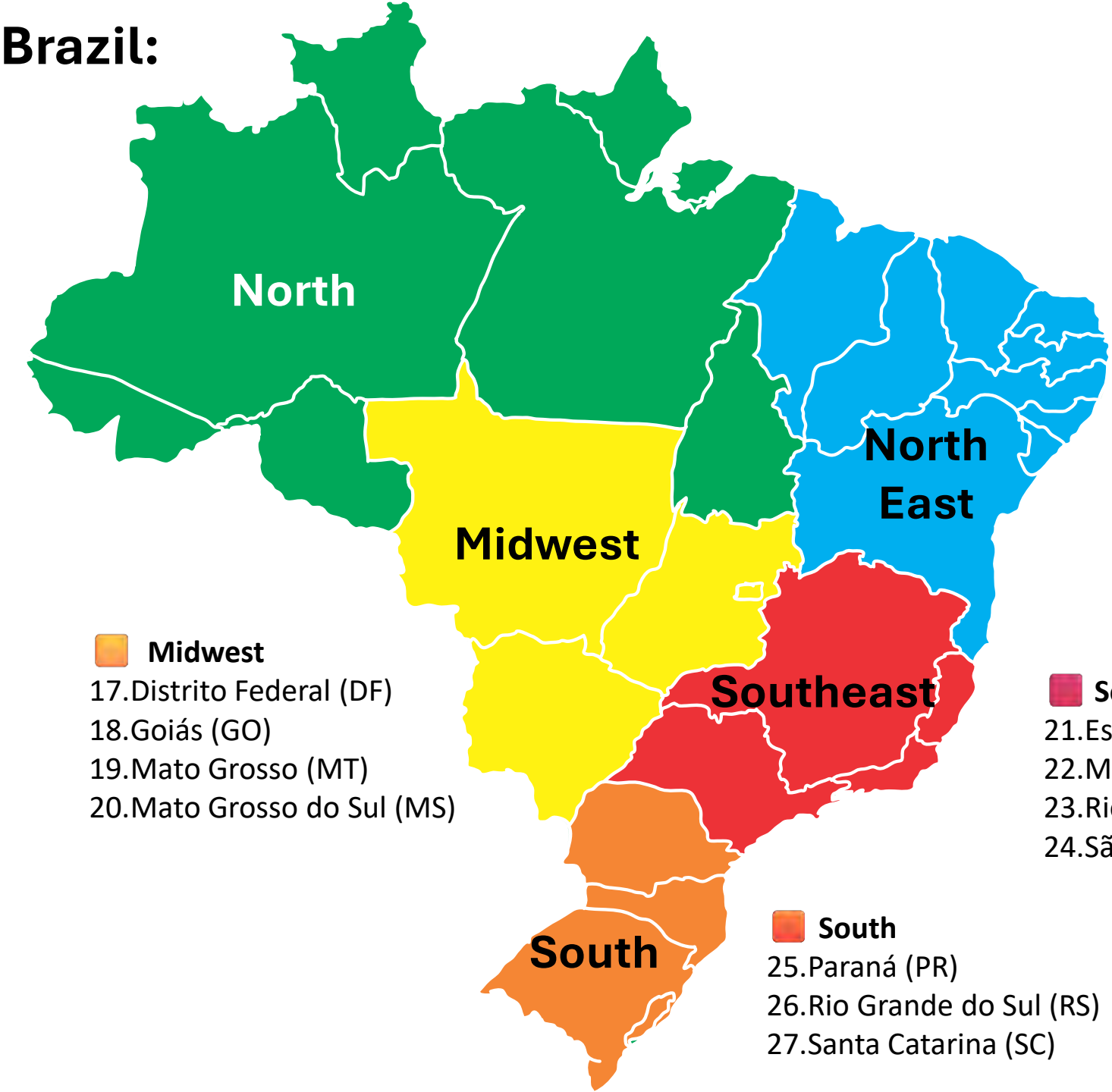
23. Roraima (RR)
24. Santa Catarina (SC)
25. São Paulo (SP)
26. Sergipe (SE)
27. Tocantins (TO)

Tropic of Capricorn

I live here,
in the state of
Rio Grande do Sul

Ways to divide Brazil: by regions



North
1.Acre (AC)
2.Amapá (AP)
3.Amazonas (AM)
4.Pará (PA)
5.Rondônia (RO)
6.Roraima (RR)
7.Tocantins (TO)

North East
8.Alagoas (AL)
9.Bahia (BA)
10.Ceará (CE)
11.Maranhão (MA)
12.Paraíba (PB)
13.Pernambuco (PE)
14.Piauí (PI)
15.Rio Grande do Norte (RN)
16.Sergipe (SE)

Midwest
17.Distrito Federal (DF)
18.Goiás (GO)
19.Mato Grosso (MT)
20.Mato Grosso do Sul (MS)

Southeast
21.Espírito Santo (ES)
22.Minas Gerais (MG)
23.Rio de Janeiro (RJ)
24.São Paulo (SP)

South
25.Paraná (PR)
26.Rio Grande do Sul (RS)
27.Santa Catarina (SC)

Ways to divide Brazil:

9 regional centers according to the Brazilian Society of Soil Science

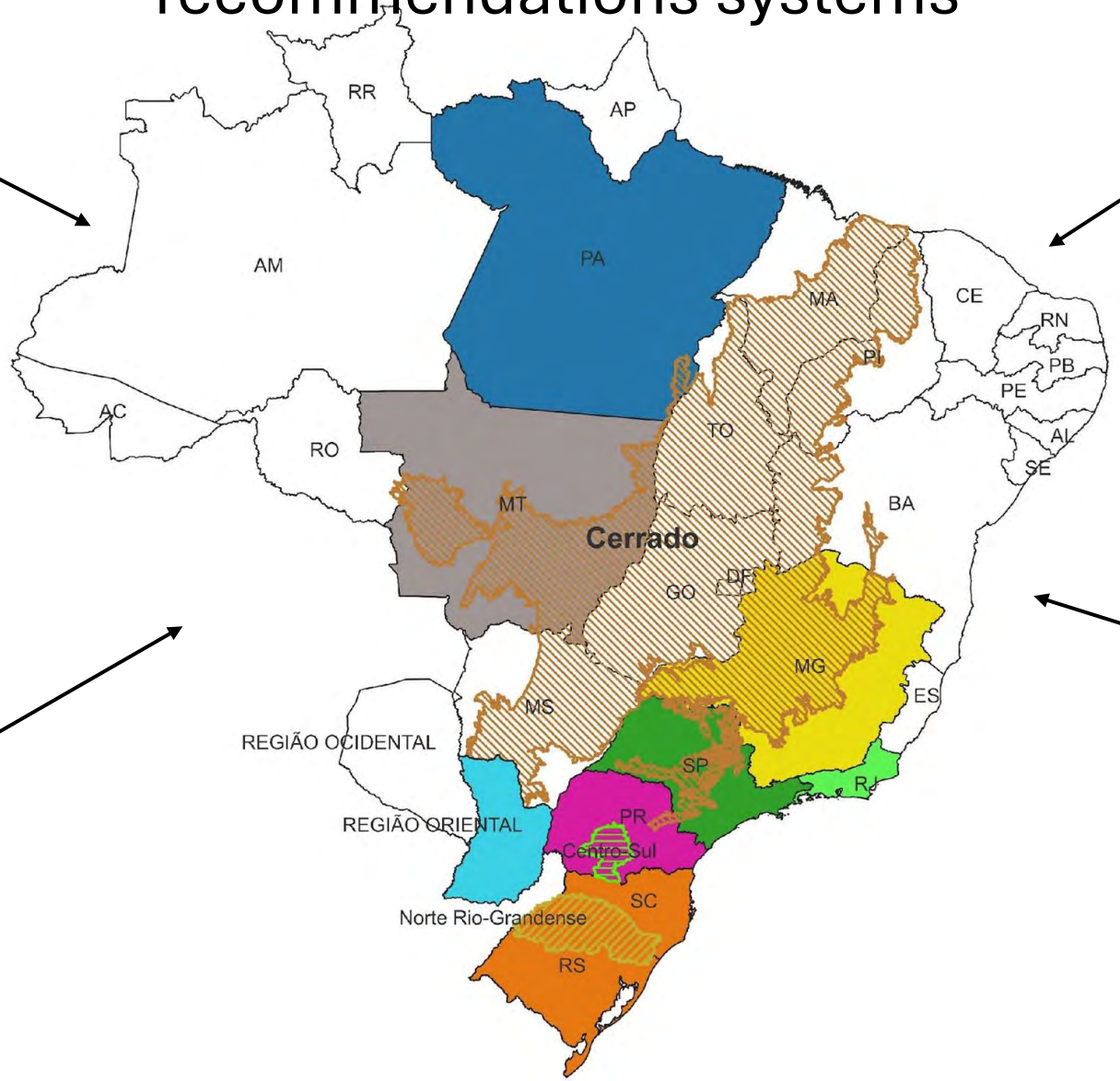
Ways to divide Brazil:

by Biomas

Hybrid way to divide Brazil:
according to liming and fertilization recommendations systems

States

Regions

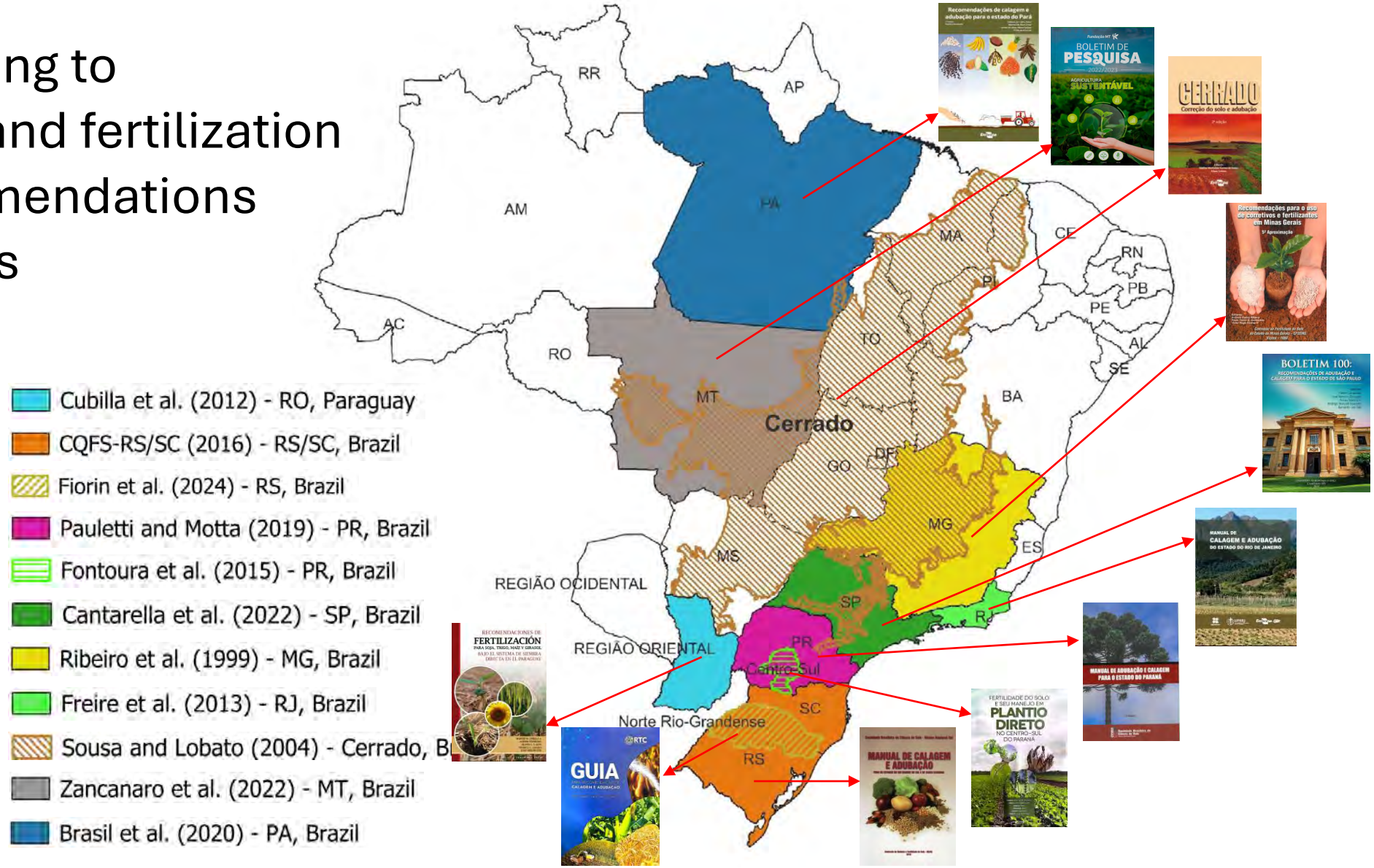


Sociedade Brasileira de Ciência do Solo

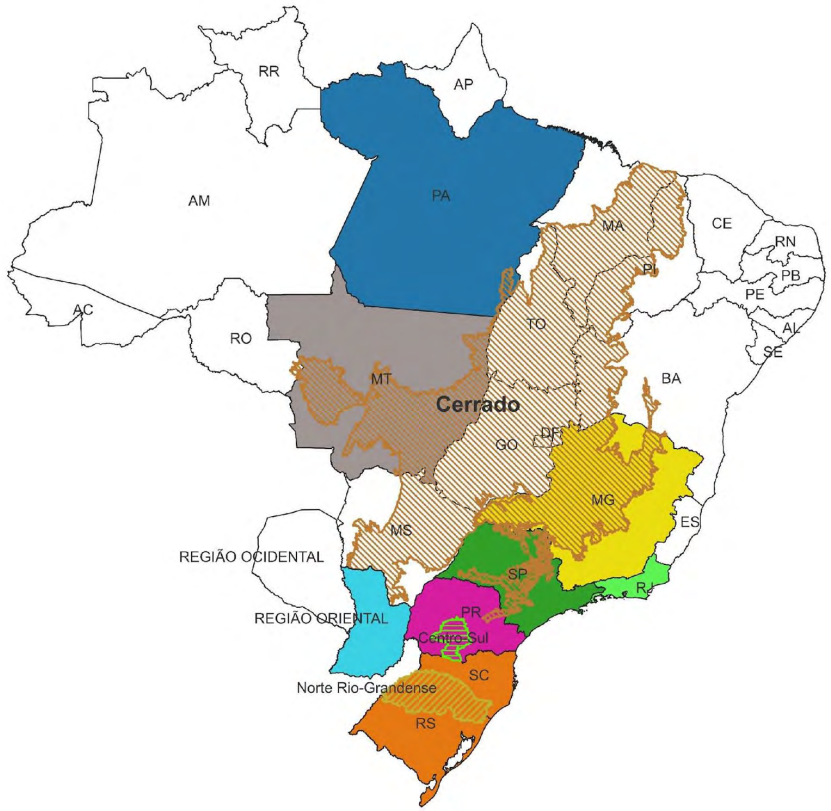
Biomas

Ways to divide Brazil:

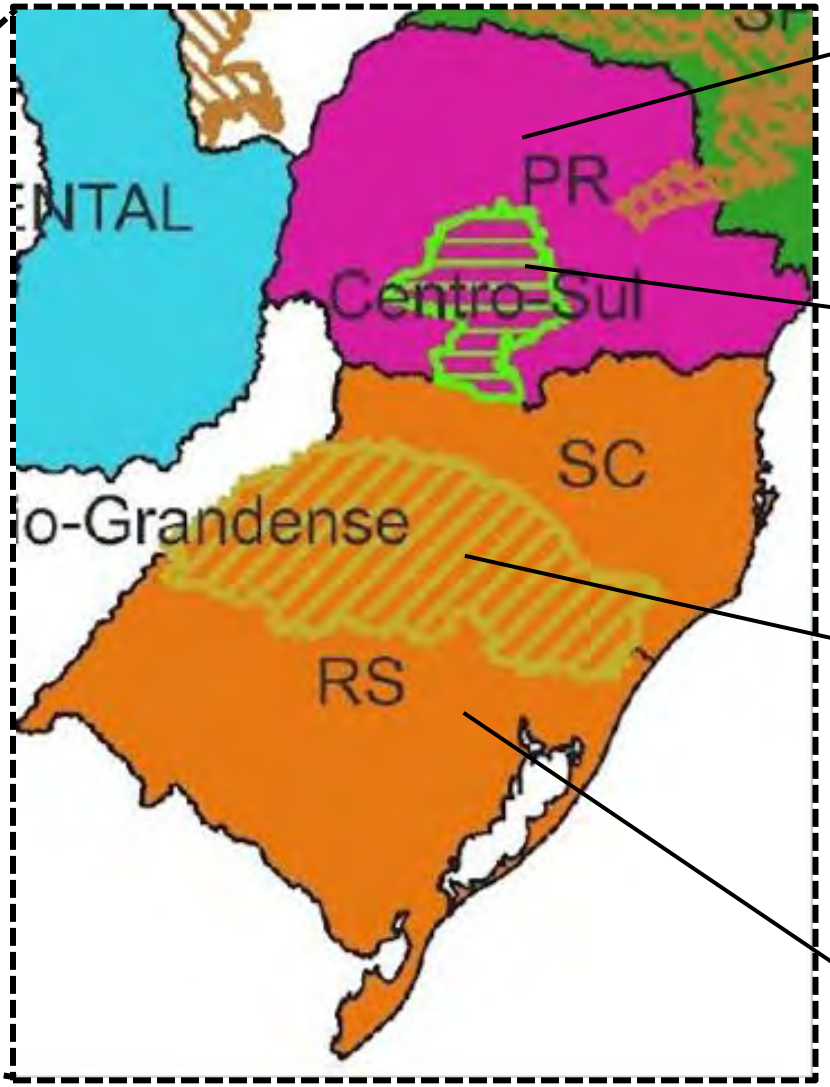
according to
liming and fertilization
recommendations
systems

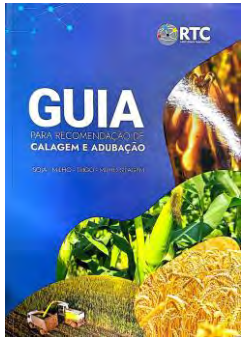


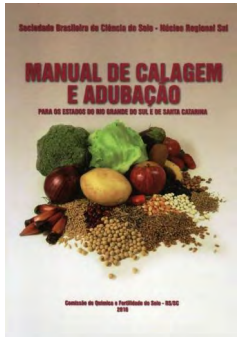
Overlapping issues



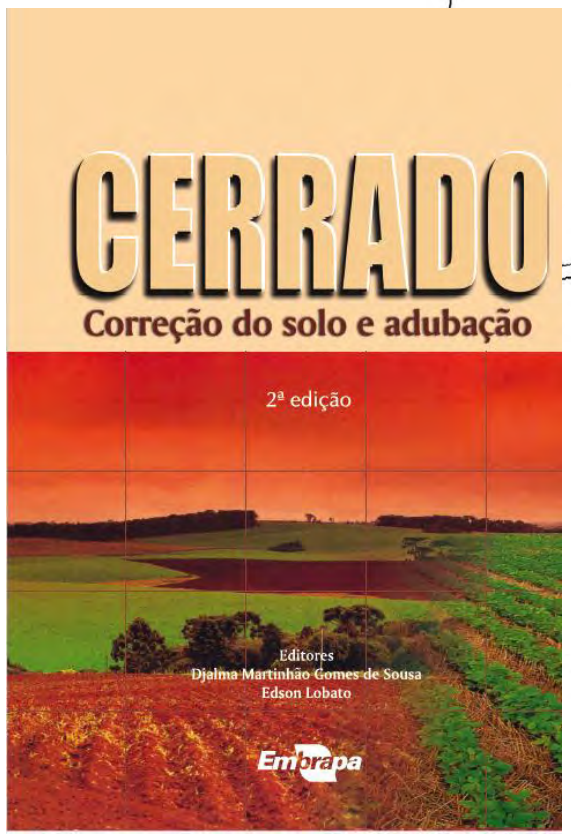
Overlapping issues

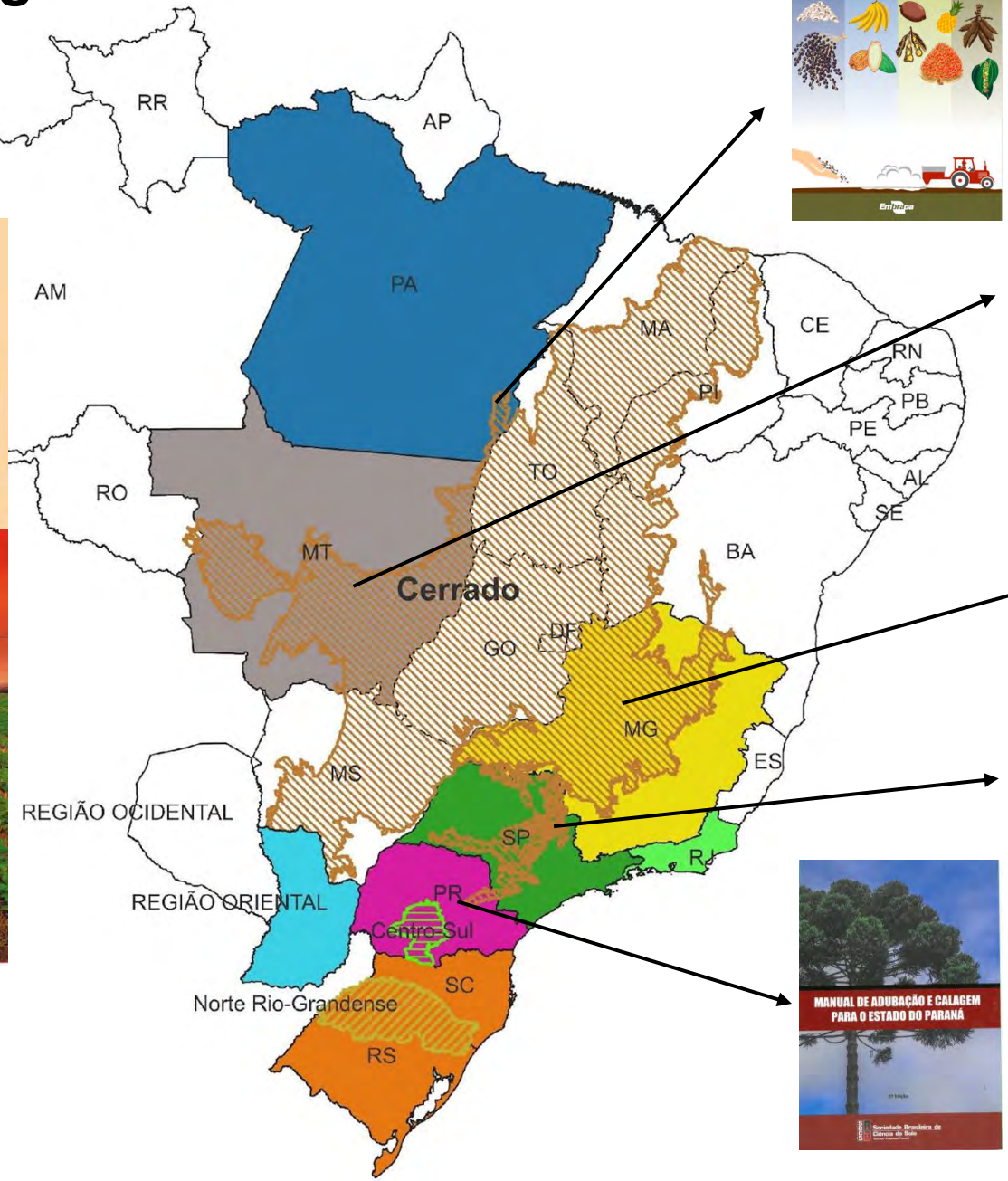






Overlapping issues



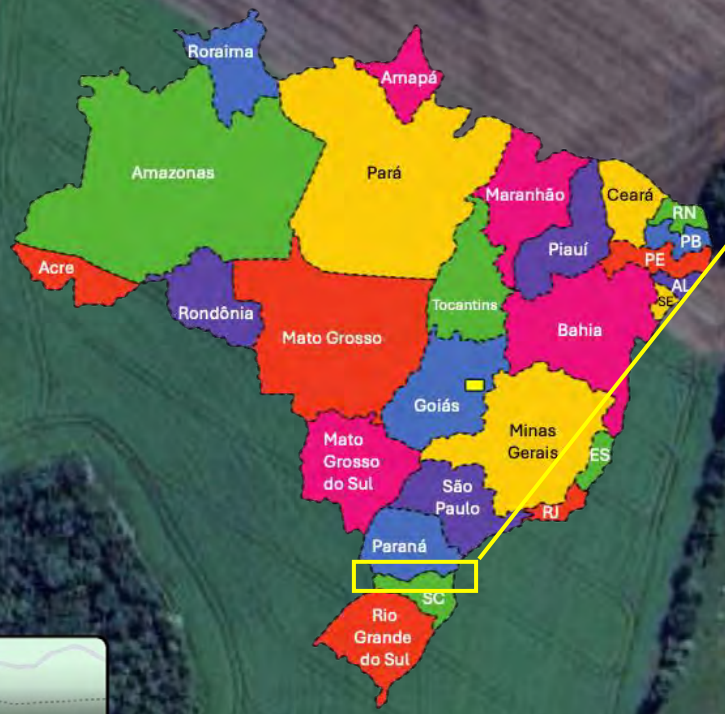


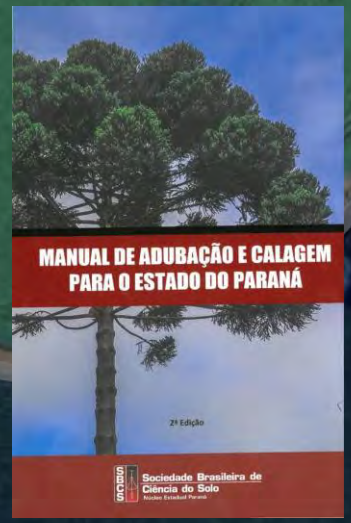
Issues of geopolitical division between states

