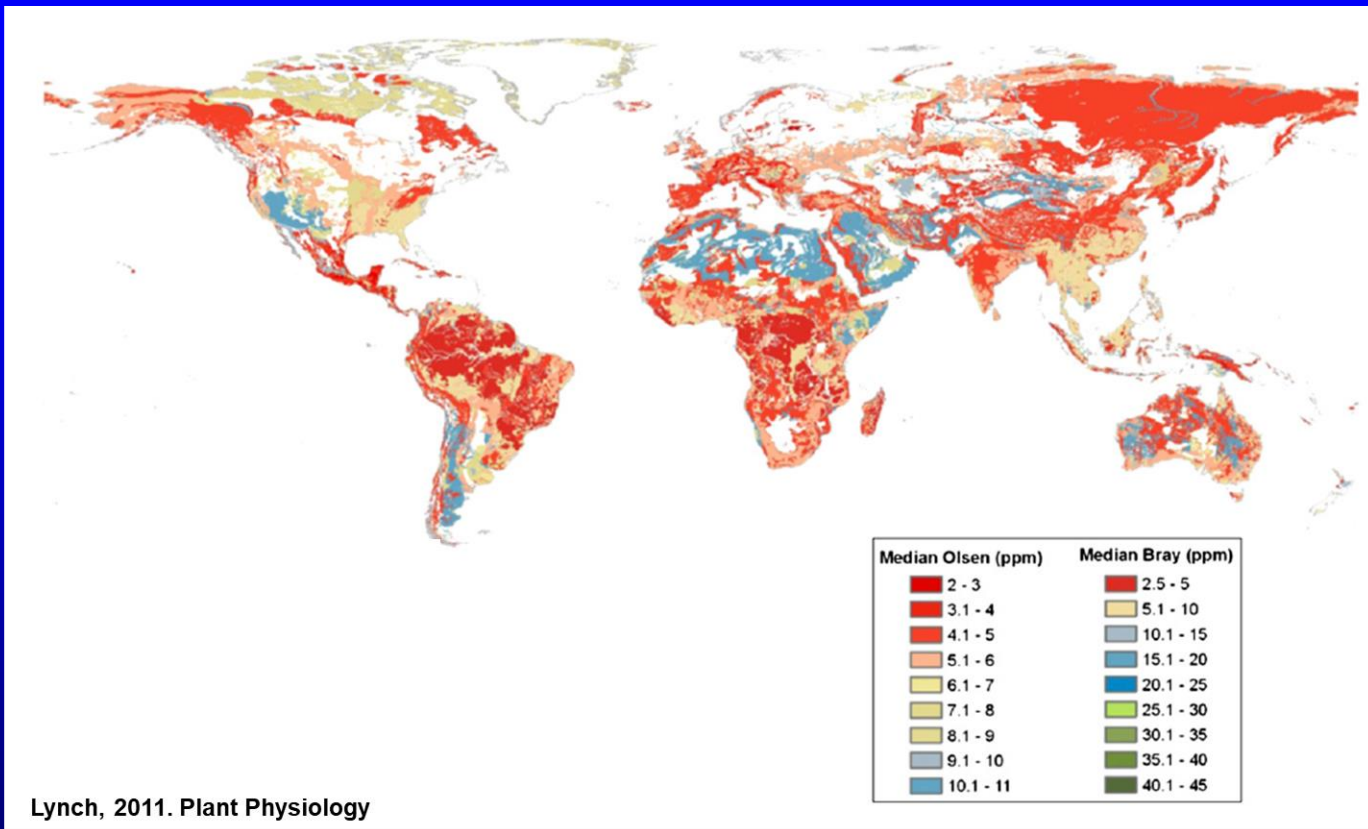




Factores a considerar para incrementar la eficiencia de uso de nutrientes en el cultivo de la papa

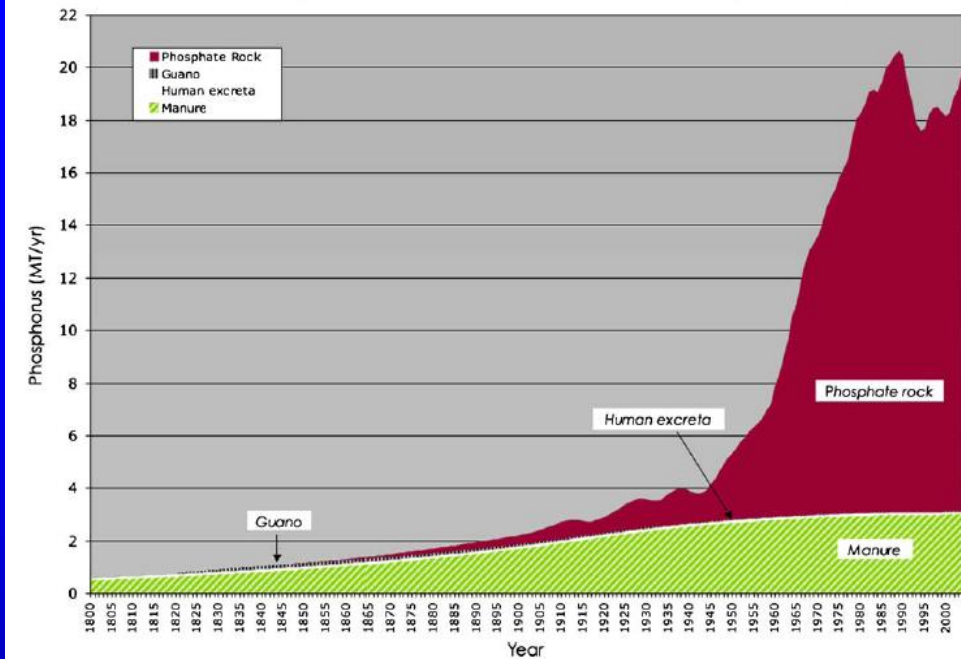
Patricio Sandaña G.



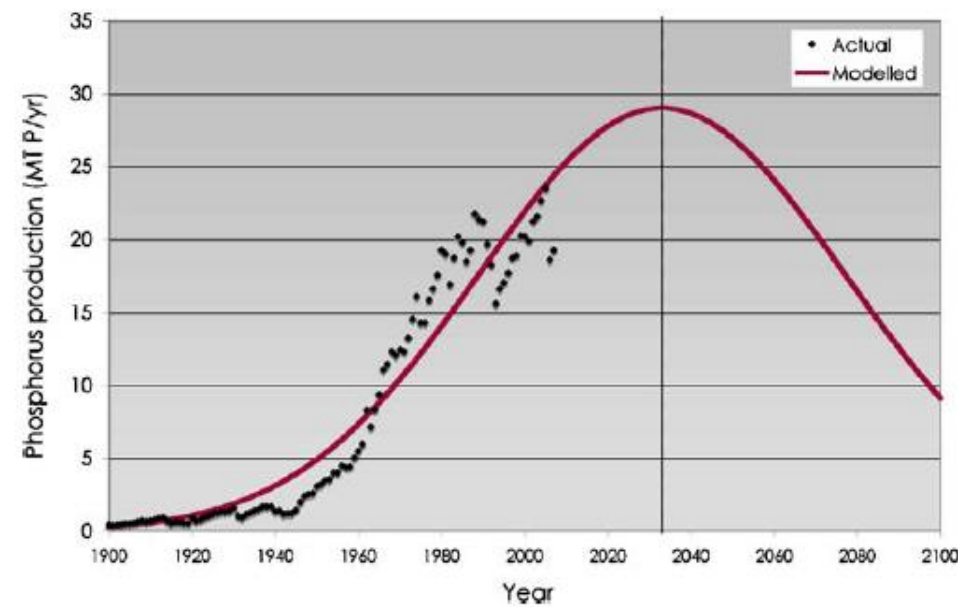
Lynch, 2011. Plant Physiology

Cordell et al.. 2009; Glob. Envi. Chang.

Historical global sources of phosphorus fertilizers (1800-2000)



Peak phosphorus curve



EFFECTO DE LA DEFICIENCIA DE FÓSFORO



Plantas pequeñas que no cubren la entre hilera. En floración.

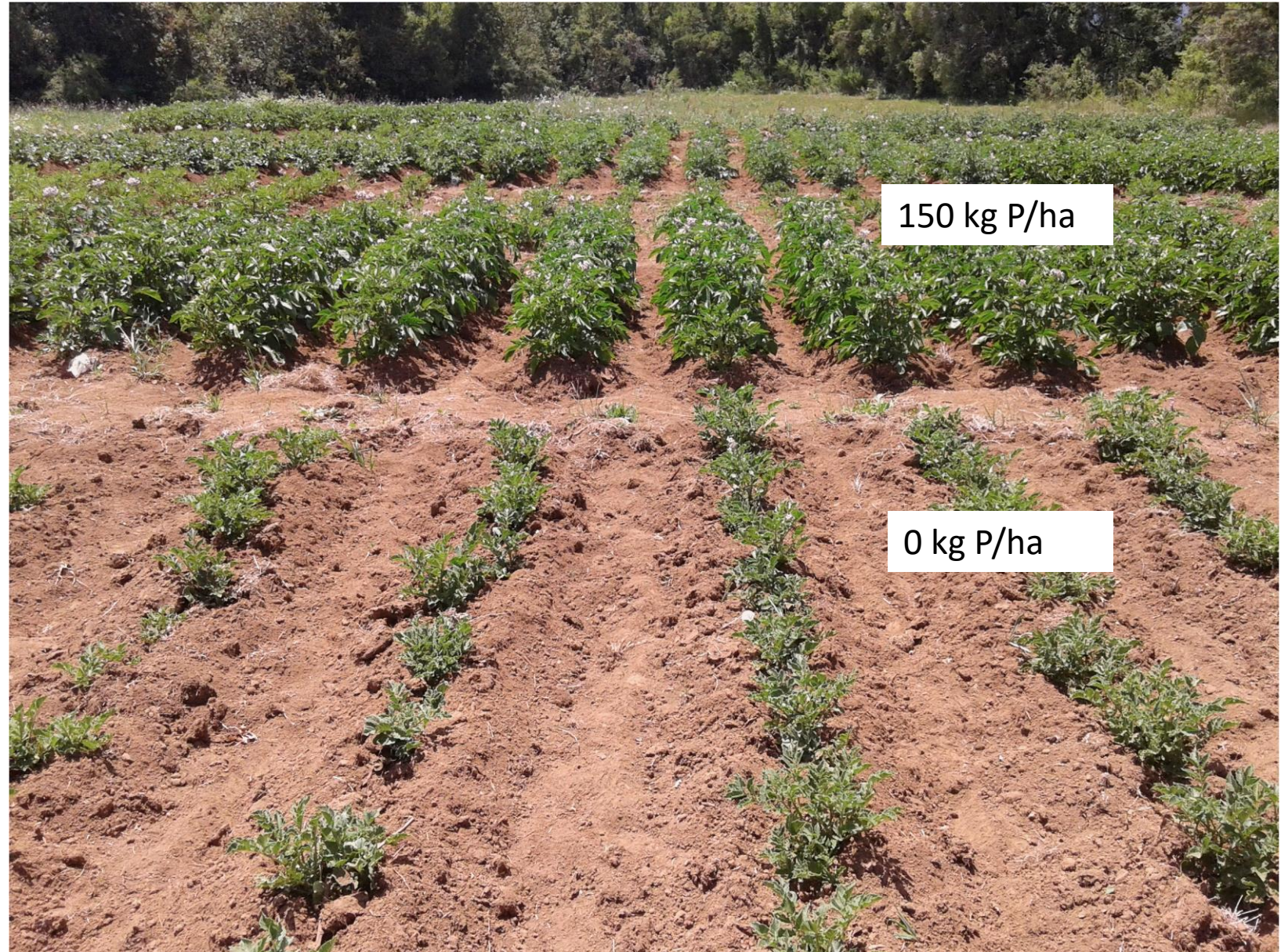


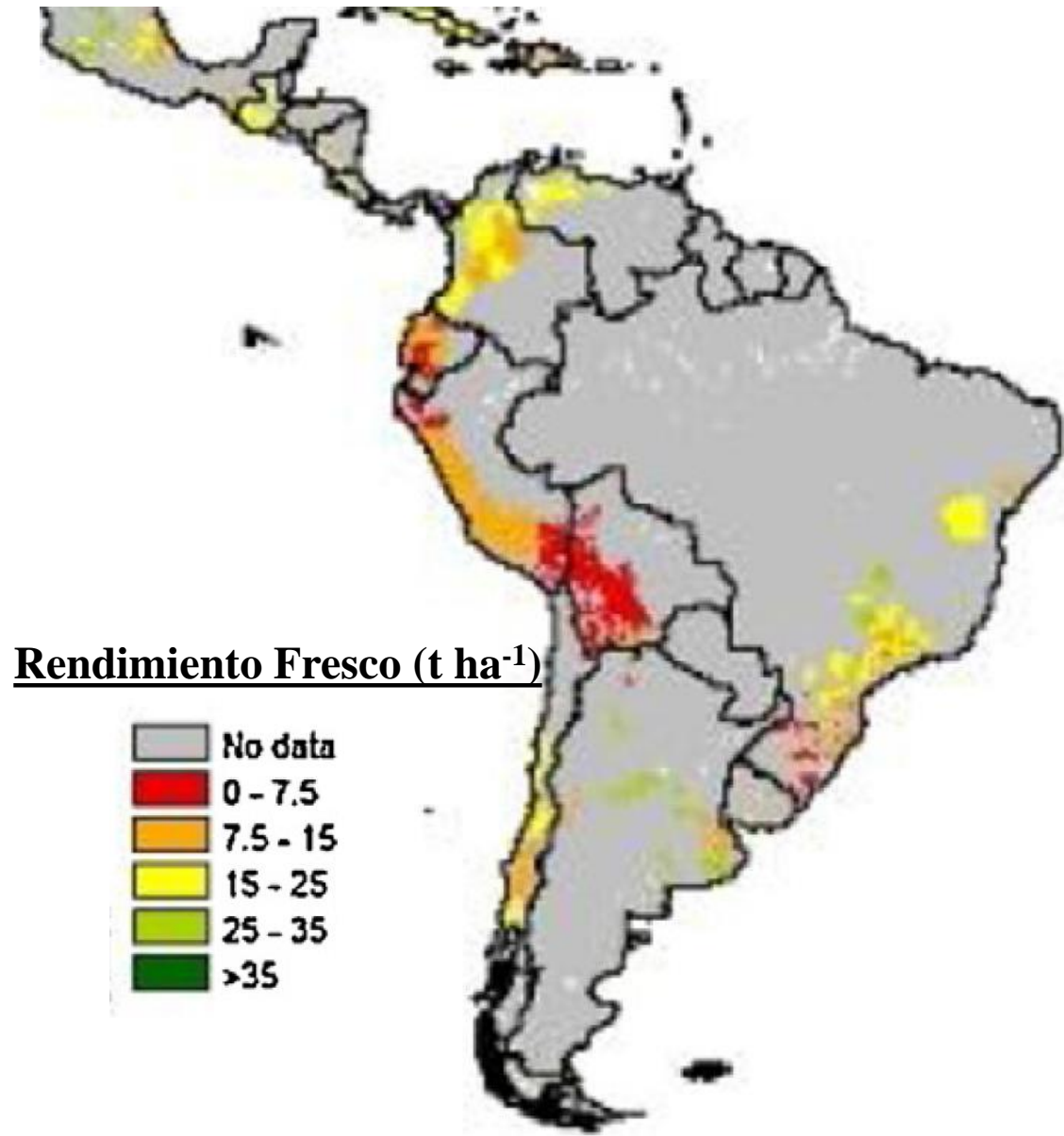
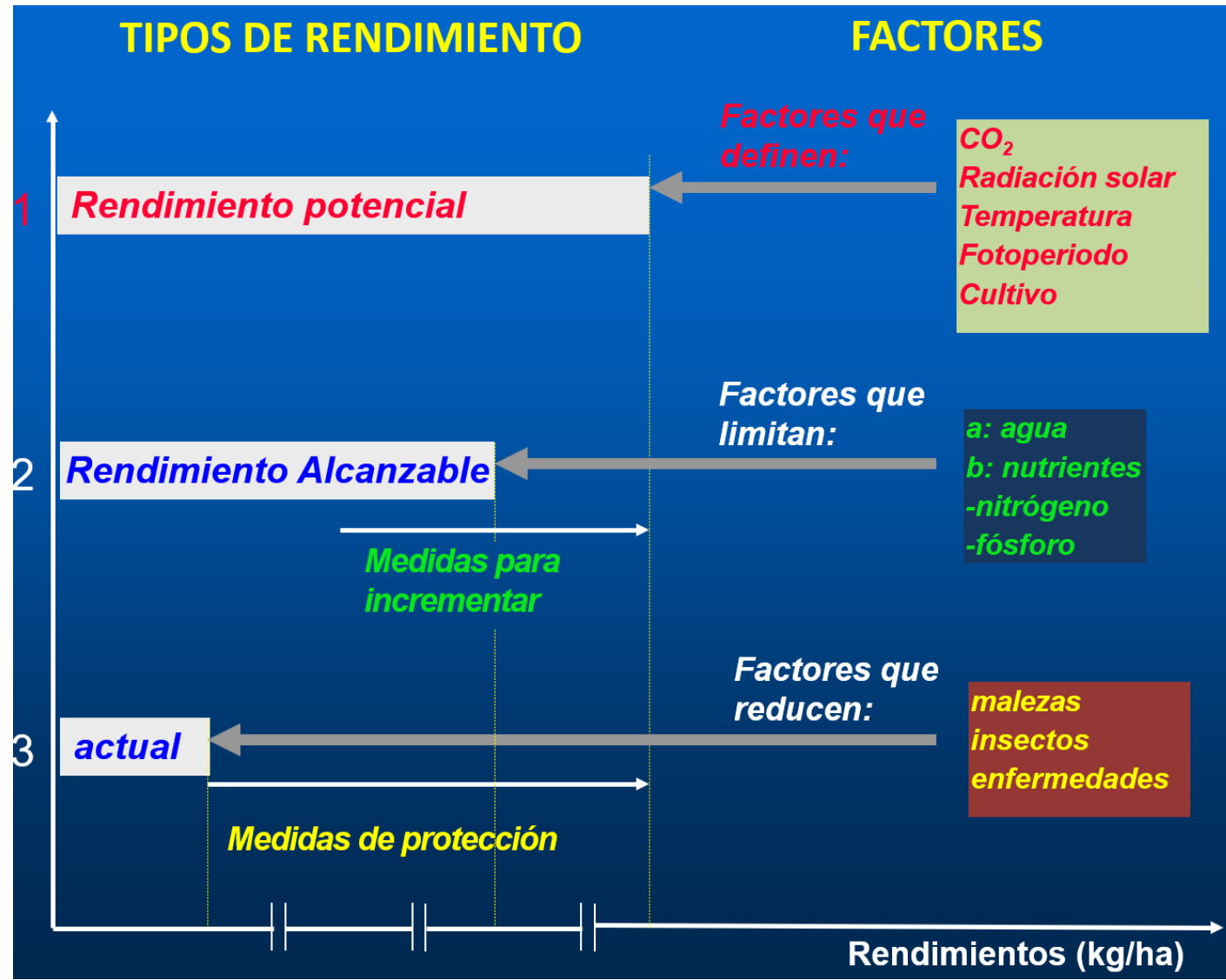
Entre hilera completamente cubierta. En floración.

