Impacto del manejo y rendimiento de maíces de diferentes fechas de siembra

Lucas Borrás y Lucas Vitantonio-Mazzini
Fac. de Cs. Agrarias UNR - CONICET

Aspectos que voy a enfocarme:

- **El valor de la genética.**
- **La relevancia de comprender y explotar las interacciones GENOTIPO x MANEJO:**
  - ***Genotipo x fungicida,***
  - ***Genotipo x densidad,***
  - ***Genotipo x nitrógeno*.**
- **Factores que afectan la respuesta del rinde al agregado de N.**

Rindes y mejoramiento en maíces sembrados temprano y tarde.

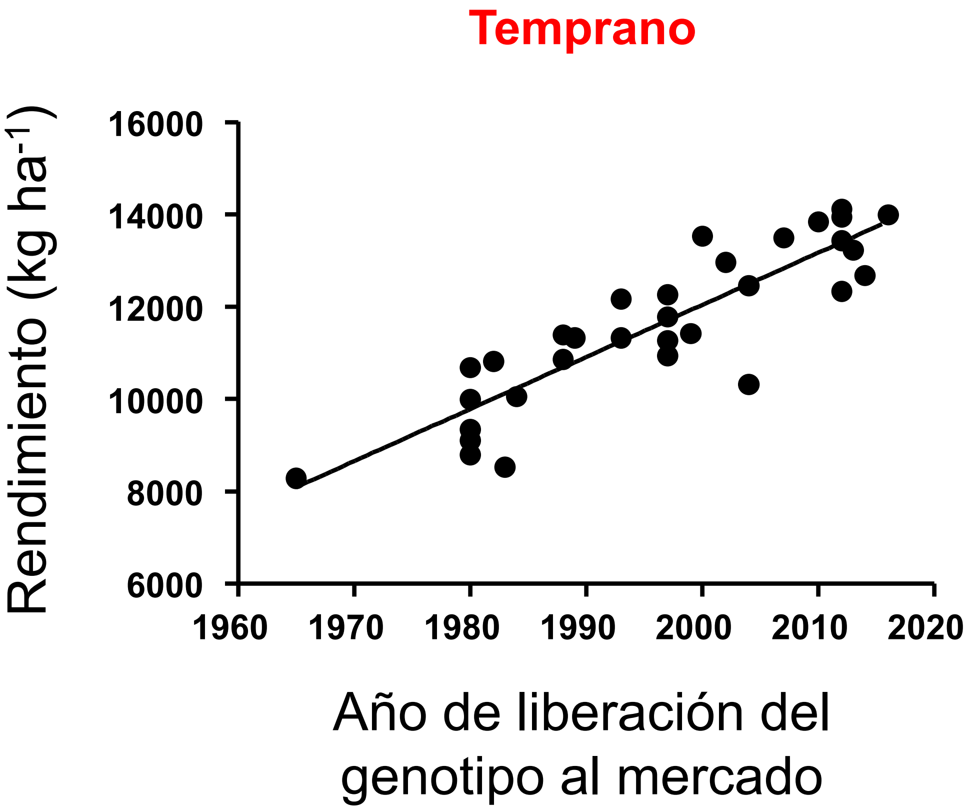
Objetivo: Describir rendimiento de genotipos liberados desde 1965 a la actualidad sobre el rendimiento en fechas tempranas y tardías.

32 genotipos liberados al mercado desde 1965 a la actualidad por Dekalb-Monsanto.

Se testearon en dos fechas de siembra Temprana (Septiembre) y Tardía (Diciembre).

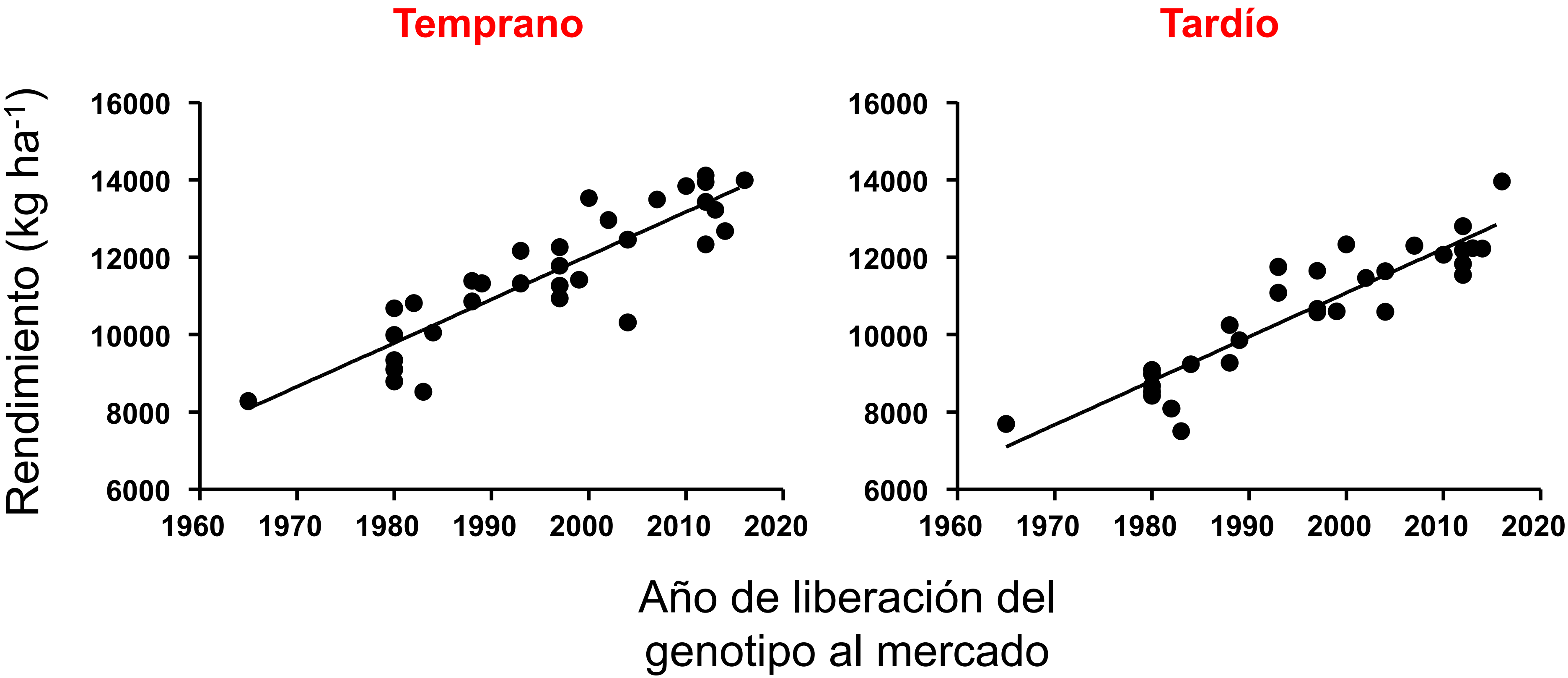
Genotipo	Año de liberación
DKF880	1965
DK2F10	1980
DK4F31	1980
DK4F32	1980
DK4F33	1980
DK4F34	1980
DK3F21	1982
DK3F22	1983
DK2F11	1984
DK3F24	1984
DK4F37	1988
DK3S41	1989
DK664 VT3PRO	1993
DK752 VT3PRO	1993
DK688 MG	1997
DK696 VT3PRO	1997
DK757 MG	1997
DK765 MG	1997
DK615 MG	1999
DK682 VT3PRO	2000
DK190 VT3PRO	2002
DK690 MG	2004
DK747 VT3PRO	2004
DK699 VT3PRO	2007
DK72-10 VT3PRO	2012
DK692 VT3PRO	2012
DK70-10 VT3PRO	2012
DK73-10 VT3PRO	2013
DK72-50 VT3PRO	2012
DK73-20 VT3PRO	2016
DK70-20 VT3PRO	2012
LT719 VT3PRO	2014

Rindes y mejoramiento en maíces sembrados temprano y tarde.



Ganancia: 113 kg ha^{-1} año^{-1}

Rindes y mejoramiento en maíces sembrados temprano y tarde.



Ganancia: 113 kg ha^{-1} $año^{-1}$

Ganancia: 114 kg ha^{-1} $año^{-1}$

Rindes y mejoramiento en maíces sembrados temprano y tarde.

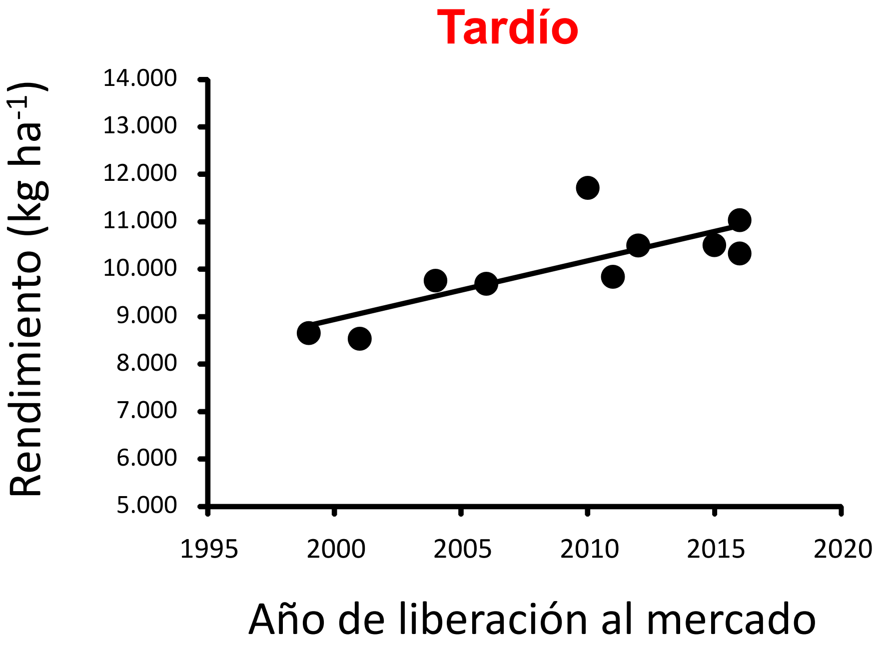
Germoplasma DOW

Genotipo	Año
M10	1999
Mil522	2001
M534	2004
M545	2006
510PW	2010
AvalonPW	2011
505PW	2012
507PW	2015
NEXT 20.6PW	2016
NEXT 22.6 PW	2016

Rindes y mejoramiento en maíces sembrados temprano y tarde.