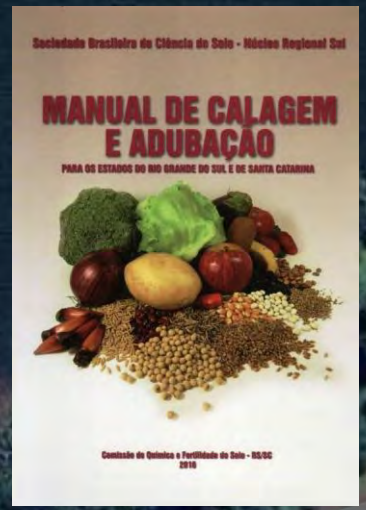
PARANÁ
SANTA CATARINA

PARANÁ
SANTA CATARINA

PARANÁ



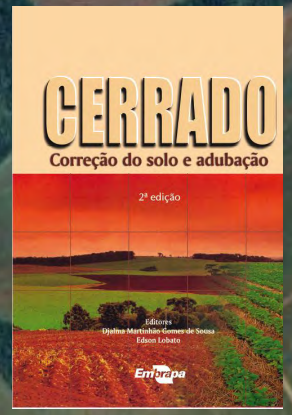


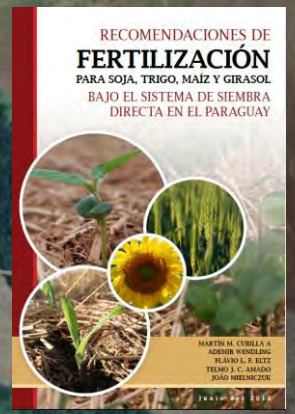


Camadas

Google

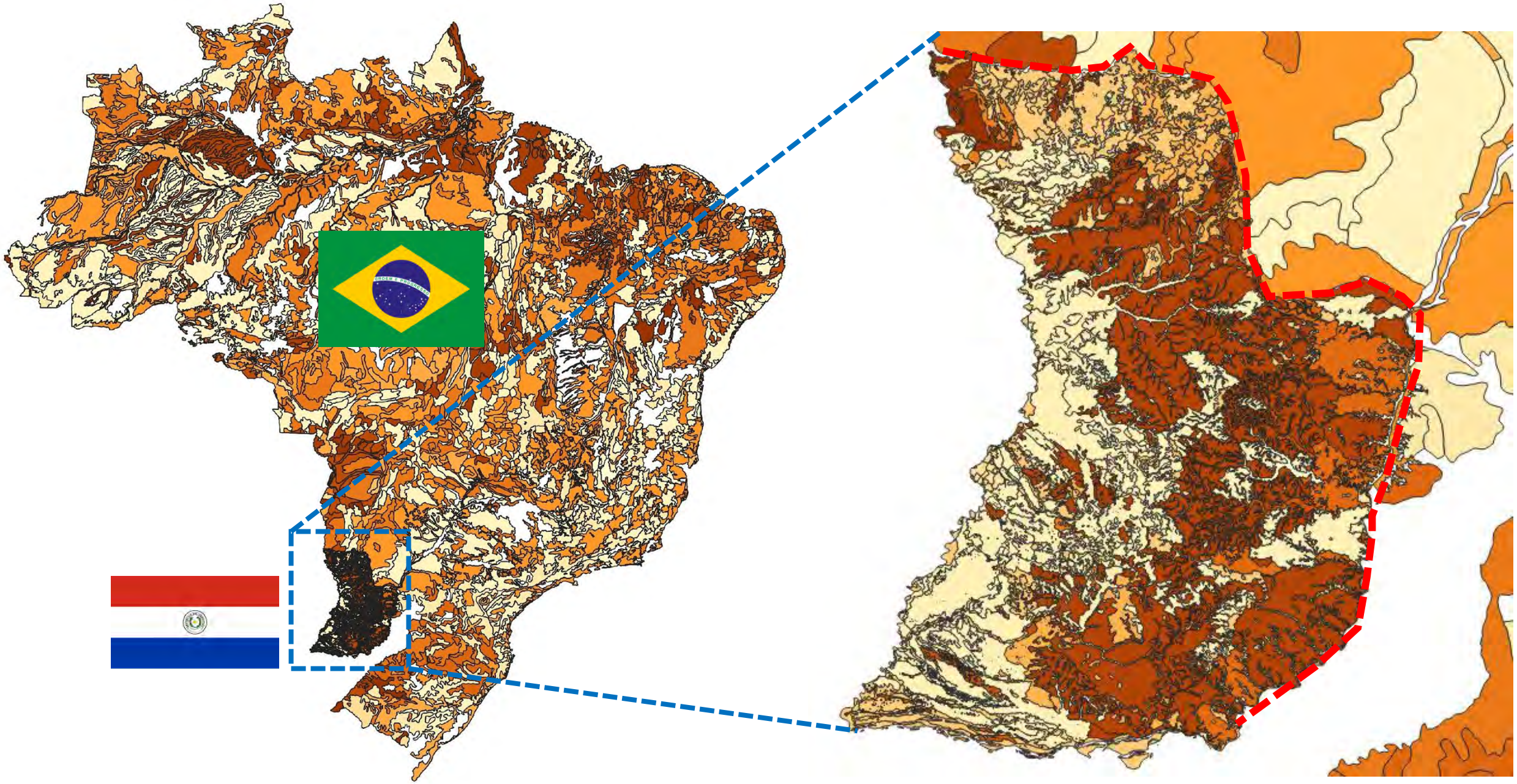
Issues of geopolitical division between countries






Guyana
Suriname
French Guiana
Venezuela
Colombia
Ecuador
Peru
Brazil
Bolivia
Paraguay
Argentina
Chile
Uruguay
Falkland
Islands


Guyana
Suriname
Venezuela
French Guiana
Colombia
Ecuador
Peru
Brazil
Bolivia
Paraguay
Argentina
Chile
Uruguay
Falkland
Islands

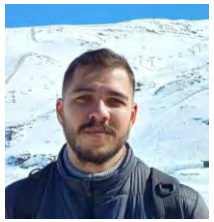


Phosphorus and potassium fertilizer recommendations in Brazil and Paraguay:
convergences, divergences, and paths towards harmonization

Phosphorus

Alder Delosantos Duarte Monzón
PhD candidate in Soil Science
Federal University of Rio Grande do Sul

Potassium



Gustavo Frosi
PhD candidate in Soil Science
Federal University of Rio Grande do Sul

Phosphorus and potassium fertilizer recommendations in Brazil and Paraguay: convergences, divergences, and paths towards harmonization

Reference	Location/Country	Diagnostic soil layer (cm)	Extractor
Cubilla et al. (2012)	Região Oriental (RO), Paraguai	0-10	Mehlich-1
CQFS-RS/SC (2016)	Estados do Rio Grande do Sul (RS) e de Santa Catarina (SC), Brasil	0-10; 10-20	Mehlich-1
Fiorin et al. (2024)	Estado do Rio Grande do Sul (RS)	0-20	Mehlich-1
Pauletti and Motta (2019)	Estado do Paraná (PR), Brasil	0-20	Mehlich-1
Fontoura et al. (2015)	Região Centro-Sul do (PR), Brasil	0-20	Mehlich-1
Cantarella et al. (2022)	Estado de São Paulo (SP), Brasil	0-20	Resina
Ribeiro et al. (1999)	Estado de Minas Gerais (MG), Brasil	0-20	Mehlich-1
Freire et al. (2013)	Estado do Rio de Janeiro (RJ), Brasil	0-20	Mehlich-1
Sousa and Lobato (2004)	Região do Cerrado, Brasil	0-20	Mehlich-1
Zancanaro et al. (2022)	Estado do Mato Grosso (MT), Brasil	0-20	Mehlich-1
Brasil et al. (2020)	Estado do Pará (PA), Brasil	0-20	Mehlich-1

Phosphorus fertilizer recommendations in Brazil and Paraguay:
convergences, divergences, and paths towards harmonization

Convergences points:

All the systems use classes of availability

Use of the same Mehlich-1 extractor (except São Paulo state)

Use of clay content as a criterion (some exceptions)

Critical P content varies with clay content (some exceptions)

Divergences points:

Use of different diagnostic soil layers

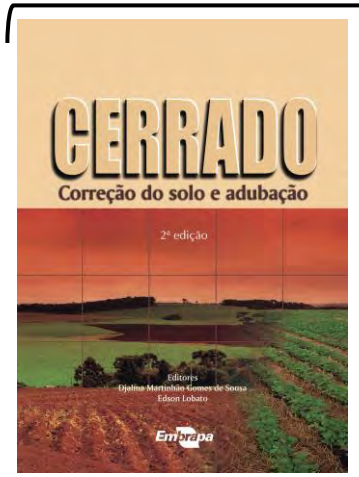
Different number of availability classes

Availability classes with different names

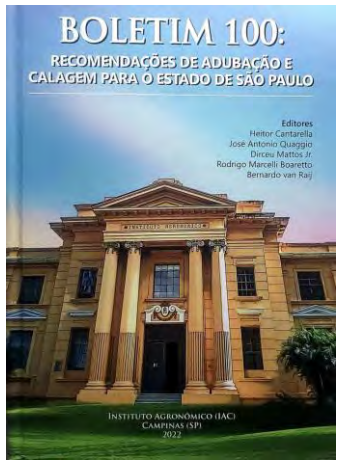
Different ranges of availability classes

Diagnostic soil layer

0-20 cm (0-8 inches)



Cerrado



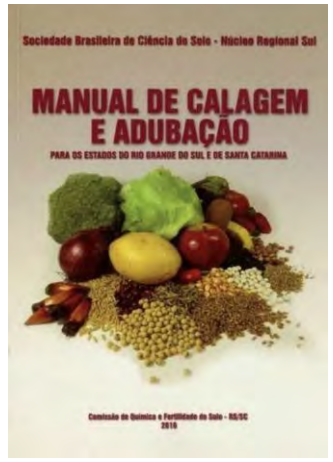
São Paulo

Minas Gerais

Paraná

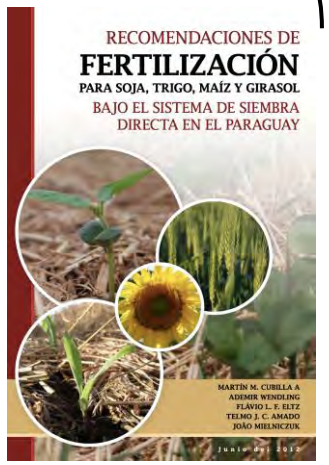
PR - Centro-Sul

0-10 and 10-20 cm (0-4 and 4-8 inches)



RS e SC

0-10 cm (0-4 inches)

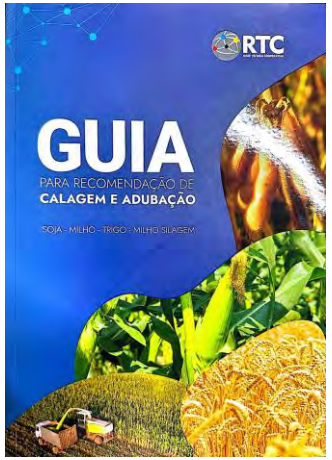


Paraguai

Pará

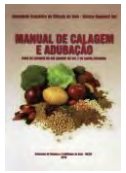
Mato Grosso

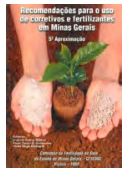
Rio de Janeiro

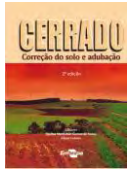


RS - Norte

Classes of P availability



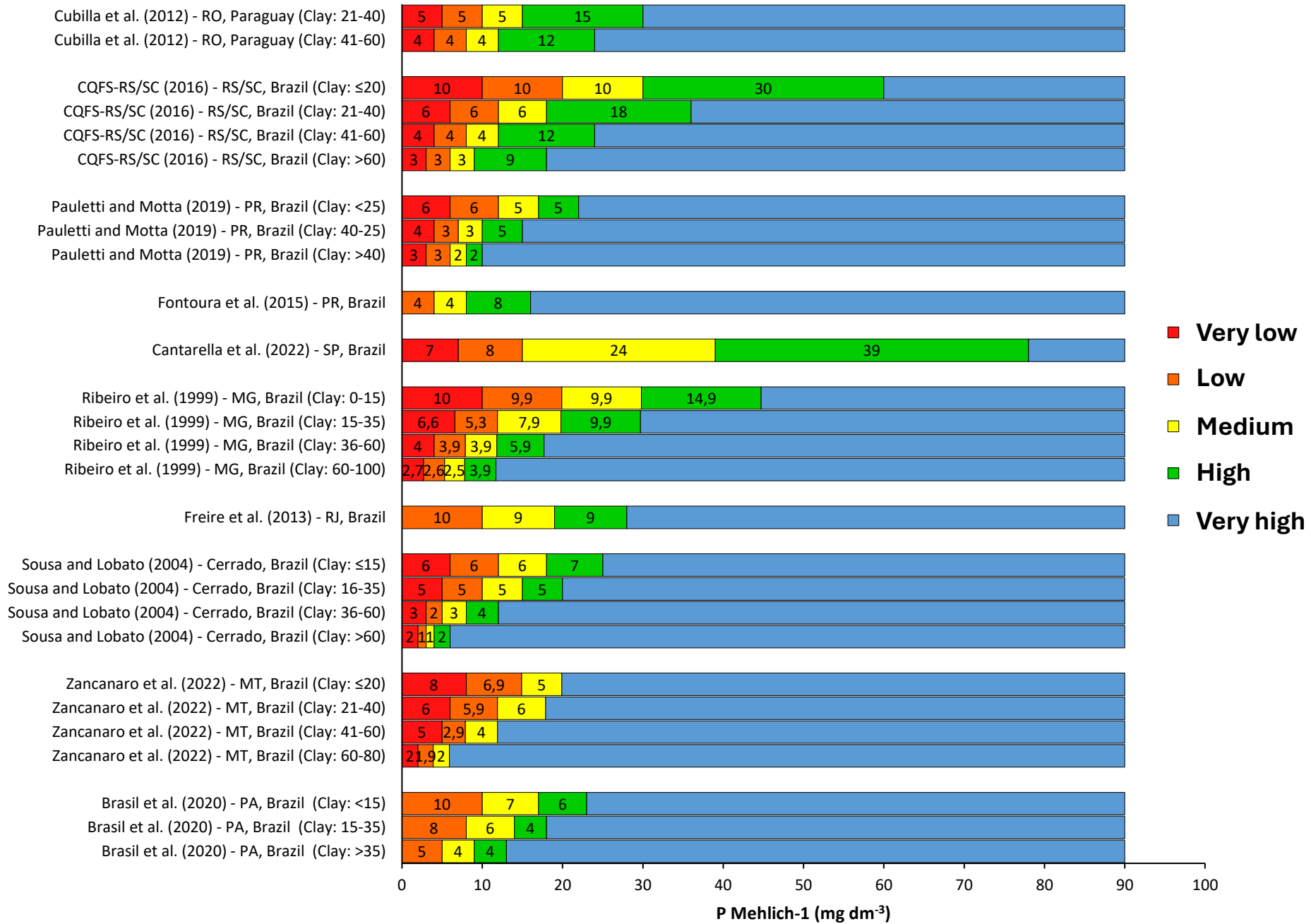


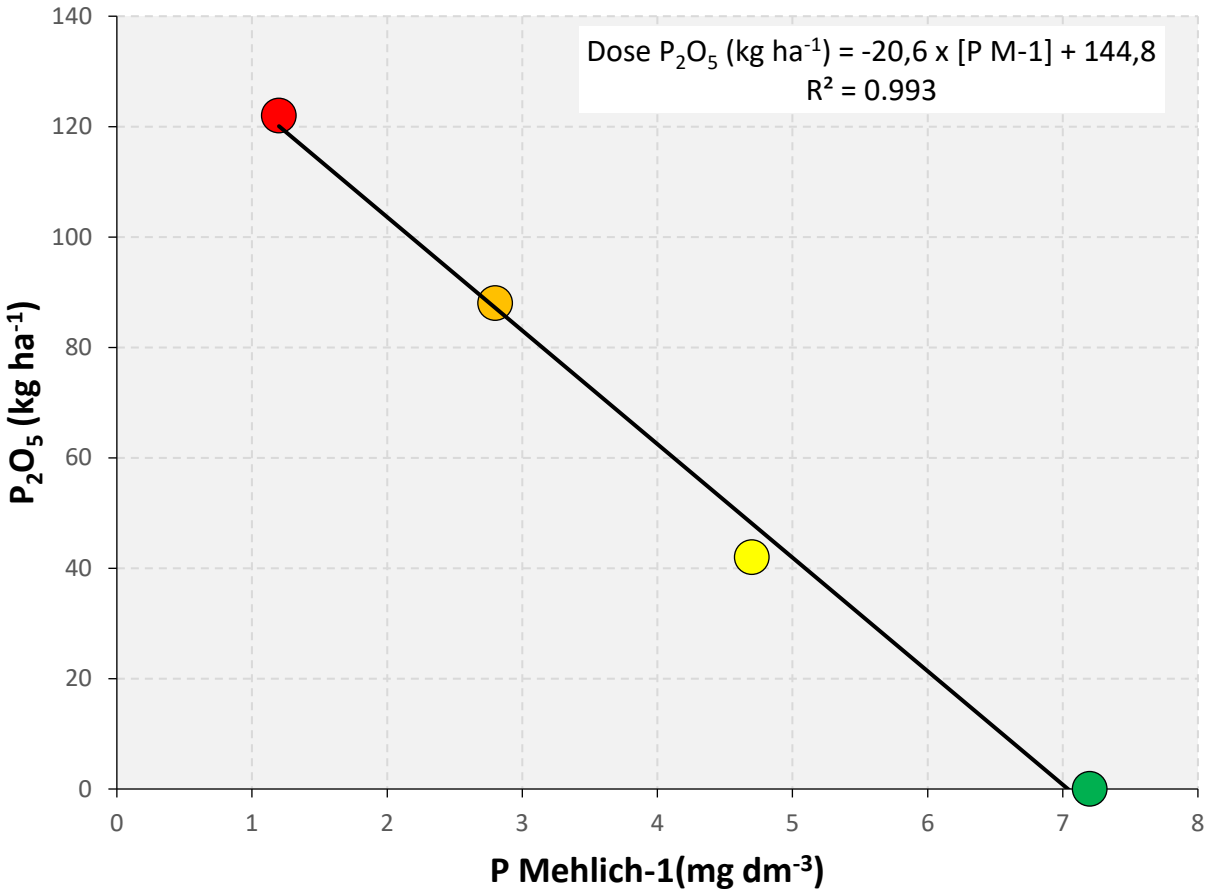


	Nível crítico					N.º Classes
Cubilla et al. (2012) RO, Paraguay	Muito baixo	Baixo	Médio	Alto	Muito alto	5
CQFS-RS/SC (2016) RS/SC, Brazil	Muito baixo	Baixo	Médio	Alto	Muito alto	5
Pauletti and Motta (2019) PR, Brazil	Muito baixo	Baixo	Médio	Alto	Muito alto	5
Fontoura et al. (2015) PR, Brazil	✕	Baixo	Médio	Alto	Muito alto	4
Cantarella et al. (2022) SP, Brazil	Muito baixo	Baixo	Médio	Alto	Muito alto	5
Ribeiro et al. (1999) MG, Brazil	Muito baixo	Baixo	Médio	Bom ⚠	Muito alto	5
Freire et al. (2013) RJ, Brazil	✕	Baixo	Médio	Alto	Muito alto	4
Sousa and Lobato (2004) Cerrado, Brazil	Muito baixo	Baixo	Médio	Suficiente ⚠	Alto ⚠	5
Zancanaro et al. (2022) MT, Brazil	Muito baixo	Baixo	Médio	Suficiente ⚠	✕	4
Brasil et al. (2020) PA, Brazil	✕	Baixo	Médio	Alto	Muito alto	4

Legend:
Muito baixo = Very low
Baixo = Low
Médio = Average
Alto = High
Muito alto = Very high
Suficiente = Enough
Bom = God

Range of classes of P availability




Dose P_2O_5 (kg ha^{-1}) = -20,6 x [P M-1] + 144,8
R^2 = 0.993
P_2O_5 (kg ha^{-1})
P Mehlich-1(mg dm^{-3})
0
20
40
60
80
100
120
140
0
1
2
3
4
5
6
7
8

Phosphate fertilization recommendations in Brazil and Paraguay BR PY : convergences, divergences and paths towards harmonization

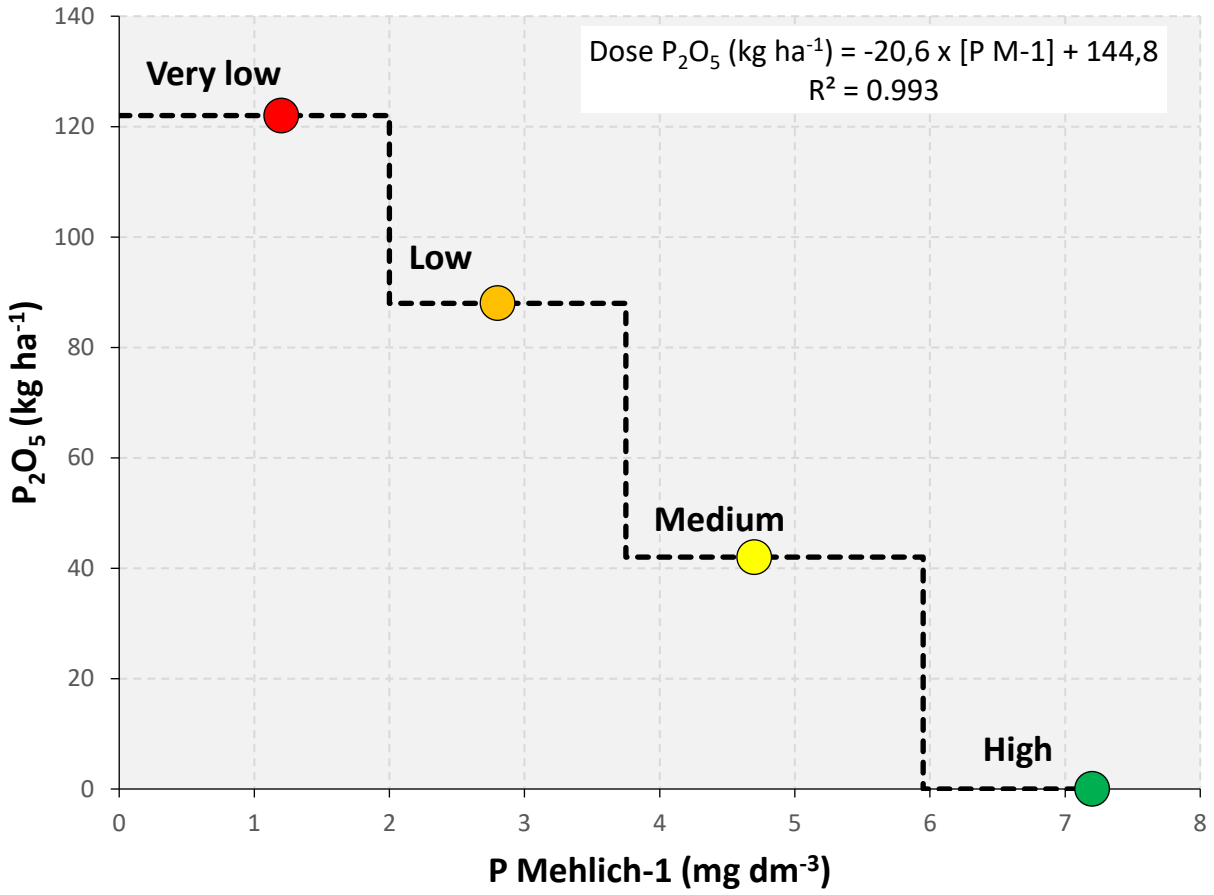


Tabela 3. Interpretação da análise de solo para P extraído pelo método Mehlich-1, de acordo com o teor de argila, para recomendação de adubação fosfatada em sistemas de sequeiro com culturas anuais.