Nivel inicial de P-Olsen 4 ppm

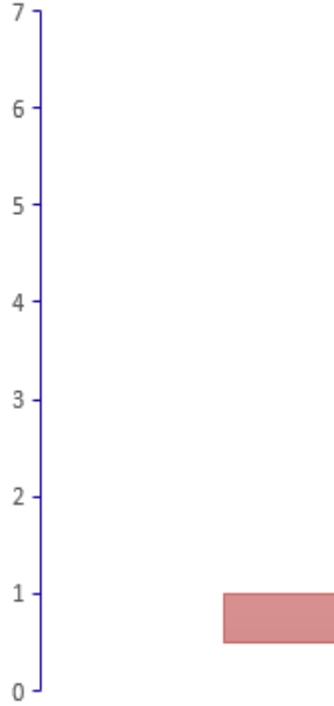
EFECTO DE LA DEFICIENCIA DE FÓSFORO VALDIVIA 2013

Suelo con P olsen inicial de 5 ppm

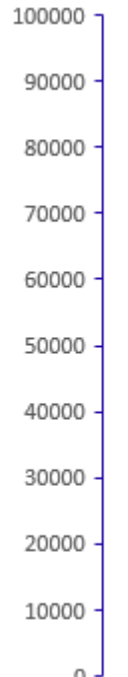




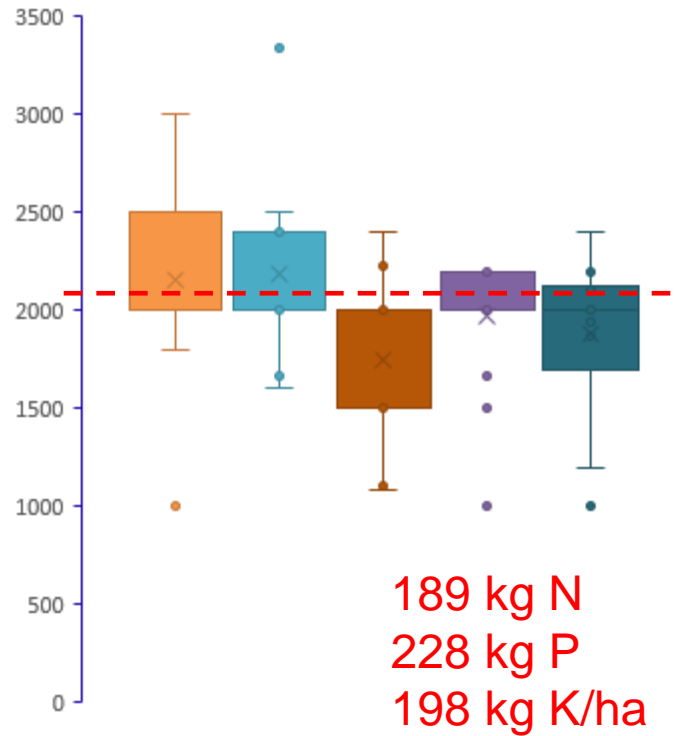
SUPERFICIE PLANTADA
(ha)



RENDIMIENTO (kg/ha)



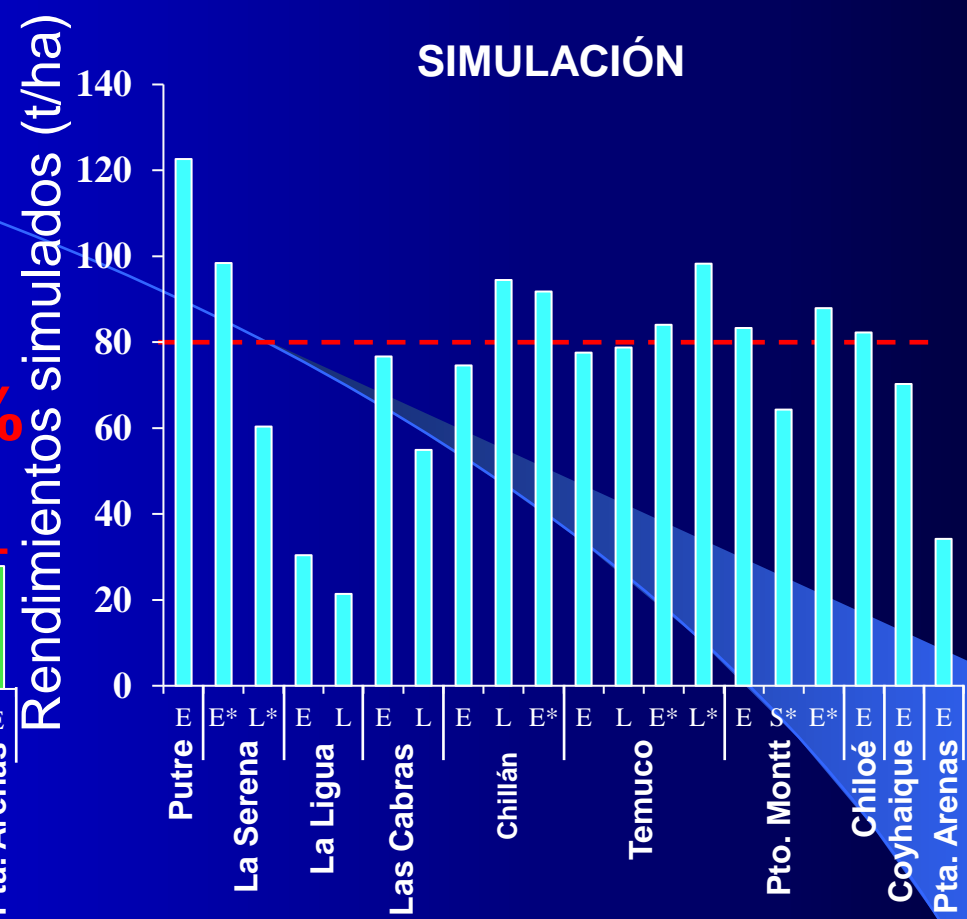
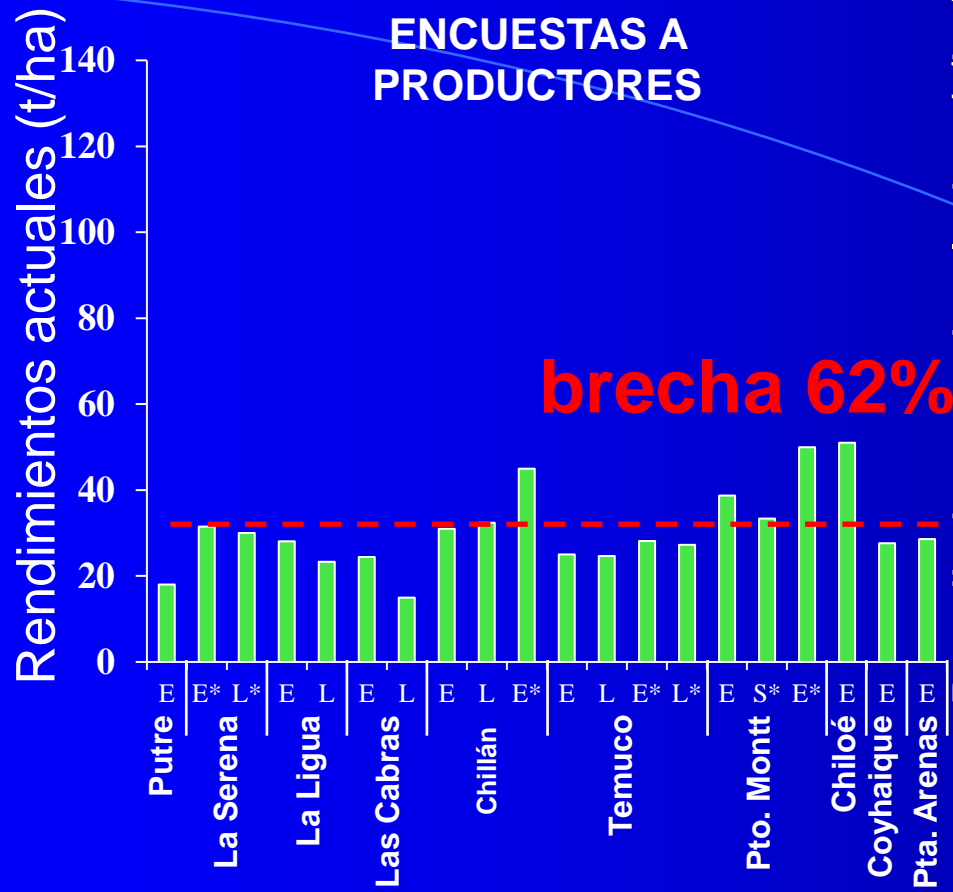
FERTILIZACION
(kg/ha)



- Los Muermos
- Fresia
- Maullin
- Puerto Montt
- Llanquihue

90 kg N
12 kg P
200 kg K/ha





- **Calidad de semilla**
- **Época de plantación**
- **Riego**
- **Fertilización**
- **Control de plagas y enfermedades**

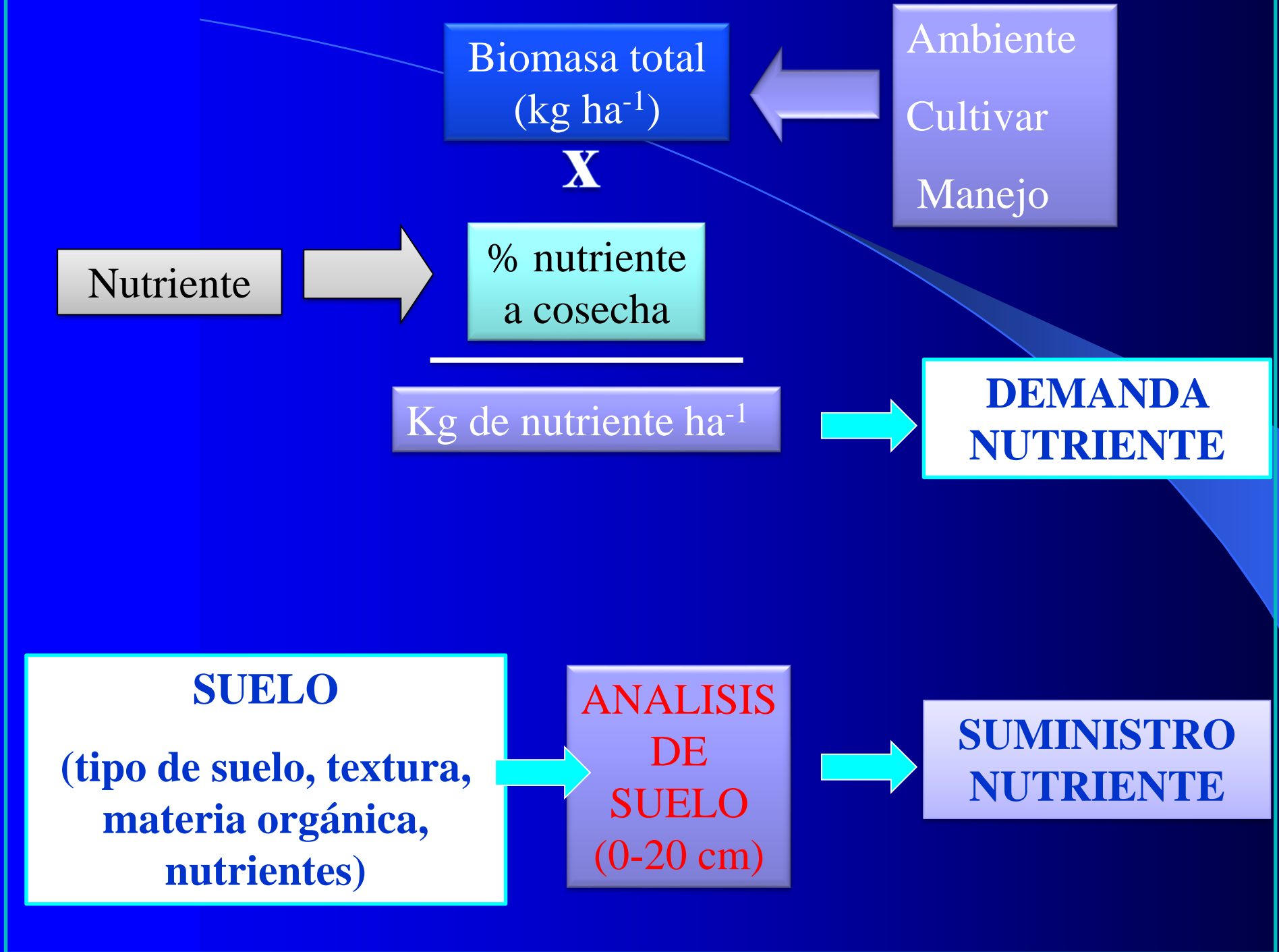
DETERMINACIÓN DE LA DOSIS DE FERTILIZACION

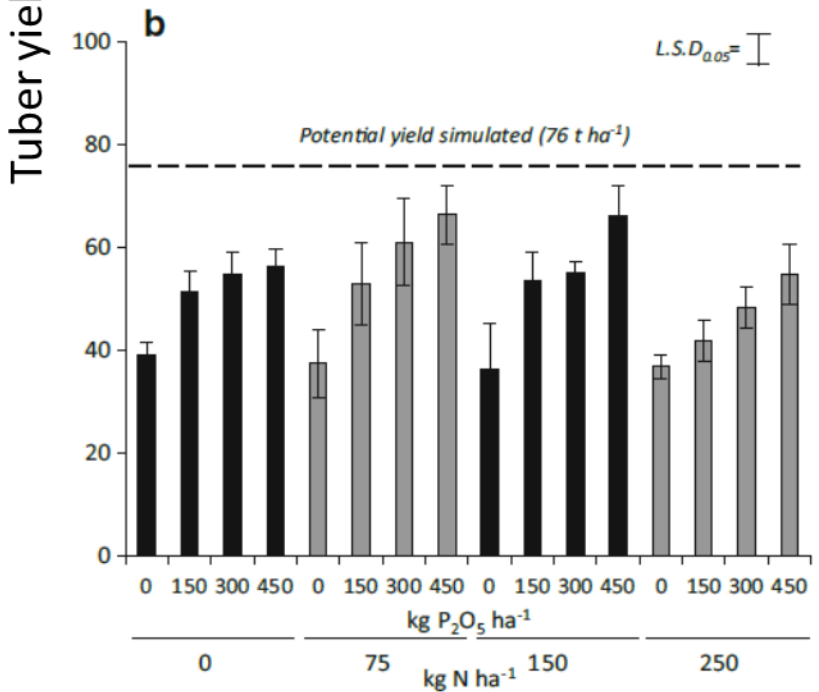
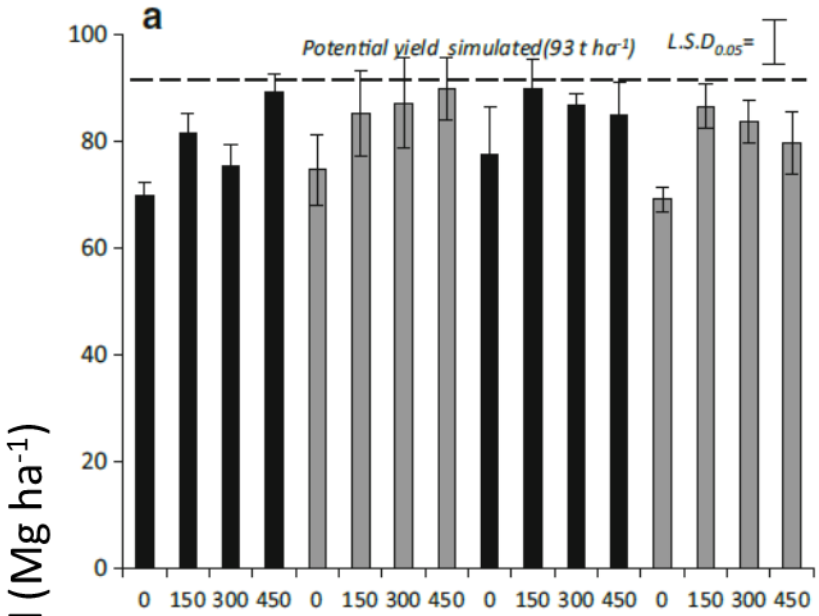
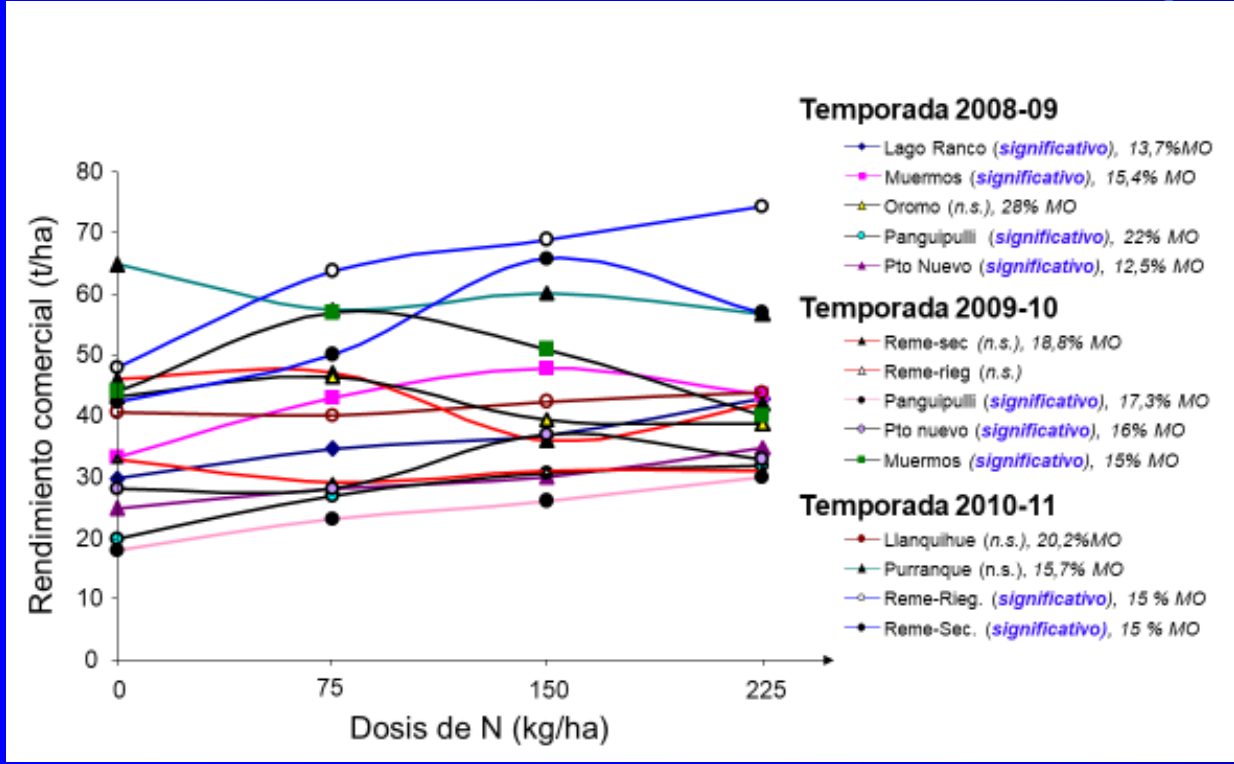
- Rendimiento alcanzable
- Concentración del nutriente

- Rotación de cultivos
- Cultivo anterior
- Manejo de residuos
- Disponibilidad del nutriente

$$\text{Dosis} = \frac{\text{Demanda} - \text{Suministro}}{\text{Eficiencia de fertilización}}$$

- Grupo de suelos
- Capacidad de retención de los suelos





Clasificación por requerimiento del vegetal

Elemento	Símbolo	Concentración en materia seca	
		Mmol g ⁻¹	ppm *(%)
<i>Obtenido del agua o del CO₂</i>			
Hidrógeno	H	60000	6*
Carbono	C	40000	45*
Oxígeno	O	30000	45*
<i>Obtenido del suelo</i>			
<i>Macronutrientes</i>			
Nitrógeno	N	1000	1.5*
Potasio	K	250	1.0*
Calcio	Ca	125	0.5*
Magnesio	Mg	80	0.2*
Fósforo	P	60	0.2*
Azufre	S	30	0.1*
Sílice	Si	30	0.1*
<i>Micronutrientes</i>			
Cloro	Cl	3	100
Hierro	Fe	2	100
Boro	B	2	20
Manganeso	Mn	1	50
Sodio	Na	0.4	10
Zinc	Zn	0.3	20
Cobre	Cu	0.1	6
Niquel	Ni	0.002	0.1
Molibdeno	Mo	0.001	0.1

¿Cuál es la concentración crítica óptima de un cultivo?

¿La concentración es constante durante el ciclo de cultivo?

¿La concentración es afectada por la disponibilidad de nutrientes en el suelo?

¿Existen diferencias entre cultivares en la concentración crítica?