Germoplasma DOW

Genotipo	Año
M10	1999
Mil522	2001
M534	2004
M545	2006
510PW	2010
AvalonPW	2011
505PW	2012
507PW	2015
NEXT 20.6PW	2016
NEXT 22.6 PW	2016



Tasa de ganancia genética: 124 kg. ha^{-1} año^{-1}

Conclusiones relacionadas con mejora genética:

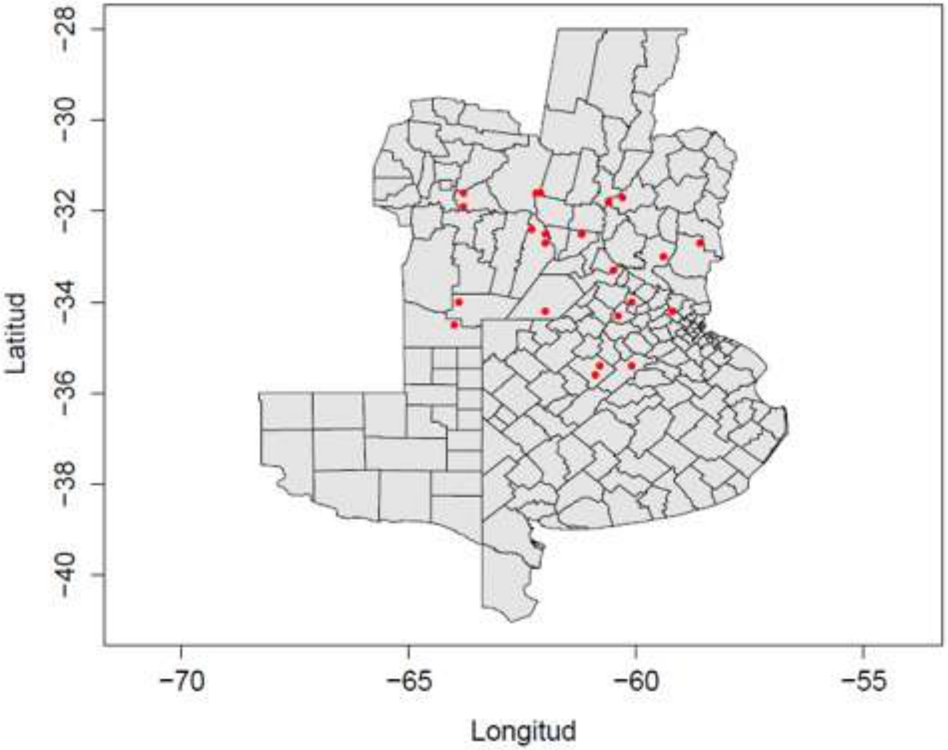
- **La mejora en rendimiento en la zona núcleo producto del mejoramiento ha sido alrededor de 110-120 kg año^{-1}.**

- **Esta mejora es similar para ambientes tempranos y tardíos.**

¿Cuán relevante es el efecto genotipo con respecto a la interacción genotipo x ambiente y manejo?

Sitios evaluados

Año	Sitio	Código	Latitud (decimal)	Longitud (decimal)
2013	Cristophersen	Cr_13	-34.2	-62.0
	Solis	So_13	-34.2	-59.2
	Laborde	La_13	-33.0	-59.4
	9 de Julio	9J_13	-35.6	-60.9
	Bustinza	Bu_13	-32.5	-61.2
	El Fortin	EF_13	-31.6	-62.2
	Rio II	RII_13	-31.9	-63.8
	25 de Mayo	25M_13	-35.4	-60.1
	Urdinarrian	Ur_13	-32.7	-58.6
2014	M.J. Moreno	MJM_14	-32.5	-62.0
	Noetinger	No_14	-32.4	-62.3
	M. Juarez	MJ_14	-32.7	-62.0
	Jovita	Jo_14	-34.5	-64.0
	9 de Julio	9J_14	-35.4	-60.8
	La Picada	LP_14	-31.7	-60.3
	Colonia	Co_14	-31.8	-60.6
	Rio II	Rll_14	-31.6	-63.8
	Laboulaye	Lab_14	-34.0	-63.9
	Godoy	Go_14	-33.3	-60.5
	Bustinza	Bu_14	-32.5	-61.2
	El Fortin	EF_14	-31.6	-62.1
	Pergamino	Pe_14	-34.0	-60.1
	Salto	S_14	-34.3	-60.4



Genotipos evaluados

Genotipo	Semillero	Madurez relativa
ACA_470	ACA	120
ADV_8112	Advanta	122
ARV_2155	Arvales	121
ARV_2194	Arvales	122
DK_7210	Monsanto	122
Dow_505	Dow Agr.	121
Dow_510	Dow Agr.	123
NK_840	Syngenta	121
NK_860	Syngenta	122


Localidad: C. Seguí. Foto: Nicolás Suiffet.

Diseño en bloques aleatorizados con 2 o 3 repeticiones por sitio.

Franjas:

6-8 surcos
200- 240 m

Variación en manejo y ambiente

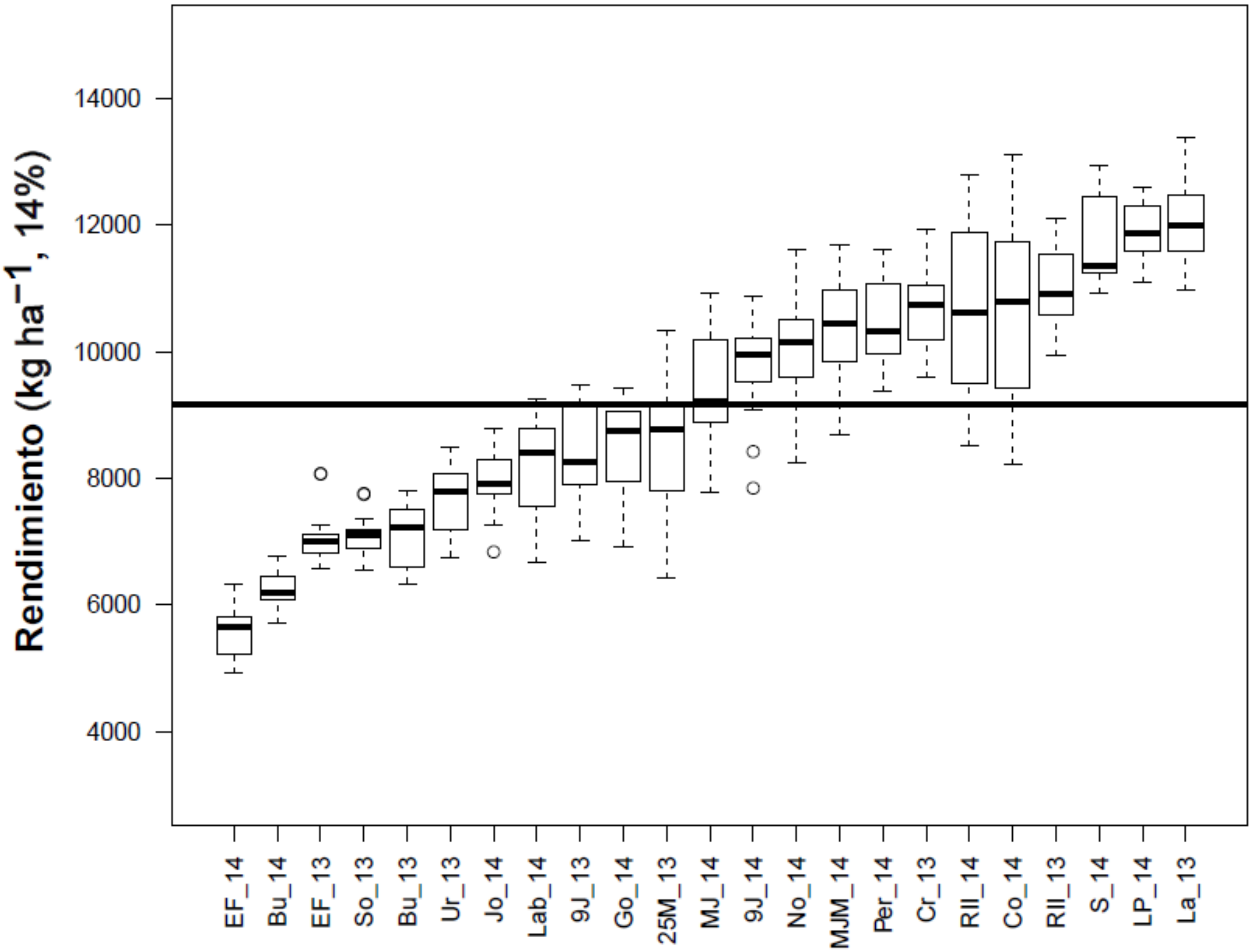
Código	Fecha de siembra	Densidad (pl m^{-2})	M.O. (%)	N a la siembra (kg ha^{-1})^1	P suelo (ppm)	P fertilizante (kg ha^{-1})	Tipo de suelo	Napa^2	Lluvias (mm)^3
Cr_13	01-Dic	6.9	2.74	127	10	0	llls	0	382
So_13	24-Dic	5.9	3.41	127	9	13	llls	0	296
La_13	20-Dic	6.8	2.07	169	19	21	llc	1	450
9J_13	20-Nov	6.3	2.73	78	8.3	17	lll	1	562
Bu_13	30-Dic	6.4	3.82	65	17	11	l	1	392
EF_13	03-Ene	6.3	2.85	81	32	9	Vlws	1	389
RII_13	24-Dic	6.5	2.11	180	20	9	lllc	0	361
25M_13	20-Dic	6.5	2.01	142	5	18	Vles	1	478
Ur_13	24-Dic	6.2	4.34	123	12	17	lll	0	696
MJM_14	01-Dic	6.5	2.63	266	68	51	lls	0	585
No_14	14-Dic	6.5	2.51	437	47	22	IIc	1	497
MJ_14	02-Dic	6.5	2.87	408	62	67	l	1	650
Jo_14	07-Dic	5.5	0.97	163	12	16	llc	1	518
9J_14	06-Dic	6.1	2.60	231	7	24	lllws	0	846
LP_14	15-Dic	6.5	1.73	463	31	30	llep	1	754
Co_14	06-Ene	7.0	2.70	372	42	20	llep	1	566
Rll_14	19-Dic	5.4	2.03	144	22	9	lllc	0	554
Lab_14	17-Dic	6.1	1.52	182	29	16	lllsc	1	663
Go_14	12-Dic	7.6	2.41	211	16	13	lllwe	1	1095
Bu_14	20-Dic	6.0	2.46	141	11.5	14	ll	1	666
EF_14	17-Dic	6.0	2.47	110	34	15	V	1	675
Per_14	16-Dic	6.6	3.50	196	58	36	llep	0	986
S_14	14-Dic	6.8	3.14	182	17	45	l	0	1156