Teor de argila	Teor de P no solo				
	Muito baixo	Baixo	Médio	Adequado	Alto
%	mg/dm³				
≤ 15	0 a 6,0	6,1 a 12,0	12,1 a 18,0	18,1 a 25,0	> 25,0
16 a 35	0 a 5,0	5,1 a 10,0	10,1 a 15,0	15,1 a 20,0	> 20,0
36 a 60	0 a 3,0	3,1 a 5,0	5,1 a 8,0	8,1 a 12,0	> 12,0
>60	0 a 2,0	2,1 a 3,0	3,1 a 4,0	4,1 a 6,0	> 6,0

Fonte: Adaptado de Sousa et al. (1987a).

Tabela 6.4. Interpretação do teor de fósforo no solo extraído pelo método Mehlich-1, conforme o teor de argila para culturas do Grupo 2 (culturas de grãos, exceto arroz irrigado; hortaliças, exceto as do Grupo 1; pastagens, exceto pastagem natural; frutíferas e gengibre)

Classe de disponibilidade	Classe de teor de argila[1,2]			
	1	2	3	4
	mg de P/dm³			
Muito baixo	≤3,0	≤4,0	≤6,0	≤10,0
Baixo	3,1 - 6,0	4,1 - 8,0	6,1 - 12,0	10,1 - 20,0
Médio	6,1 - **9,0**	8,1 - **12,0**	12,1 - **18,0**	20,1 - **30,0**
Alto	9,1 - 18,0	12,1 - 24,0	18,1 - 36,0	30,1 - 60,0
Muito alto	>18,0	>24,0	>36,0	>60,0

[1] Teores de argila: classe 1 = >60%; classe 2 = 60 a 41%; classe 3 = 40 a 21%; classe 4 = ≤ 20%.
[2] Caso a análise tenha sido feita por Mehlich-3, transformar previamente os teores em "equivalentes Mehlich-1", conforme equação PM1= PM3/(2 - (0,02 x arg)) (Capítulo 4).

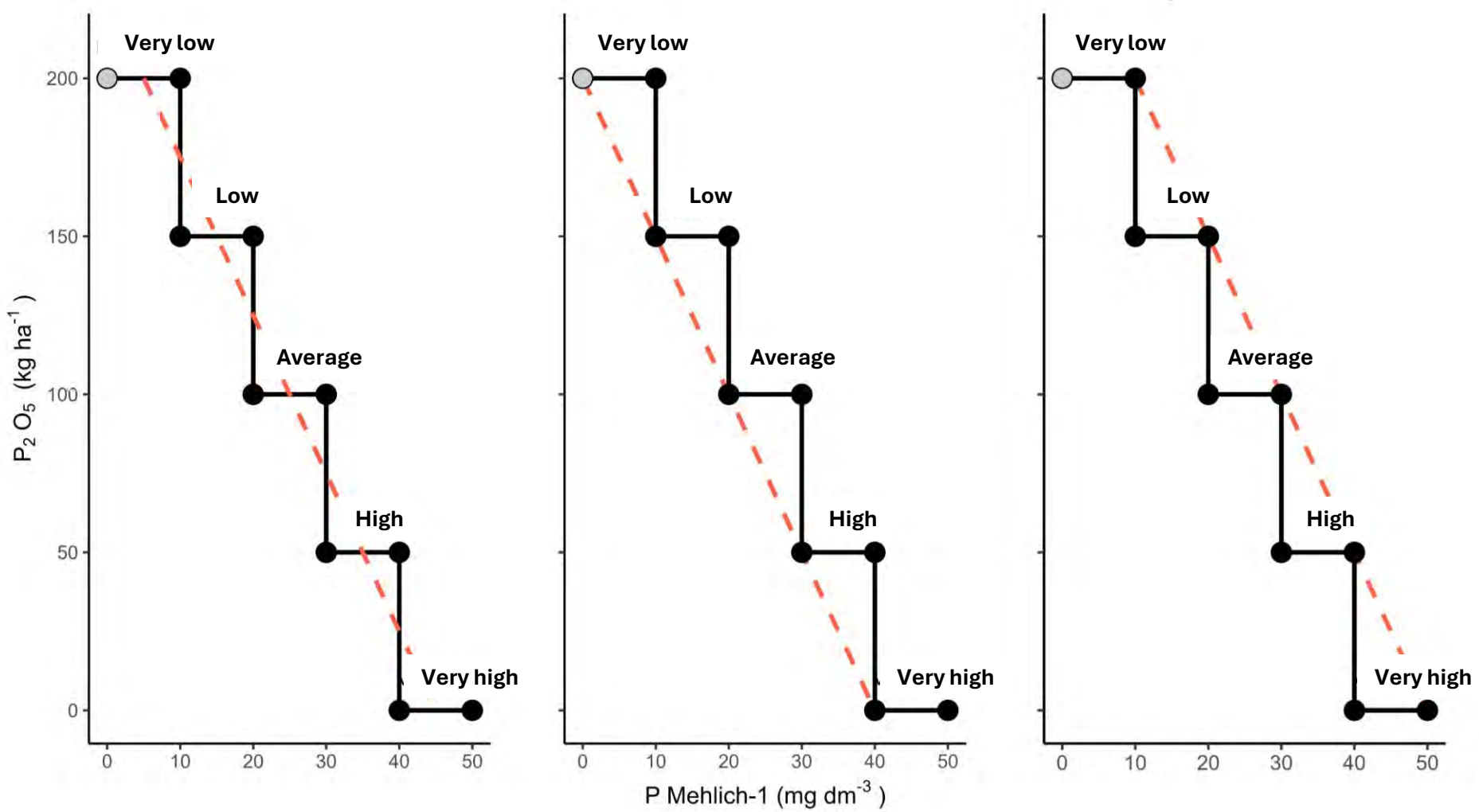
Tabla 2. Categoría de disponibilidad de P para los cultivos, tenor de P extraíble por Mehlich-1 en cada categoría, rendimiento relativo esperado y probabilidad de respuesta de los cultivos a la aplicación de fertilizantes fosfatados para la Clase 1 de suelo.

CATEGORÍA	P MEHLICH-1 (mg dm^{-3})	RR [1]	PROBABILIDAD DE RESPUESTA
Muy baja	≤ 4,0	Menor 55%	Alta
Baja	4,1 – 8,0	56 – 80%	Media
Media	8,1 – 12,0	81 – 90%	Baja
Alta	12,1 – 24,0	90 – 100%	Muy baja
Muy alta	> 24	100%	Muy baja o casual

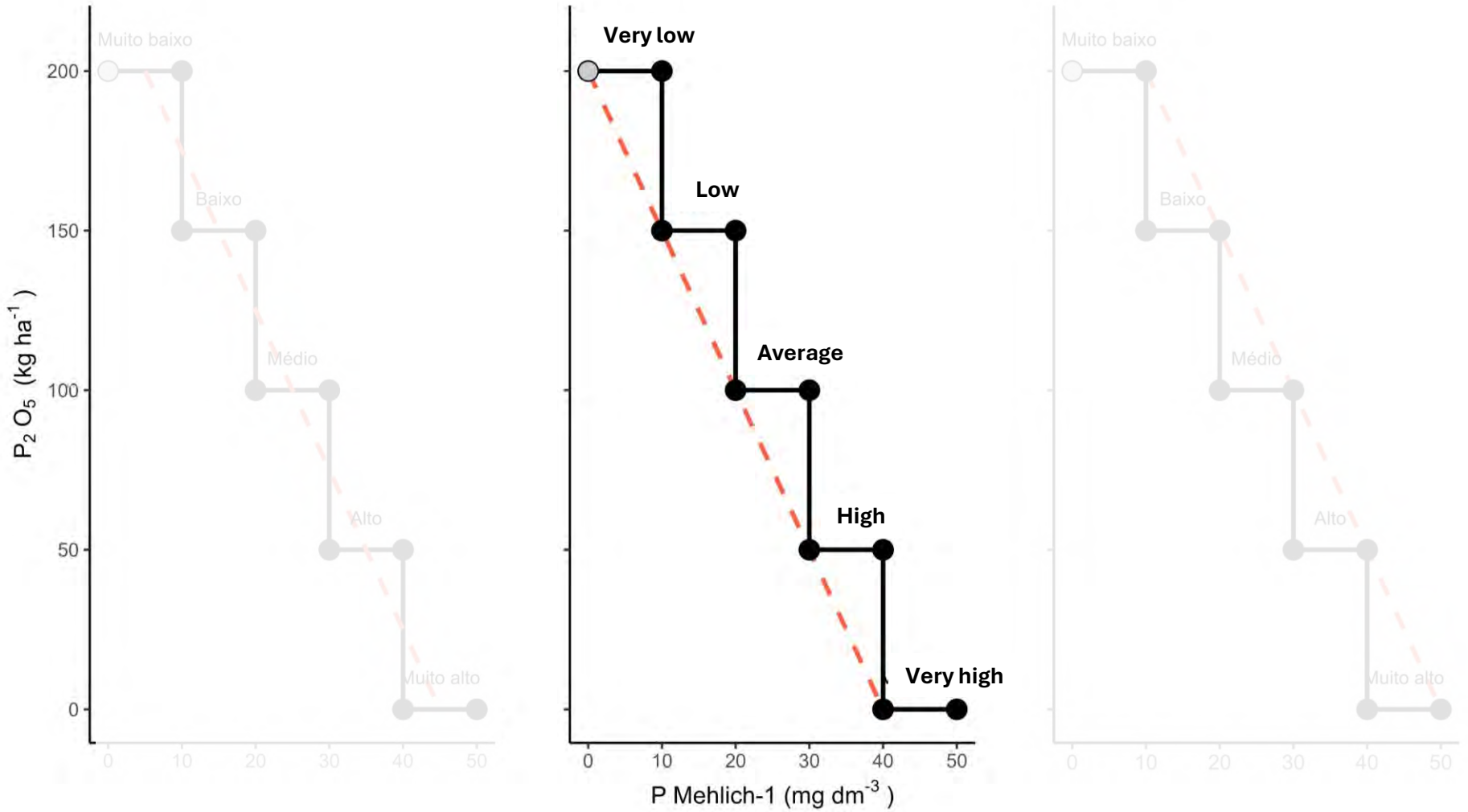
[1] RR = Rendimiento Relativo

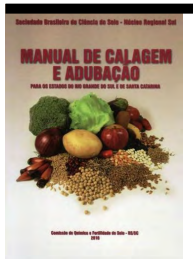
Fuente: Cubilla (2005)

Phosphate fertilization recommendations in Brazil and Paraguay BR PY : convergences, divergences and paths towards harmonization

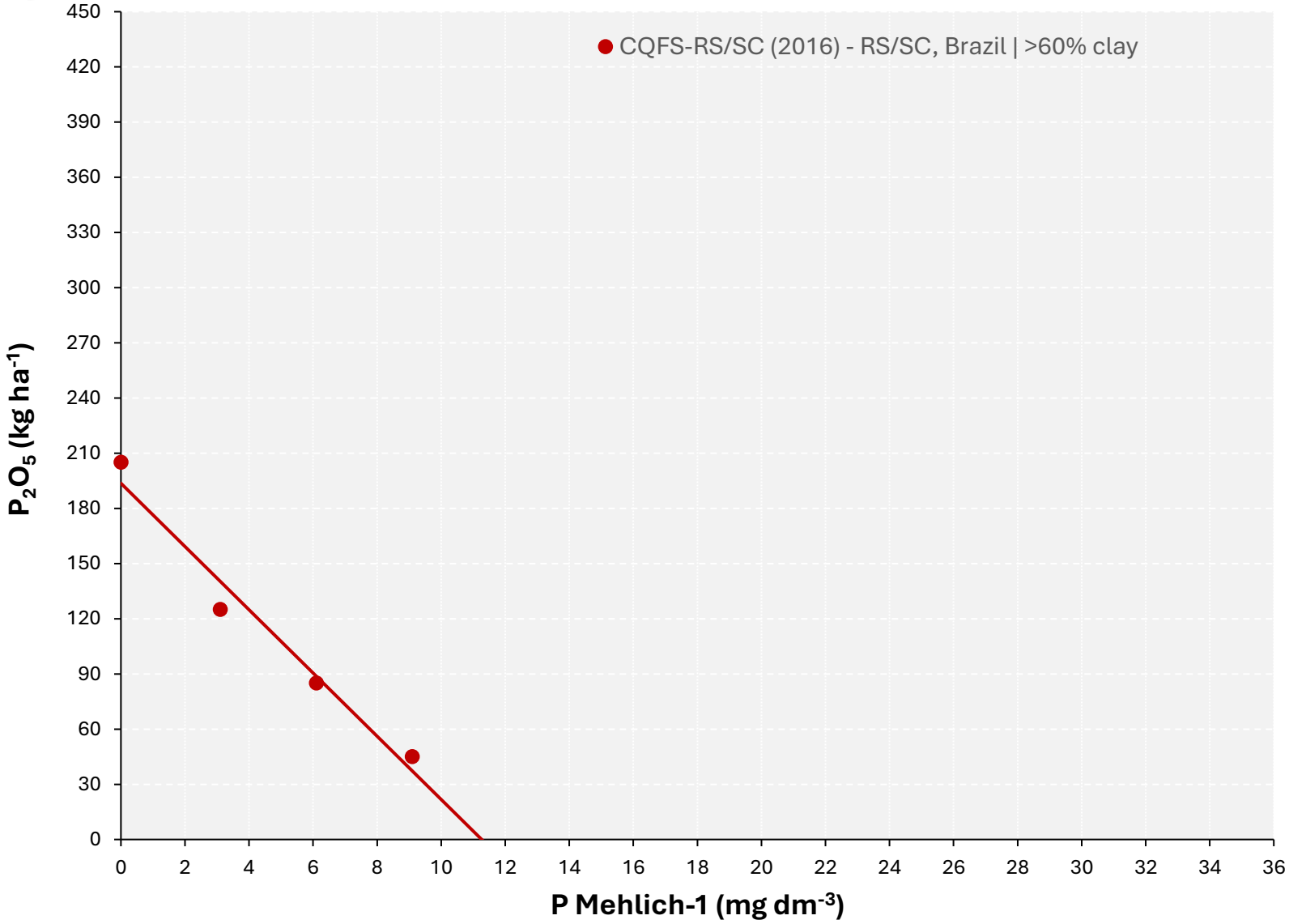


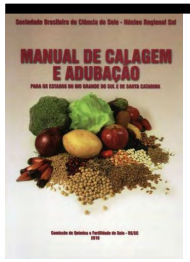
Phosphate fertilization recommendations in Brazil and Paraguay BR PY : convergences, divergences and paths towards harmonization



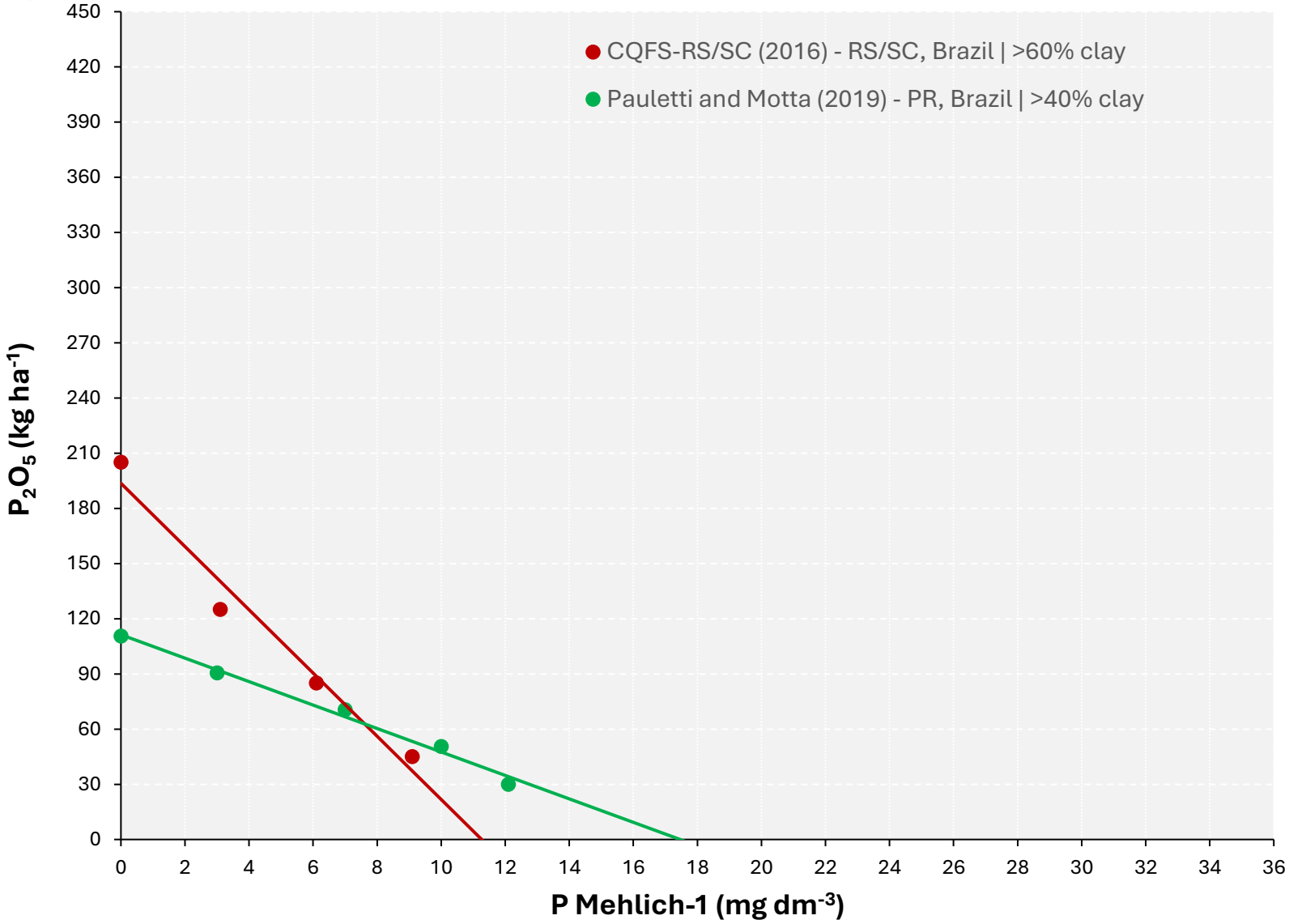


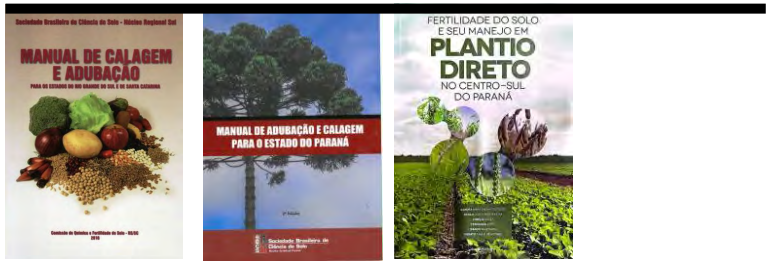
Rate of P_2O_5 for 3 ton/ha of soybean [45 bu/ac]



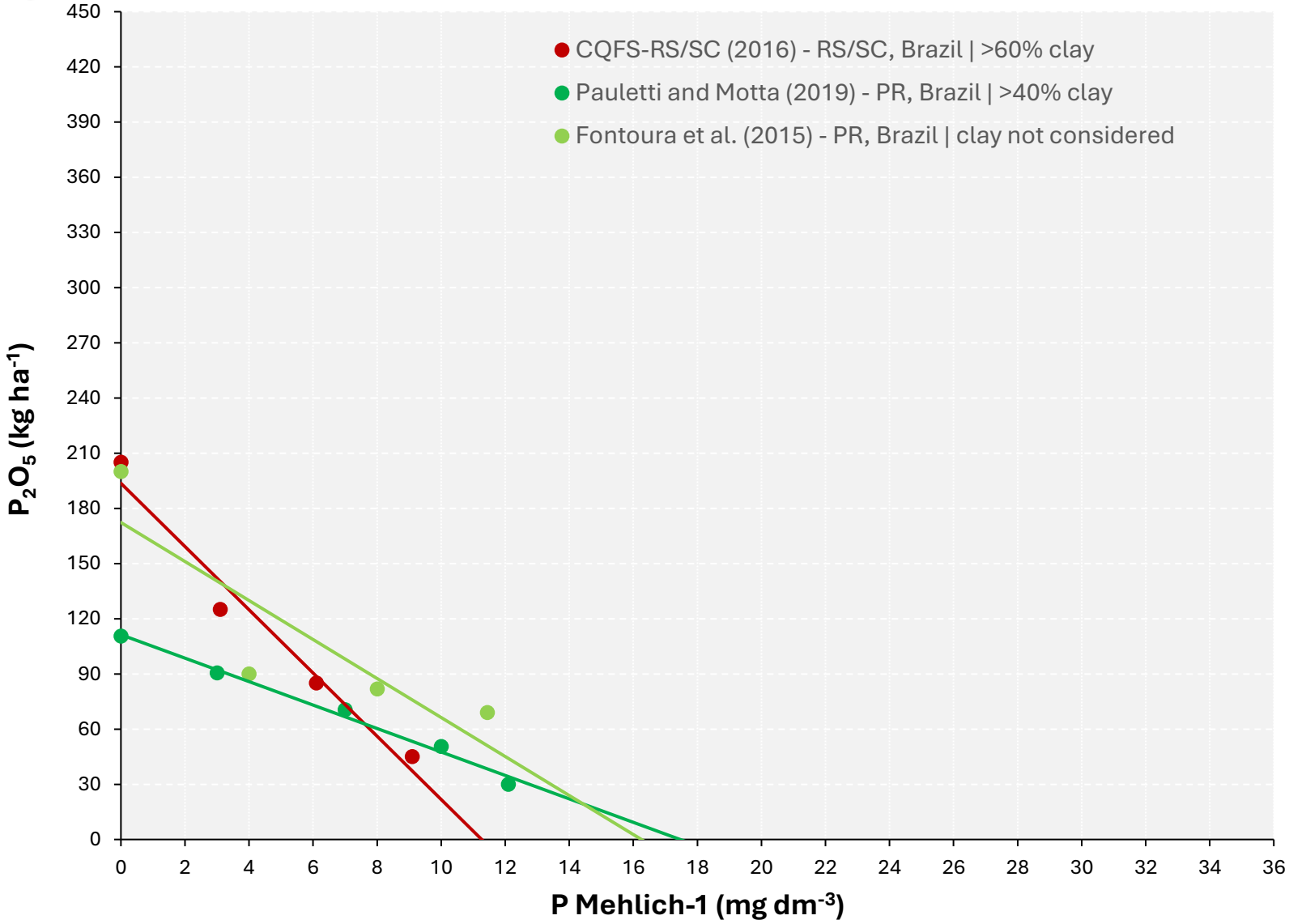


Rate of P_2O_5 for 3 ton/ha of soybean [45 bu/ac]