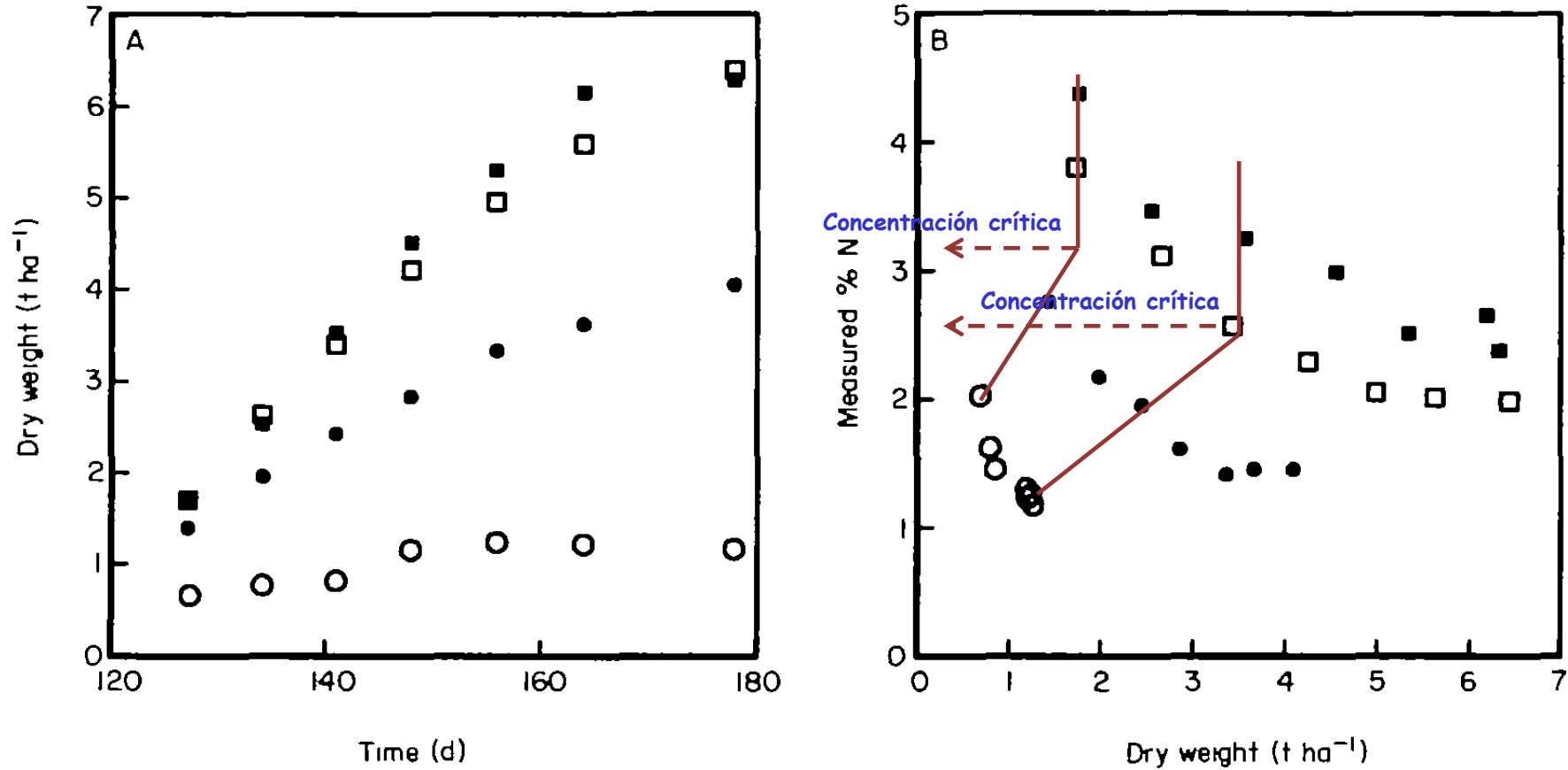


FIG. 1. A, Dry weight (t ha⁻¹) of the above ground parts of tall fescue cv. Ludelle at different times after the first cut (day 106) obtained with: (○) 0 kg N ha⁻¹; (●) 50 kg N ha⁻¹; (□) 100 kg N ha⁻¹; (■) 150 kg N ha⁻¹, applied immediately after cutting. B, % N in foliage dry matter and corresponding d. wts with the fertilizer N levels and symbols in (A).

Greenwood et al 1990, *Annals of Botany*

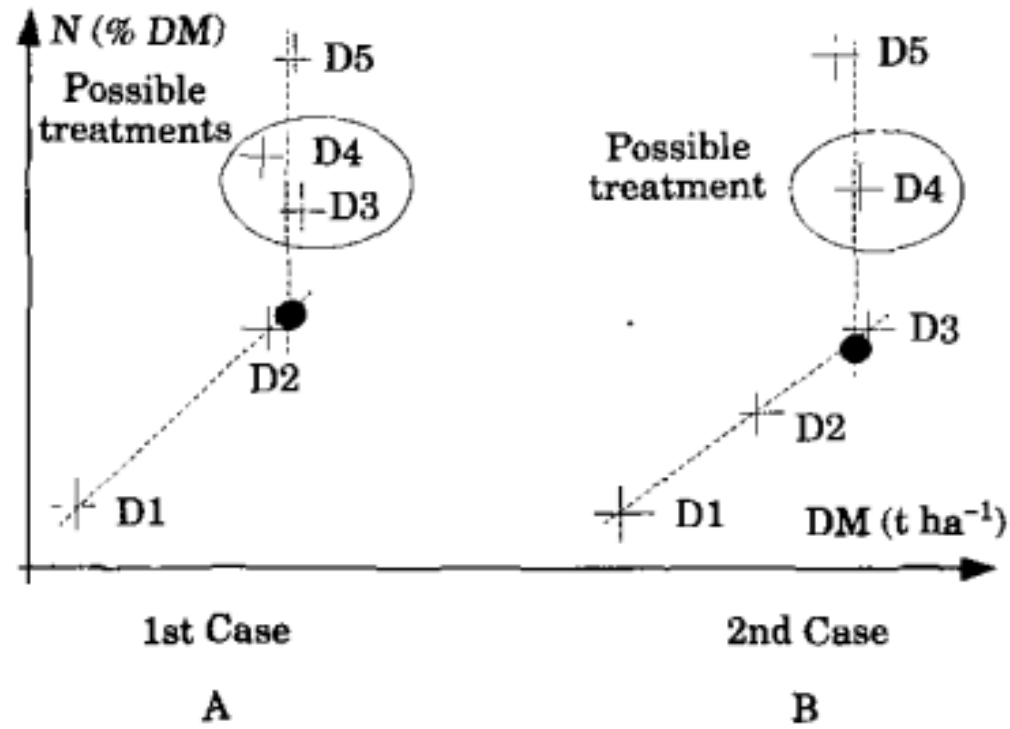
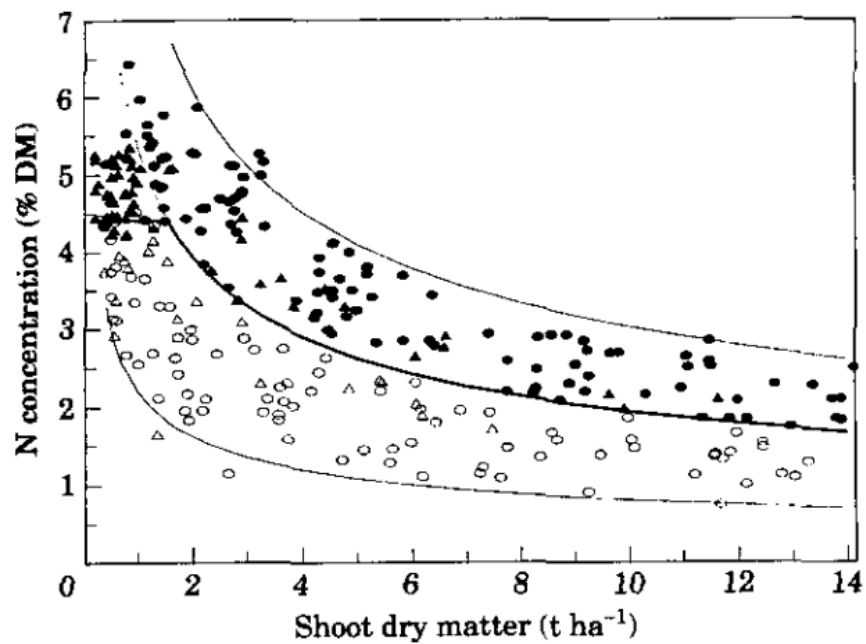
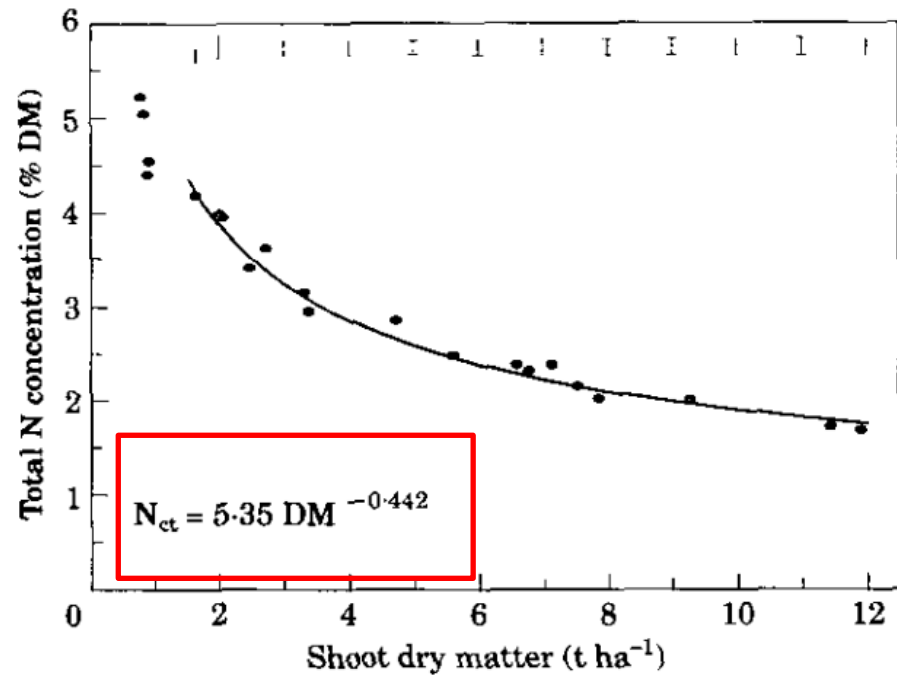
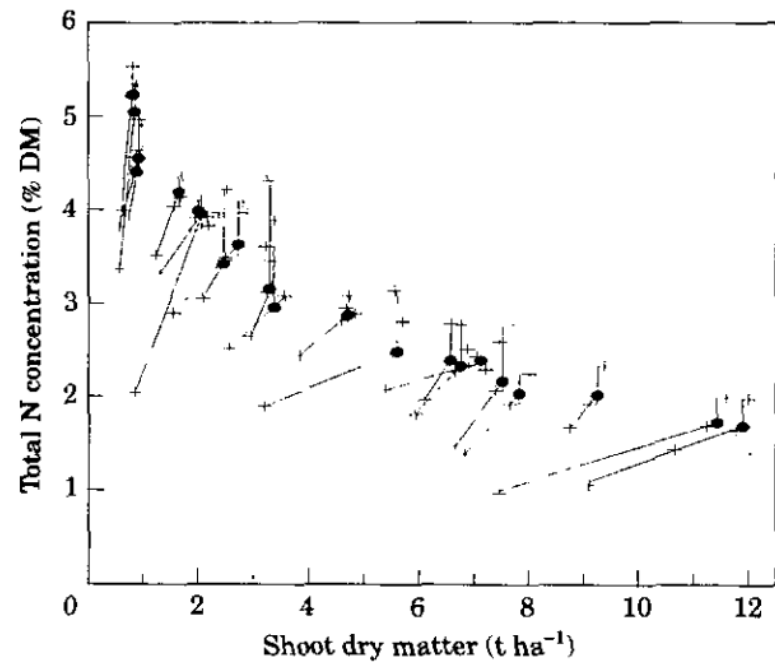
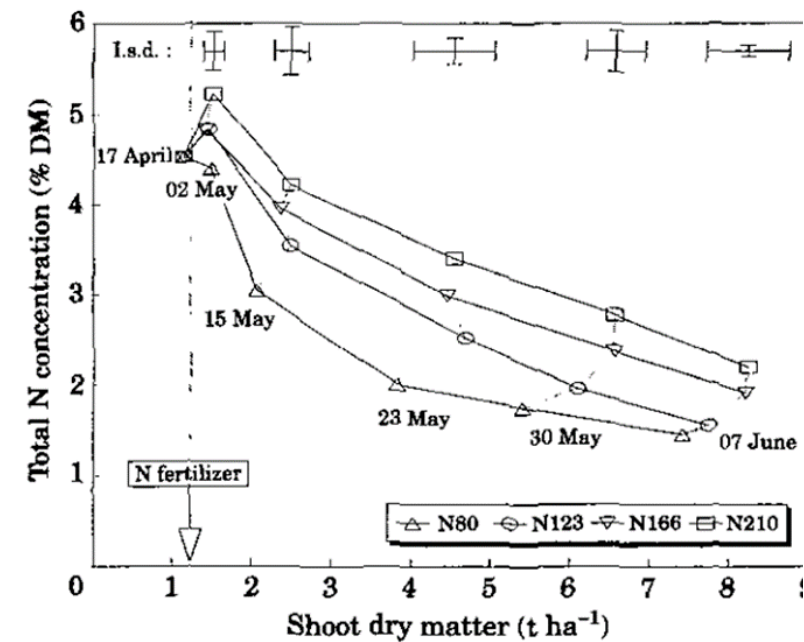
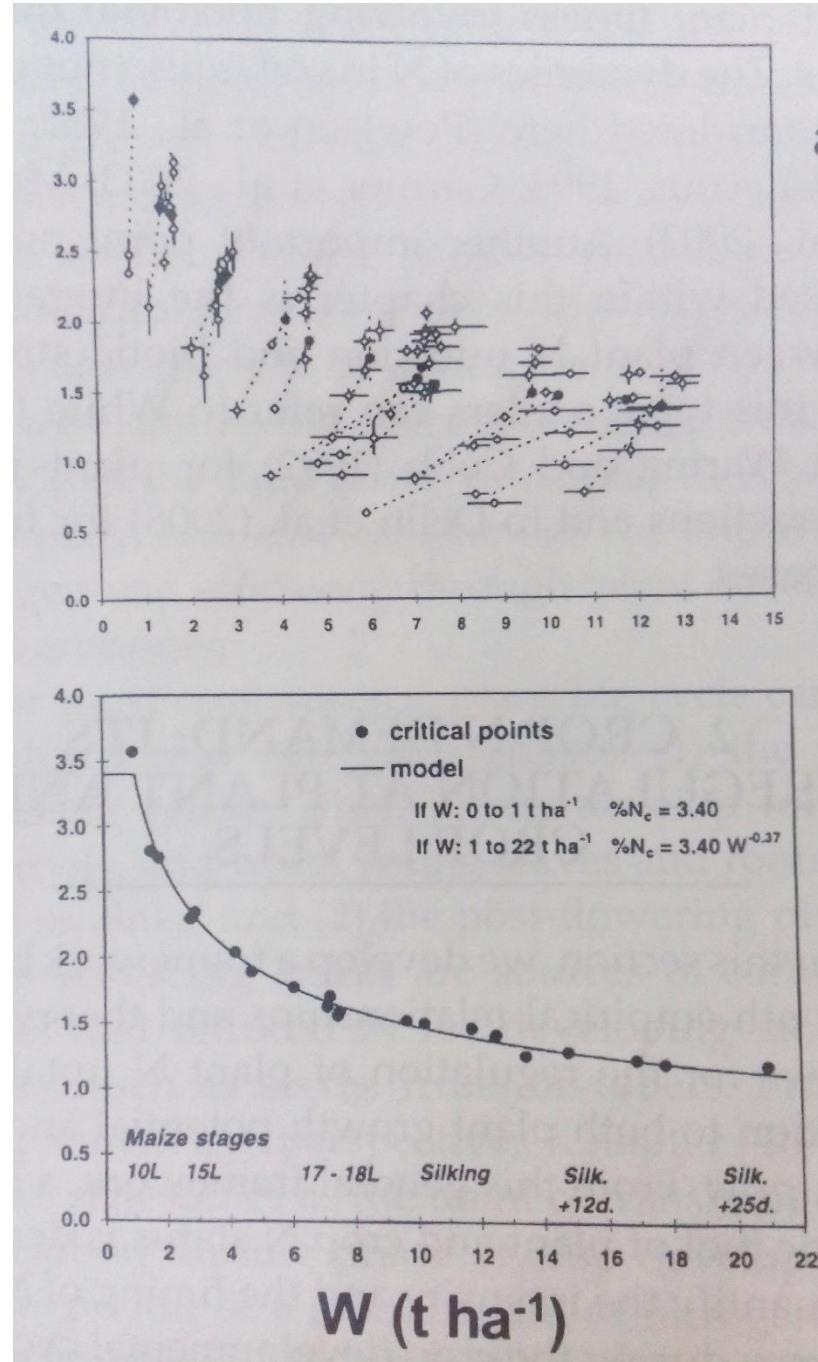


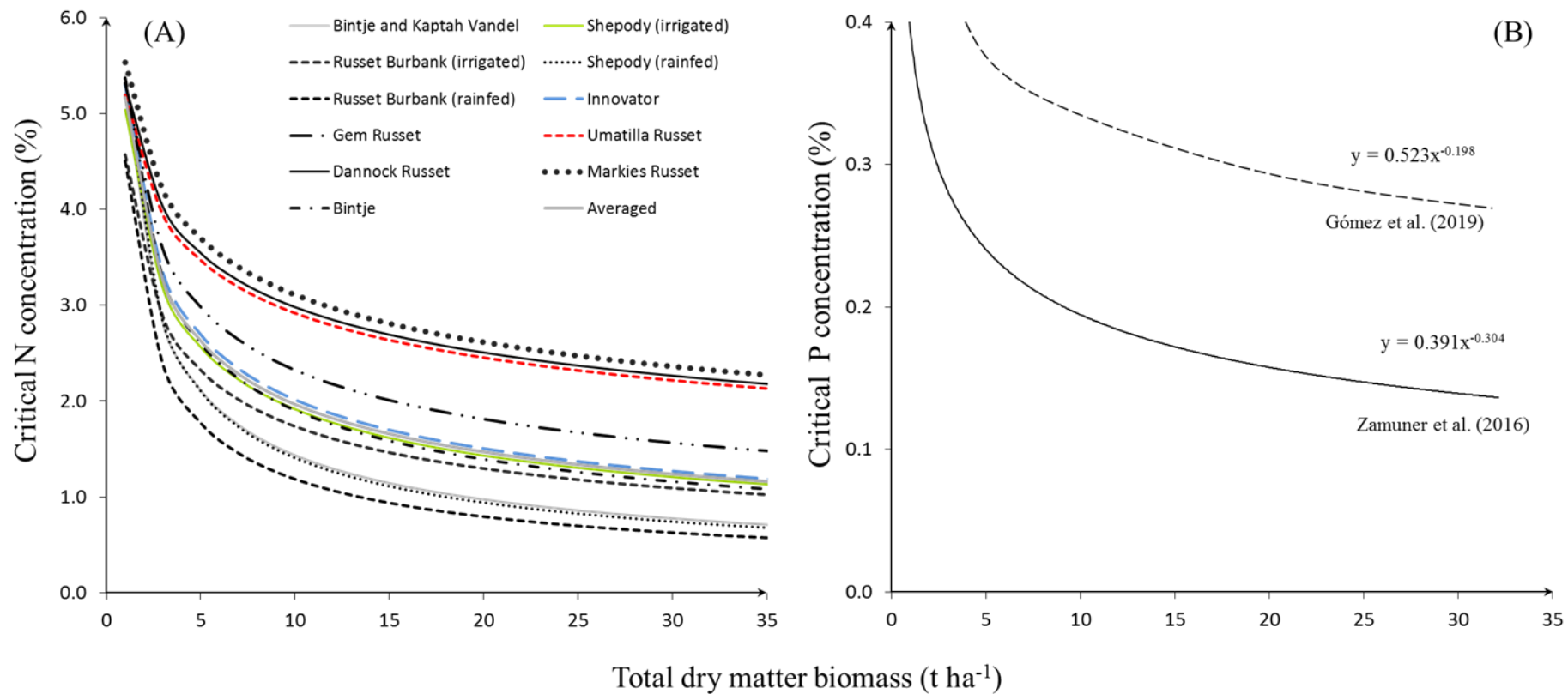
FIG. 1. Diagram representing N concentration versus accumulated dry matter in shoots. (+) Values measured in the different nitrogen fertilization treatments (D1–D5) at a given date; (●) calculated 'critical' point, at this date.



Curva crítica de dilución de N en Maíz

FIG. 8.1 Determination of the critical dilution curve from data obtained with different N fertilization rate experiments in maize. (a) Open symbols are the different experiments. Dark symbols are the critical N concentration calculated as the intersection of the oblique line representing response of crop mass to increased plant N concentration, and the vertical line representing the increases in plant N concentration without any increase in crop mass (accumulation of excess of N). (b) The critical dilution curve of maize. From Plénet and Lemaire (1999).