[1] Nitrógeno es expresado en kg ha-1 suelo (0-60 cm) + fertilizante.

[2] Presencia (1) o ausencia (0) de napa a la siembra (menos de 2 m de profundidad).

[3] Lluvias durante el ciclo (de siembra a cosecha).

Variación en rendimiento entre sitios



Modelo para contestar la pregunta

Rendimiento = Efecto G + Efecto A + Efecto G x A

Modelo para contestar la pregunta

Rendimiento = Efecto G + Efecto A + Efecto G x A

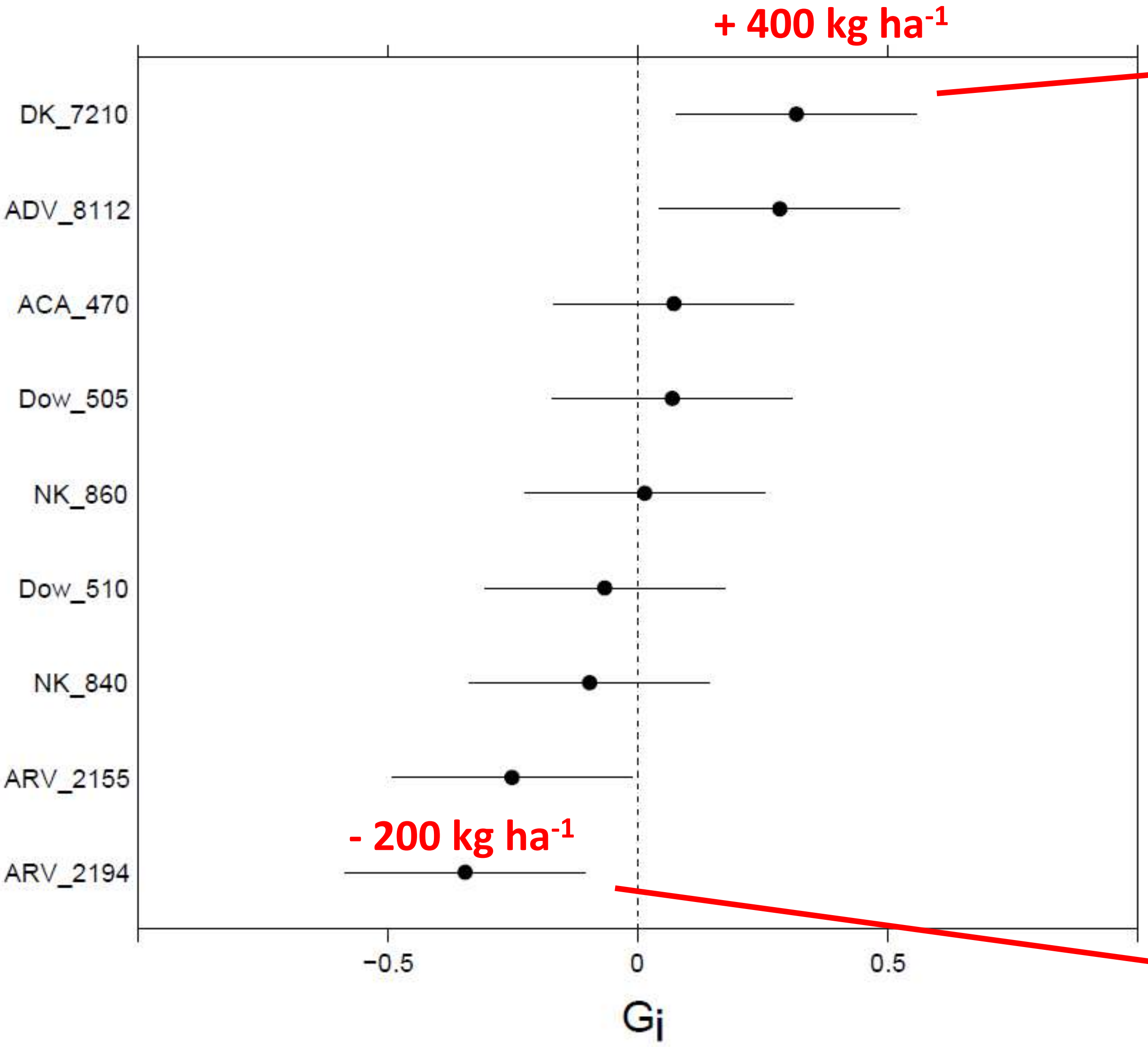
AMBIENTE:
- *Suelo*
- *Lluvias*
- *AU*
- *Napa…*

MANEJO:
- *Fecha de siembra*
- *Densidad de plantas*
- *Nitrógeno*
- *Fósforo*

- *Respuesta diferencial al MANEJO O AMBIENTE:*

  Ejemplo: Gen x Densidad

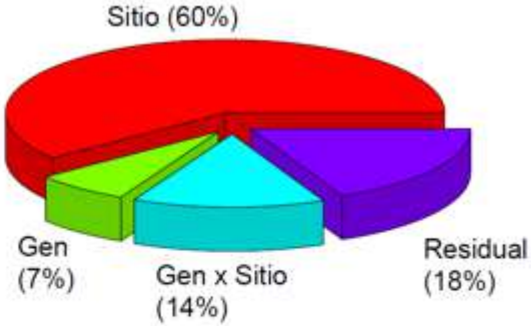
Zuur et al. 2009 (Springer), Smith et al. 2005 (J. of Agric. Sc), Malosetti et al. 2013 (Frontiers in Phys).



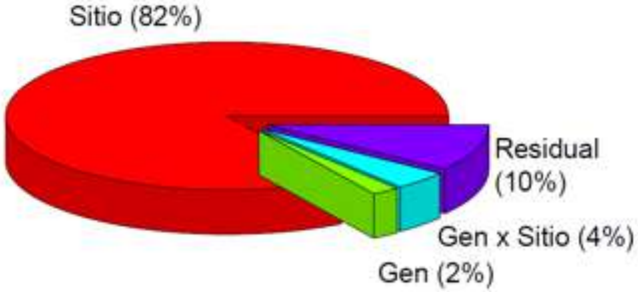
Genotipo de comportamiento SUPERIOR a través de todos los ambientes

Genotipo de comportamiento INFERIOR a través de todos los ambientes

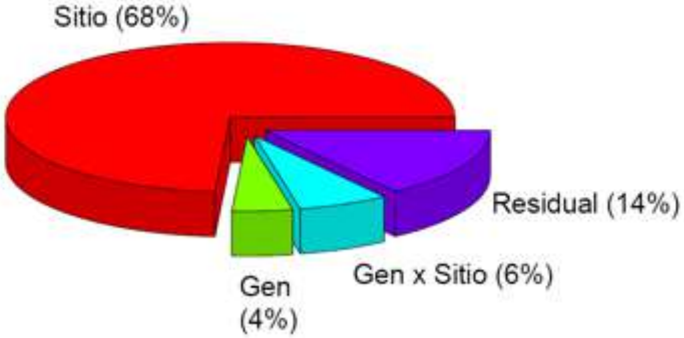
Proporción de la variación en rendimiento asociada a cada componente:



Campaña 11-12



Campaña 12-13



Campaña 13-14

¿El uso de FUNGICIDAS explica una parte de esta interacción?

RED DE
EVALUACIÓN
DE MAÍZ EN
FECHAS DE
SIEMBRA TARDÍA

CAMPAÑA 2016-2017

¿Es necesaria la aplicación de fungicidas en maíces de siembras tardías?

» La aplicación de fungicida tuvo una respuesta en rendimiento promedio a través de ambientes y genotipos de 700 kg ha^{-1}.

» ***La respuesta varió entre sitios y genotipos***, mostrando en la gran mayoría de los casos respuestas de diferente magnitud. Esto enfatiza la importancia de la elección del genotipo y ambiente productivo en la decisión de la aplicación de fungicidas en maíz tardío.

» Aún con niveles bajos de Roya y Tizón en varios genotipos, las respuestas en rendimiento fueron positivas.