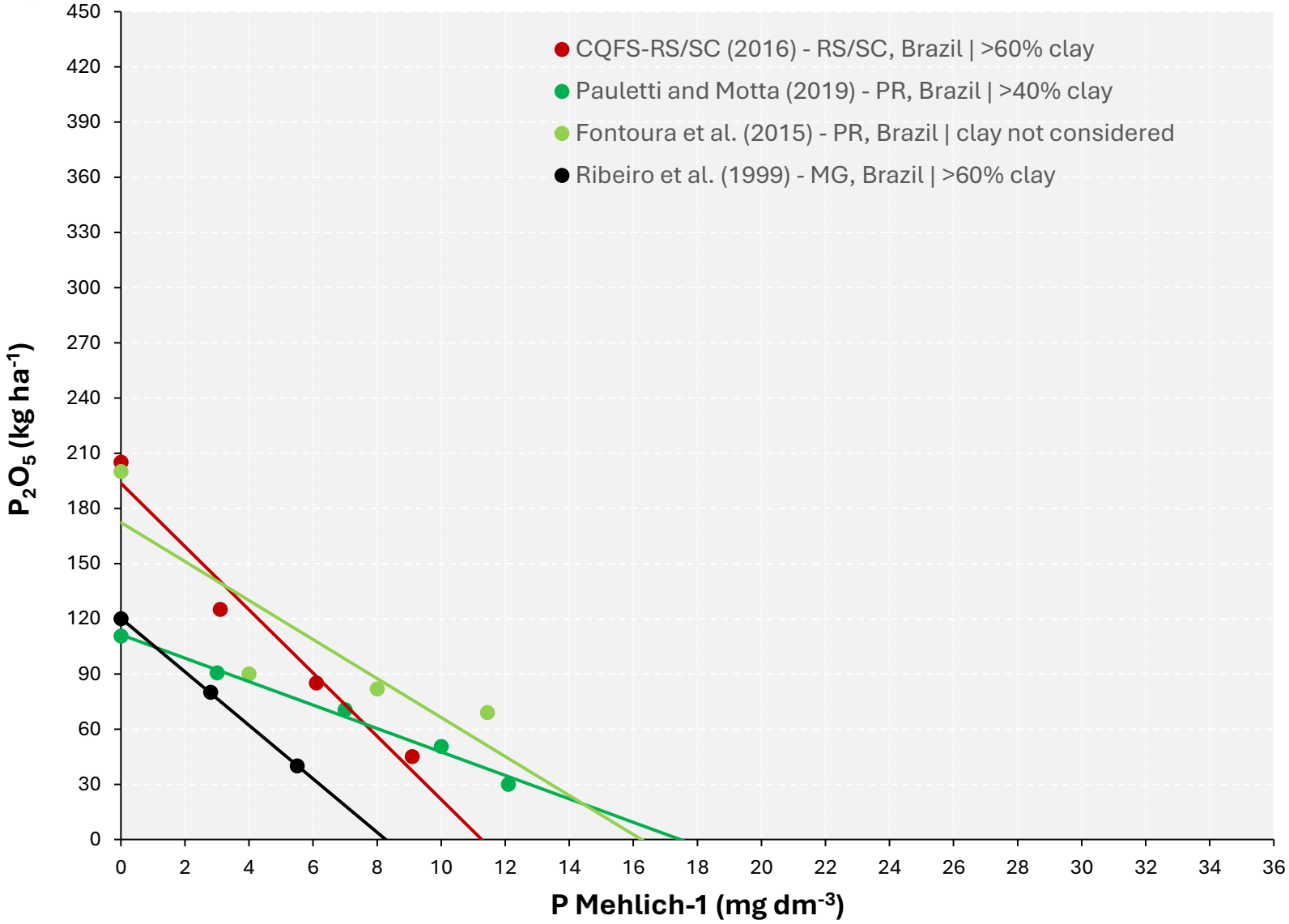


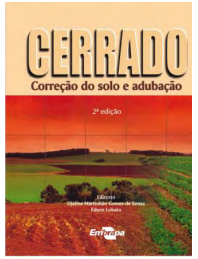


Rate of P_2O_5 for 3 ton/ha of soybean [45 bu/ac]

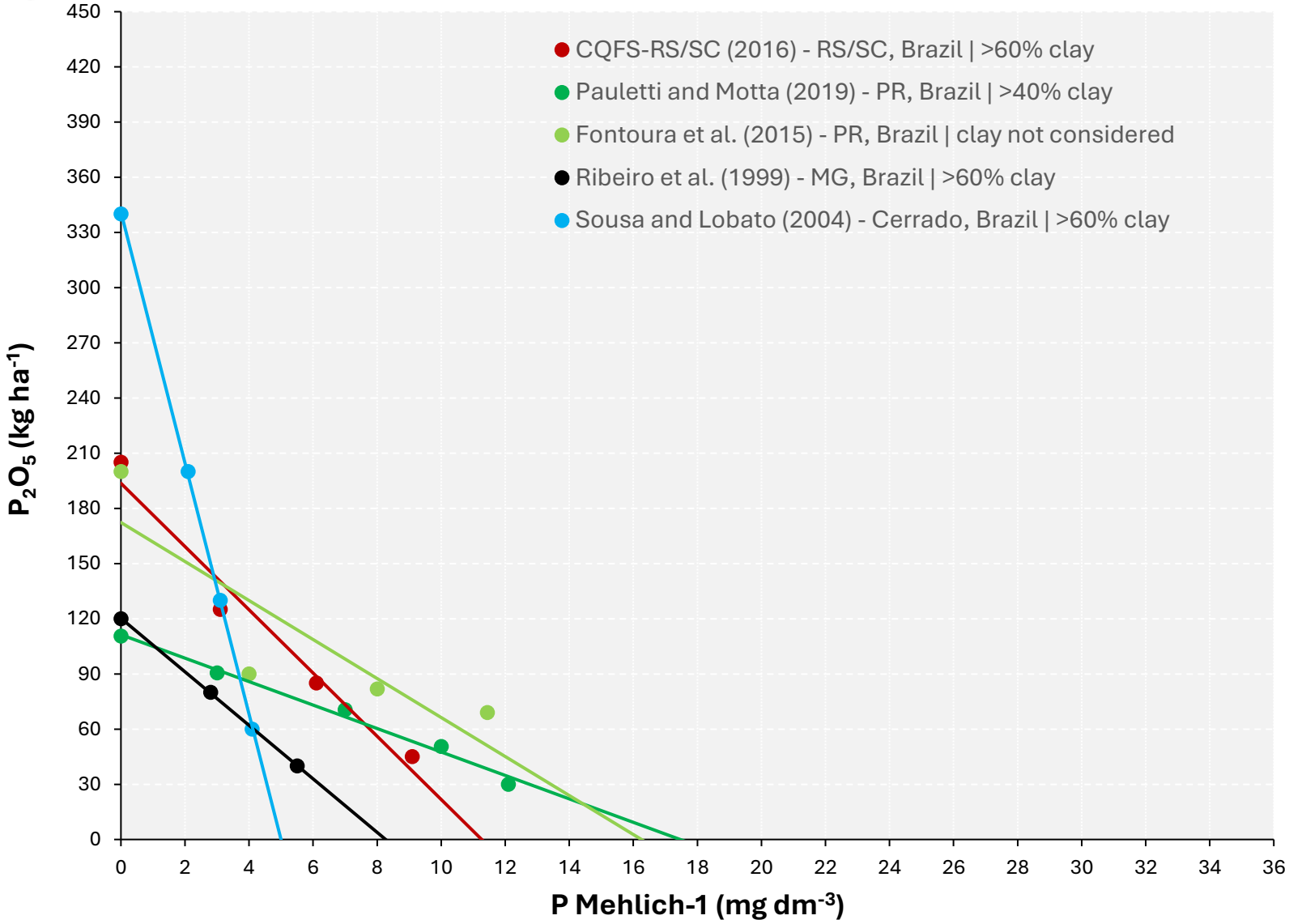


Rate of P_2O_5 for 3 ton/ha of soybean [45 bu/ac]



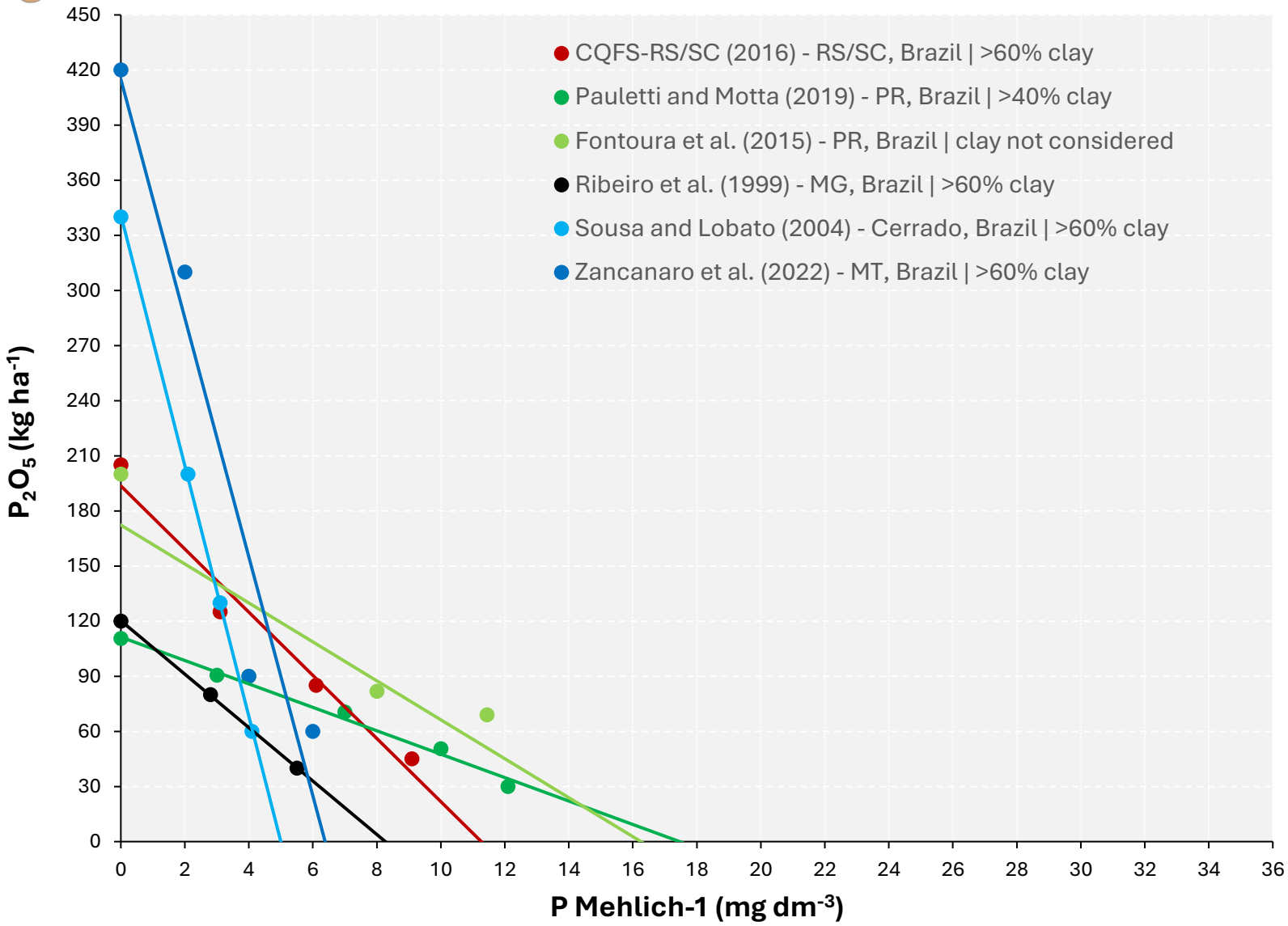


Rate of P_2O_5 for 3 ton/ha of soybean [45 bu/ac]



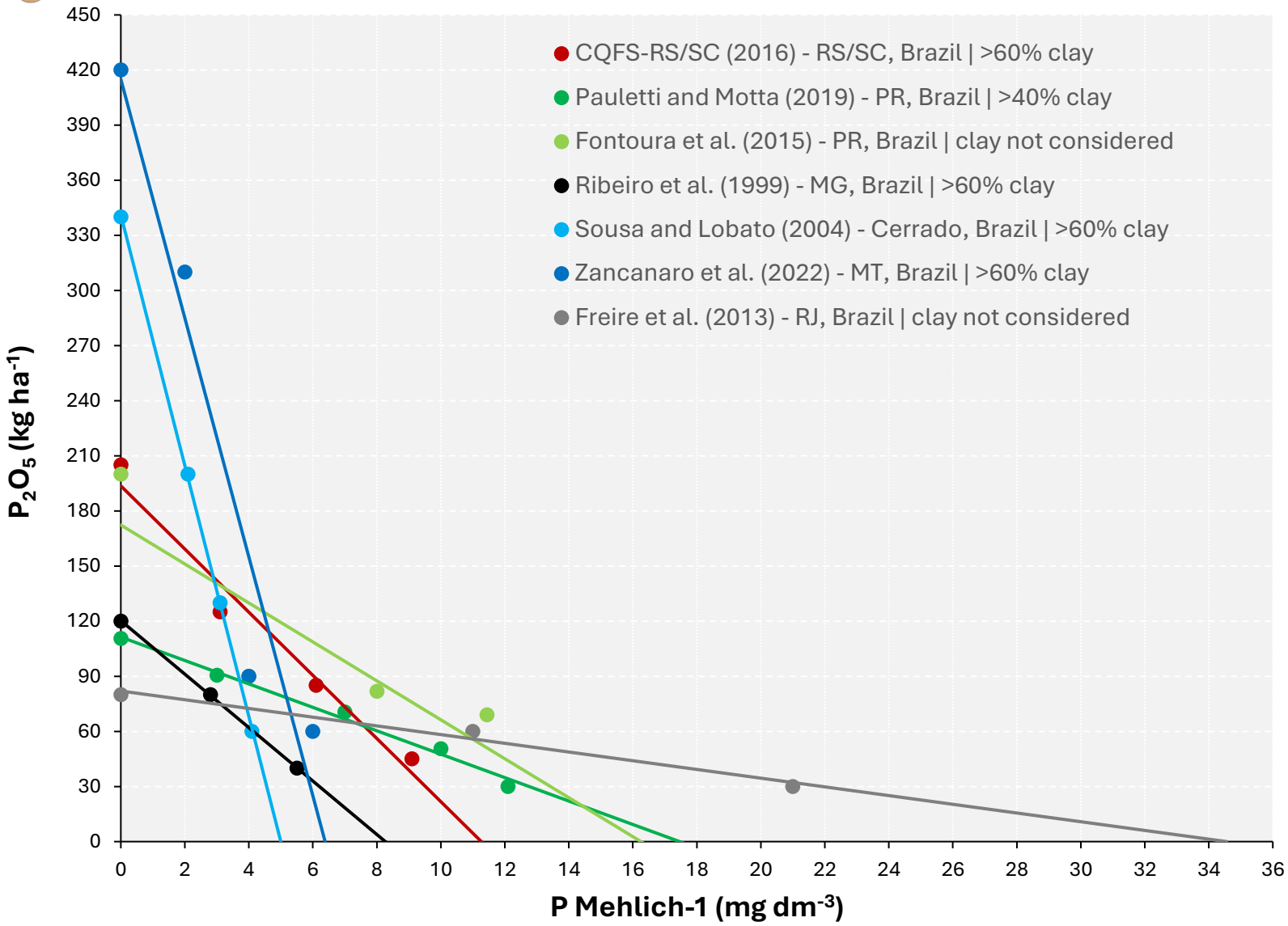
Phosphate fertilization recommendations in Brazil and Paraguay BR PY : convergences, divergences and paths towards harmonization

Rate of P_2O_5 for 3 ton/ha of soybean [45 bu/ac]



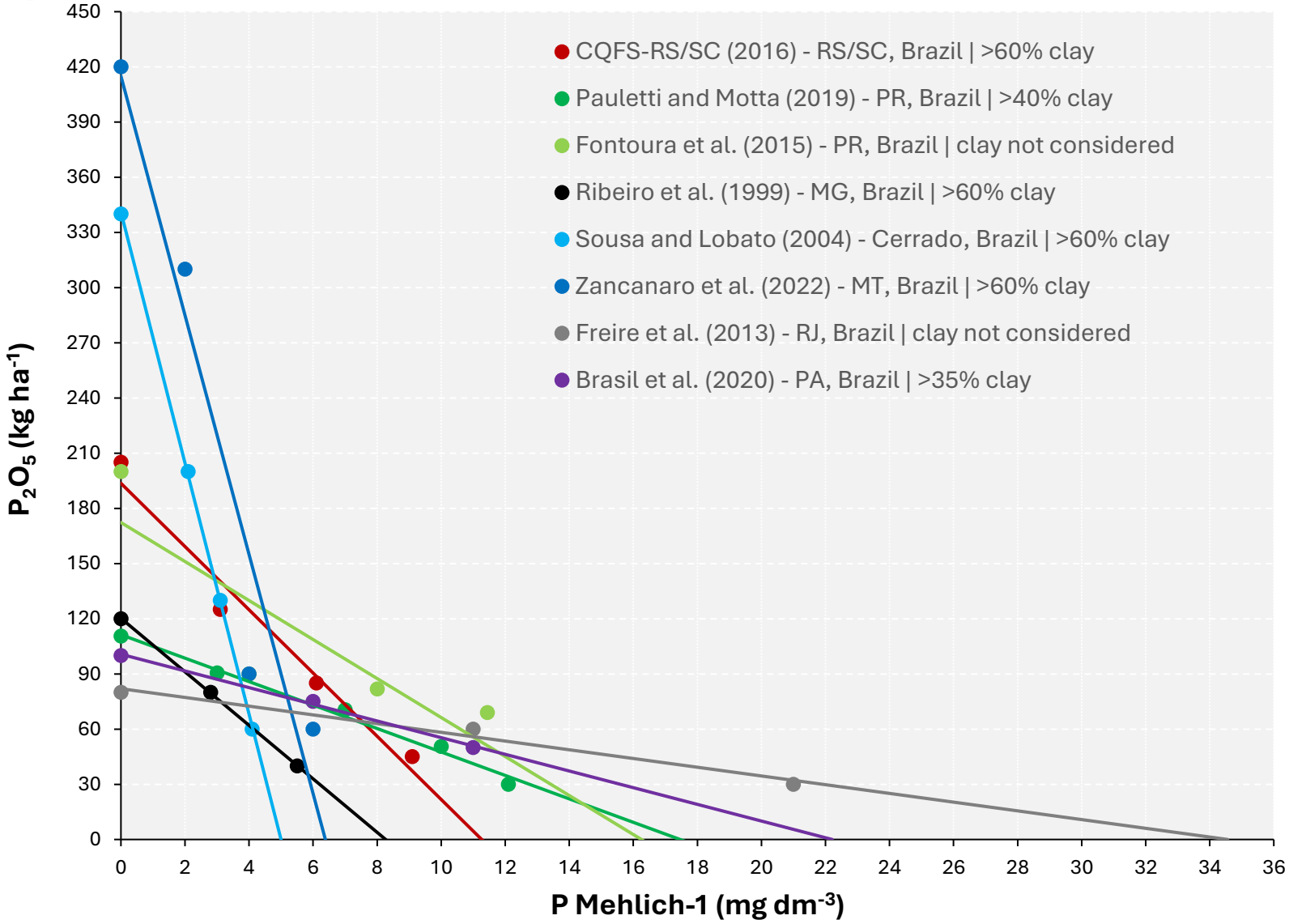
Phosphate fertilization recommendations in Brazil and Paraguay BR PY : convergences, divergences and paths towards harmonization

Rate of P_2O_5 for 3 ton/ha of soybean [45 bu/ac]



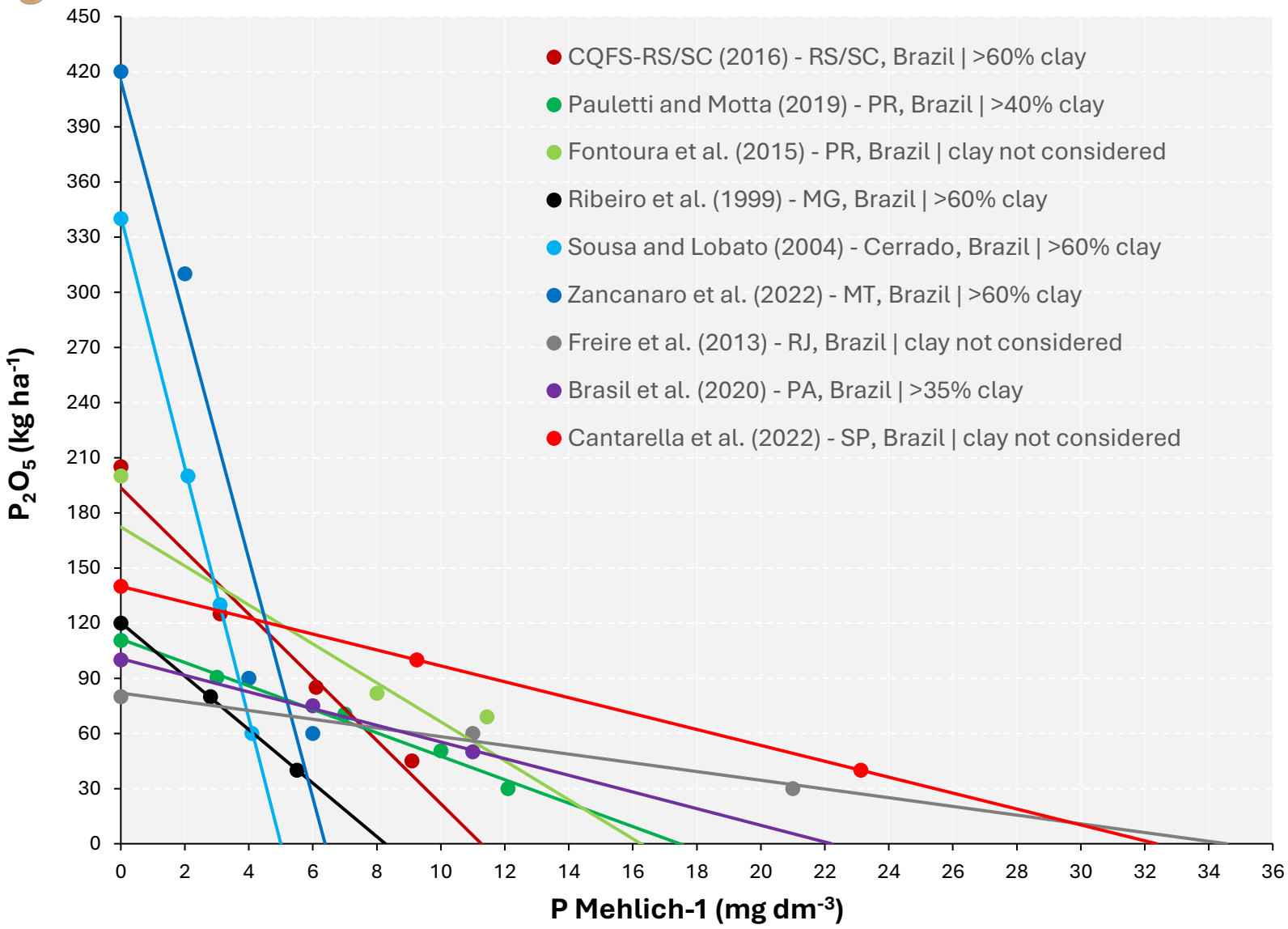
Phosphate fertilization recommendations in Brazil and Paraguay BR PY : convergences, divergences and paths towards harmonization

Rate of P_2O_5 for 3 ton/ha of soybean [45 bu/ac]