Cultivar	Country	A ₁	A ₂	Reference	F
Bintje and Kaptah Vandel	France	5.21	0.56	Duchenne et al. (1997)	
Shepody (irrigated)	Canada	5.04	0.42	Bélangier et al. (2001)	
Russet Burbank (irrigated)	Canada	4.57	0.42	Bélangier et al. (2001)	
Shepody (rainfed)	Canada	5.36	0.58	Bélangier et al. (2001)	
Russet Burbank (rainfed)	Canada	4.50	0.58	Bélangier et al. (2001)	
Innovator	Argentina	5.30	0.42	Giletto and Echeverría (2012)	
Gem Russet	Argentina	5.32	0.36	Giletto and Echeverría (2015)	
Umatilla Russet	Argentina	5.19	0.25	Giletto and Echeverría (2015)	
Dannock Russet	Argentina	5.30	0.25	Giletto and Echeverría (2015)	
Markies Russet	Argentina	5.53	0.25	Giletto and Echeverría (2015)	
Bintje	Belgium	5.37	0.45	Ben Abdallah et al. (2016)	
Agata and Electra in all SYs	Brazil	3.86 CI (3.51, 4.26)	0.34 CI (0.28, 0.40)	Medians of this study	

Analyzing uncertainty in critical nitrogen dilution curves

David Makowski ^{a, b}, Ben Zhao ^c, Syed Tahir Ata-Ul-Karim ^d, Gilles Lemaire ^e

```

Nc[i]~dnorm(Nc[Date[i]], tau_n)
mu[i]<-min(Bmax[Date[i]], Bmax[Date[i]]+S[Date[i]]*(Nf[i]-Nc[Date[i]]))
}
for (j in 1:K)
{
  Nc[j]=A1*Bmax[j]^(1-A2)
  Bmax[j]~dnorm(Mu_Bmax, Prec_Bmax)T(0,)
  S[j]~dnorm(Mu_S, Prec_S)T(0,)
}

#Weakly informative
Mu_Bmax~dnorm(6,0.1)
Mu_S~dnorm(0,0.1)
A1~dunif(2,6)
A2~dunif(0,0.5)

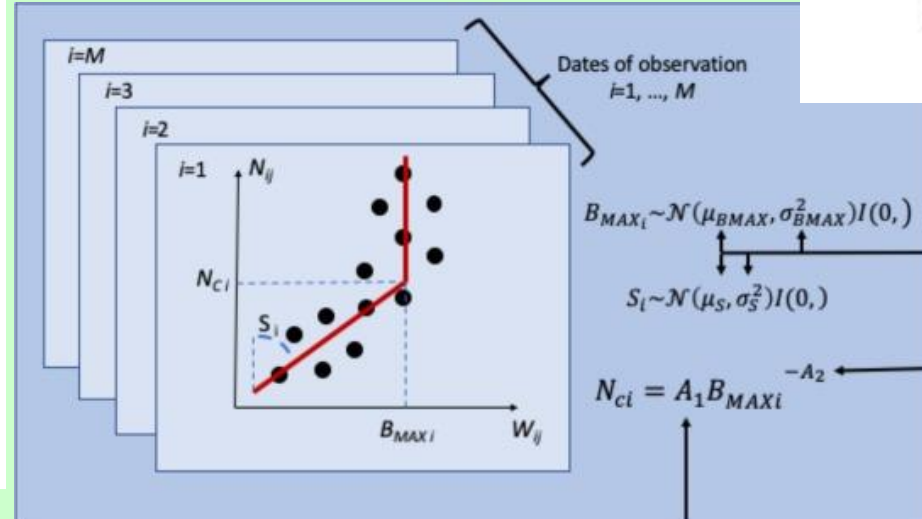
#informative prior C3
#A1~dnorm(4.89, 7.72)T(4,5.5)
#ZA2~dbeta(2.12, 2.12)
#A2=(0.4-0.3)*ZA2+0.3
#ZMu_Bmax~dbeta(2.31, 2.31)
#Mu_Bmax=(15-1)*ZMu_Bmax+1
#Mu_S~dnorm(0,0.1)

#informative prior C4
#ZA1~dbeta(2.03, 1.5)
#A1=(4-3)*ZA1+3
#ZA2~dbeta(2.12, 2.12)
#A2=(0.4-0.3)*ZA2+0.3
#ZMu_Bmax~dbeta(2.31, 2.31)
#Mu_Bmax=(15-1)*ZMu_Bmax+1
#Mu_S~dnorm(0,0.1)

Prec_Bmax~dgamma(0.001, 0.001)
Prec_S~dgamma(0.001, 0.001)
tau_b~dgamma(0.001, 0.001)
tau_n~dgamma(0.001, 0.001)
}
writeLines(modelstring, con="model.txt")

model<-jags.model("model.txt", data=list("W"=W, "N"=N, "Date"=Date, "Q"=Q, "K"=K),
n.chains=3, n.adapt=10000)

```



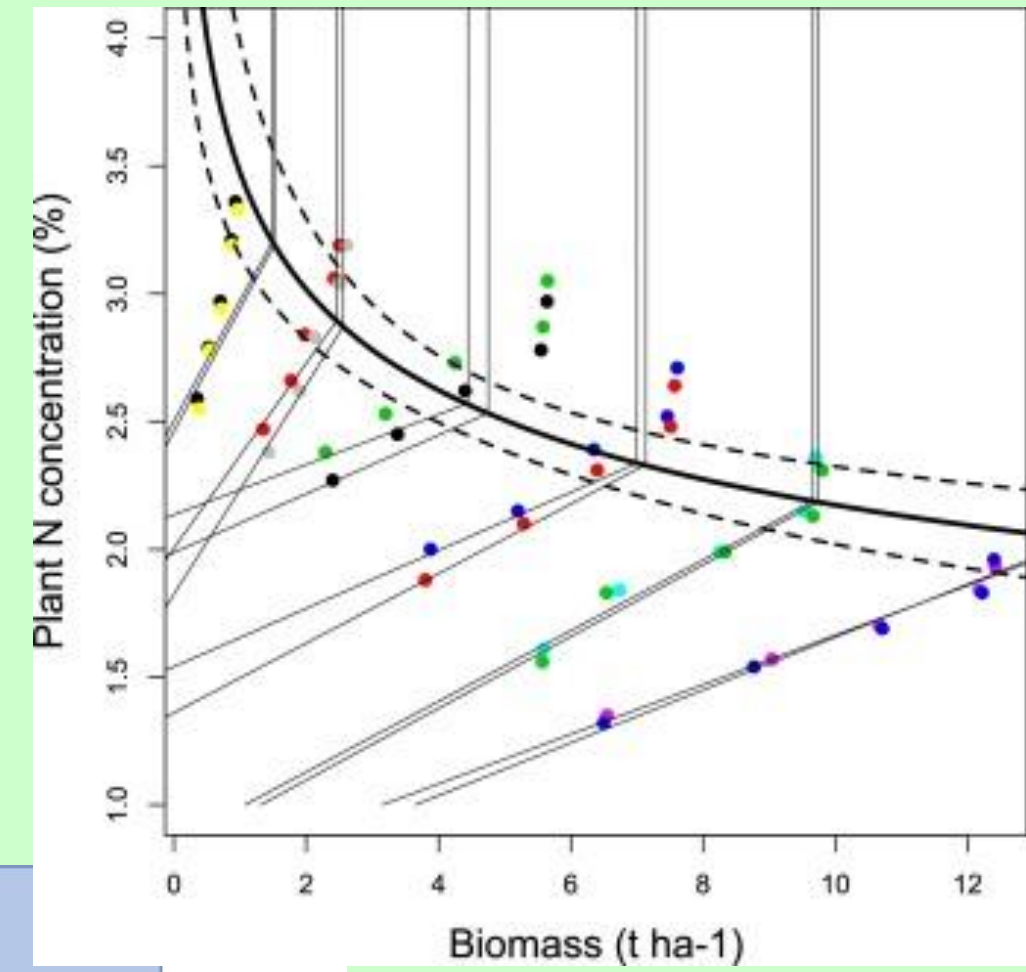
$$B_{MAX_i} \sim \mathcal{N}(\mu_{B_{MAX}}, \sigma_{B_{MAX}}^2) I(0, \infty)$$

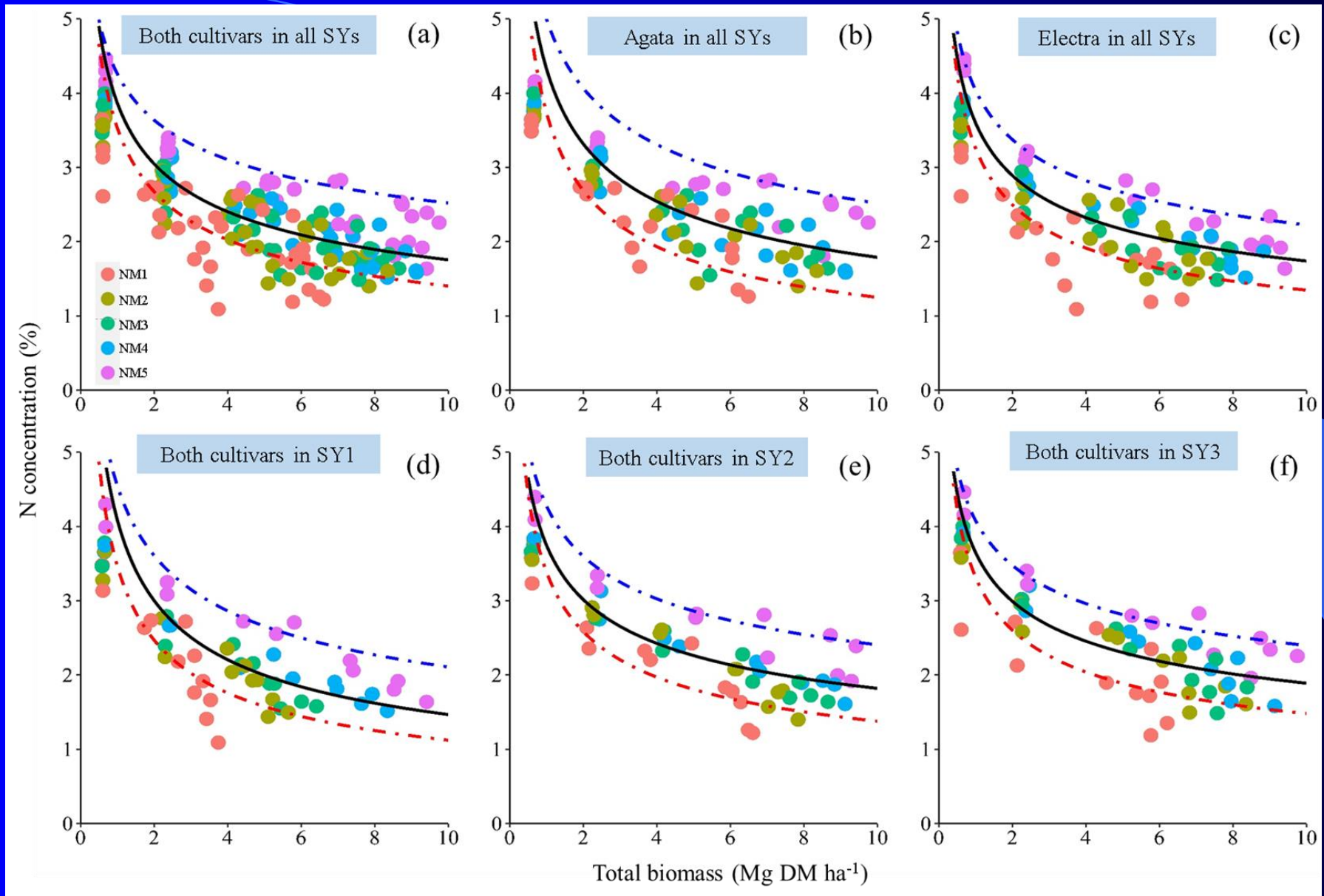
$$S_i \sim \mathcal{N}(\mu_S, \sigma_S^2) I(0, \infty)$$

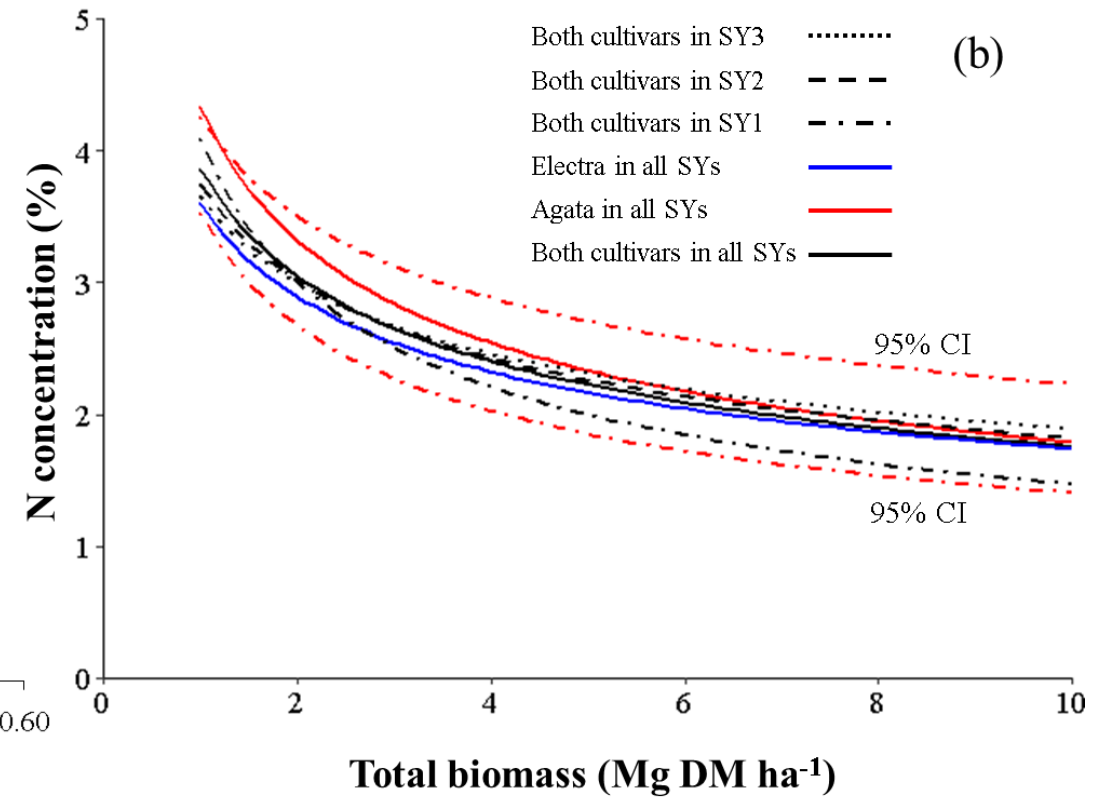
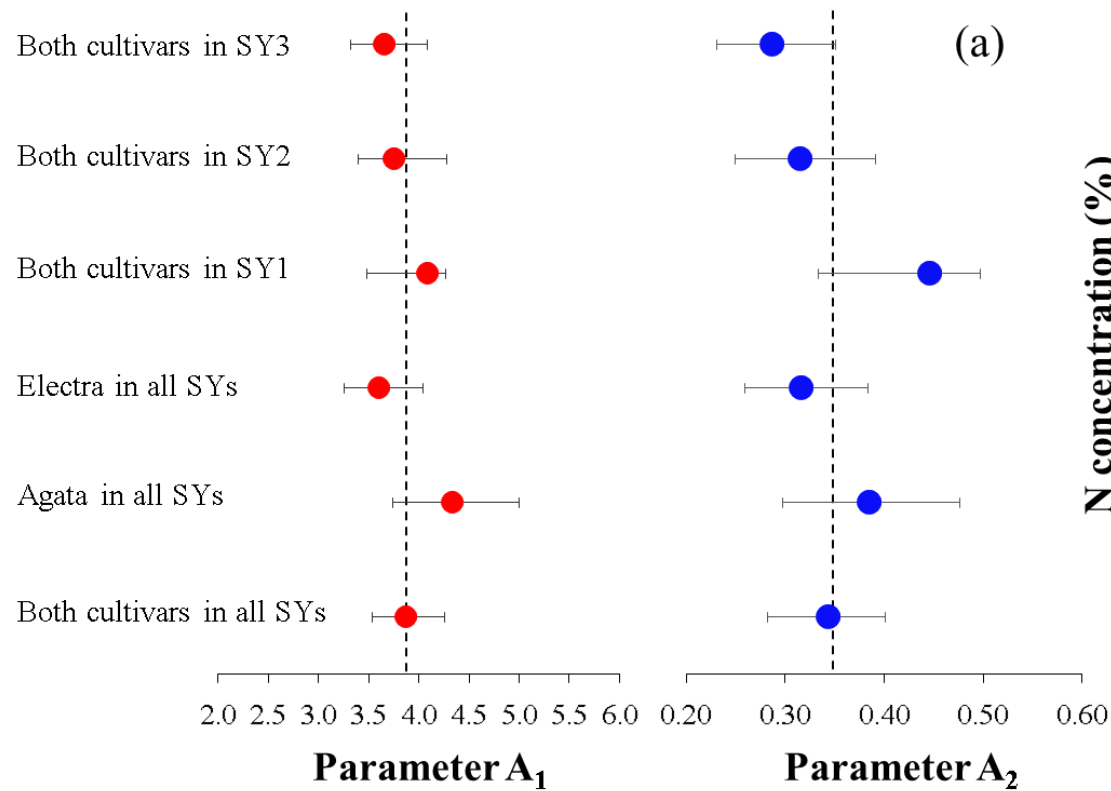
$$N_{ci} = A_1 B_{MAX_i}^{-A_2}$$

Priors
Prior knowledge about A_2

Prior knowledge about A_1



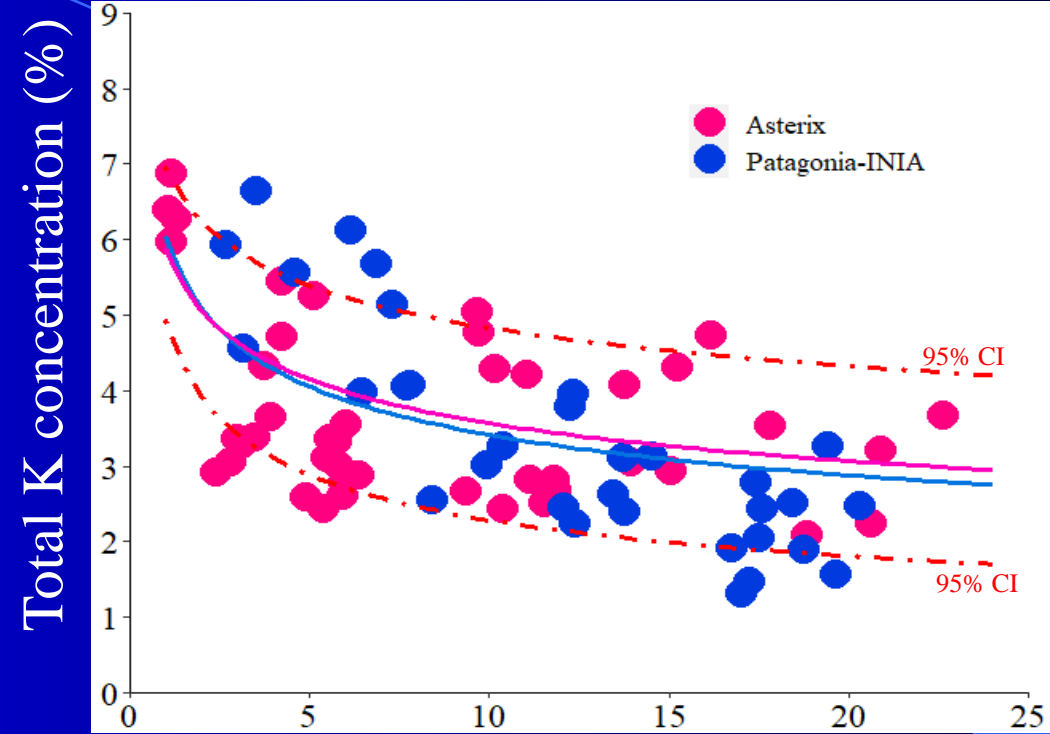
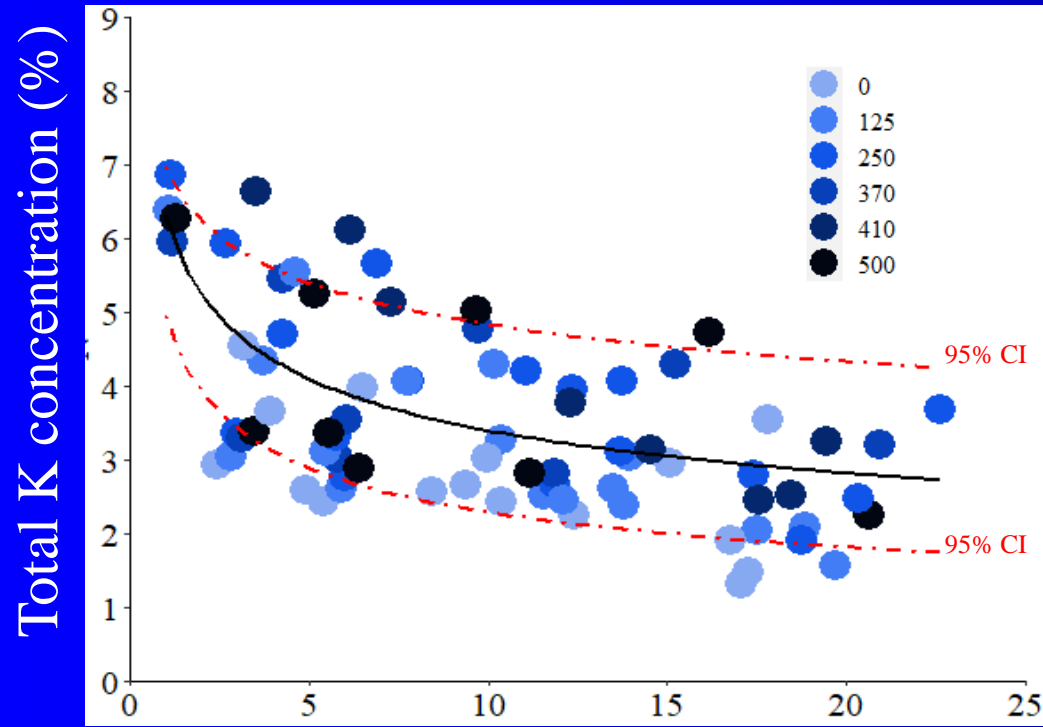