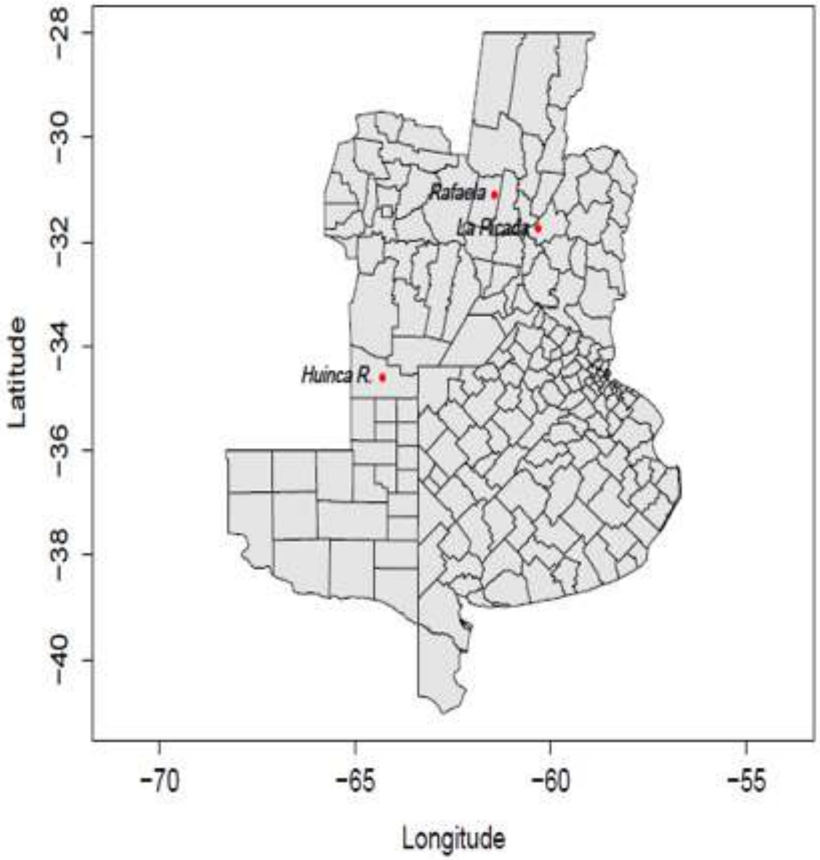
3 Sitios

11 Genotipos

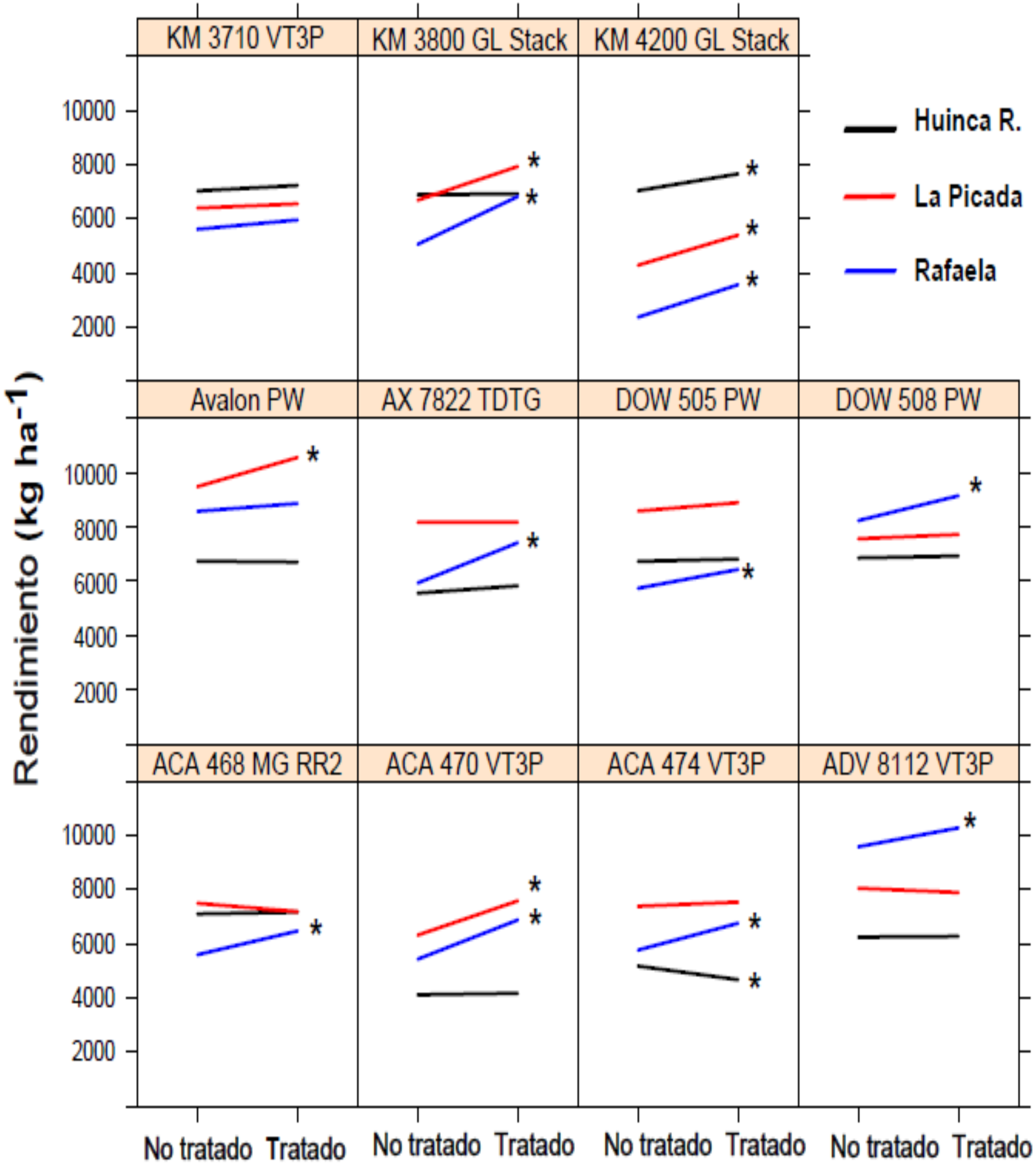
Funguicida:
Tratado – No tratado

¿Qué impacto tiene la aplicación de funguicidas sobre el rendimiento? ¿Varía con el genotipo?

Resultados Red AAPRESID 2014-2015:



Resultados Red AAPRESID 2014-2015:

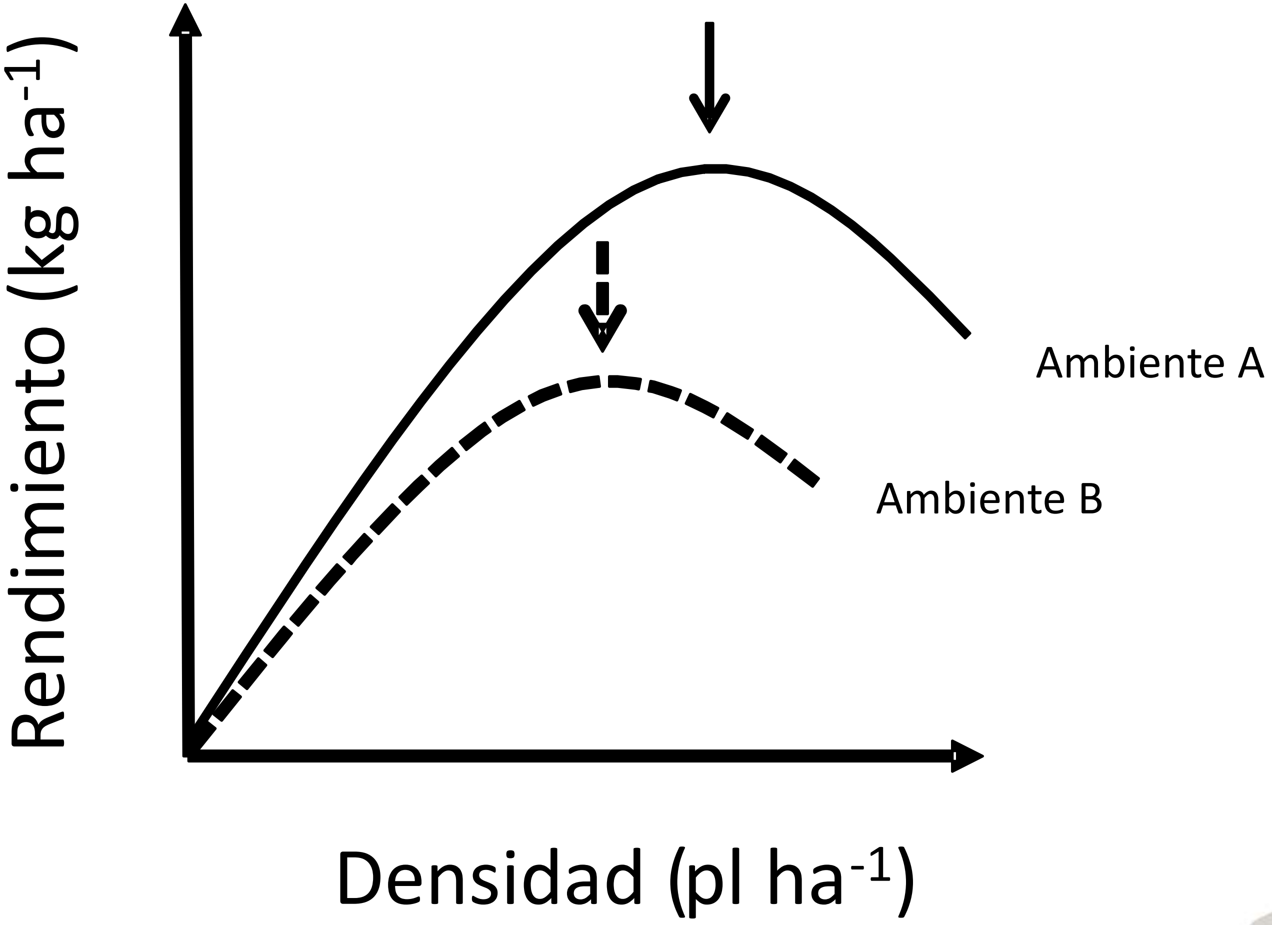


Fungicida	**Rinde**	
No tratado	6559	b
Tratado	7003	a
Respuesta	**440 kg ha^{-1}**	

Interacción genotipo x fungicida x sitio significativa ($p<0.01$)

¿Las diferencias en densidad óptima entre genotipos comerciales es relevante?