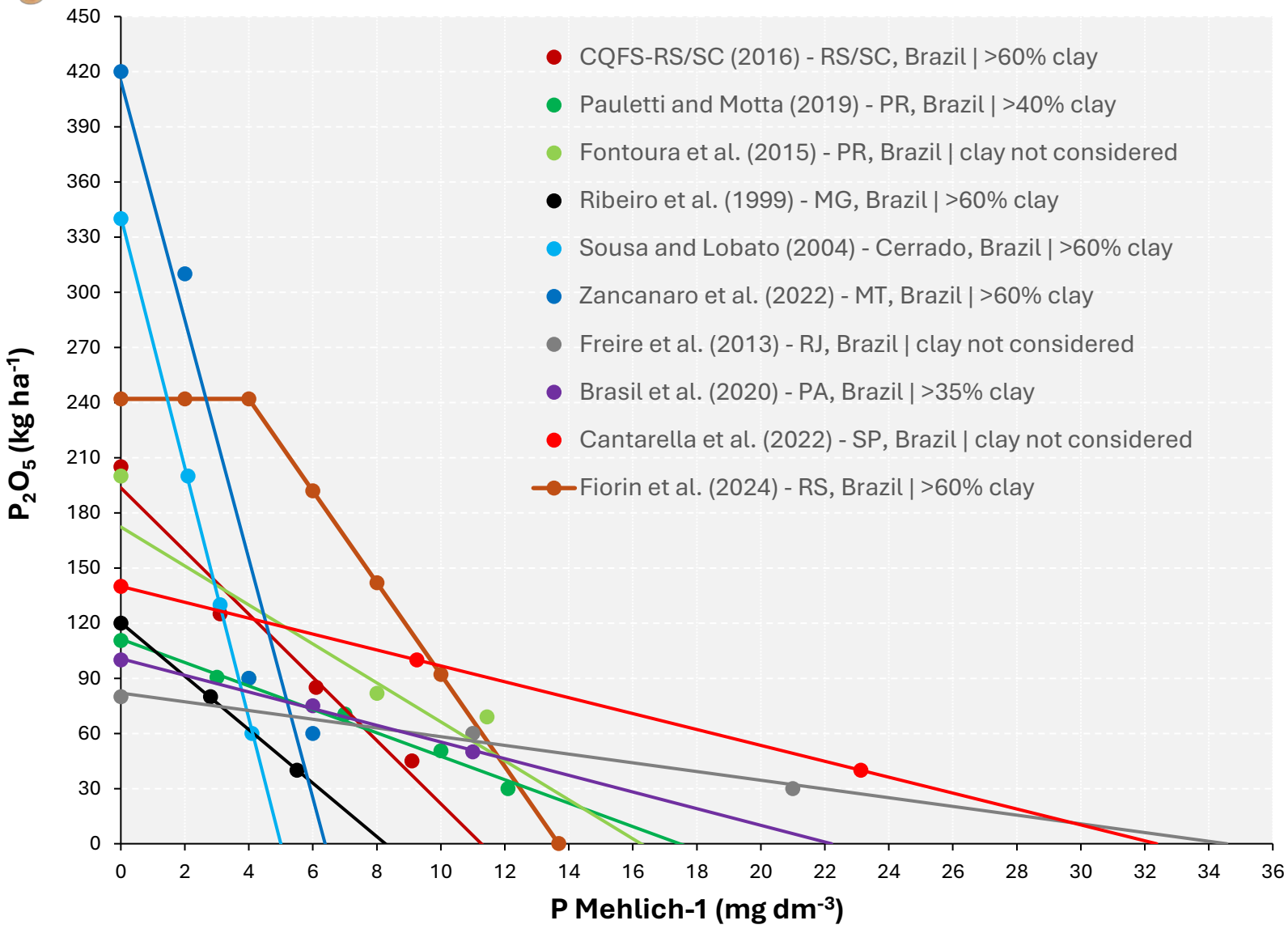
Phosphate fertilization recommendations in Brazil and Paraguay BR PY : convergences, divergences and paths towards harmonization

Rate of P_2O_5 for 3 ton/ha of soybean [45 bu/ac]



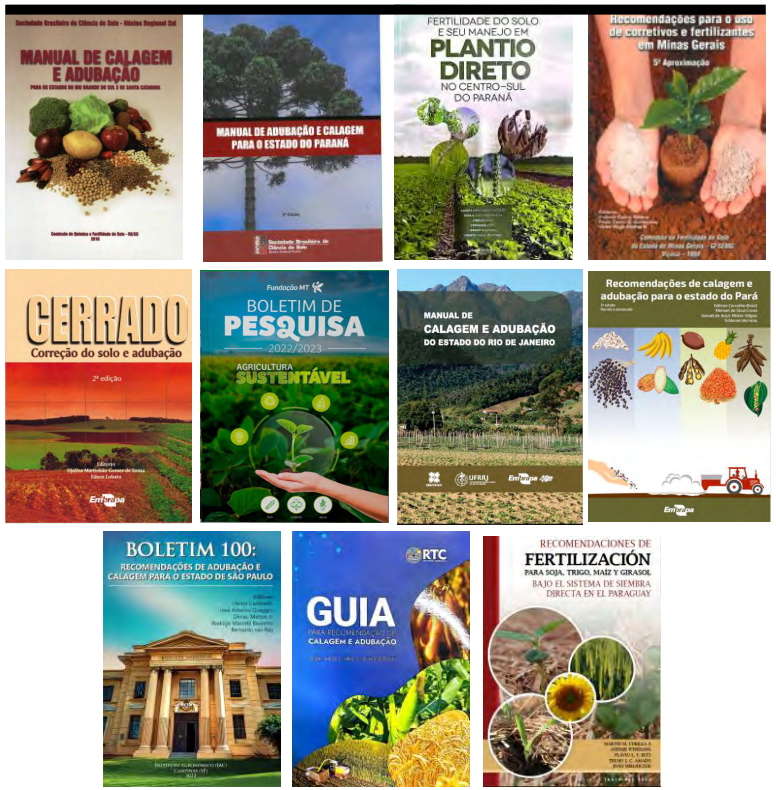
Phosphate fertilization recommendations in Brazil and Paraguay BR PY : convergences, divergences and paths towards harmonization

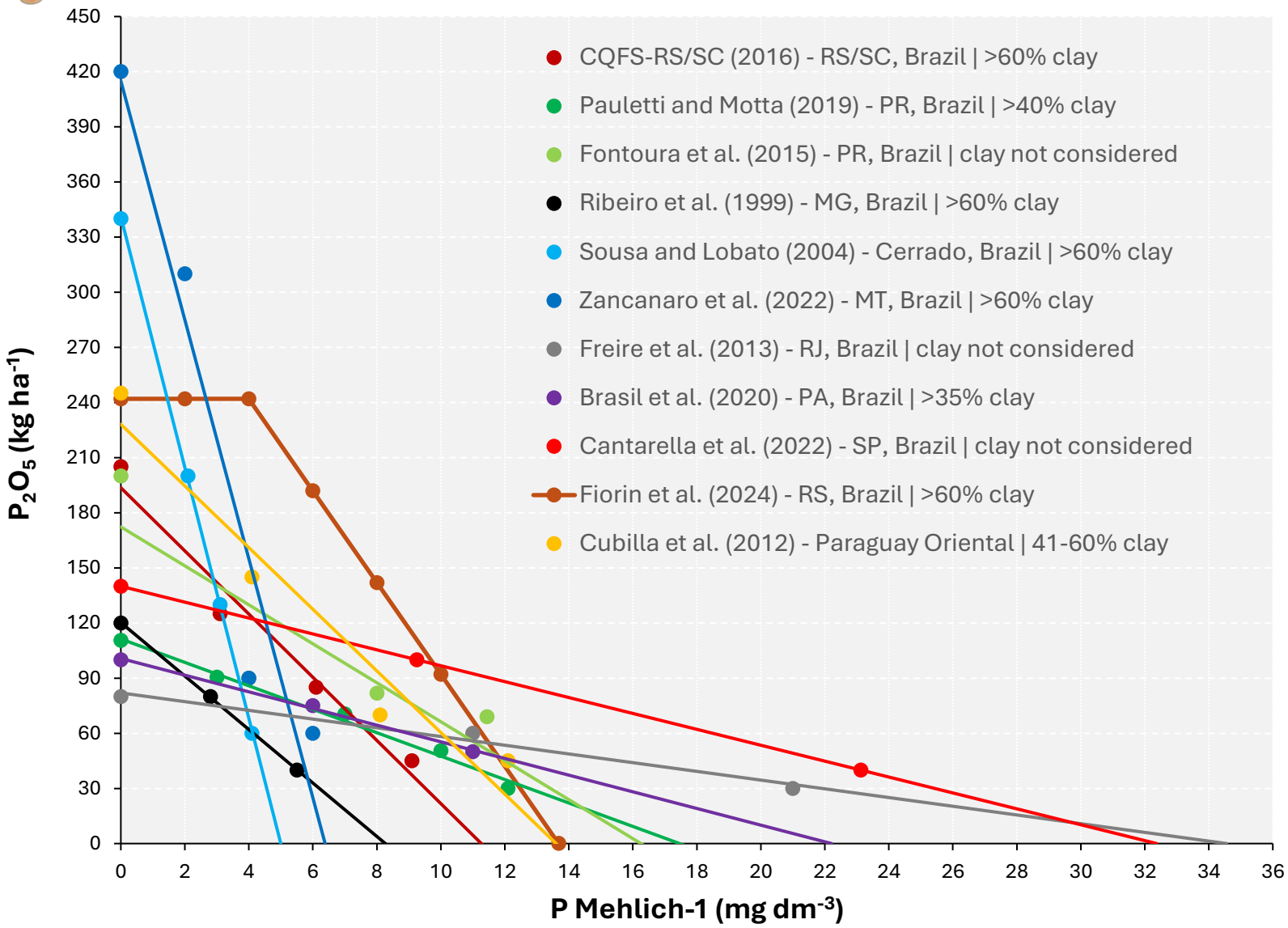
Rate of P_2O_5 for 3 ton/ha of soybean [45 bu/ac]

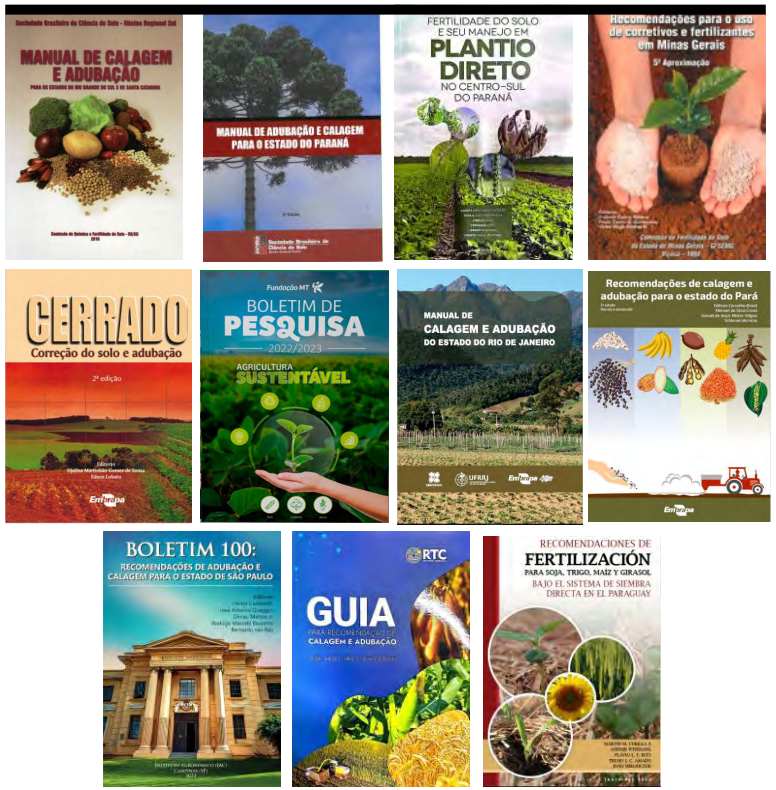


Phosphate fertilization recommendations in Brazil and Paraguay BR PY : convergences, divergences and paths towards harmonization

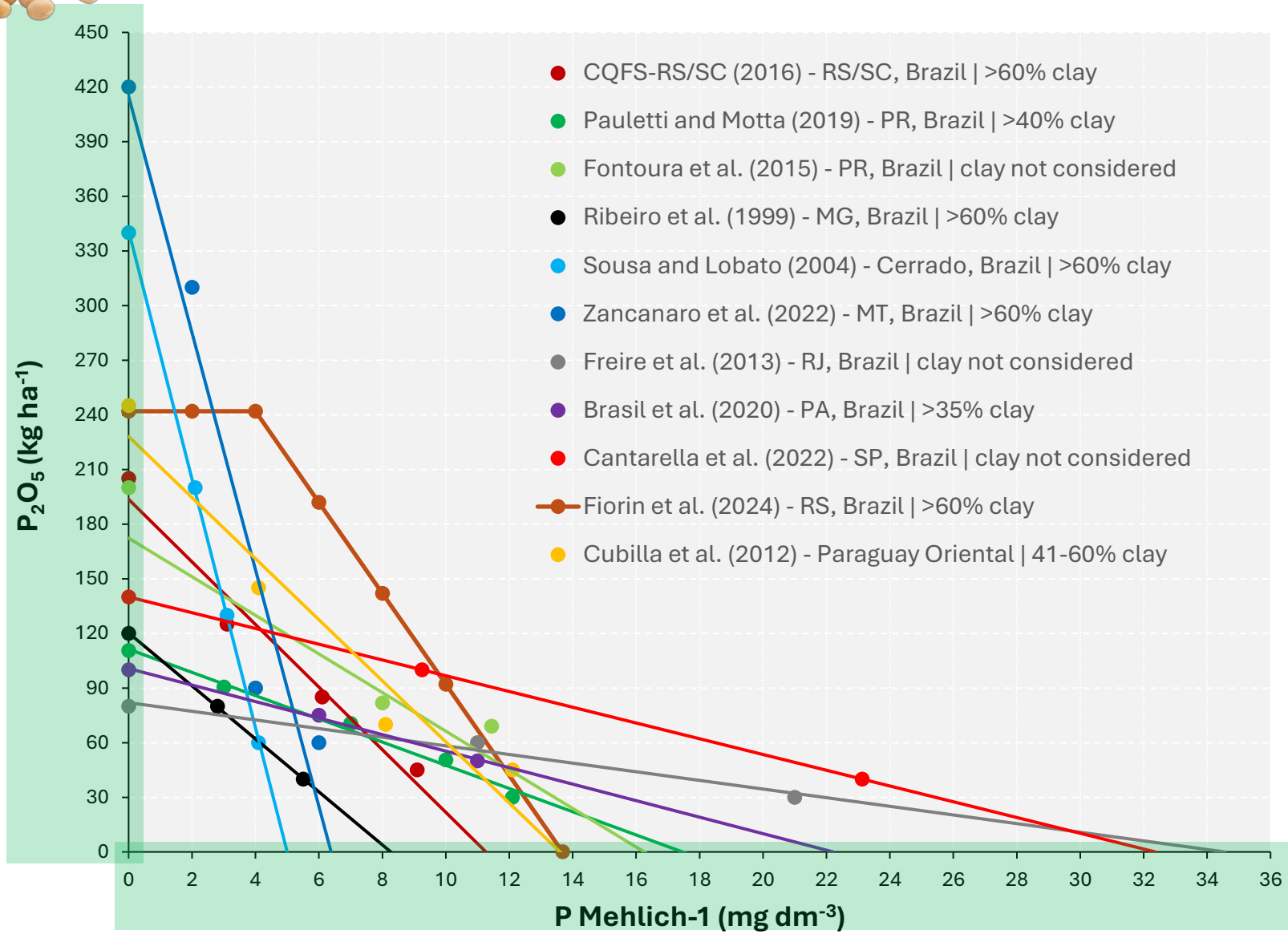
Rate of P_2O_5 for 3 ton/ha of soybean [45 bu/ac]





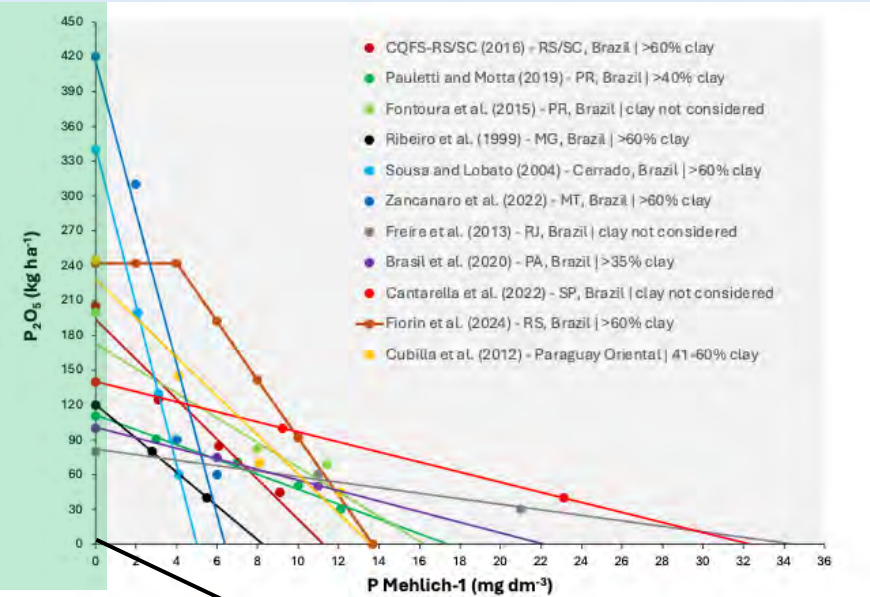


Rate of P_2O_5 for 3 ton/ha of soybean [45 bu/ac]

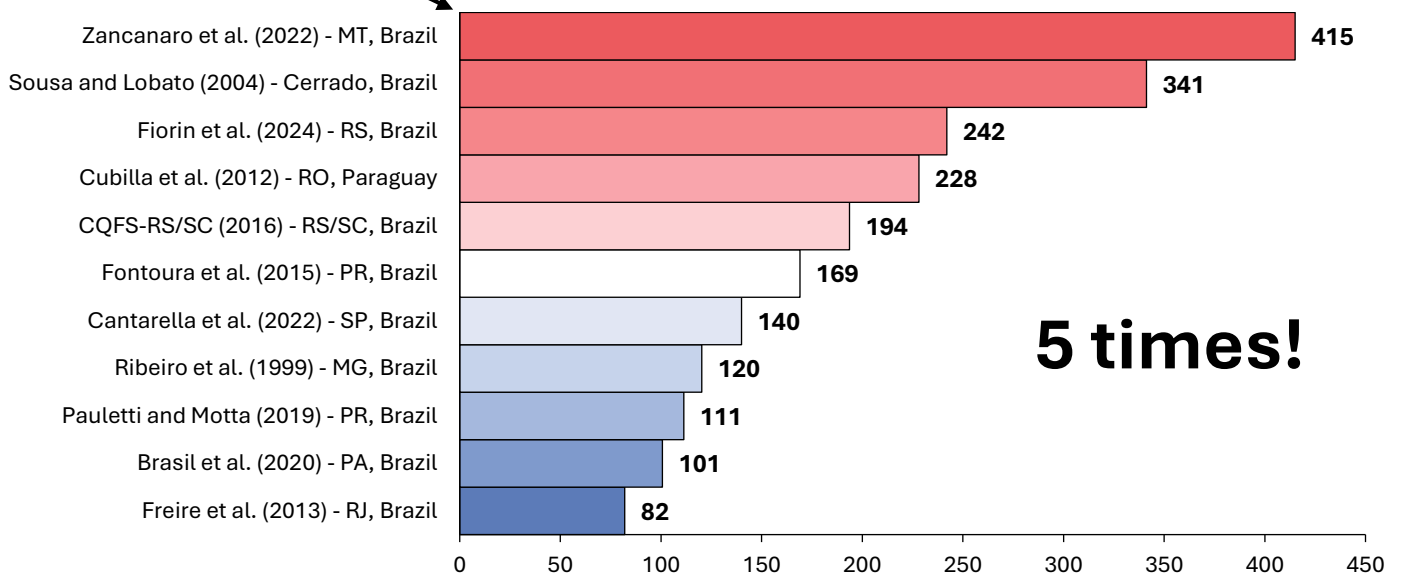



S.C.INTERNACIONAL
1909
High
Low
1903
GRÊMIO
FBPA

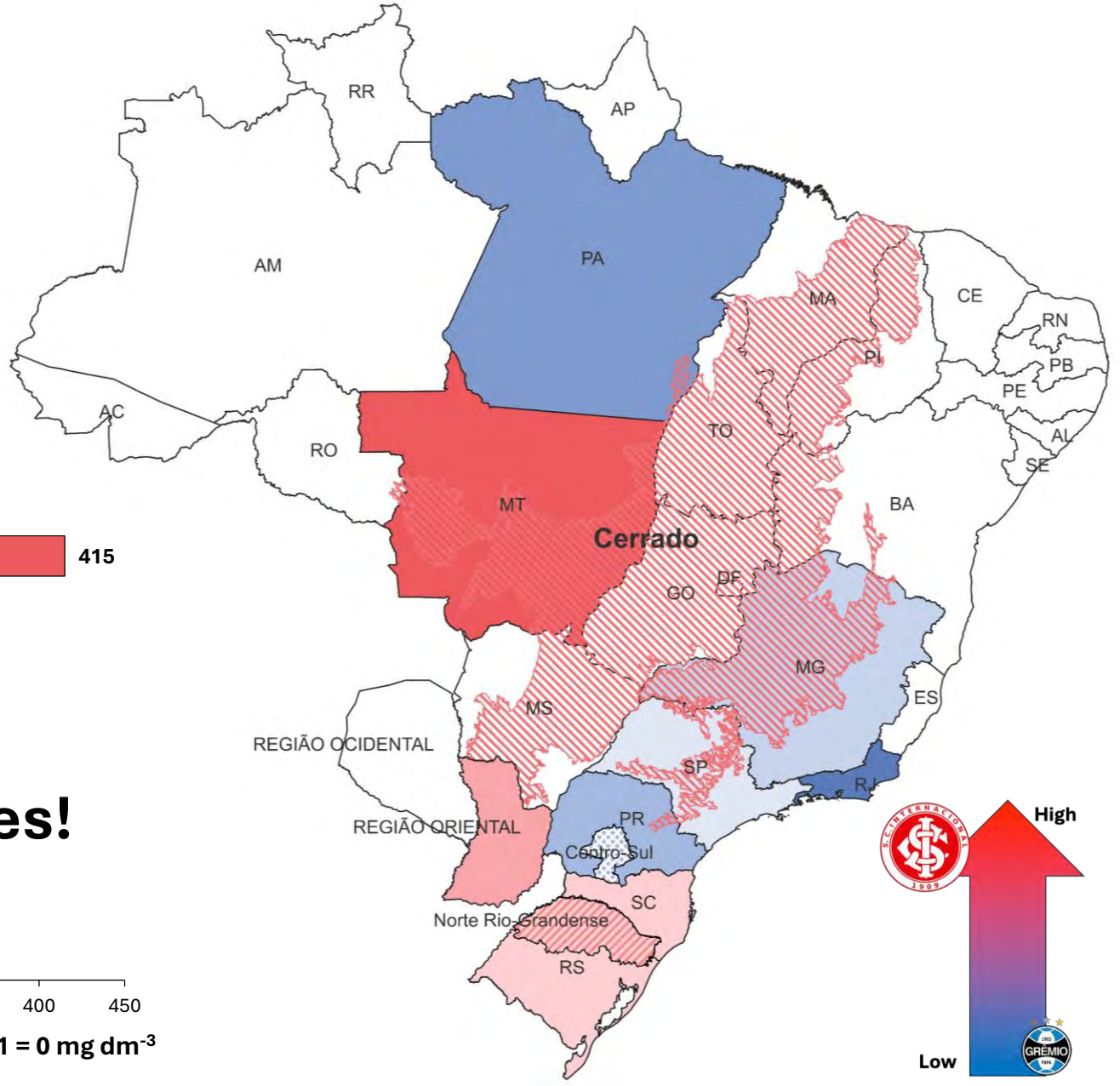
Phosphate fertilization recommendations in Brazil and Paraguay BR PY : convergences, divergences and paths towards harmonization



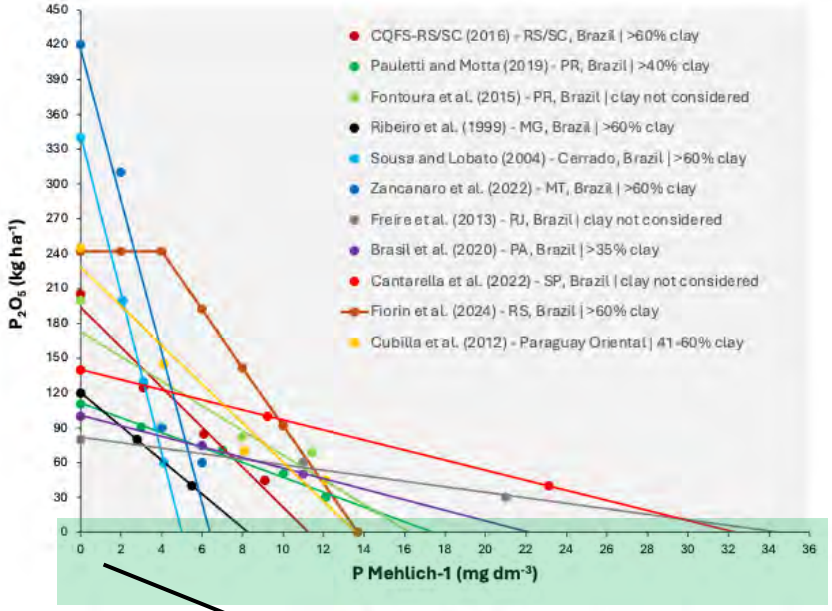
Rate of P_2O_5 for 3 ton/ha of soybean when P-Mehlich-1 = 0 mg dm^{-3}

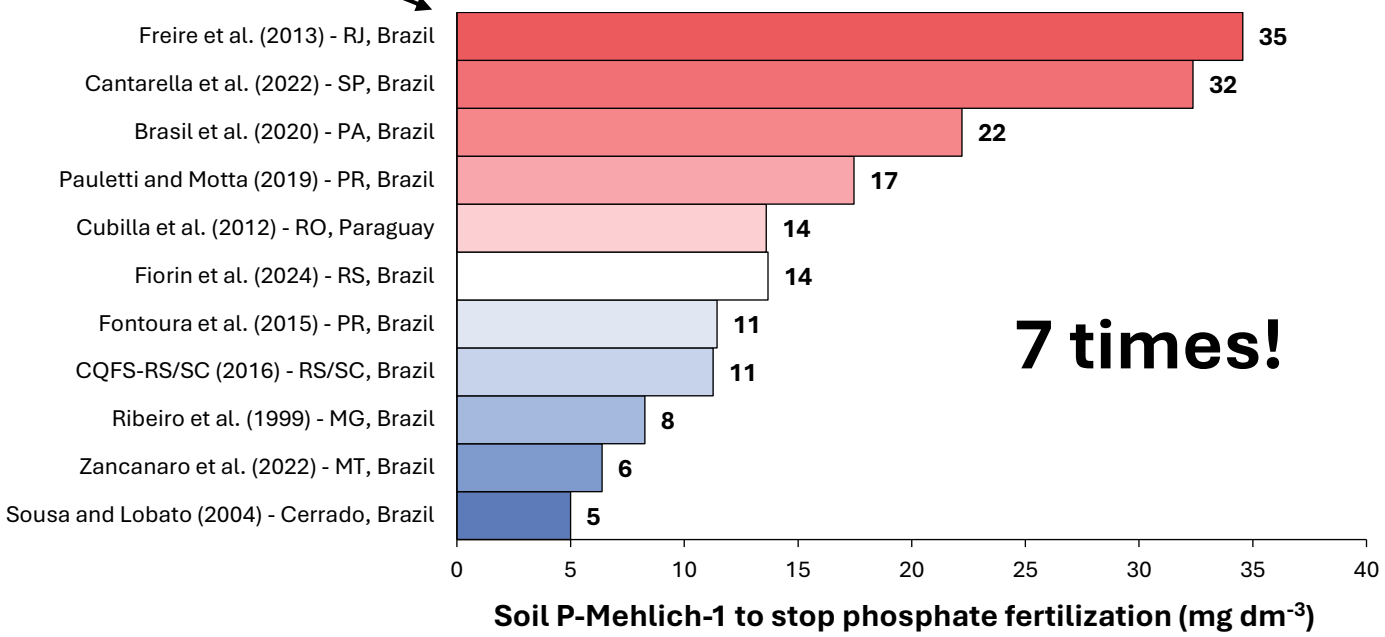


5 times!