$$N_c \% = A_1 \times W^{-A_2}$$

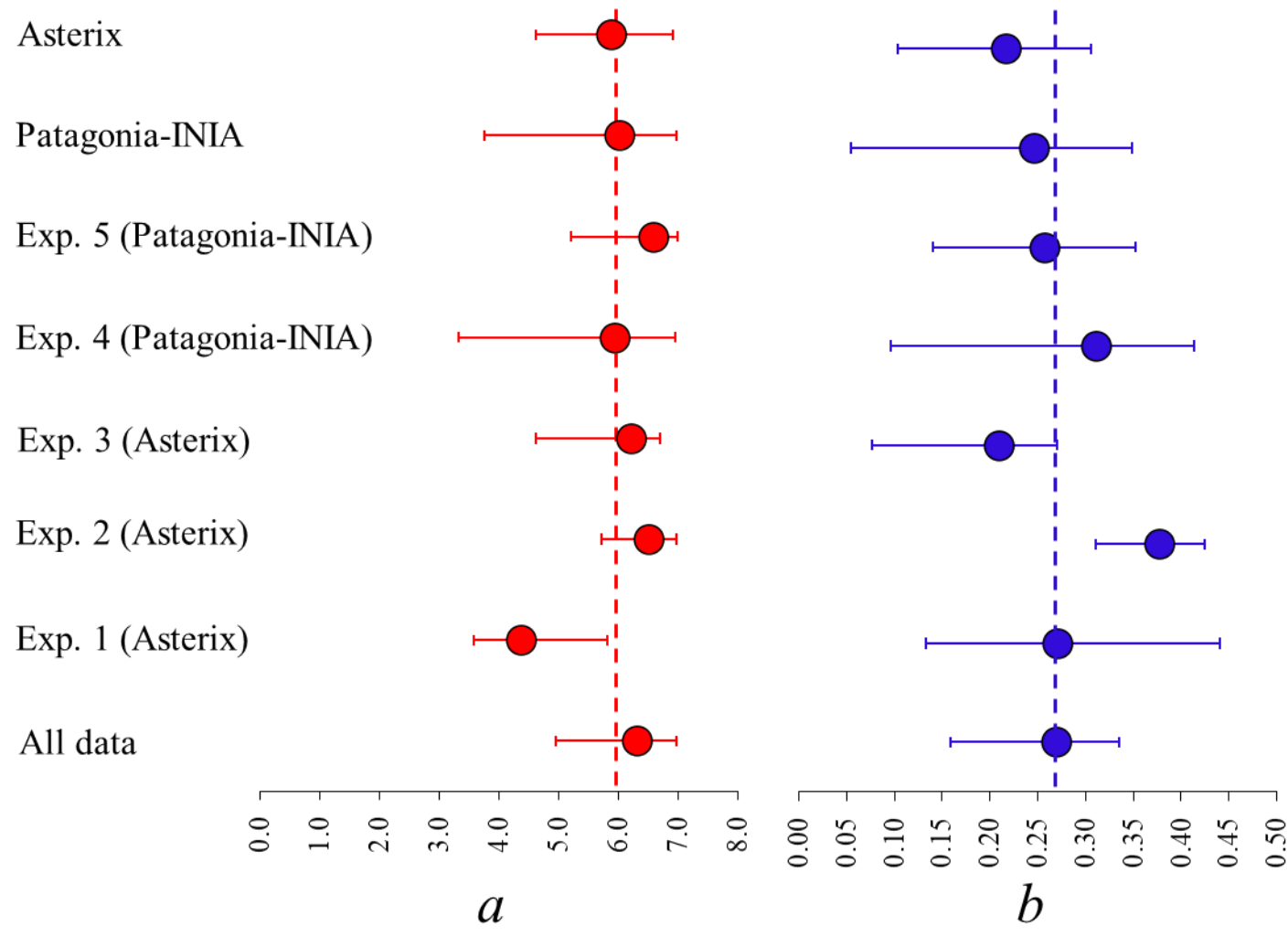
$$N_c \% = 3.86 \times W^{-0.34}$$

CURVA CRITICA DE DILUCIÓN DE POTASIO



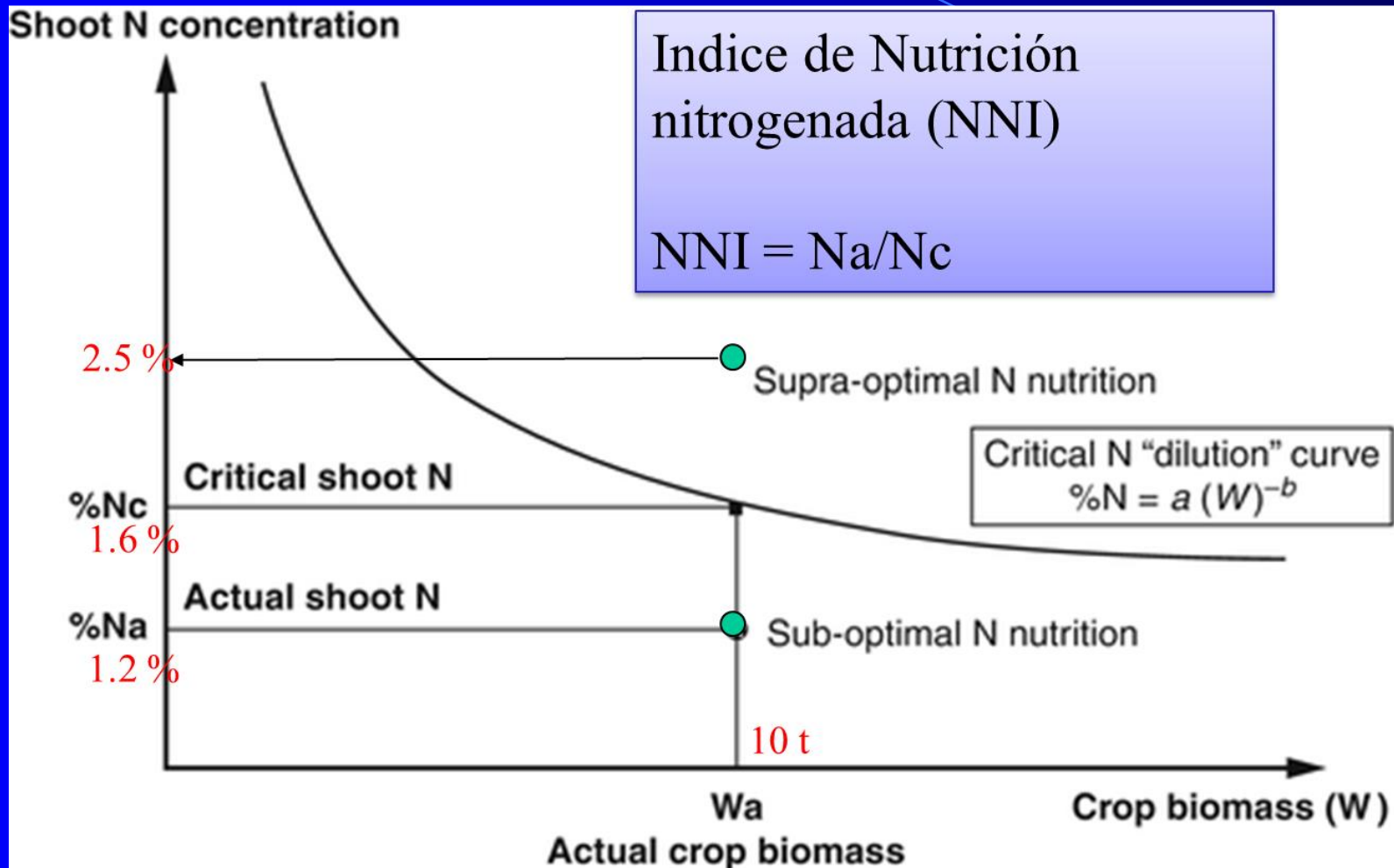
Total biomass (Mg DM ha⁻¹)

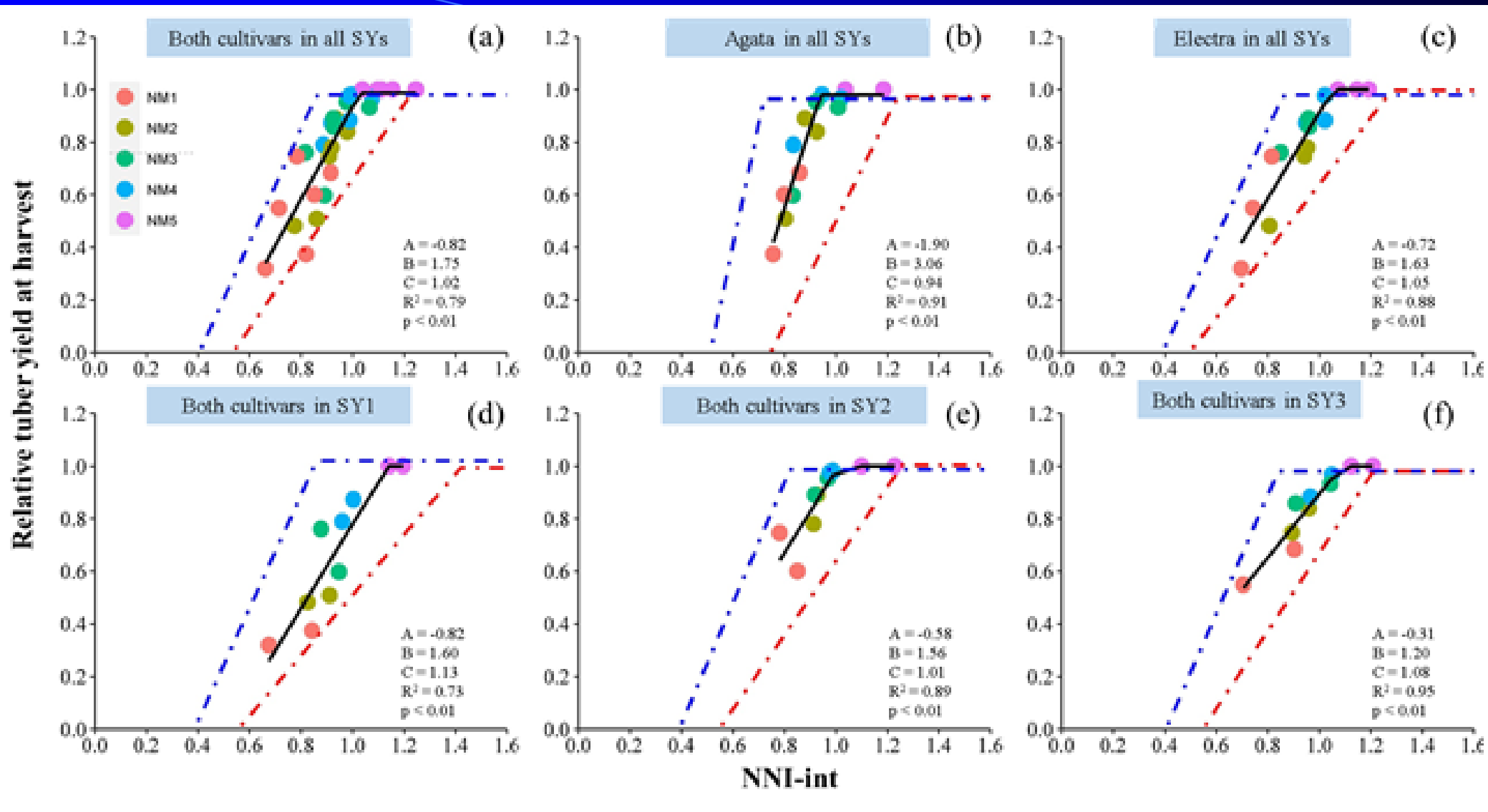
$$Kc\% = 6.32 \times W^{-0.27}$$

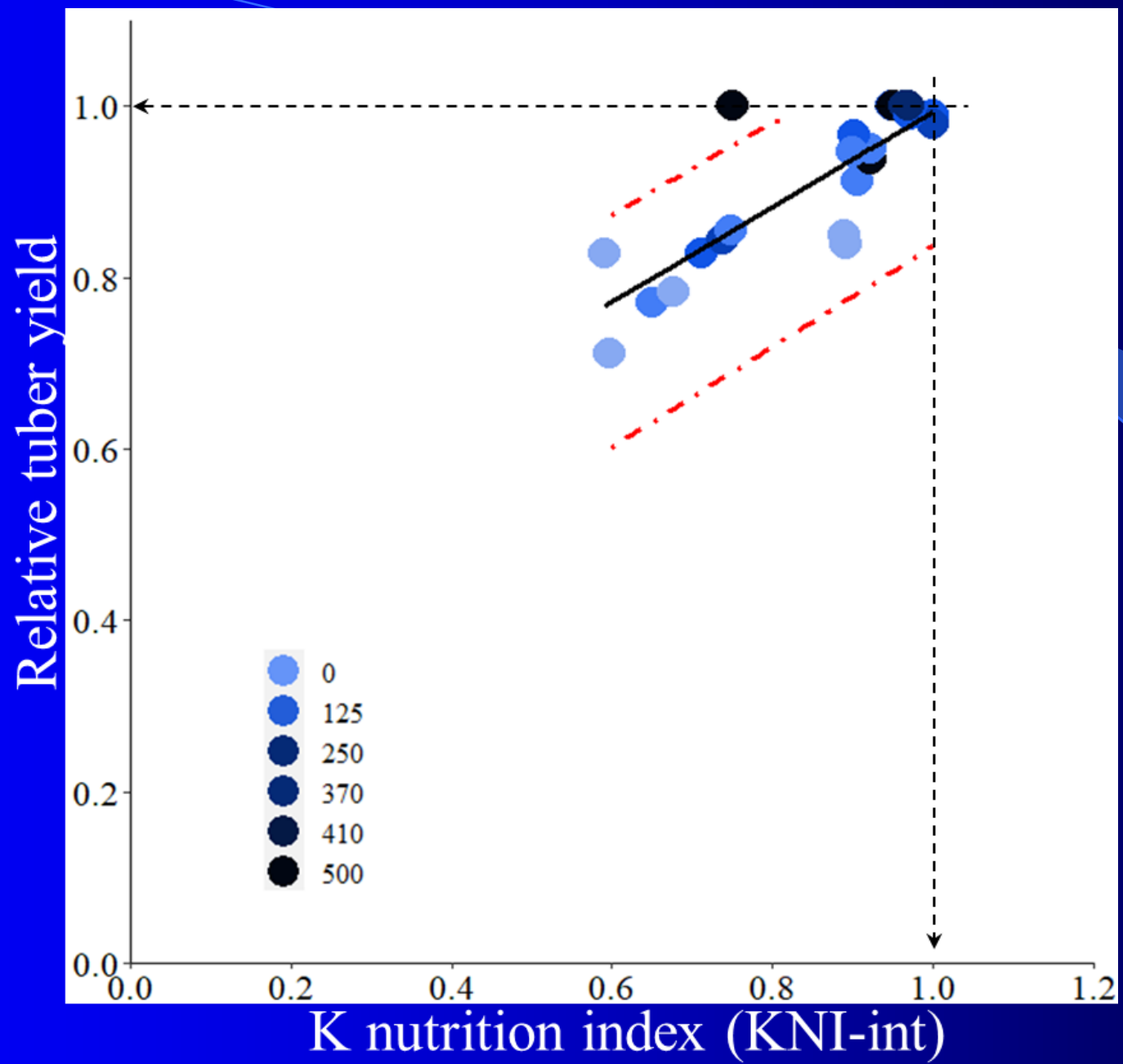


$$Kc\% = 6.32 \times W^{-0.27}$$

Monitoreo del estado nutricional del cultivo







Curva para fósforo

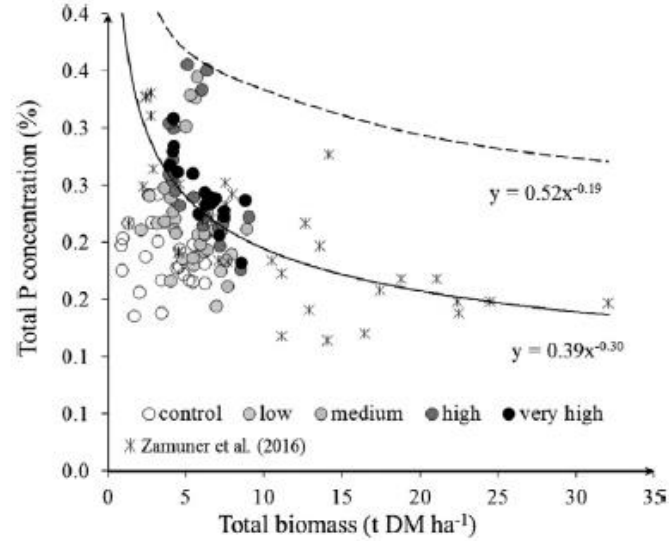
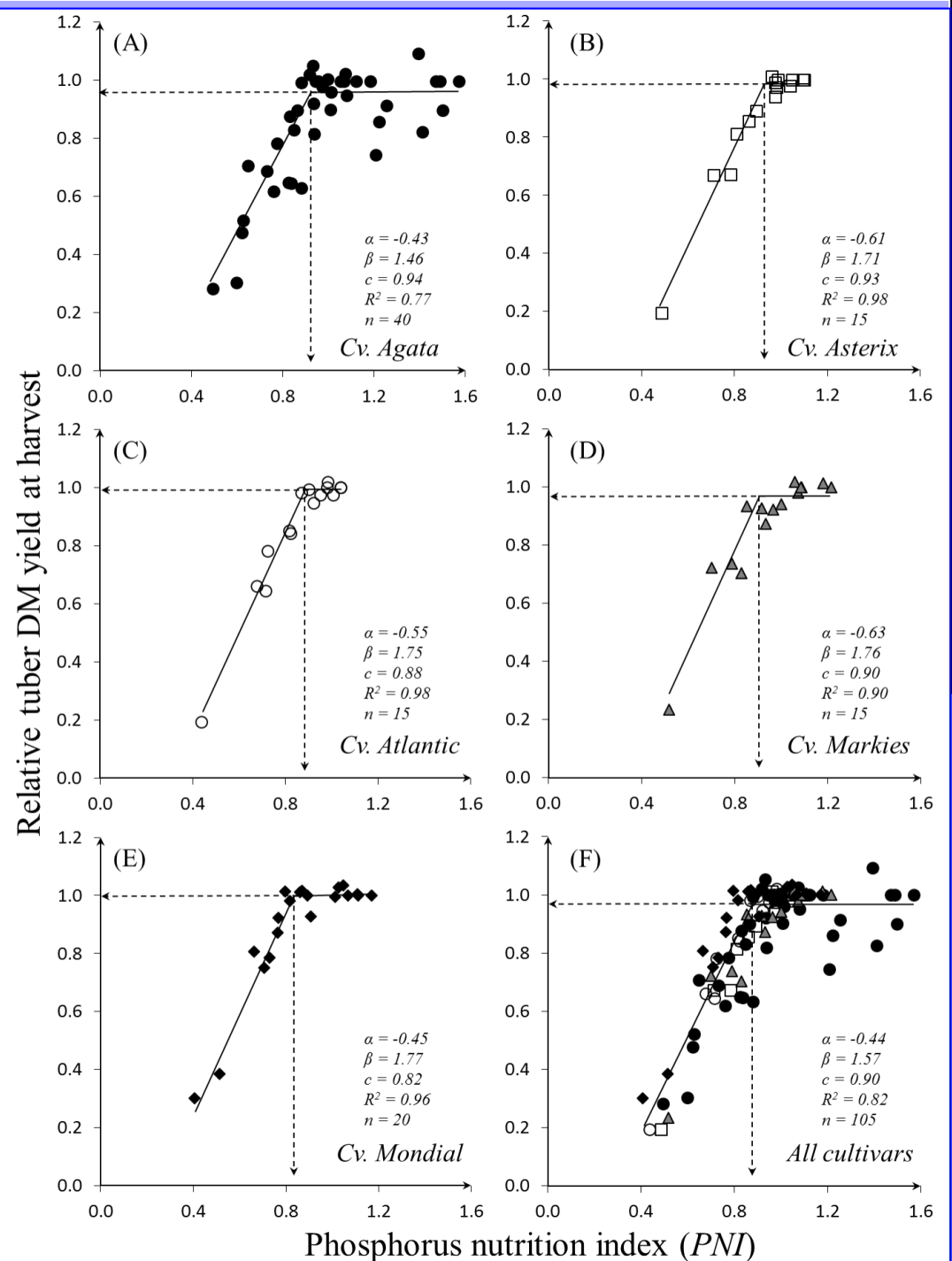