Respuesta del rendimiento del cultivo de maíz a la densidad de siembra:



Diferencias en Densidad Optima (DO) para cada genotipo:

Genotipo	Densidad Optima
	pl m^{-2}
NK860	
NK910	
P1979	
P2069	
P2053	
DK670	
DK692	
AX852	
AX886	
AX887	
Prec. Nid.	

Hernández et al. Agronomy Journal 2014.

Diferencias en Densidad Optima (DO) para cada genotipo:

Genotipo	**Densidad Optima**
	pl m^{-2}
NK860	8,6
NK910	7,4
P1979	9,5
P2069	8,8
P2053	9,4
DK670	11,8
DK692	11,1
AX852	10,3
AX886	8,3
AX887	8,7
Prec. Nid.	10,2

Efecto
genotipo x densidad
significativa (p<0.001)

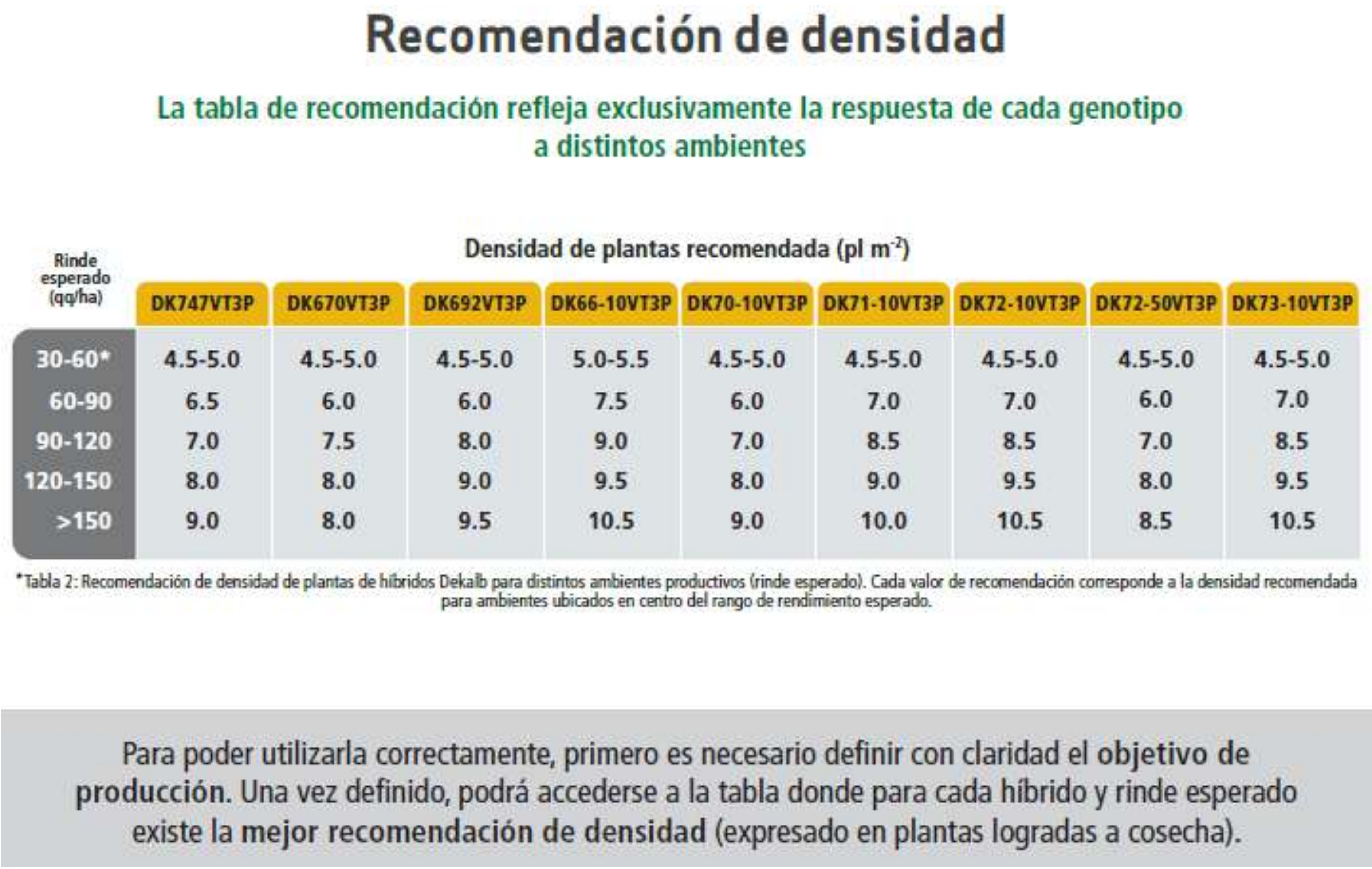
Hernández et al. Agronomy Journal 2014.

DENSIDADES RECOMENDADAS

	SIEMBRA PRIMERA			SIEMBRA TARDIA	
Nivel ambiental	BAJO	MEDIO	ALTO	BAJO	MEDIO
Tn/ha esperados	6.5 a 8.5	9.5 a 11.5	12.5 a 14.5	6 a 8	9 a 10
AX852MG	66000	82000	88000	60000	67000
AX852HX	66000	82000	88000	60000	67000
AX852MGRR2	66000	82000	88000	60000	67000
AX870MGRR2	66000	75000	82000	60000	65000
AX878MG	66000	75000	82000	60000	65000
AX881HCL-MG	60000	72000	80000	58000	65000
AX882HCL-MG	66000	75000	82000	60000	65000
AX886MG	60000	72000	80000	58000	65000
AX886MGRR2	60000	72000	80000	58000	65000
AX887MG	66000	75000	85000	60000	67000
AX894HX	62000	75000	82000	60000	67000
AX896MG	60000	72000	80000	60000	65000
0971N0002MG	72000	85000	95000	62000	70000

Presentación NIDERA 28/7/2011 Jornada Elección de Densidad de Siembra

Recomendaciones Dekalb actuales:



Recomendación de densidad

La tabla de recomendación refleja exclusivamente la respuesta de cada genotipo a distintos ambientes

Densidad de plantas recomendada (pl m^{-2})

Rinde esperado (qq/ha)	DK747VT3P	DK670VT3P	DK692VT3P	DK66-10VT3P	DK70-10VT3P	DK71-10VT3P	DK72-10VT3P	DK72-50VT3P	DK73-10VT3P
30-60*	4.5-5.0	4.5-5.0	4.5-5.0	5.0-5.5	4.5-5.0	4.5-5.0	4.5-5.0	4.5-5.0	4.5-5.0
60-90	6.5	6.0	6.0	7.5	6.0	7.0	7.0	6.0	7.0
90-120	7.0	7.5	8.0	9.0	7.0	8.5	8.5	7.0	8.5
120-150	8.0	8.0	9.0	9.5	8.0	9.0	9.5	8.0	9.5
>150	9.0	8.0	9.5	10.5	9.0	10.0	10.5	8.5	10.5

*Tabla 2: Recomendación de densidad de plantas de híbridos Dekalb para distintos ambientes productivos (rinde esperado). Cada valor de recomendación corresponde a la densidad recomendada para ambientes ubicados en centro del rango de rendimiento esperado.

Para poder utilizarla correctamente, primero es necesario definir con claridad el **objetivo de producción**. Una vez definido, podrá accederse a la tabla donde para cada híbrido y rinde esperado existe la **mejor recomendación de densidad** (expresado en plantas logradas a cosecha).

Diferencias genotípicas en respuesta a Nitrógeno disponible.


Localidad: C. Seguí. Foto: Nicolás Suiffet.

Diseño en bloques aleatorizados con 2 o 3 repeticiones por sitio.

Franjas:

6-8 surcos
200- 240 m

Variación en manejo y ambiente

Código	Fecha de siembra	Densidad (pl m^{-2})	M.O. (%)	N a la siembra (kg ha^{-1})[1]	P suelo (ppm)	P fertilizante (kg ha^{-1})	Tipo de suelo	Napa[2]	Lluvias (mm)[3]
Cr_13	01-Dic	6.9	2.74	127	10	0	llls	0	382
So_13	24-Dic	5.9	3.41	127	9	13	llls	0	296
La_13	20-Dic	6.8	2.07	169	19	21	llc	1	450
9J_13	20-Nov	6.3	2.73	78	8.3	17	lll	1	562
Bu_13	30-Dic	6.4	3.82	65	17	11	l	1	392
EF_13	03-Ene	6.3	2.85	81	32	9	Vlws	1	389
RII_13	24-Dic	6.5	2.11	180	20	9	lllc	0	361
25M_13	20-Dic	6.5	2.01	142	5	18	Vles	1	478
Ur_13	24-Dic	6.2	4.34	123	12	17	lll	0	696
MJM_14	01-Dic	6.5	2.63	266	68	51	lls	0	585
No_14	14-Dic	6.5	2.51	437	47	22	IIc	1	497
MJ_14	02-Dic	6.5	2.87	408	62	67	l	1	650
Jo_14	07-Dic	5.5	0.97	163	12	16	llc	1	518
9J_14	06-Dic	6.1	2.60	231	7	24	lllws	0	846
LP_14	15-Dic	6.5	1.73	463	31	30	llep	1	754
Co_14	06-Ene	7.0	2.70	372	42	20	llep	1	566
Rll_14	19-Dic	5.4	2.03	144	22	9	lllc	0	554
Lab_14	17-Dic	6.1	1.52	182	29	16	lllsc	1	663
Go_14	12-Dic	7.6	2.41	211	16	13	lllwe	1	1095
Bu_14	20-Dic	6.0	2.46	141	11.5	14	ll	1	666
EF_14	17-Dic	6.0	2.47	110	34	15	V	1	675
Per_14	16-Dic	6.6	3.50	196	58	36	llep	0	986
S_14	14-Dic	6.8	3.14	182	17	45	l	0	1156