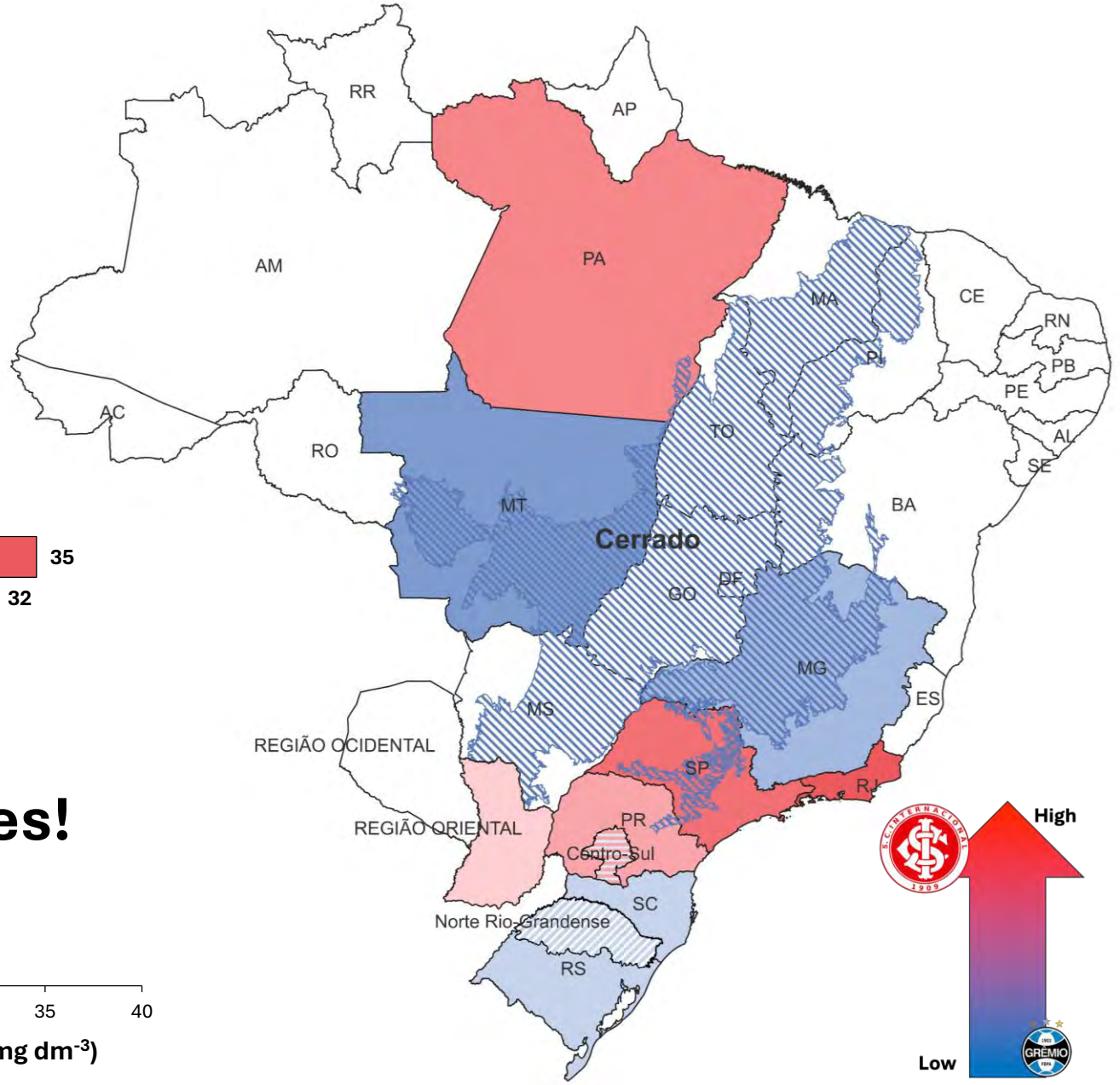
Phosphate fertilization recommendations in Brazil and Paraguay BR PY : convergences, divergences and paths towards harmonization



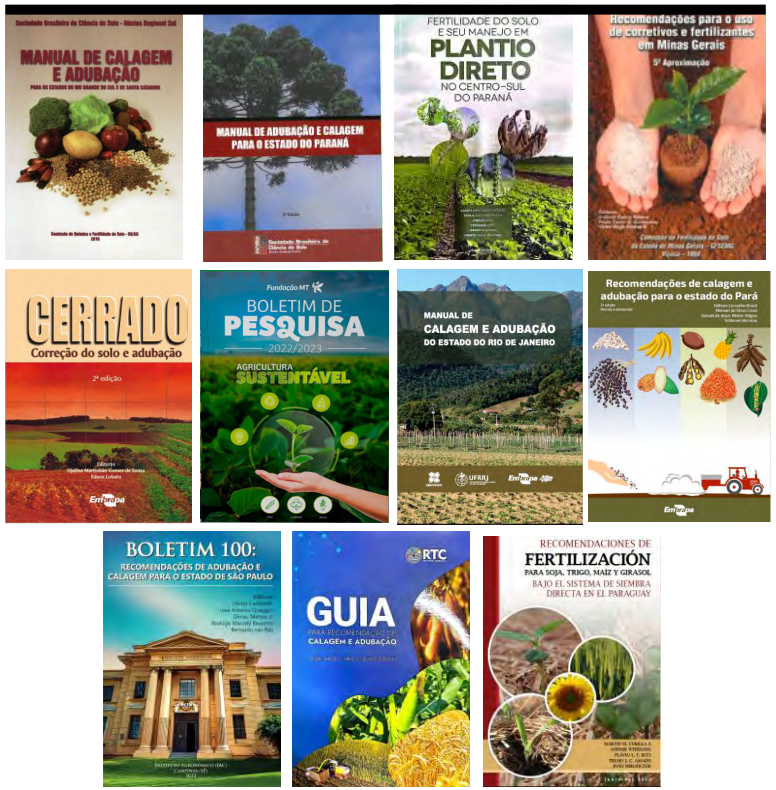


7 times!

Soil P-Mehlich-1 to stop phosphate fertilization (mg dm^{-3})

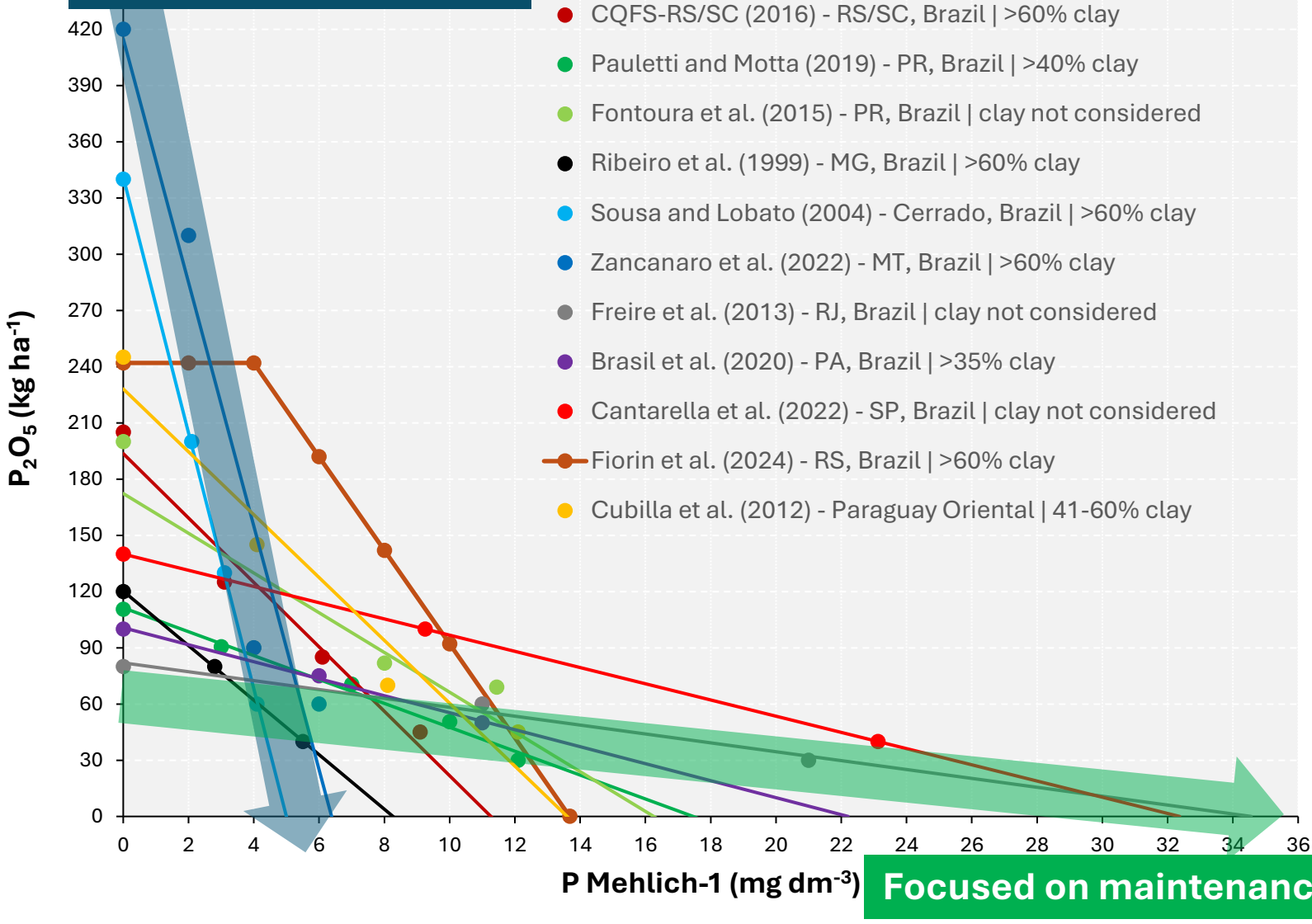


Phosphate fertilization recommendations in Brazil and Paraguay BR PY : convergences, divergences and paths towards harmonization



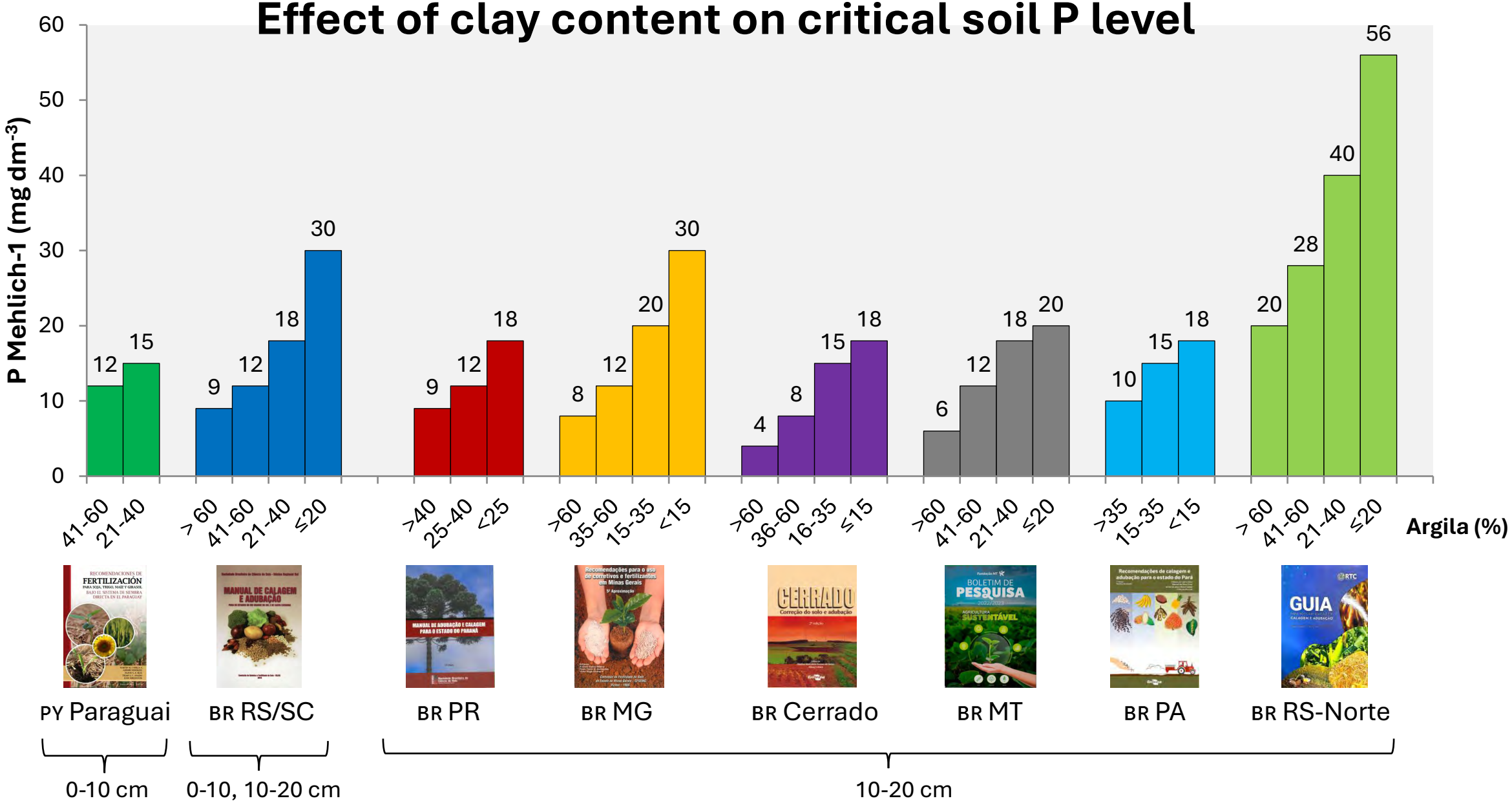
Rate of P_2O_5 for 3 ton/ha of soybean [45 bu/ac]

Focused on correction

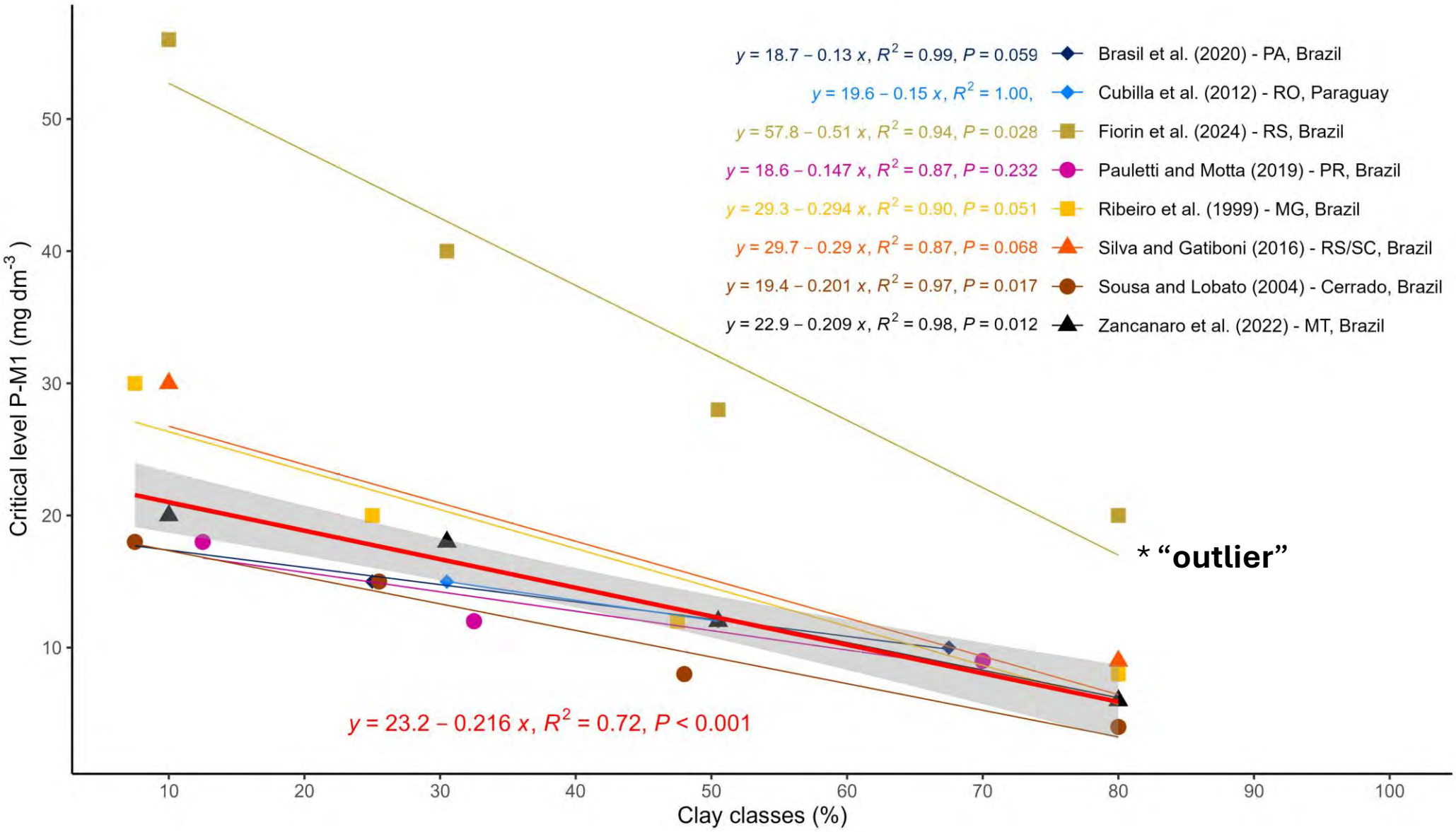


Focused on maintenance

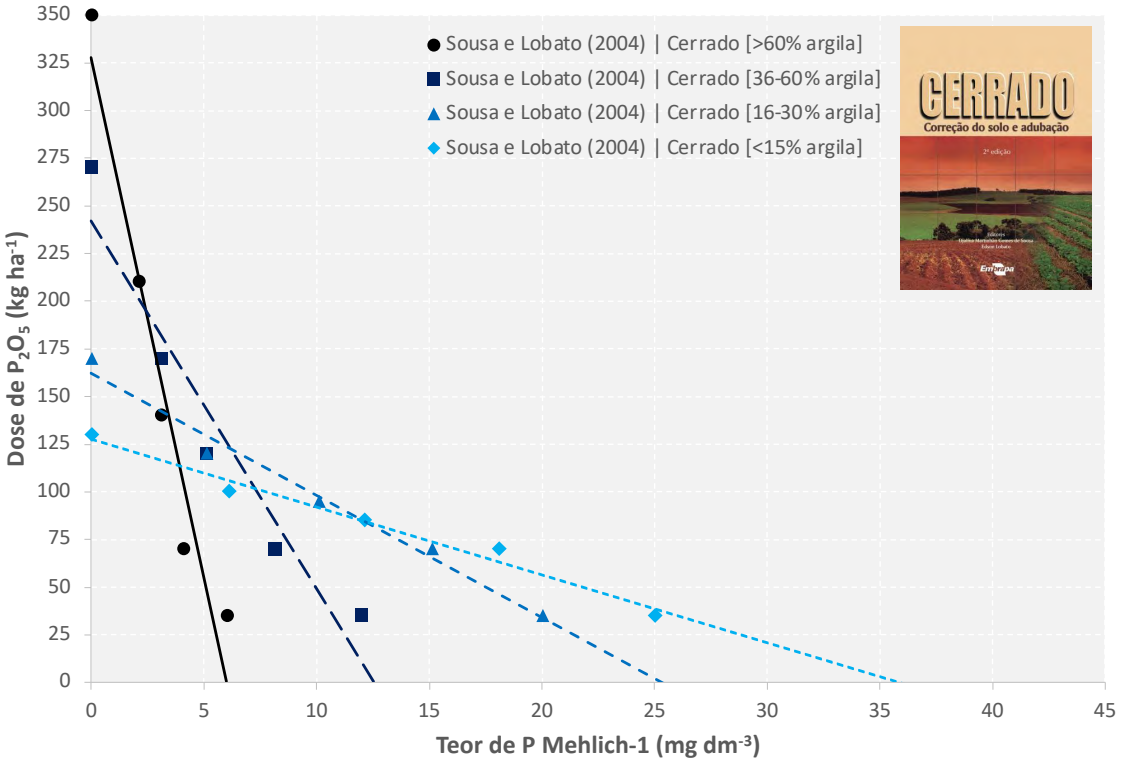
Effect of clay content on critical soil P level