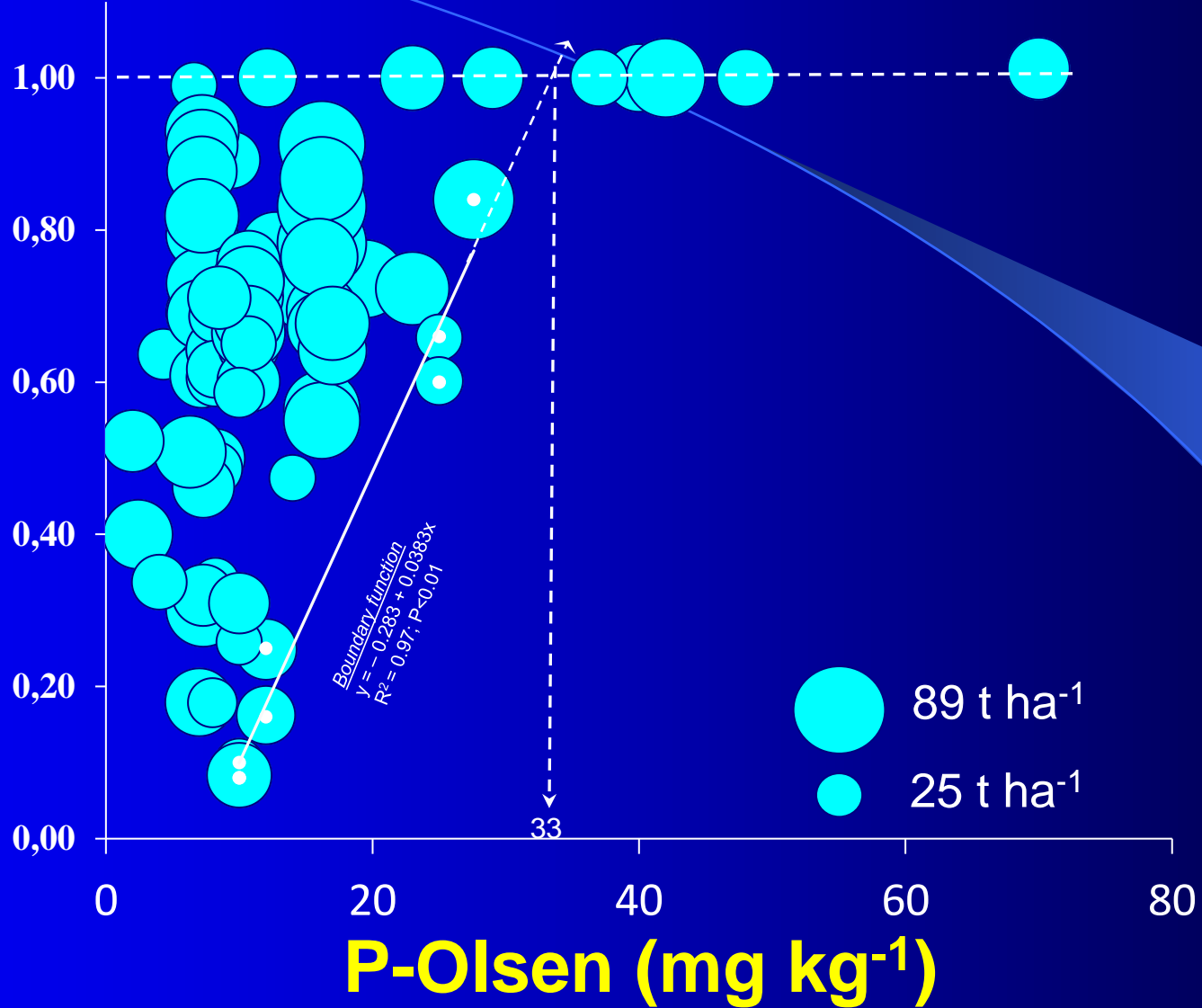
FIG. 18.17 Relationship between total P concentration and total dry matter biomass for five potato cultivars under different P rates. Data were compared with the data (*) and critical P dilution curve (solid curve) from Zamuner et al. (2016) (for cv. Innovator) and critical P dilution curve (dashed curve) from Gómez et al. (2019). Data from: Soratto, R.P., Sandaña, P., Fernandes, A.M., Martins, J.D.L., Job, A.L.G., 2020. Testing critical phosphorus dilution curves for potato cropped in tropical oxisols of southeastern Brazil. *Eur. J. Agron.* 115, 126020. <https://doi.org/10.1016/j.eja.2020.126020>.

Índice de Nutrición de P (PNI)
 $PNI = Pa/Pc$

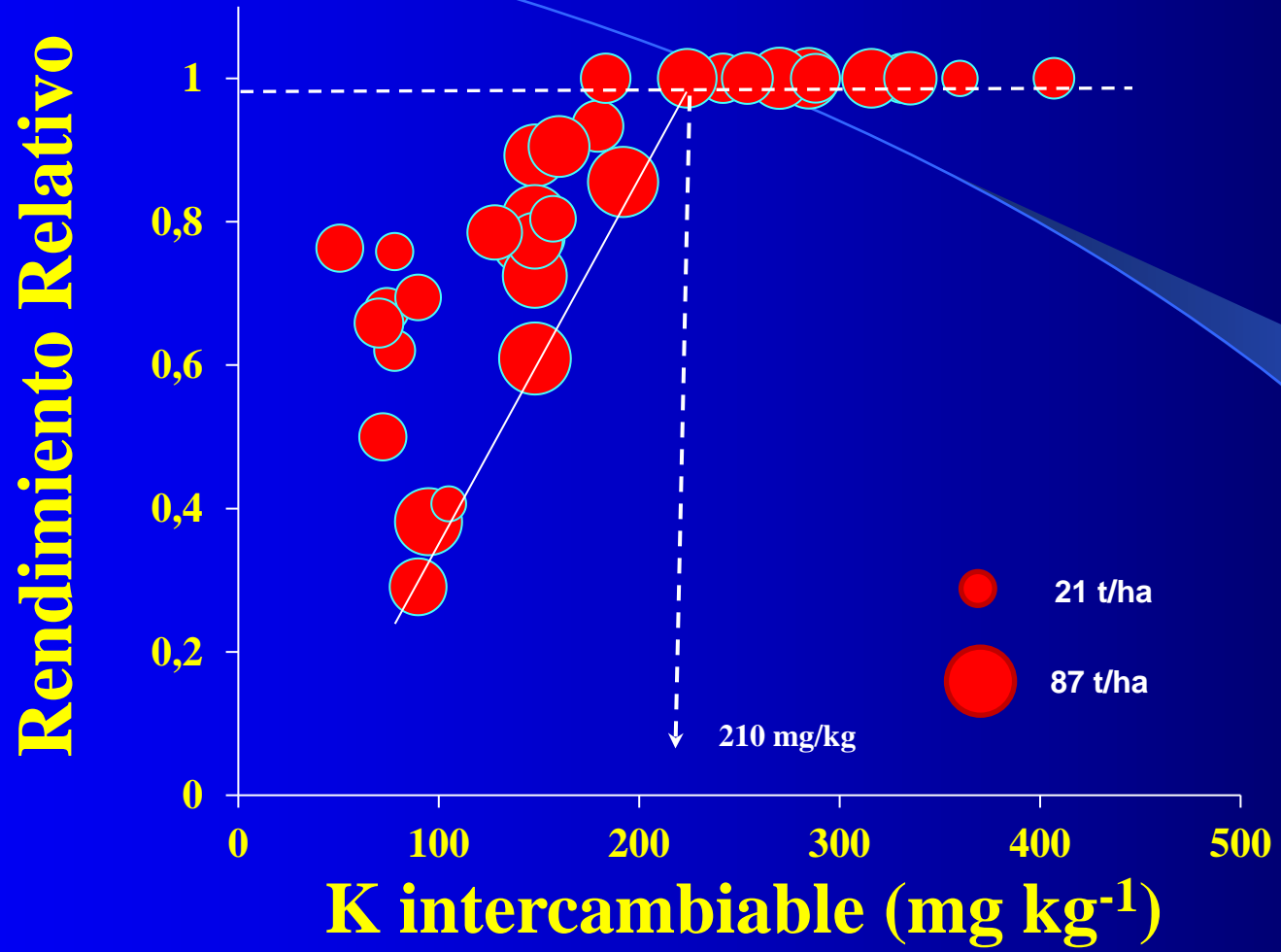


NIVEL CRITICO DE P-OLSEN

Rendimiento Relativo



NIVEL CRITICO DE K



MANUAL INTERACTIVO DE LA PAPA INIA	INICIO	CICLO CULTIVO
	MANEJO DEL CULTIVO	MANEJO SANITARIO
HERRAMIENTAS DE APOYO	GALERIAS	
NOTICIAS	CONTACTO	

Para ver un ejemplo de utilización, visita el [Tutorial Calculadora de Fertilización](#)

Calculadora desarrollada por:

Patricio Sandaña G.

Ing. Agr., M.Cs., Dr

E-mail: patricio.sandana@inia.cl

CALCULADORA DE FERTILIZACIÓN RAZONADA PARA EL CULTIVO DE PAPA

Tipo de Suelo:

Rendimiento Total esperado (según clima, suelo y agronomía) (t/ha)

 1600 sacos/ha

Datos del análisis suelo (a 20 cm profundidad) (mg/kg)

N-NO ₃ (mg/kg)	<input type="text" value="15"/>
P-Olsen (mg/kg)	<input type="text" value="20"/>
K intercambiable (mg/kg)	<input type="text" value="150"/>

Dosis del nutriente según rendimiento y análisis de suelo (kg/ha)

N (kg/ha)	<input type="text" value="244"/>
P ₂ O ₅ (kg/ha)	<input type="text" value="291"/>
KCl (kg/ha)	<input type="text" value="467"/>

*Los sacos de rendimiento y fertilizantes son de 50 kg

DOSIS DE CORRECCIÓN SEGUN FERTILIZANTE

Opción 1: Dosis usando Mezcla Comercial

a) Mezcla Comercial (%)

N en mezcla (%)	<input type="text" value="10"/>
P ₂ O ₅ en mezcla (%)	<input type="text" value="30"/>
KCl en mezcla (%)	<input type="text" value="20"/>

(kg/ha) (Sacos/ha)

Dosis total segun Mezcla Comercial 2436 49

Opción 2: Dosis usando Fertilizantes por separado

b) Fertilizantes (%)

N en fertilizante Nitrogenado (%)	<input type="text" value="46"/>
P ₂ O ₅ en fertilizante Fosforado (%)	<input type="text" value="46"/>
KCl en fertilizante Potásico (%)	<input type="text" value="60"/>

(kg/ha) (Sacos/ha)

Dosis de fertilizante Nitrogenado (kg/ha)	<input type="text" value="530"/>	11
Dosis de fertilizante Fosforado (kg/ha)	<input type="text" value="633"/>	13
Dosis de fertilizante Potásico (kg/ha)	<input type="text" value="778"/>	16

Dosis total segun Mezcla propia 1941 40

DOSIS DE MANTENCIÓN

Dosis del nutriente	(kg/ha)
P ₂ O ₅ (kg/ha)	64
KCl (kg/ha)	264
Concentración de nutrientes en Fertilizantes disponibles	%

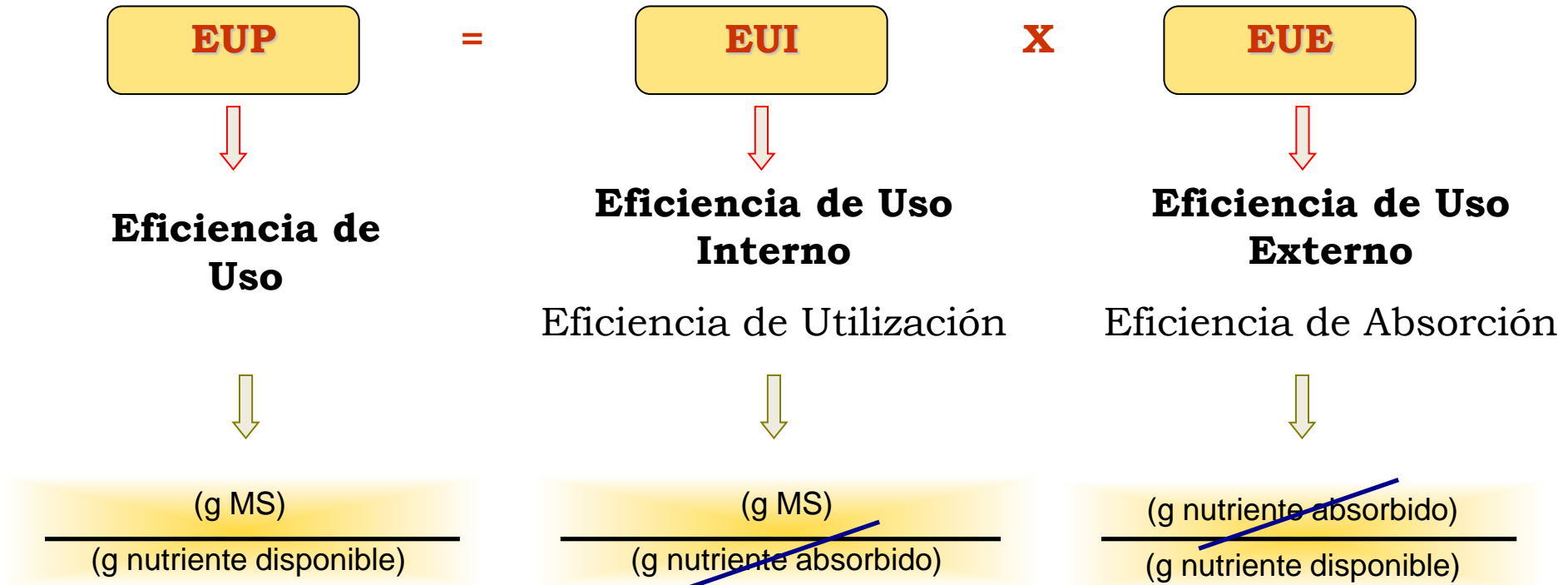
Participan en esta iniciativa:



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Eficiencia de uso de nutrientes

Eficiencia de uso de nutrientes (EUP)



Eficiencia de uso externo de fósforo

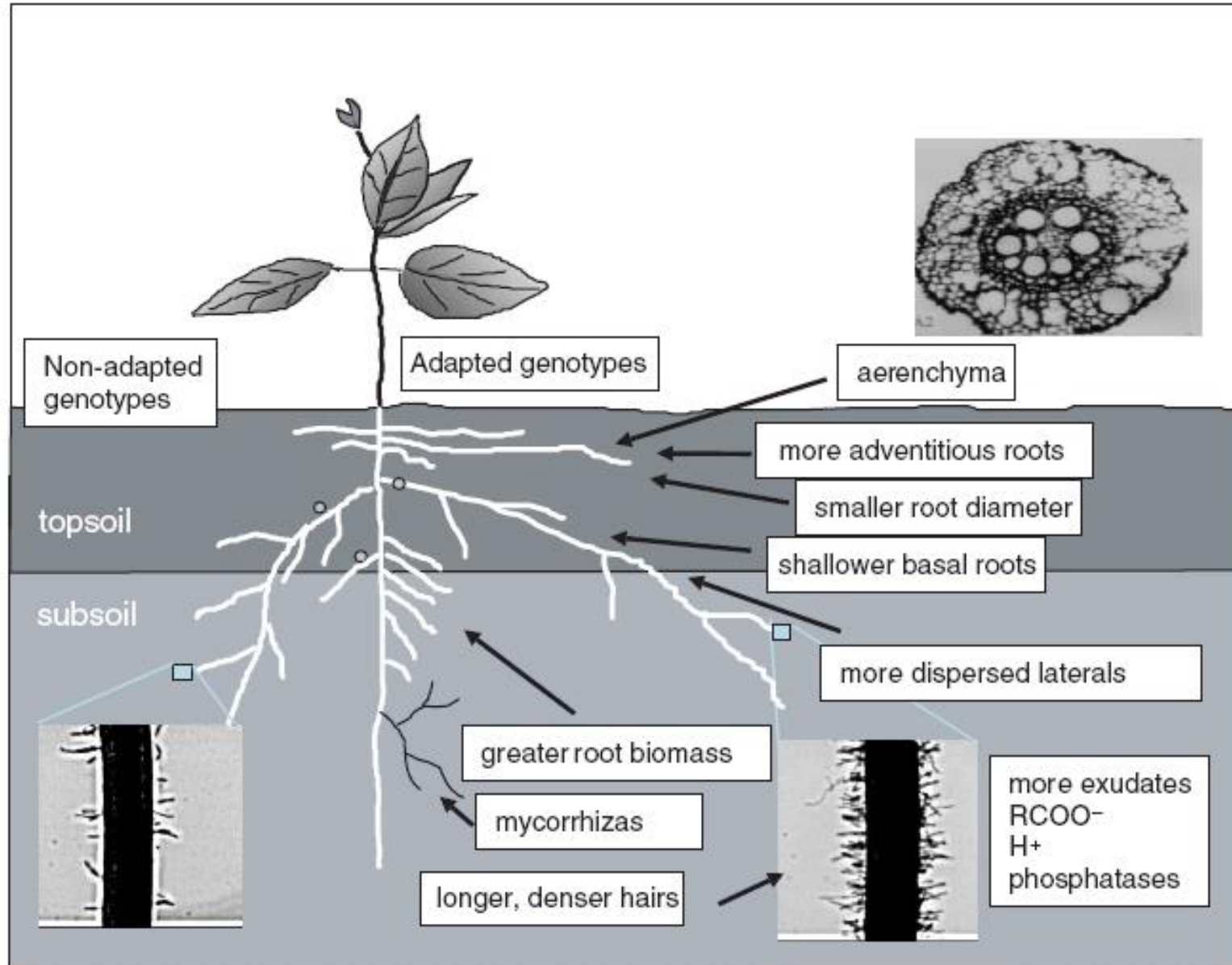
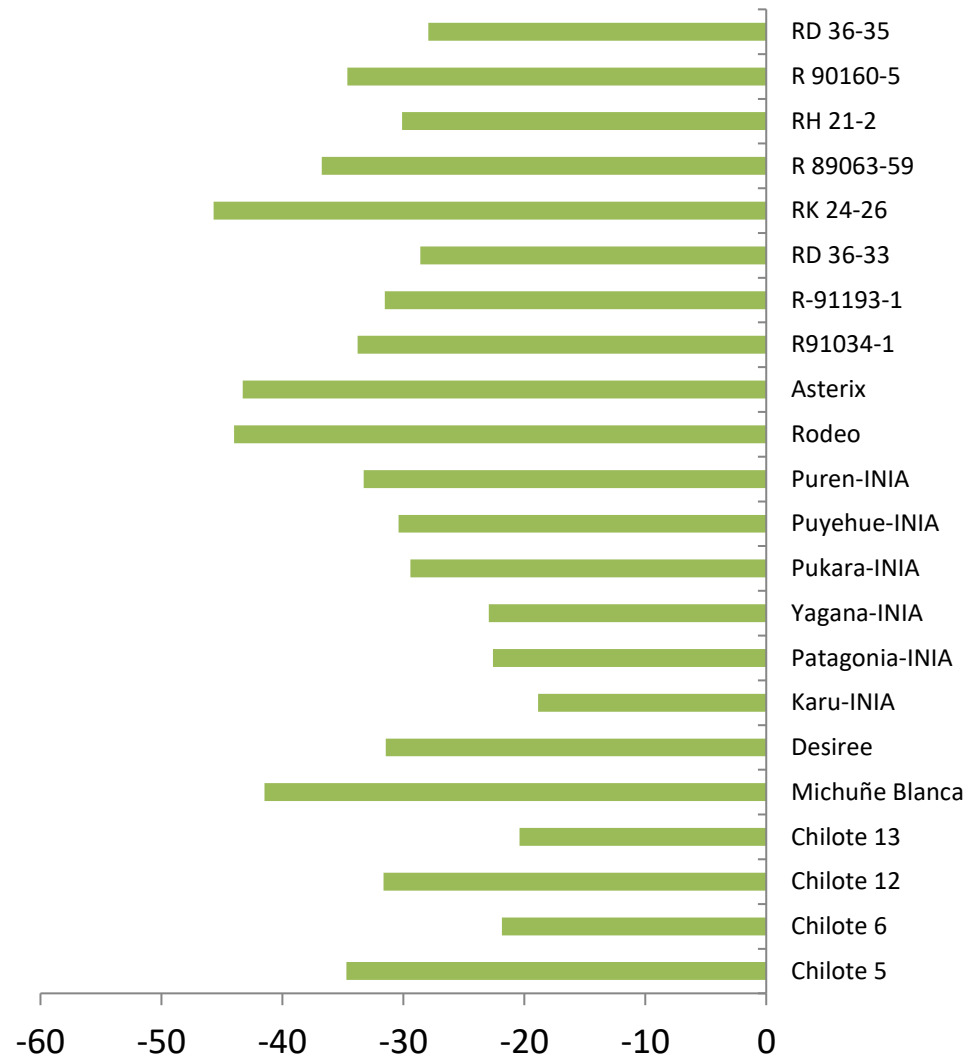


Fig. 4. Root adaptations to low phosphorus availability, as discussed in the text.