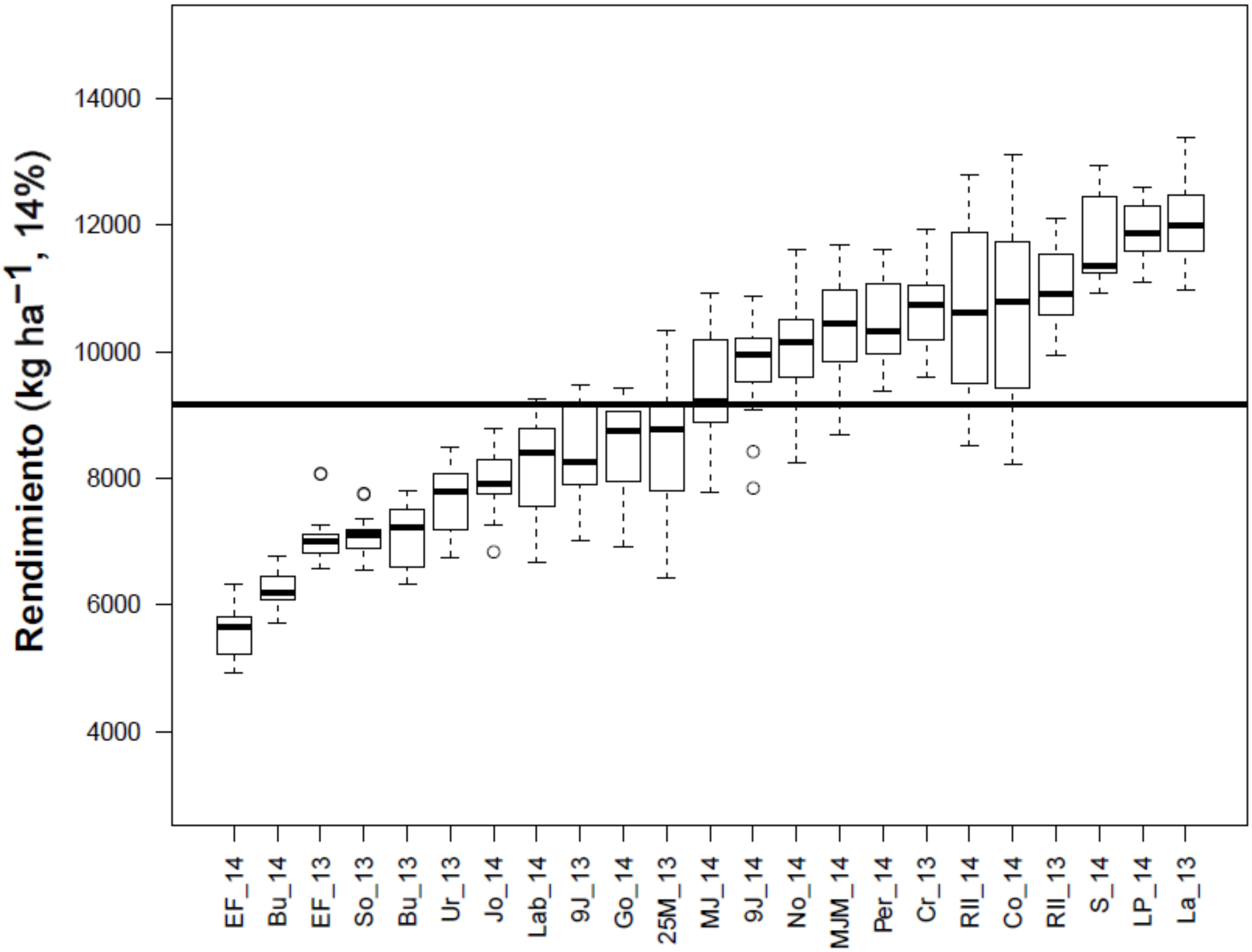
---

[1] Nitrógeno es expresado en kg ha-1 suelo (0-60 cm) + fertilizante.

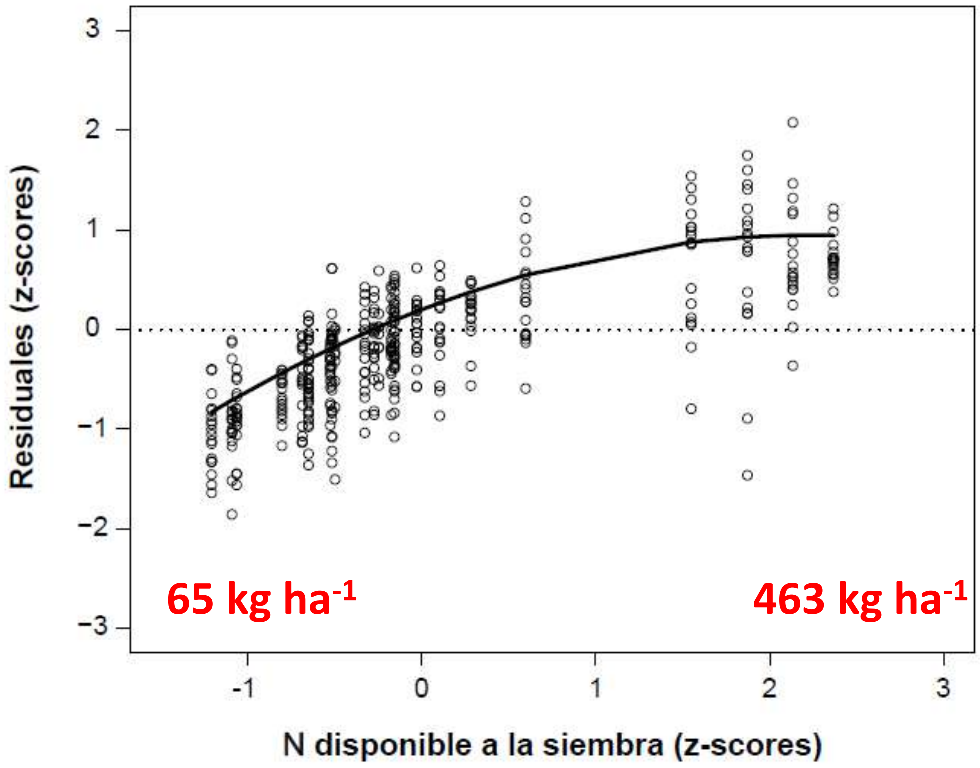
[2] Presencia (1) o ausencia (0) de napa a la siembra (menos de 2 m de profundidad).

[3] Lluvias durante el ciclo (de siembra a cosecha).

Variación en rendimiento entre sitios

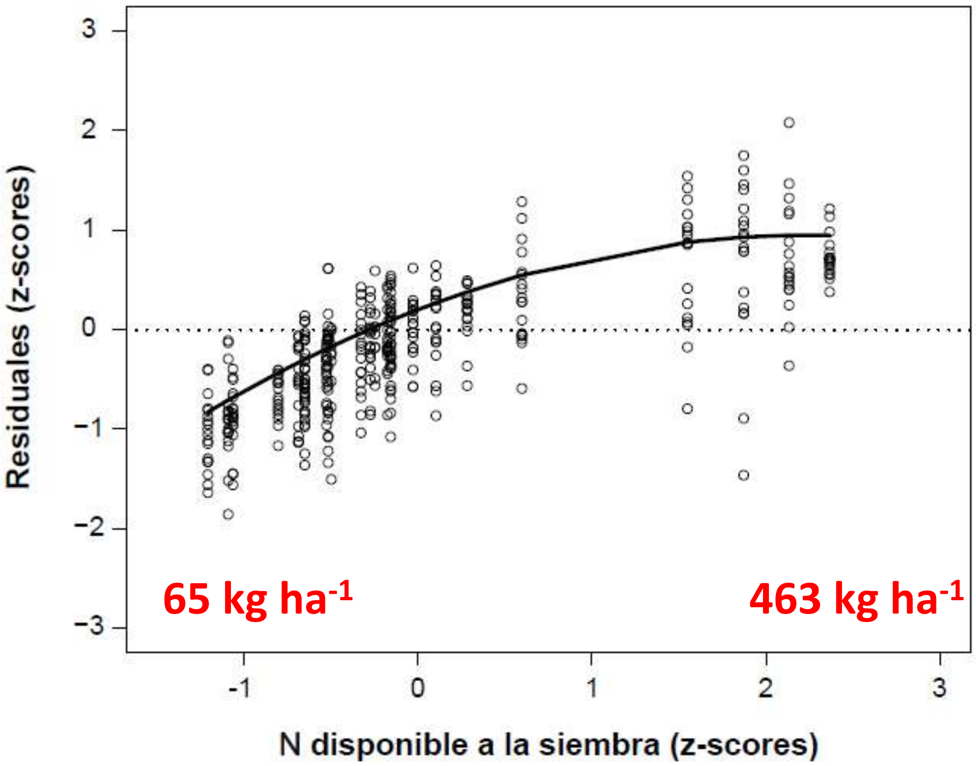


Efecto de la fertilización nitrogenada



Efecto inicial de 22 kg ha^{-1} por kg N ha^{-1} disponible a la siembra.