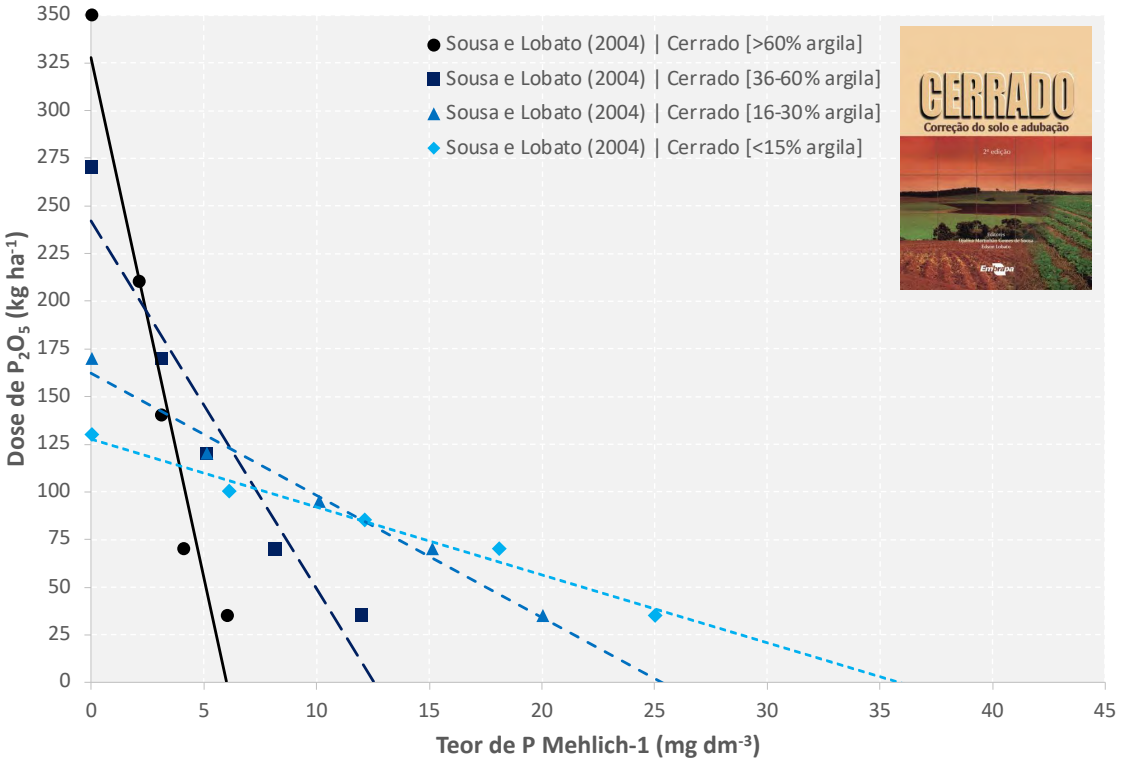
Effect of clay content on critical soil P level



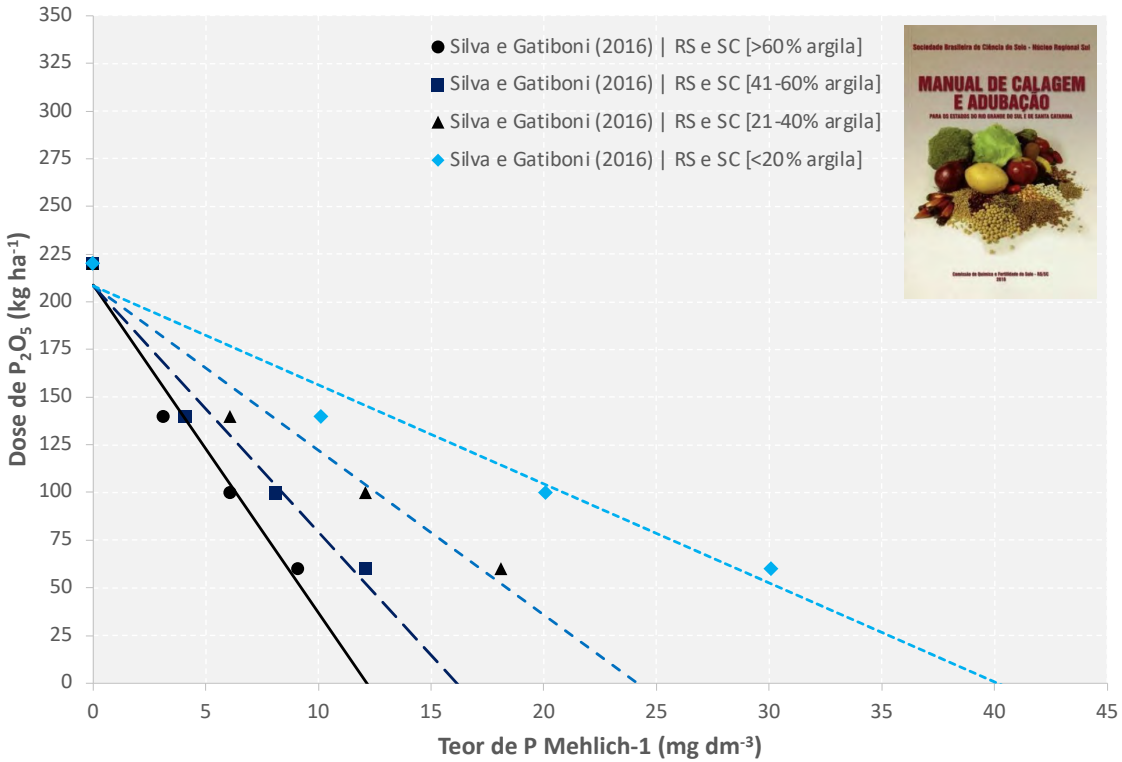
Clay taken into account for interpretation
Clay is taken into account for defining the P rate



Clay taken into account for interpretation
Clay is taken into account for defining the P rate



Clay taken into account for interpretation
Clay is not taken into account for defining the P rate

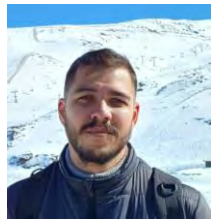


Phosphorus and potassium fertilizer recommendations in Brazil and Paraguay: convergences, divergences, and paths towards harmonization

Phosphorus

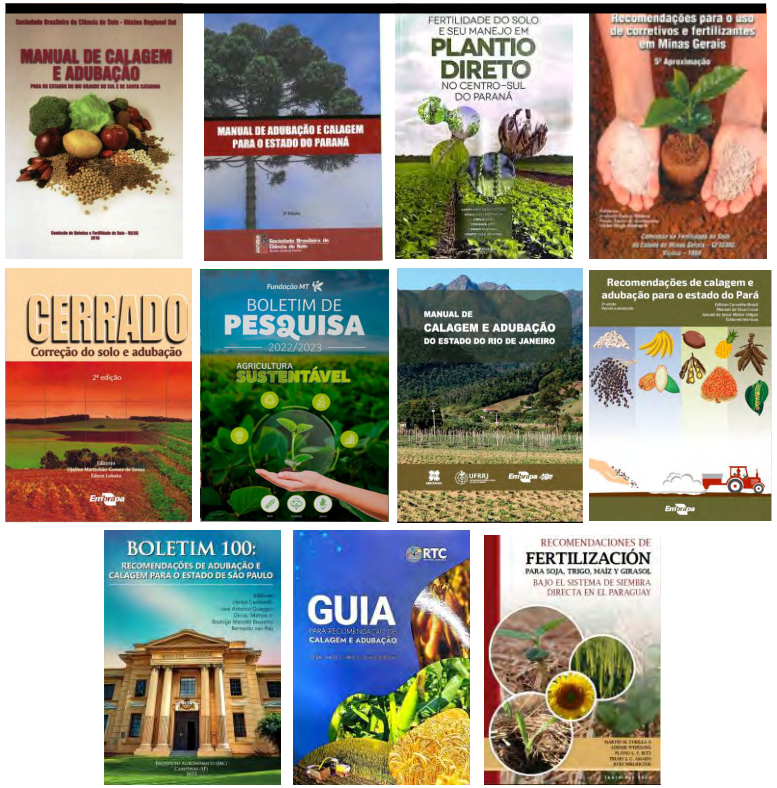
Alder Delosantos Duarte Monzón
PhD candidate in Soil Science
Federal University of Rio Grande do Sul

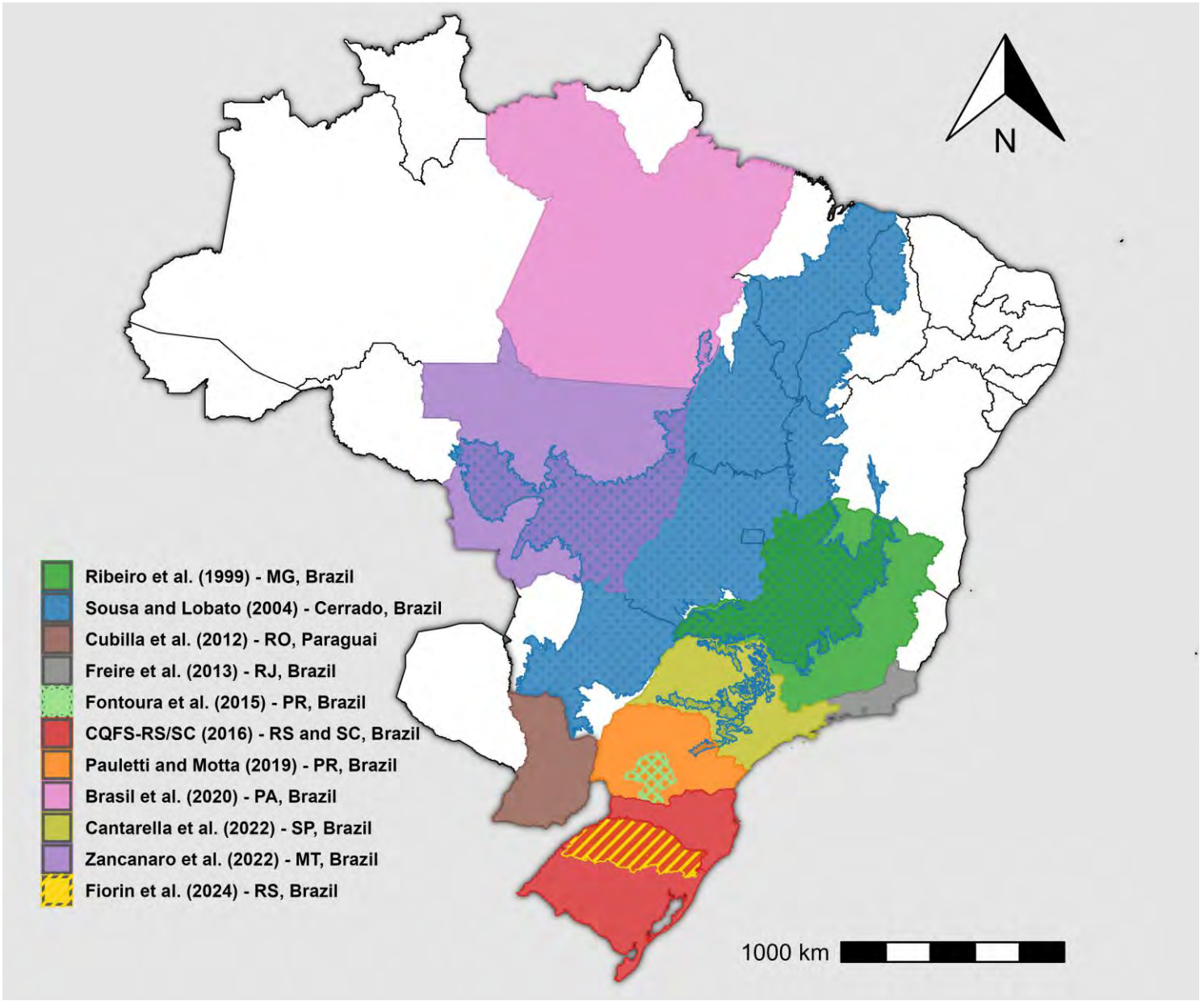
Potassium

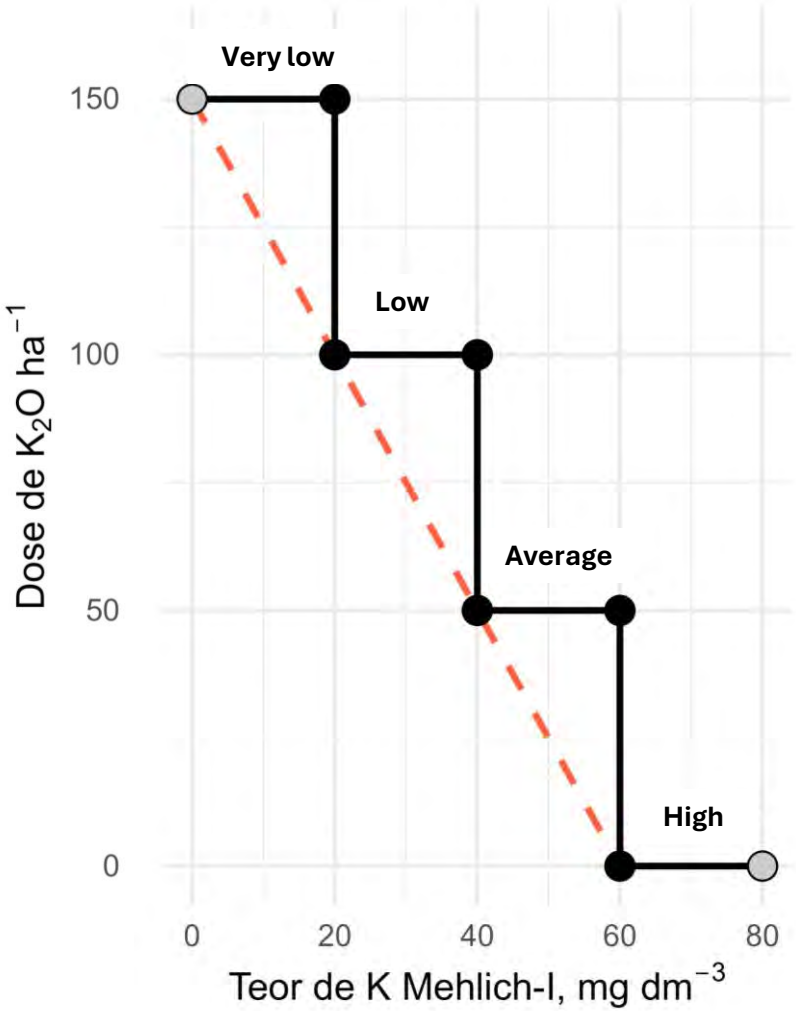


Gustavo Frosi
PhD candidate in Soil Science
Federal University of Rio Grande do Sul

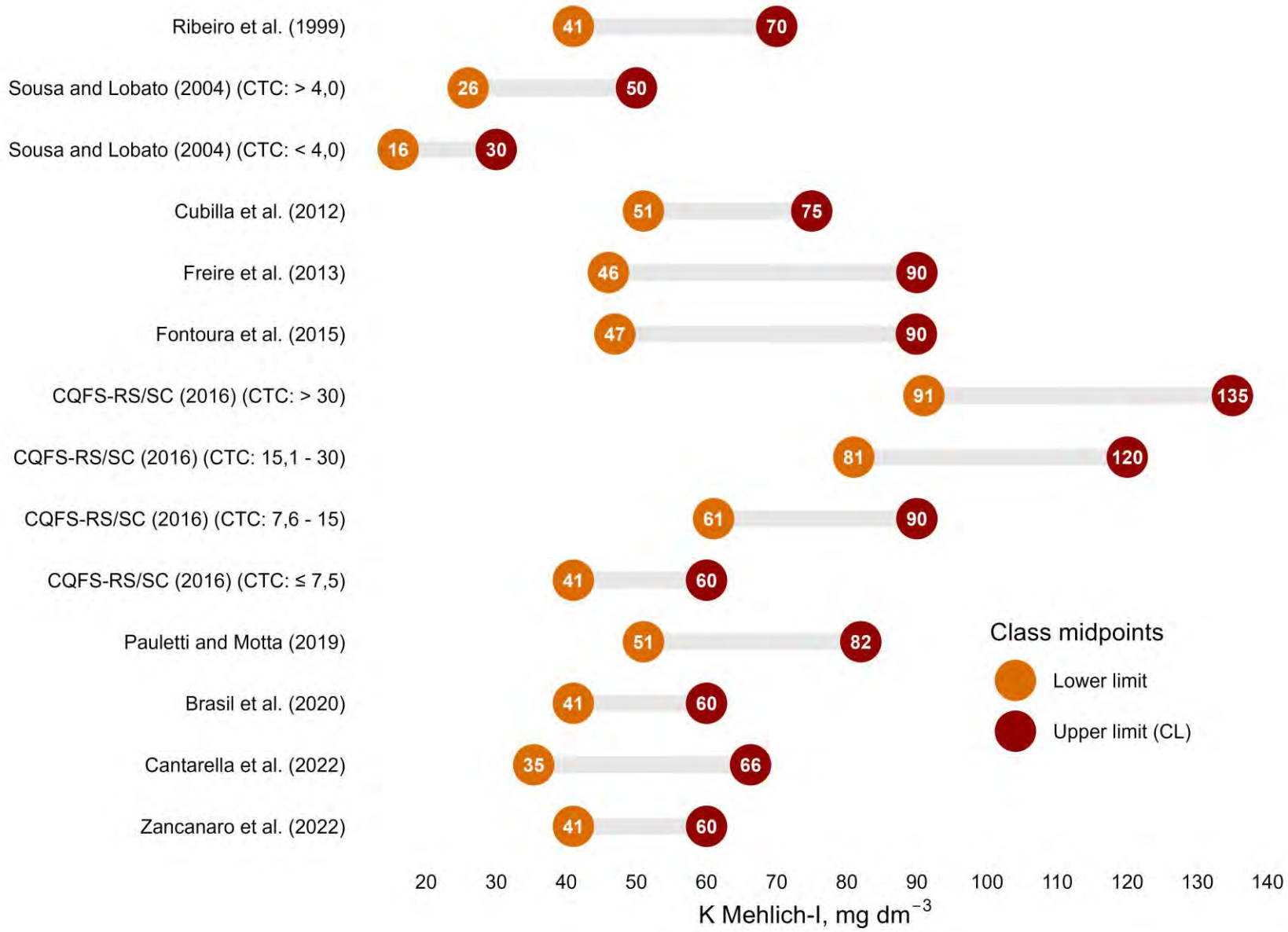
Phosphate fertilization recommendations in Brazil and Paraguay BR PY : convergences, divergences and paths towards harmonization



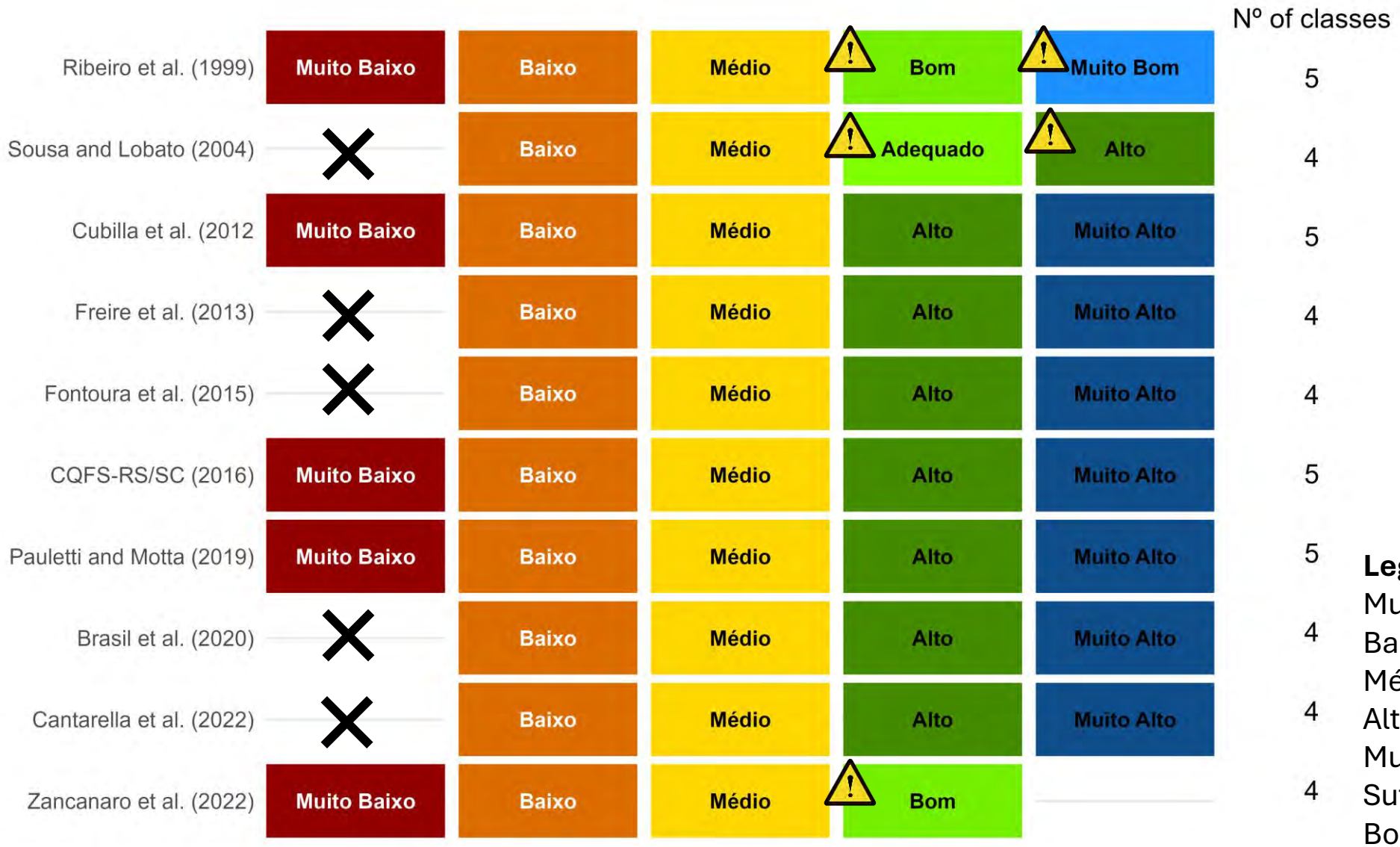



Very low
Low
Average
High
150
100
50
0
Dose de K_2O ha^{-1}
0
20
40
60
80
Teor de K Mehlich-I, mg dm^{-3}

Critical soil K content (mg dm^{-3})

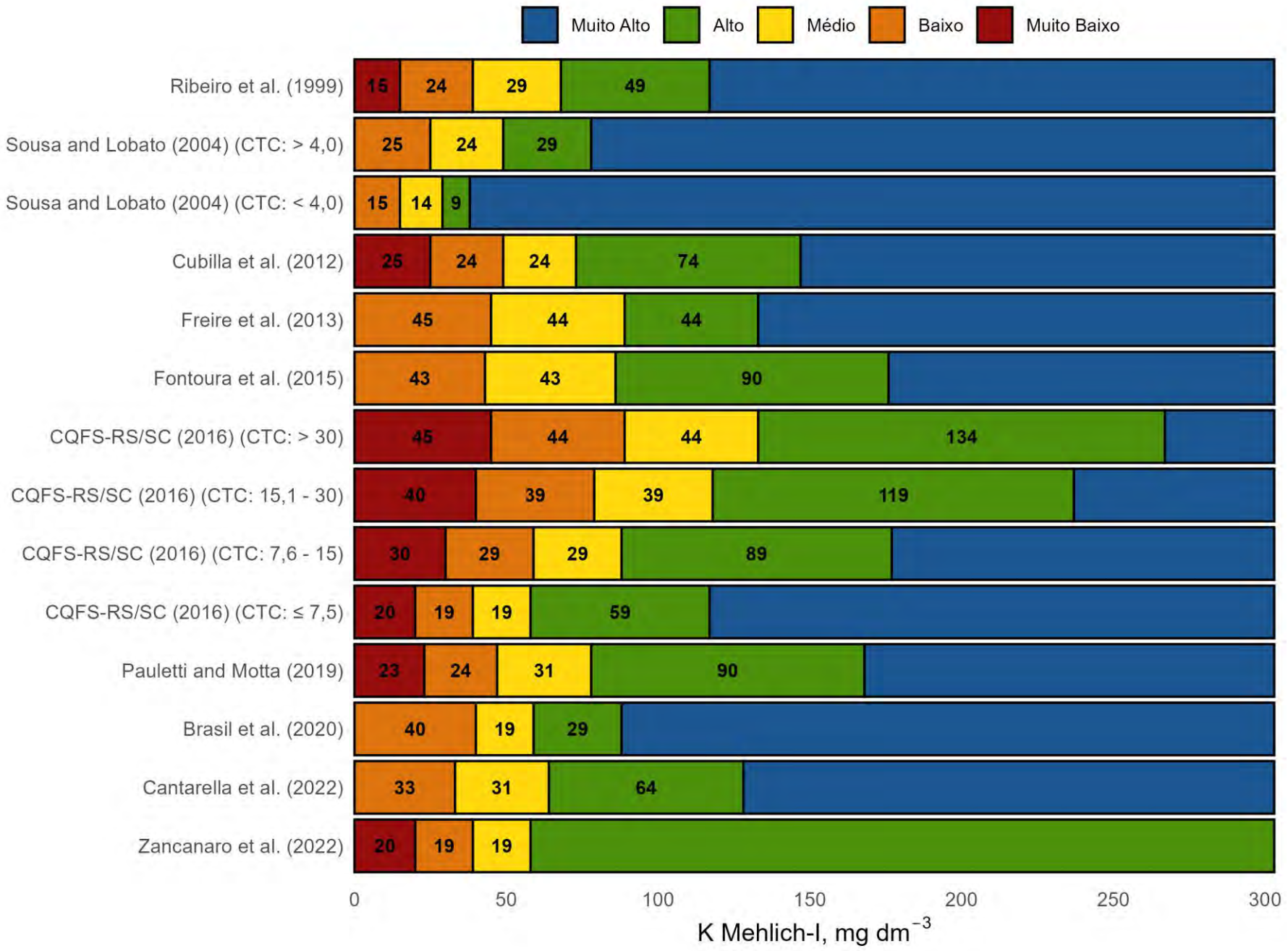


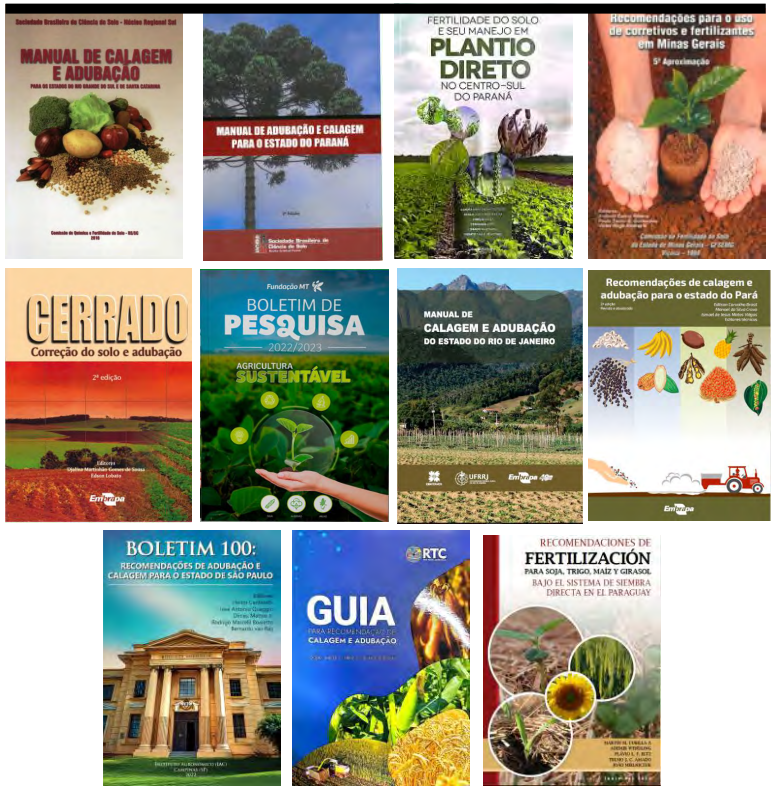
Number of classes and nomenclatures given to the K availability classes for the soybean crop in the K recommendation systems evaluated.