(Lynch. 2007; Australian Journal of Botany)

Reducción promedio del rendimiento (%) en tres ambientes



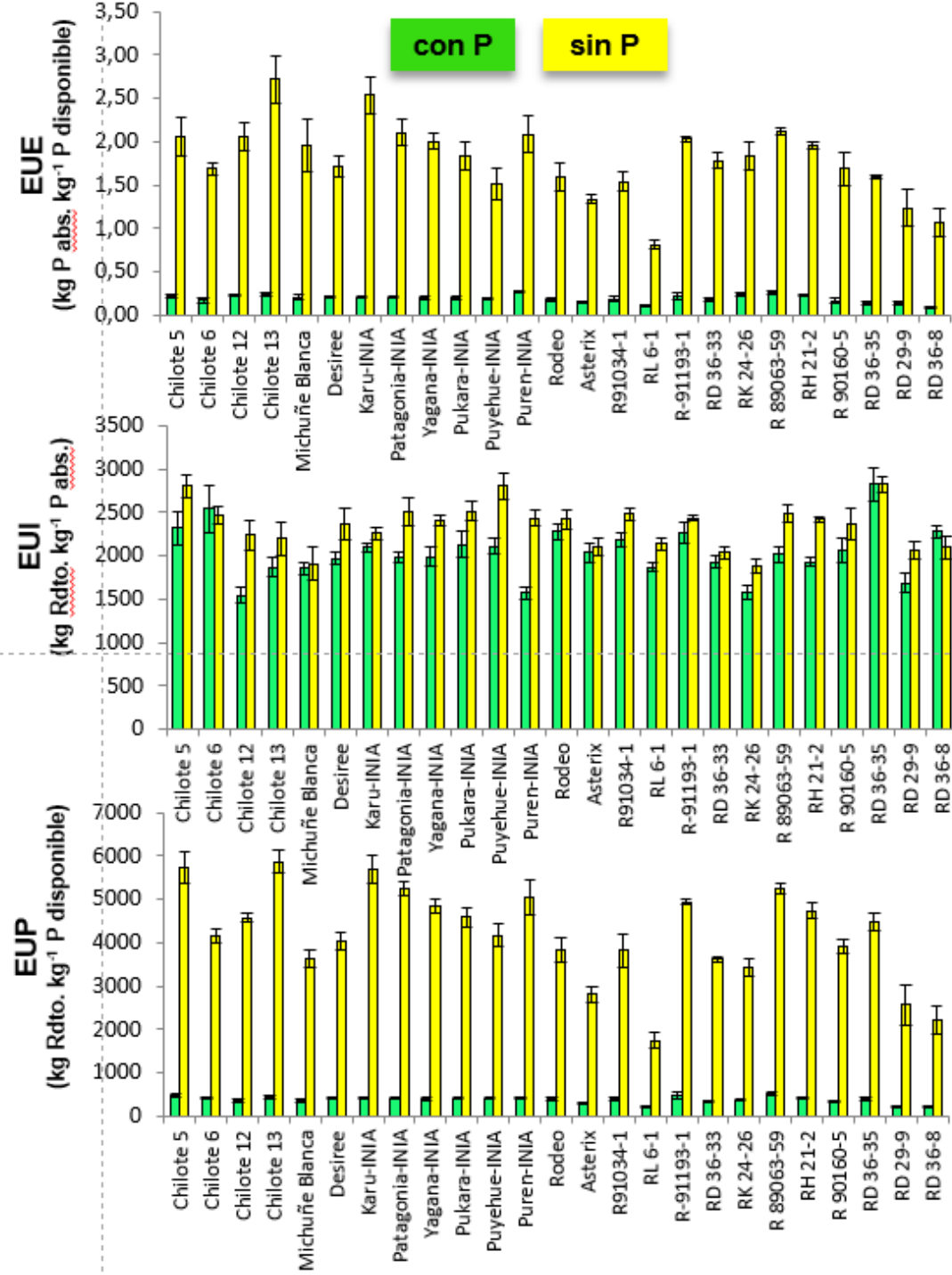
Osorno 2012-13
Osorno 2013-14
Valdivia 2013-14

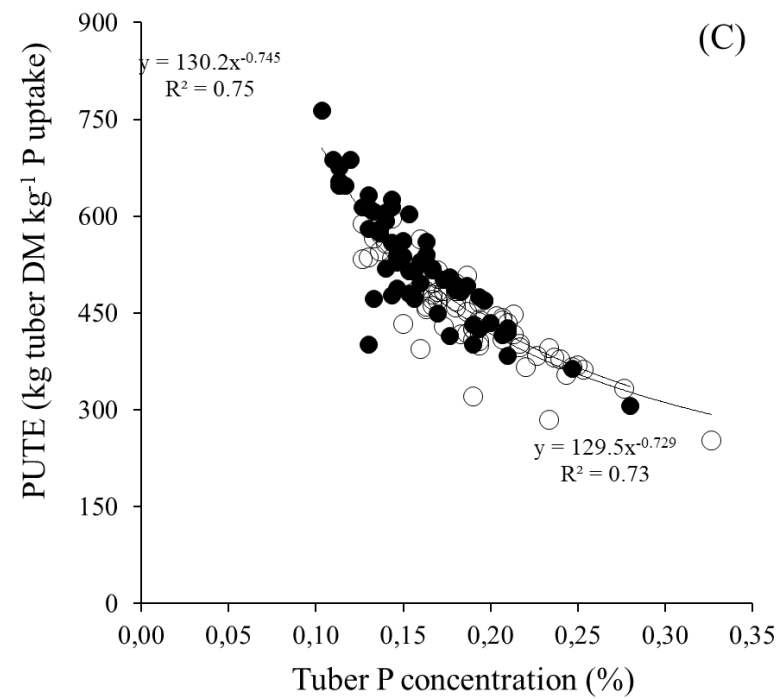
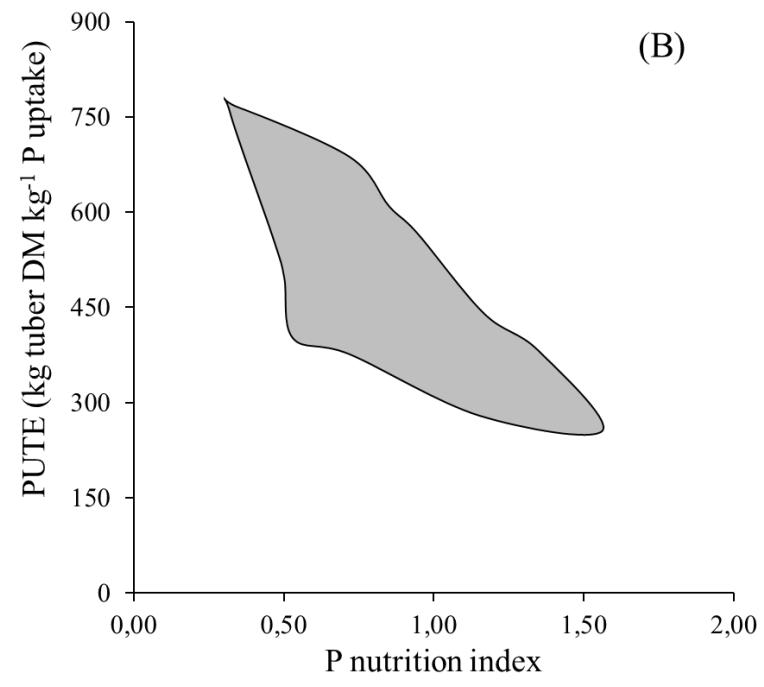
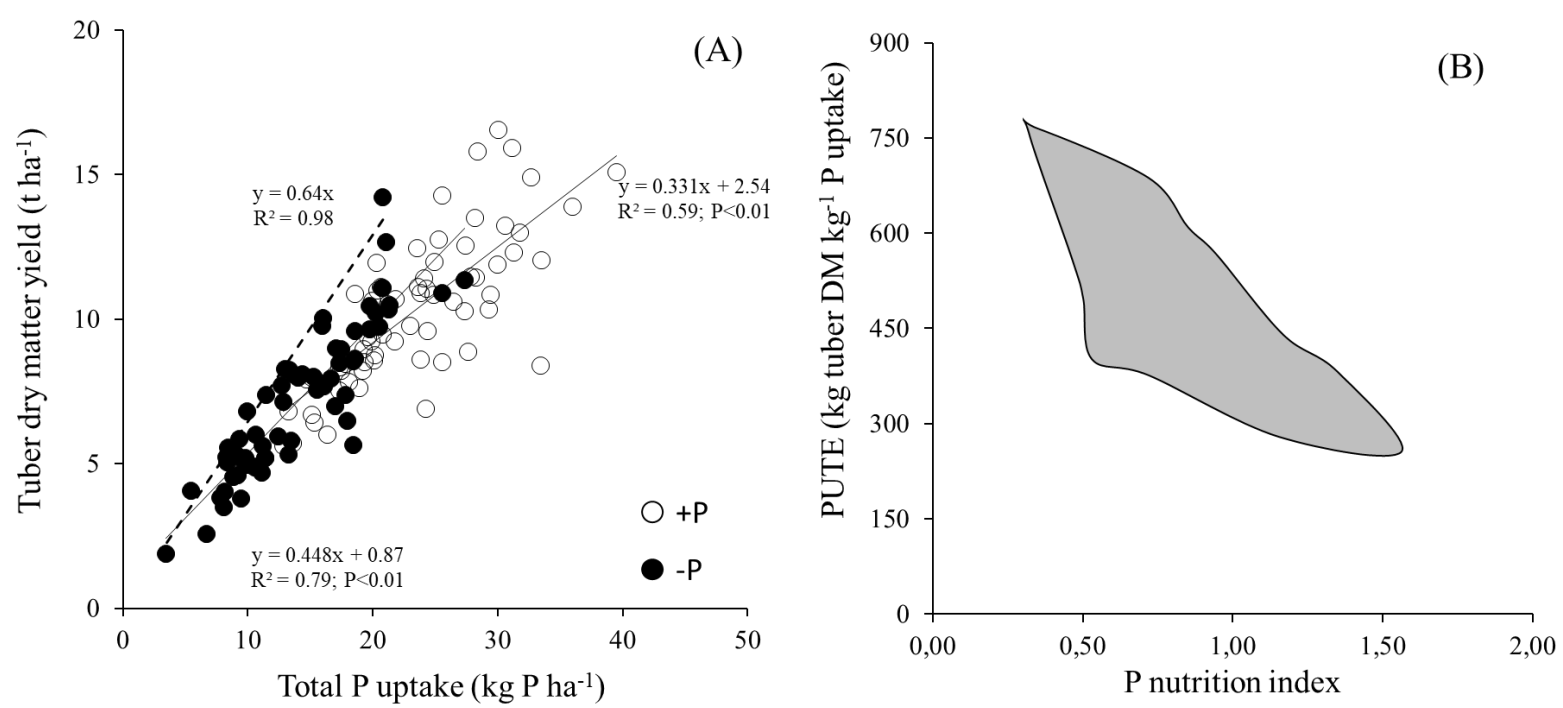
Reducción del rendimiento (%)

➤ La EAP fue reducida por la fertilización fosforada y los genotipos mostraron importante variación en condiciones de deficiencia de P (desde 0.8 a 2.7 kg P absorbido kg^{-1} P disponible).

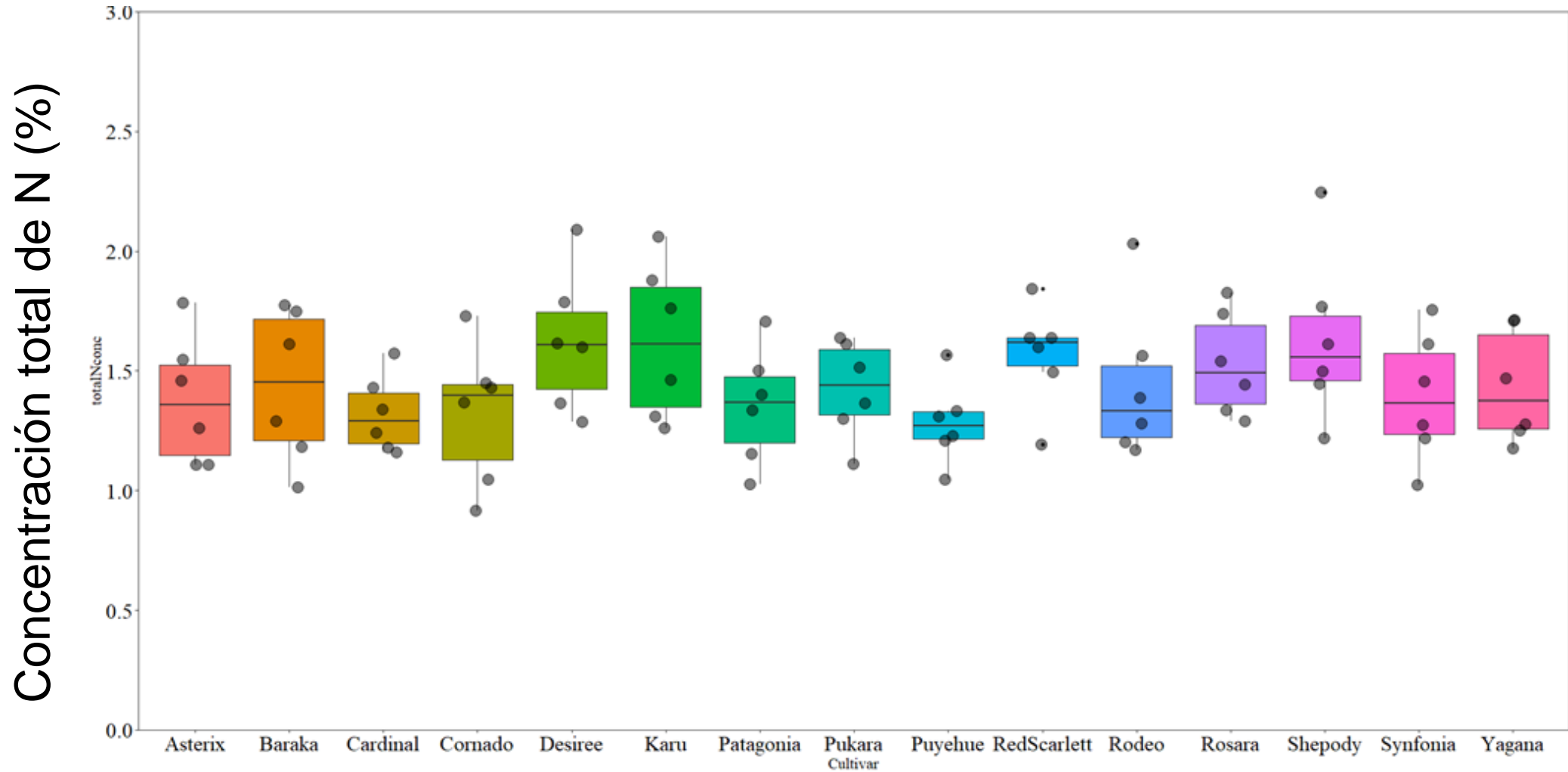
➤ La EUIP tuvo una menor respuesta frente a los efectos del genotipo y la fertilización fosforada .

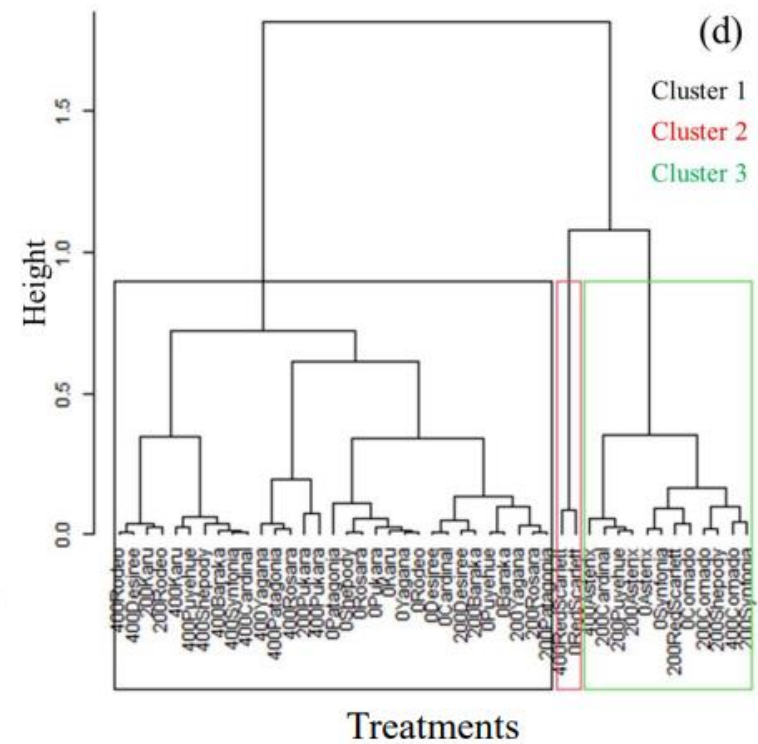
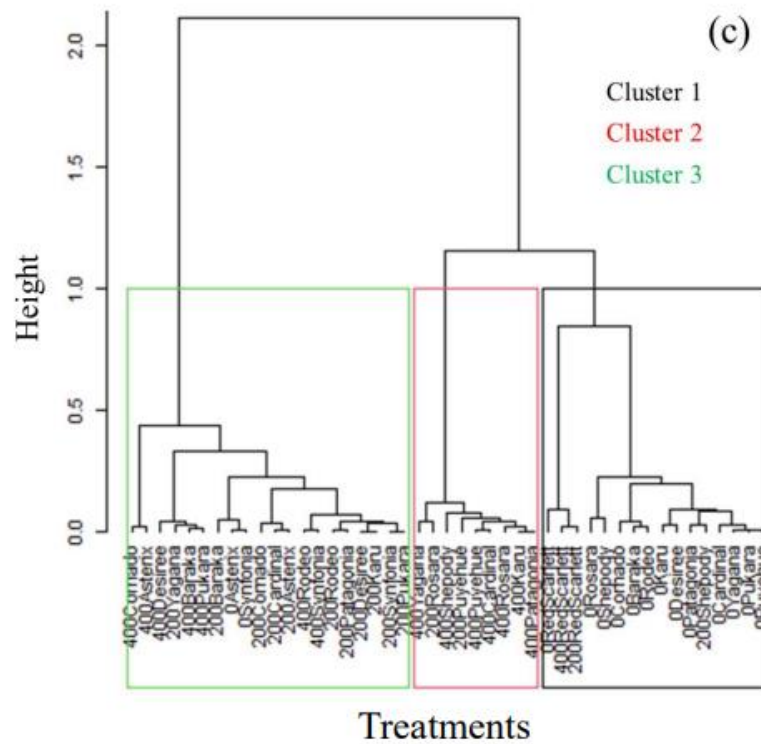
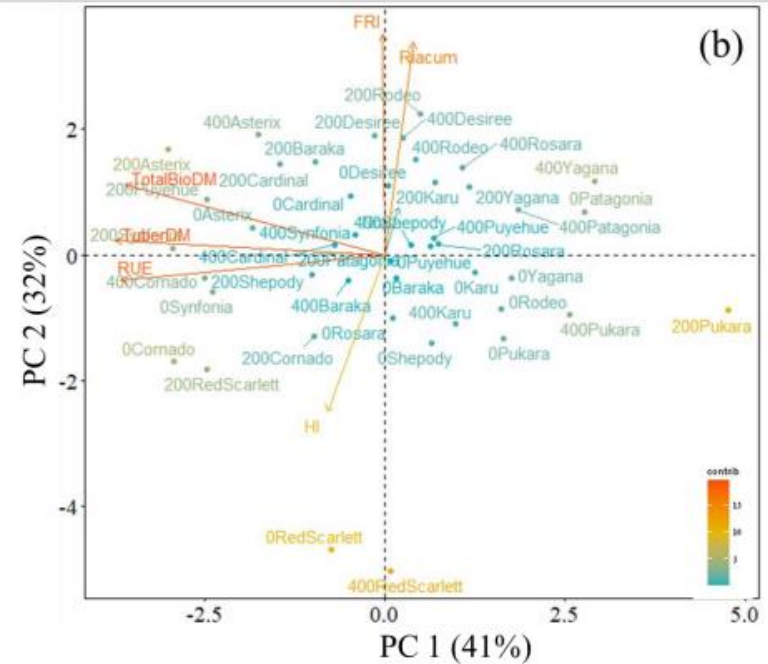
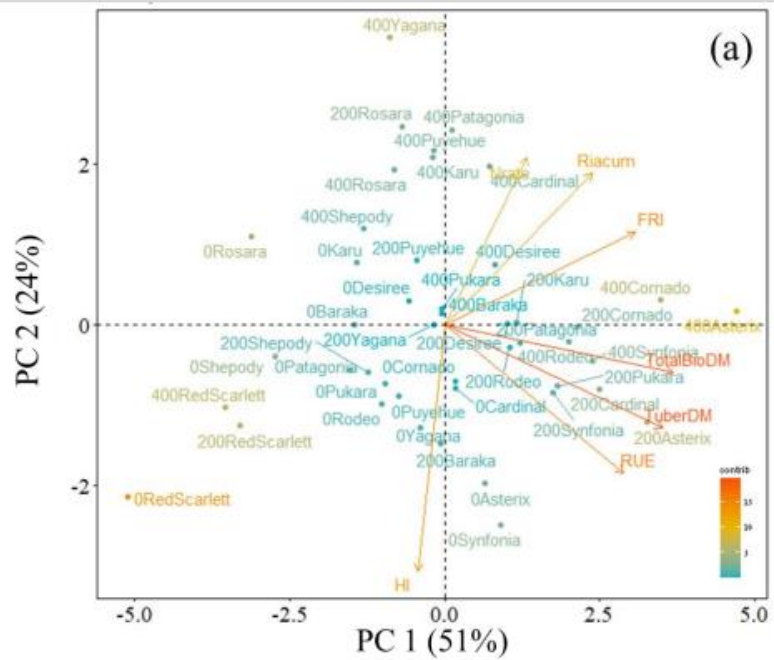
➤ Finalmente, la EUP mostró una importante respuesta tanto a la fertilización fosforada como al efecto de los distintos genotipos. En condiciones de deficiencia esta variable fluctuó entre 1754 y 5871 kg rendimiento kg^{-1} P disponible.