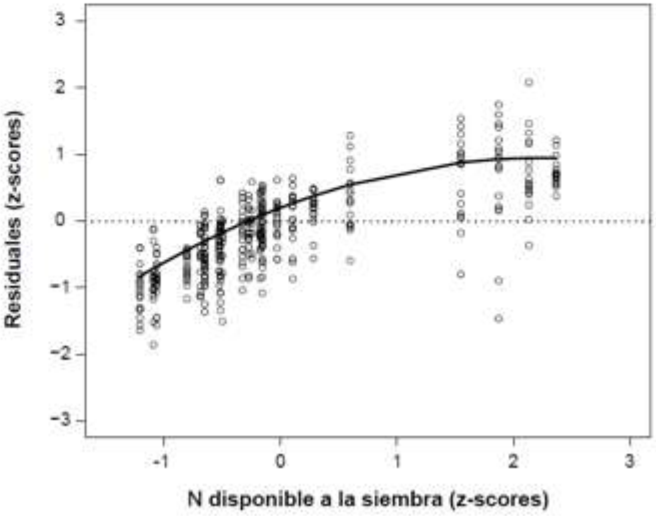
Efecto de la fertilización nitrogenada

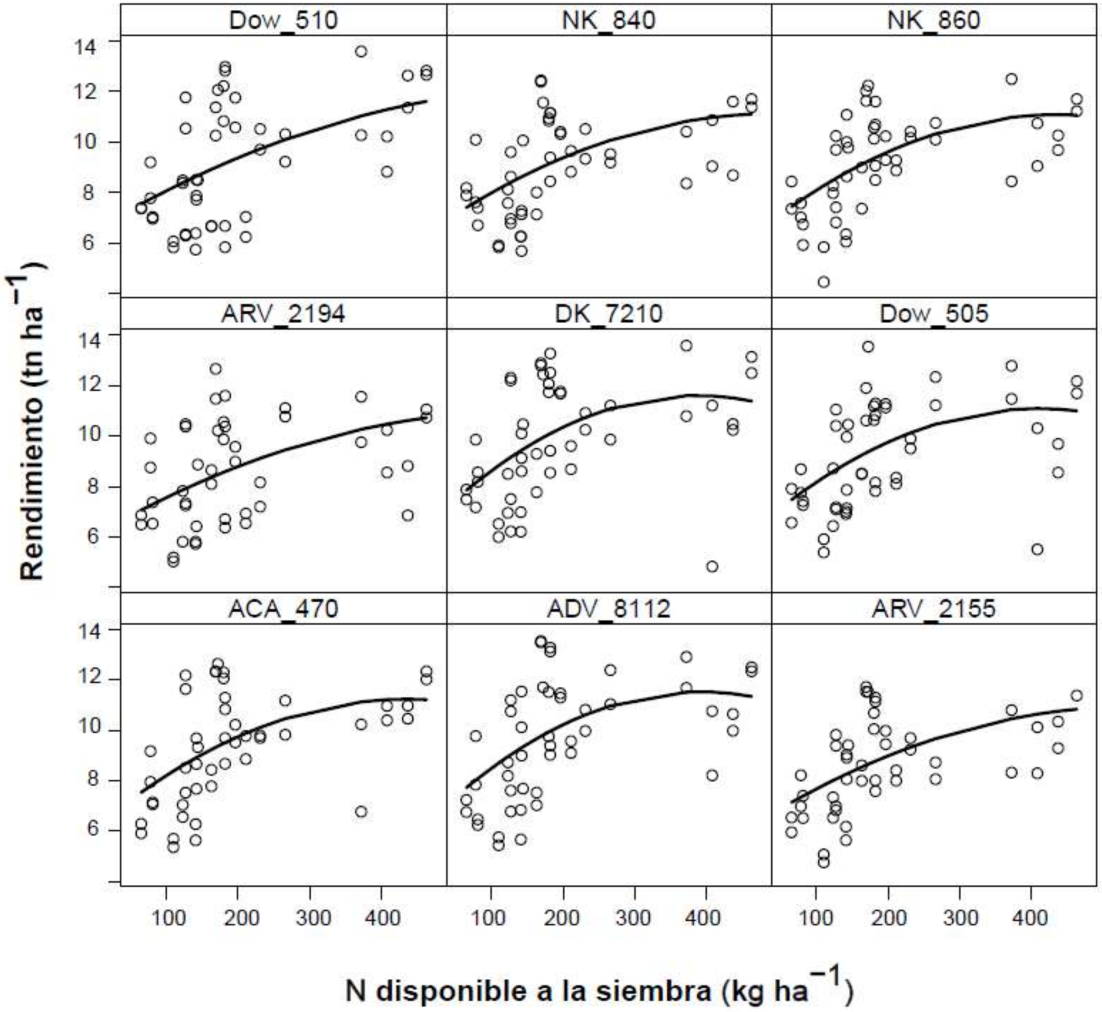


Umbral de respuesta de 140 kg N ha^{-1} suelo + fertilizante.

Efecto inicial de 22 kg ha^{-1} por kg N ha^{-1} disponible a la siembra.

Efecto de la fertilización nitrogenada

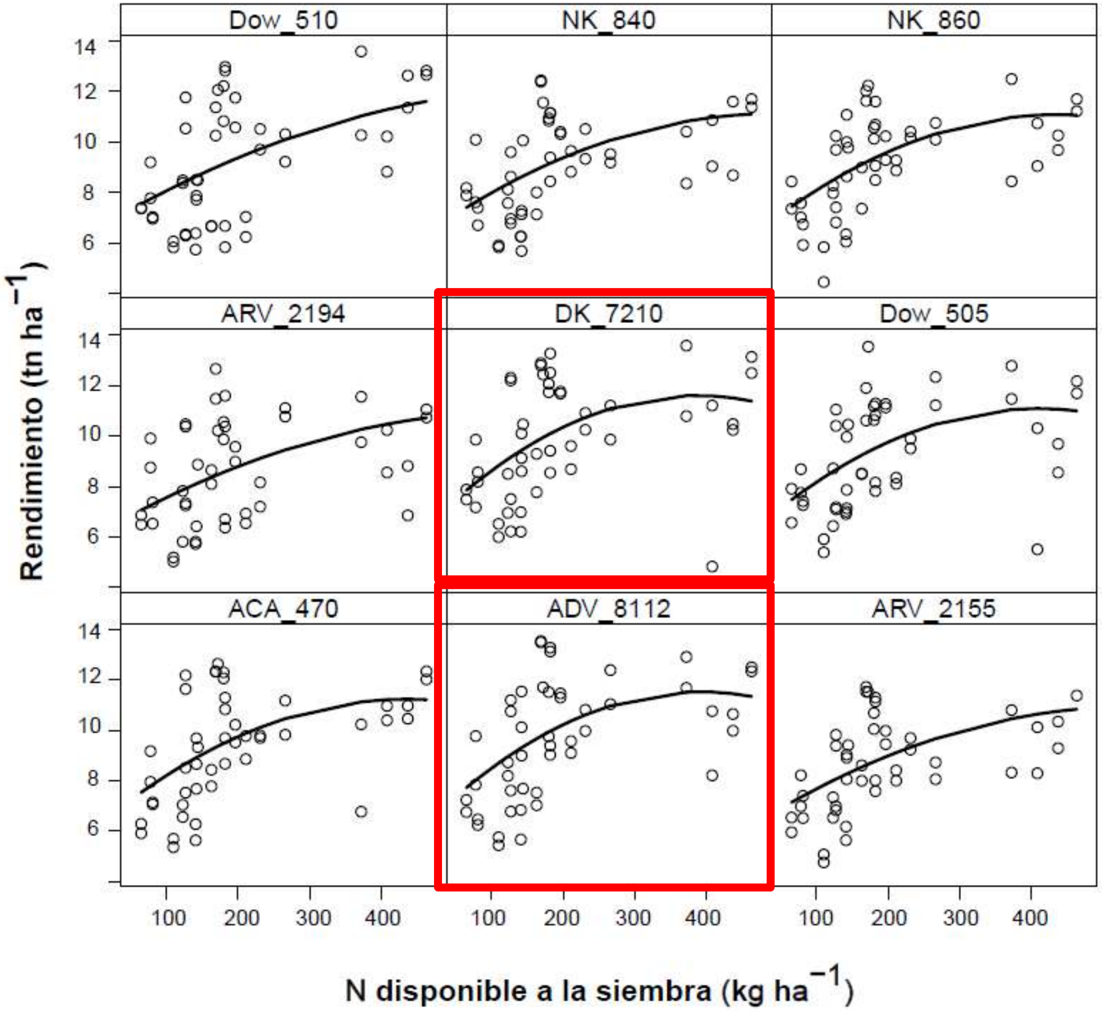




Efecto inicial de 22 kg ha^{-1} por kg N ha^{-1} disponible a la siembra.