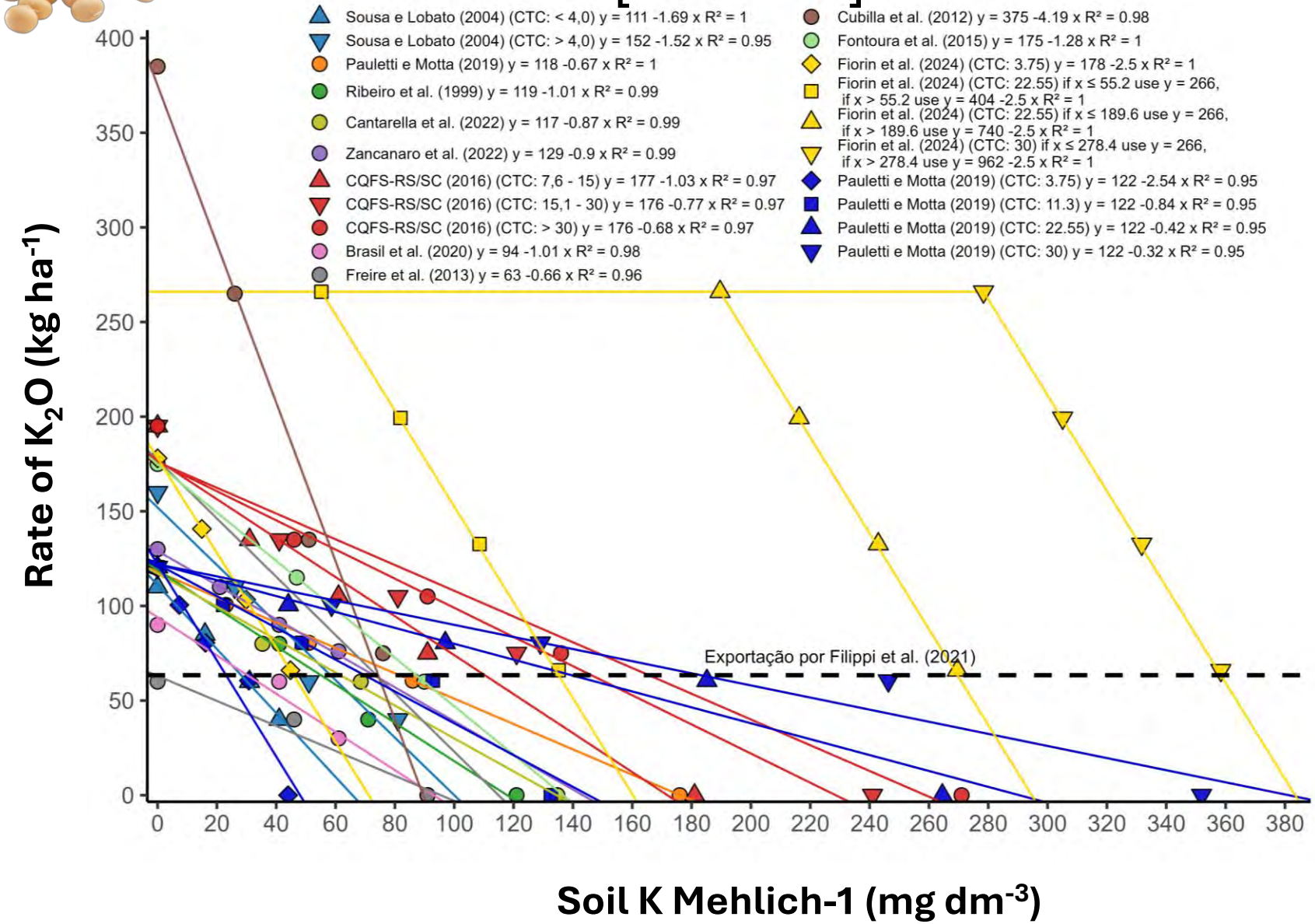
Legend:
Muito baixo = Very low
Baixo = Low
Médio = Average
Alto = High
Muito alto = Very high
Suficiente = Enough
Bom = God

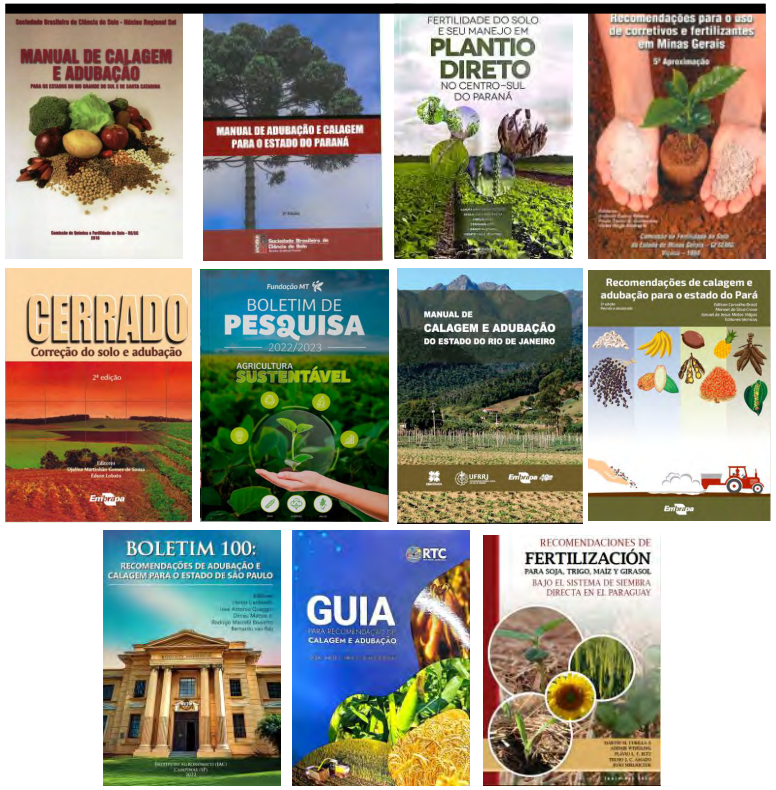
Range of classes of K availability





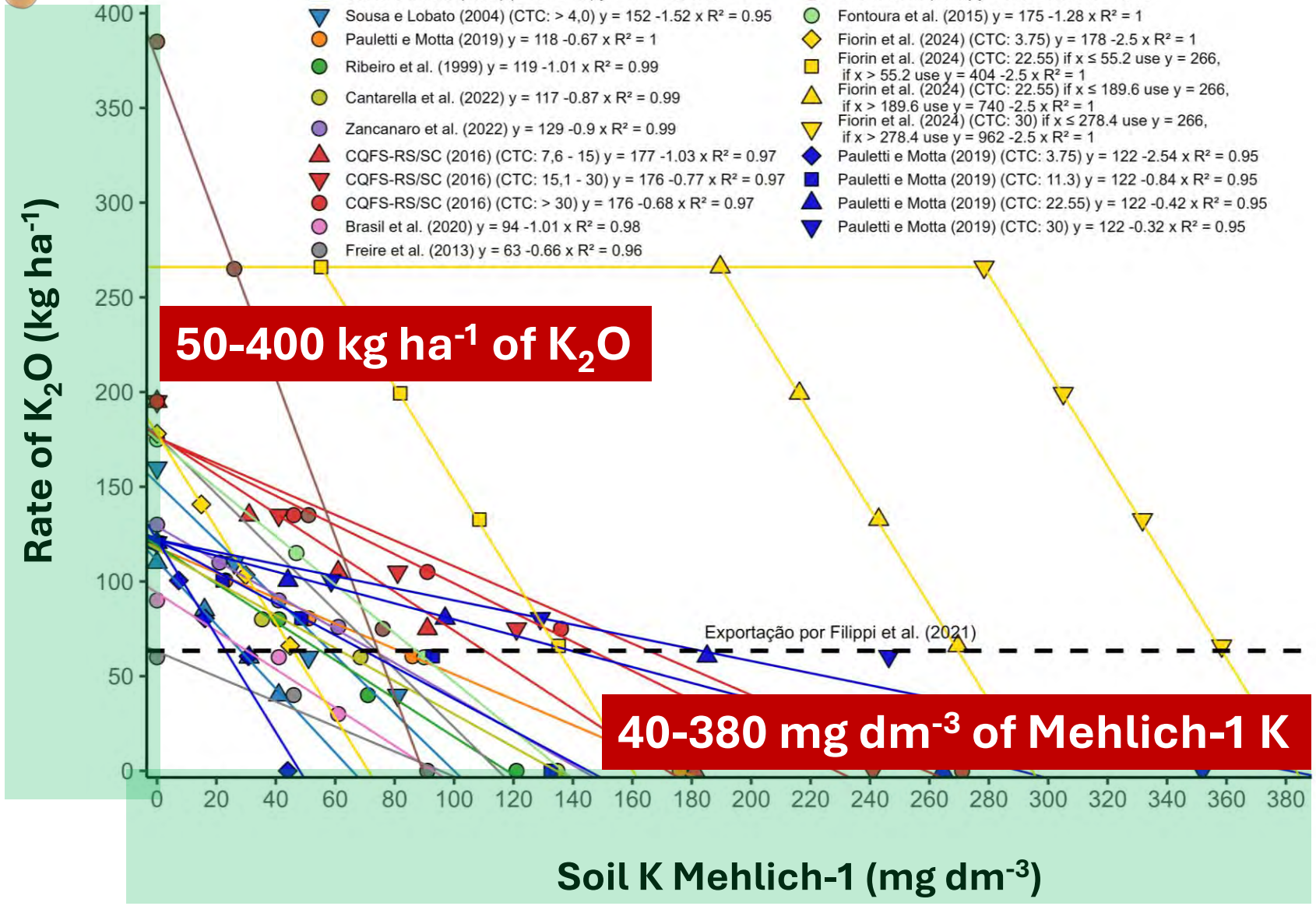
Rate of K_2O for 3 ton/ha of soybean [45 bu/ac]





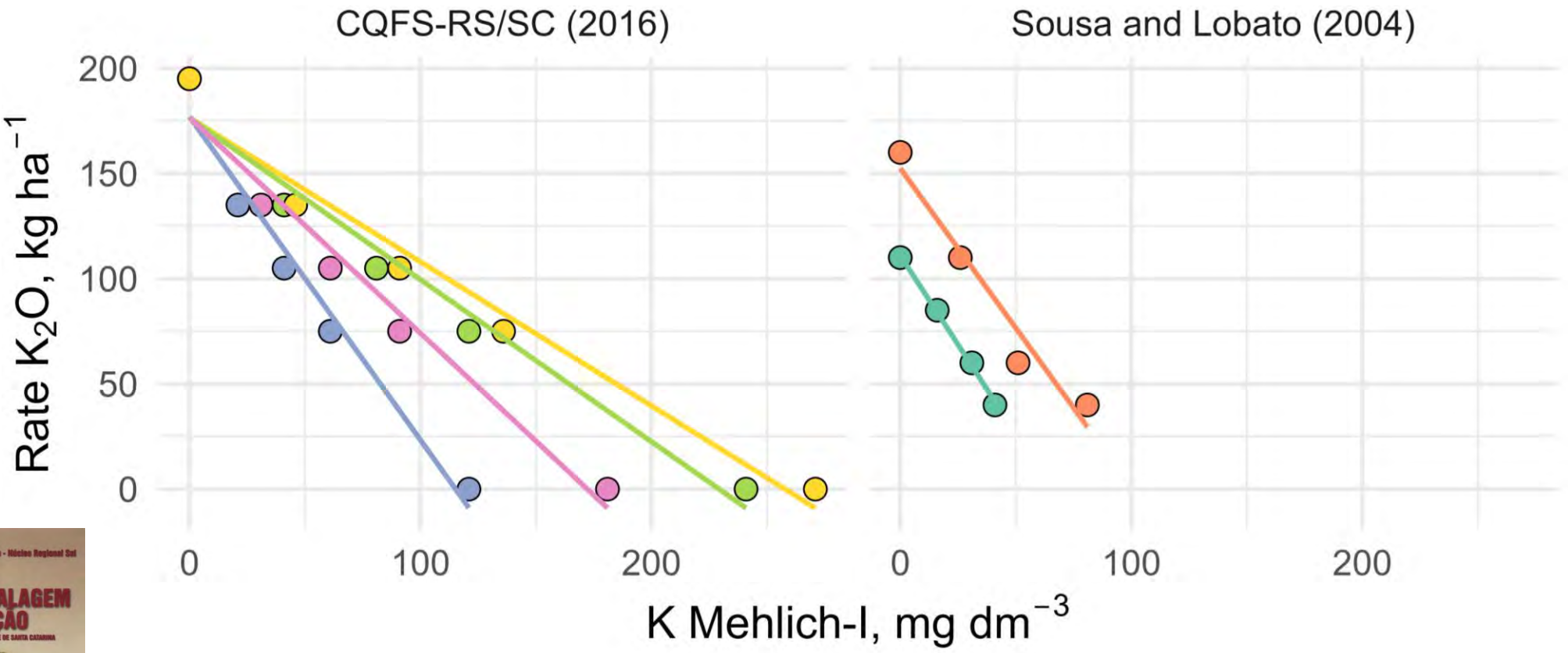
Rate of K_2O for 3 ton/ha of soybean

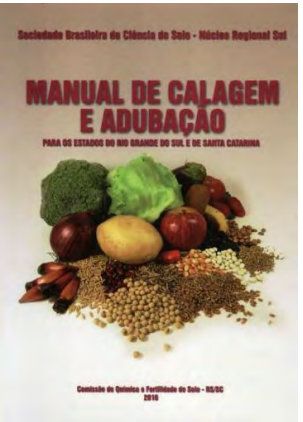
[45 bu/ac]

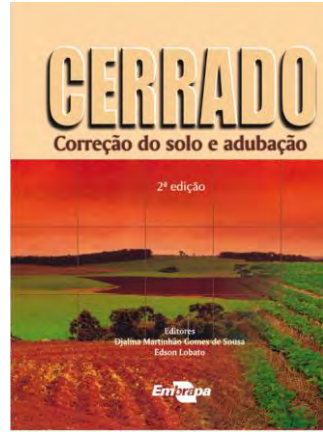


CEC taken into account for interpretation
CEC is not taken into account for defining the K rate

CEC taken into account for interpretation
CEC is taken into account for defining the K rate







Preliminary conclusions

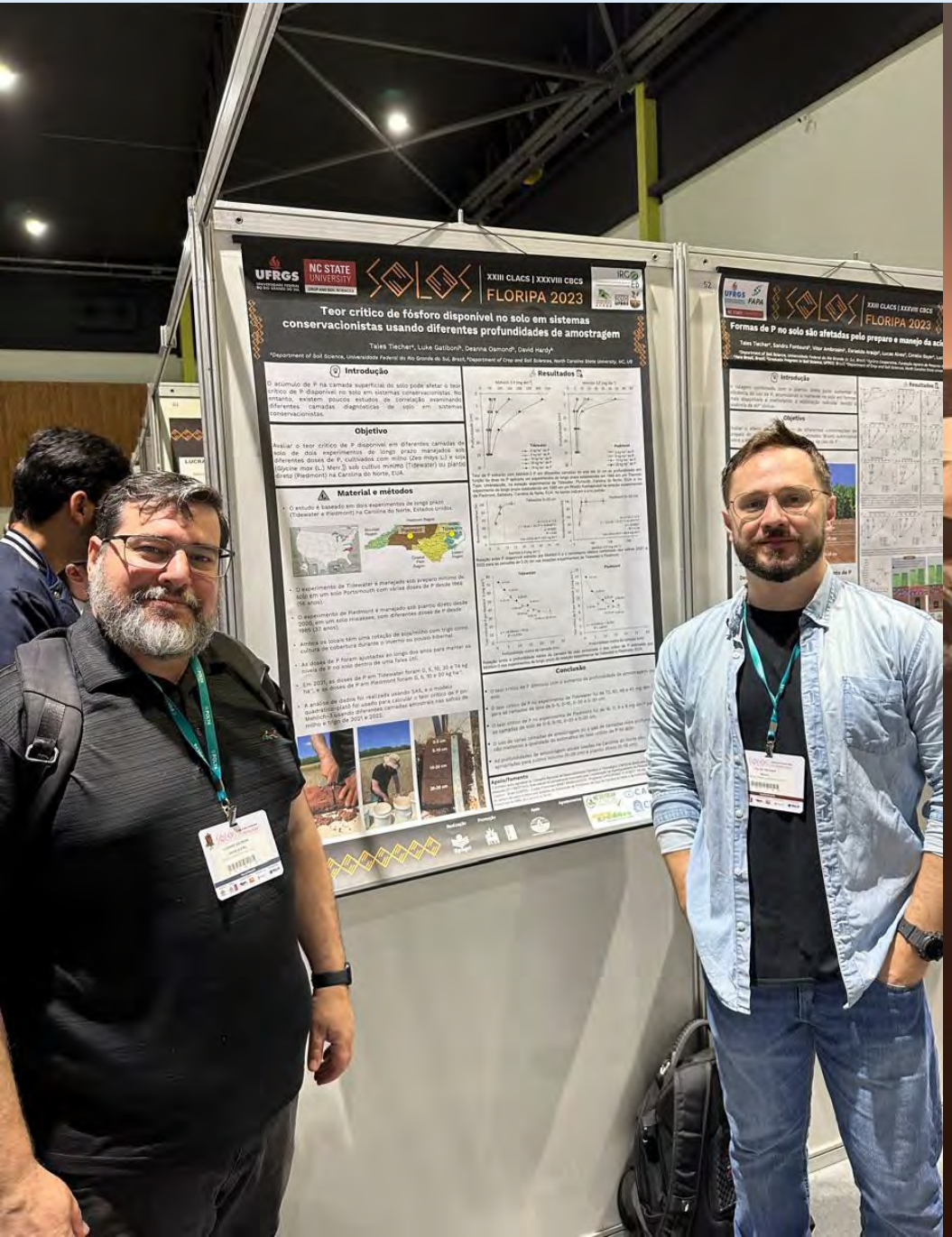
1. Phosphorus and potassium recommendations show high variability across the studied systems.

2. Despite differences, a common methodological structure exists:

a) Defined soil sampling depth
b) Using the same P and K extractor
c) Classification of soil P and K availability into ranges
d) Establishment of a critical level
e) Decreasing fertilizer rates as available P and K increases

3. This shared framework enables harmonization between systems and can help **bridge gaps** caused by region-specific guidelines.

4. Shifting from class-based systems to equation-based models could reduce discrepancies and **improve cross-regional comparability.**



- In 2023 at the **38th Brazilian Congress of Soil Science** and **23rd Latin American Congress of Soil Science** in Florianópolis-Brazil, Dr. Luke Gatiboni's lecture instigated our scientific society to jump in the FRST idea.

Sociedade Brasileira de Ciência do Solo

CNPJ: 42.137.836/0001-82
I.E.: 713.020822-0010
Ed. Silvio Brandão
Cx.P. 231 – Campus da UFV
36570-900 – Viçosa – MG
sbcs@sbcs.org.br

ATO DA PRESIDÊNCIA 08/2023

Ref.: Criação do Grupo de Trabalho Sistema de recomendação de calagem e adubação.

A Presidente da Sociedade Brasileira de Ciência do Solo (SBCS), no uso de suas atribuições legais e amparado no §2º do Artigo 16 do Regimento da SBCS,

RESOLVE:

Criar no âmbito da SBCS e vinculado à "Divisão 3 - Uso e Manejo do Solo", o Grupo de Trabalho Sistema de recomendação de calagem e adubação, com o objetivo de revisar e propor critérios de unificação e, ou melhorias nos sistemas de recomendação de calagem e adubação adotados no Brasil, e nomear os sócios Leandro Souza da Silva - UFSM (Líder) e Paulo Guilherme Salvador Wadt - Embrapa Rondônia (Vice-líder) para integrarem a sua coordenação. O GT será ainda composto pelos seguintes membros: Henrique Antunes de Souza – Embrapa Meio Norte, Milton Ferreira de Moraes – UFMT e Paulo Sérgio Pavinato - Esalq/USP.

Publique-se.

Viçosa, 21 de dezembro de 2023.

Maria Eugenia Ortiz Escobar
Presidente
Sociedade Brasileira de Ciência do Solo

Working Group on Liming and Fertilization Recommendation Systems

Objective of reviewing and proposing criteria for unification and/or improvements in the liming and fertilization recommendation systems adopted in Brazil.

i. Leandro Souza da Silva - UFSM (Leader)
ii. Paulo Guilherme S. Wadt - Embrapa Rondônia (Vice-Leader)
iii. Henrique Antunes de Souza - Embrapa Meio Norte
iv. Milton Ferreira de Moraes - UFMT
v. Paulo Sérgio Pavinato - Esalq/USP

Phosphorus and potassium fertilizer recommendations in Brazil and Paraguay: convergences, divergences, and paths towards harmonization

UFRGS
UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

Tales Tiecher
Departamento de Solos
Faculdade de Agronomia
tales.tiecher@ufrgs.br

DEPARTAMENTO DE SOLOS UFRGS

PÓS-GRADUAÇÃO EM CIÊNCIA DO SOLO UFRGS

IRGEB
interdisciplinary research group on environmental biogeochemistry