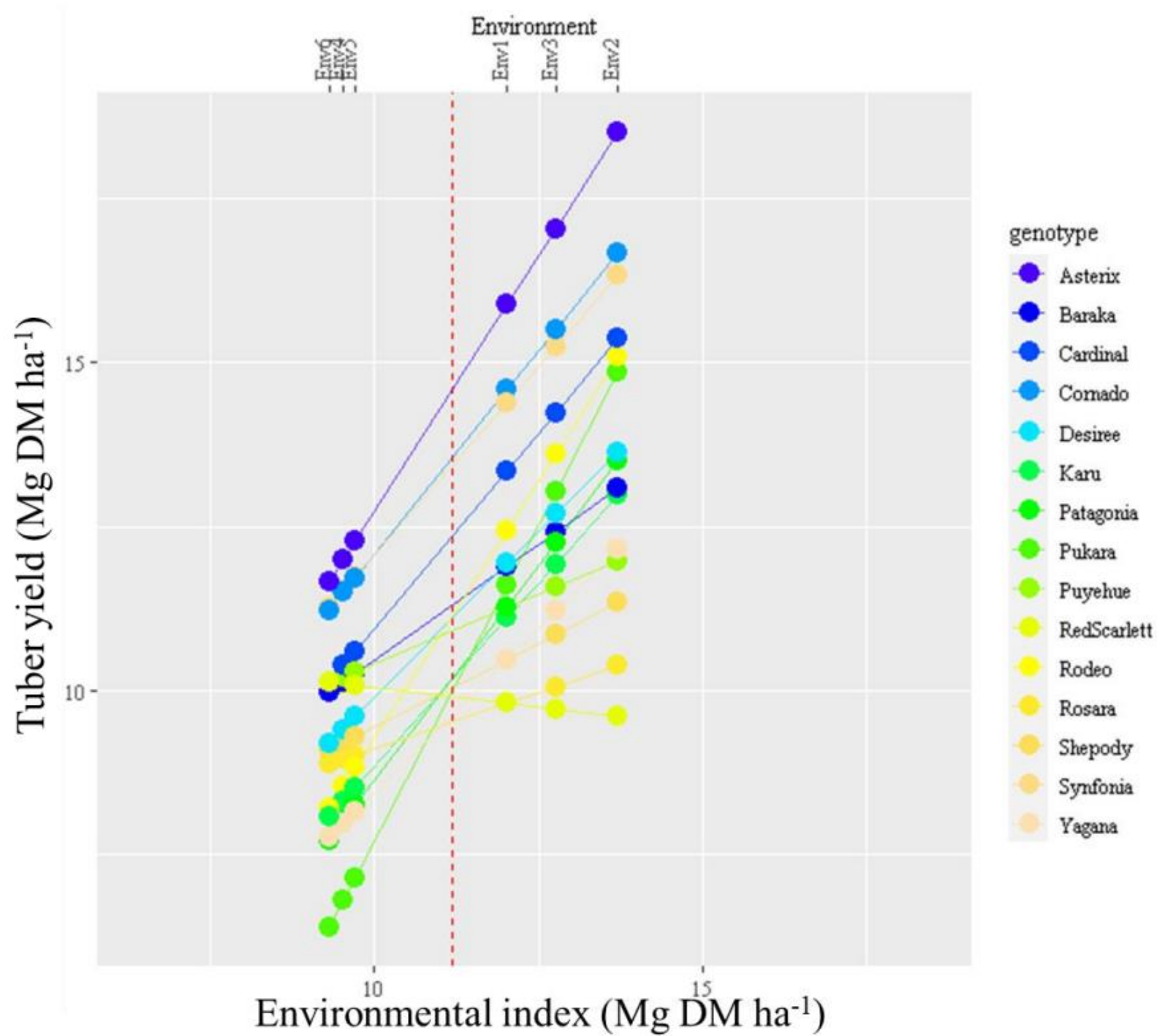




FONDECYT REGULAR 1211719 “APPLICATION OF THE CROP SIMULATION MODEL SUBSTOR-POTATO TO ASSESS THE NITROGEN USE EFFICIENCY OF POTATO CROPS IN RESPONSE TO GENOTYPE, NITROGEN AND ENVIRONMENTS”

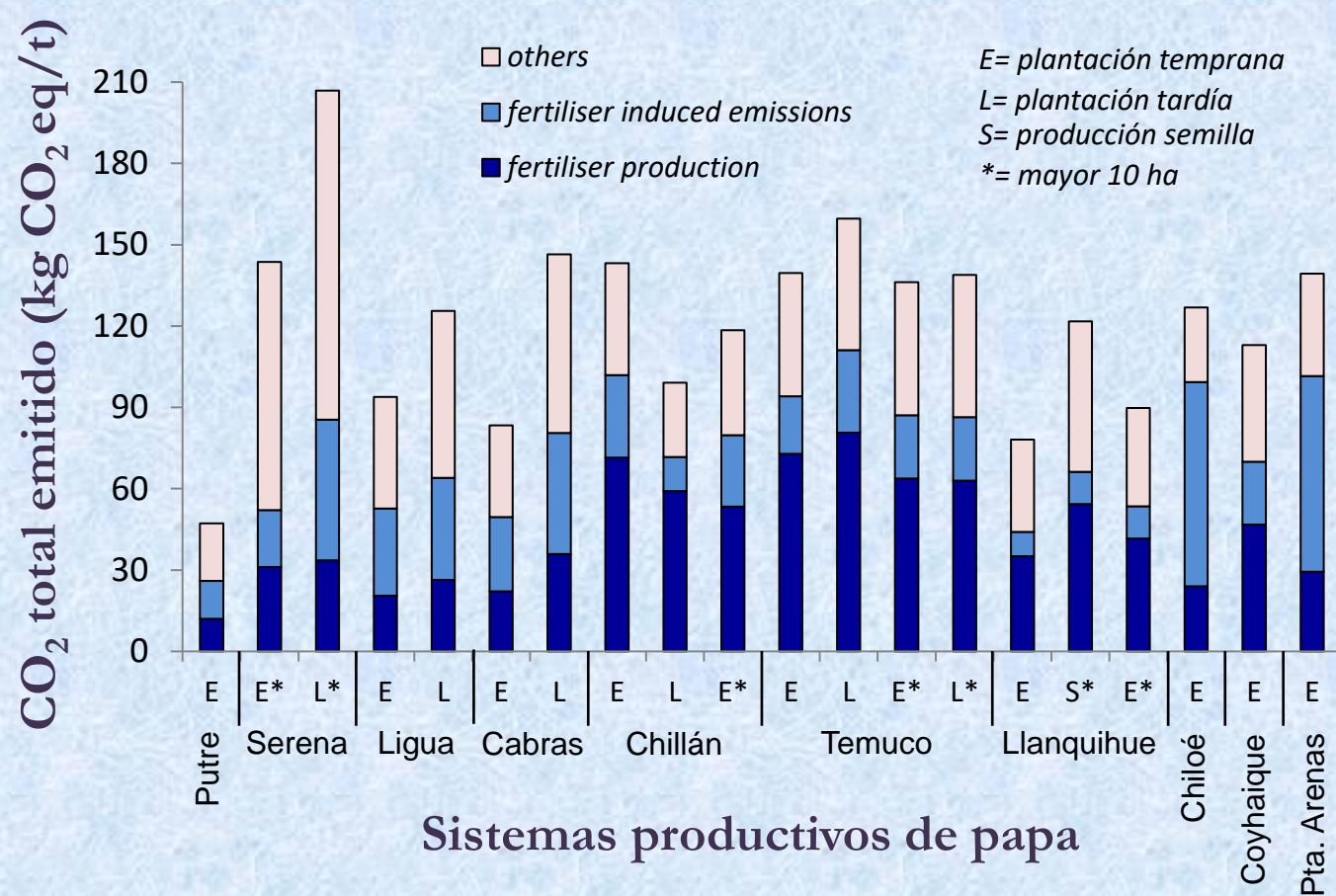




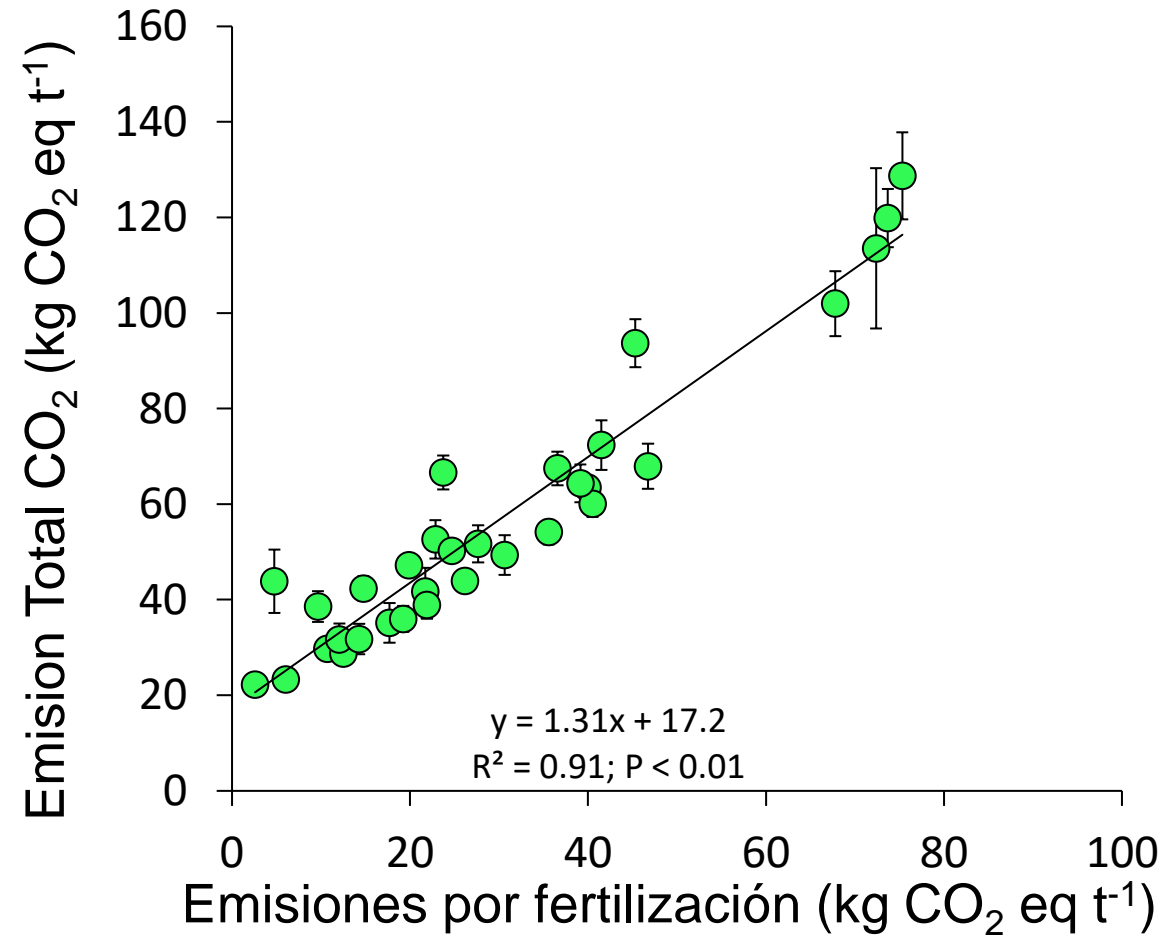


SUSTENTABILIDAD DEL CULTIVO

Impacto ambiental asociado a la fertilización del cultivo de papa en diferentes sistemas



Total CO₂ vs. fertilización



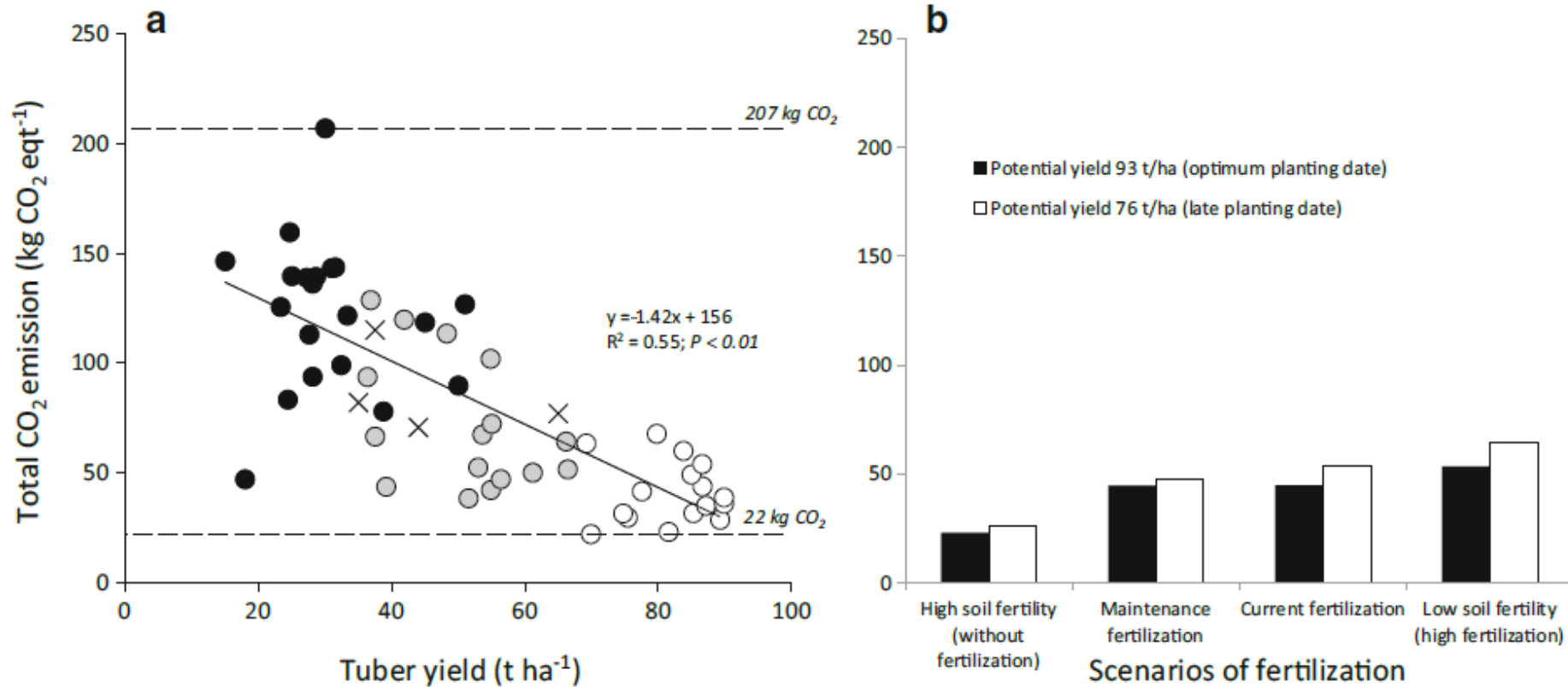


Fig. 6 a Relationships between total CO₂ emissions and tuber yields from different production systems. *Closed circles* correspond to data from Haverkort et al. (2014), *open and grey circles* correspond to data from experiments 1 and 2, respectively from the present study. The X corresponds to potato production system data (ware, seeds, organic, starch potatoes) from the Netherlands published by Haverkort and Hillier (2011). **b** Four scenarios of fertilization using technology for

agronomy presented in table 4 by Haverkort and Hillier (2011). CO₂ emissions were calculated using potential yields and soil conditions of the present study (southern Chile). The scenarios were without fertilization (0 N, 0 P₂O₅, 0 K₂O ha⁻¹), maintenance fertilization (250 kg N, 90 kg P₂O₅ and 250 kg K₂O ha⁻¹), current fertilization (150 kg N, 400 kg P₂O₅ and 280 kg K₂O ha⁻¹) and high fertilization (250 kg N, 450 kg P₂O₅ and 350 kg K₂O ha⁻¹)

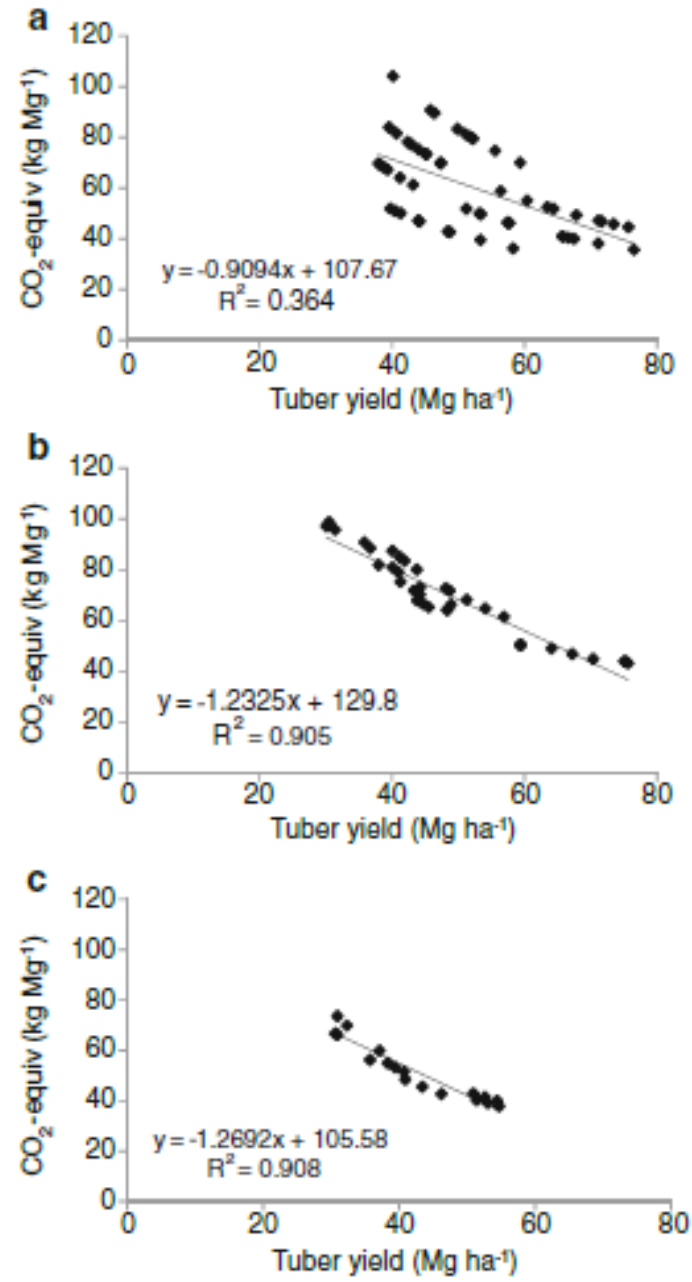


Fig. 7 Relationship between tuberyield and CO₂ emissions due to yield increments from N (a), P (b) and S (c)

COMENTARIOS FINALES

Para mejorar la sustentabilidad del cultivo es necesario generar herramientas para facilitar la toma de decisiones en cuanto a la fertilización del cultivo (diagnóstico de nutrición y de umbrales críticos en el suelo).

El mejoramiento genético es una vía importante para incrementar la eficiencia de uso de los recursos (nutrientes) en los cultivos. Es necesario tener evaluaciones comparando genotipos frente a factores de importancia agronómica.

La determinación de la huella de carbono es una herramienta útil para diagnosticar la eficiencia en el uso de recursos y sustentabilidad de los sistemas productivos.