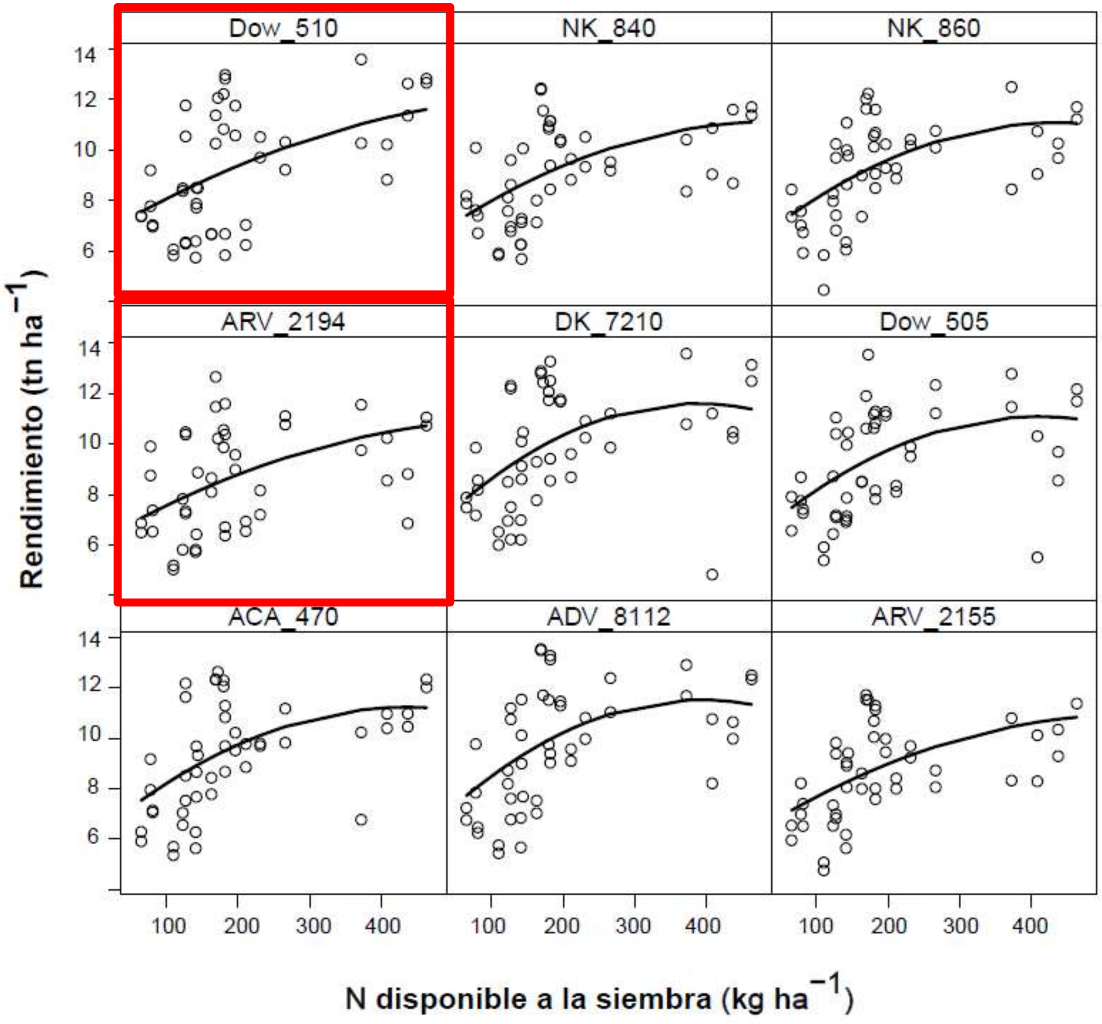
Efecto de la fertilización nitrogenada

Hay genotipos que responden más a la fertilización con N (DK_7210, ADV_8112) con 28 kg ha^{-1} por kg N ha^{-1}.



Efecto de la fertilización nitrogenada

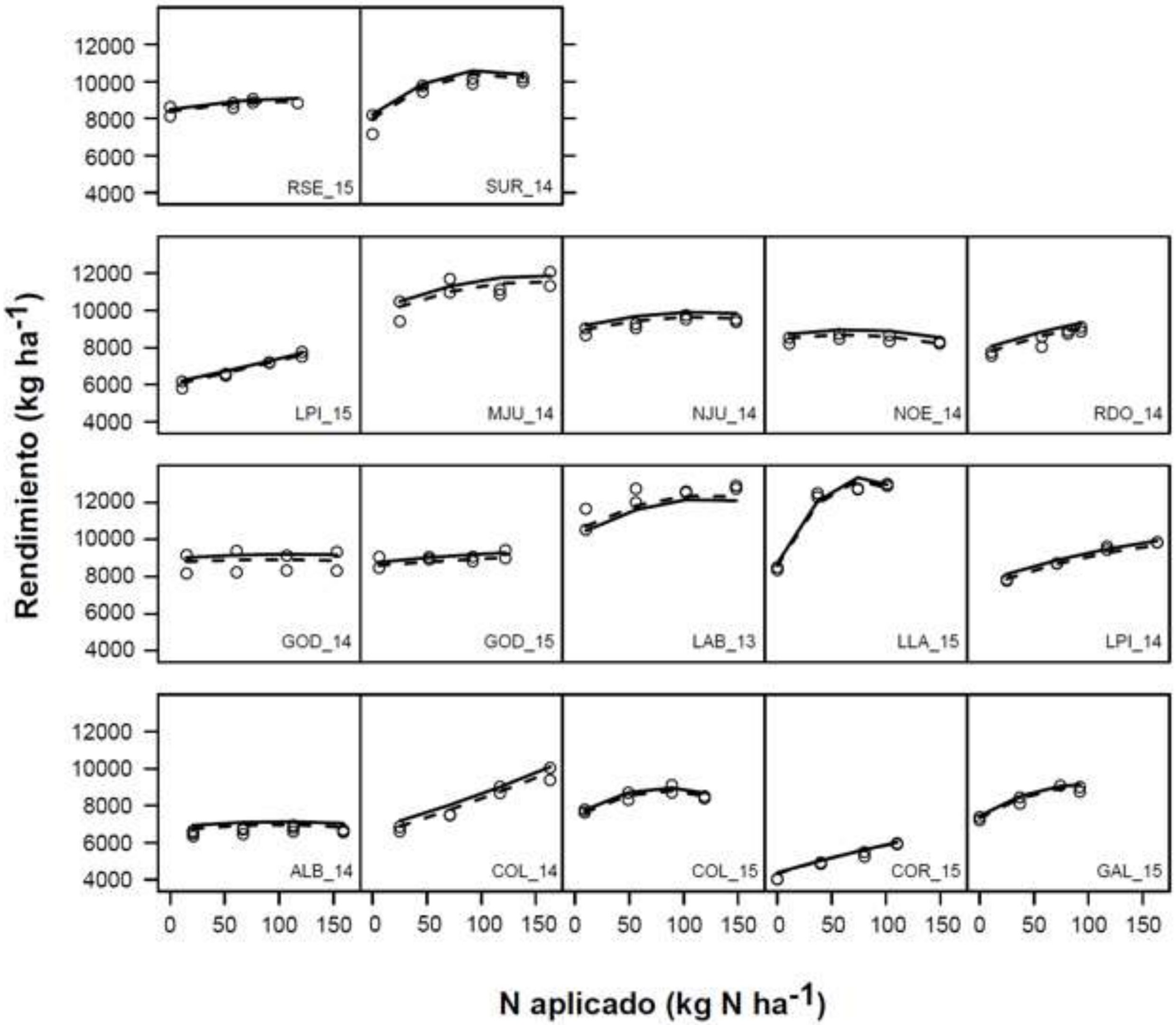
Hay genotipos que responden menos a la fertilización con N (ARV_2194, Dow_510) con 16 kg ha^{-1} por kg N ha^{-1}.



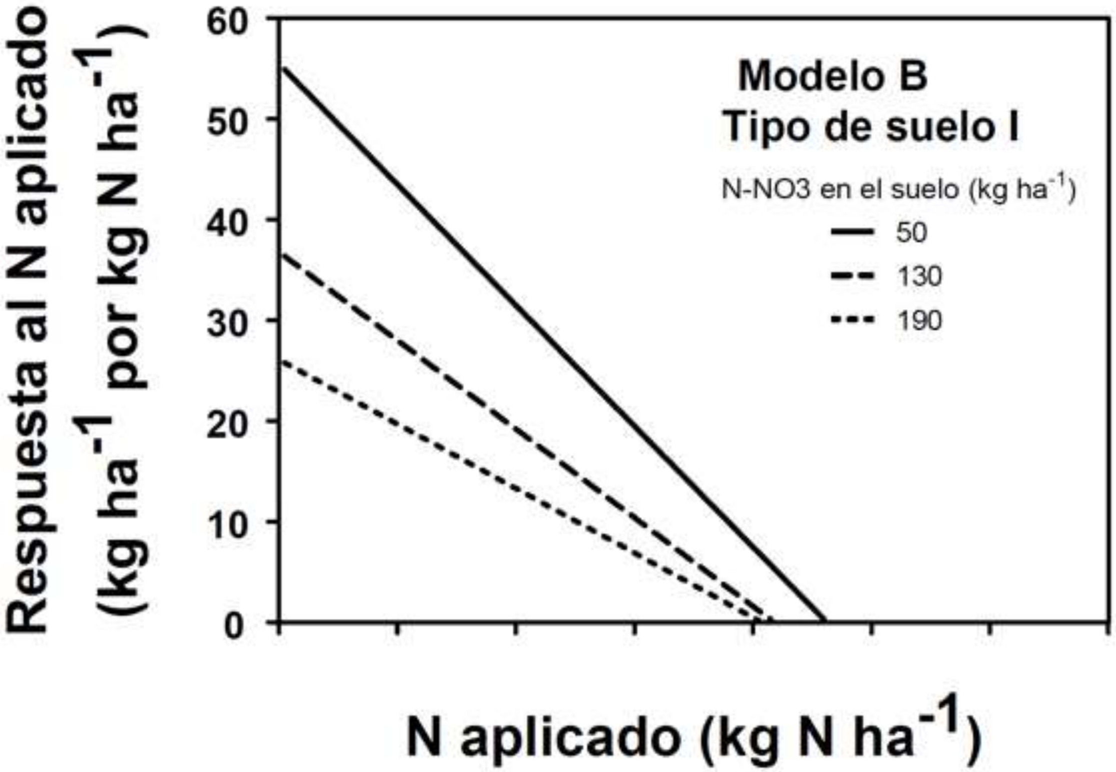
Un segundo análisis nos permitió ver más en detalle algunas cuestiones de respuesta del rendimiento al N aplicado en maíz tardío.

Sitio	N suelo (kg ha^{-1})	MO (%)	P suelo (ppm)	Tipo de suelo	Agua disponible a la siembra (mm)	Napa	Lluvias (mm)	Fecha de siembra	Densidad (pl m^{-2})	Híbrido
LAB_13	75	2.07	19	IIc	292	1	337	13-Dic	7.5	DK7210
ALB_14	125	3.96	7	IIw	320	1	578	17-Dic	3.8	DK7210
COL_14	112	2.70	42	IIep	317	1	461	7-Ene	6.8	DM2771
COL_15	64	2.80	10	IIep	317	0	415	6-Ene	6.9	DK7210
COR_15	176	3.32	60	IIIc	292	0	619	3-Ene	6.0	PROAVE467
GAL_15	156	2.90	27	I	375	1	476	24-Dic	7.0	ACA468
GOD_14	150	2.41	16	IIIws	317	1	780	12-Dic	7.3	AX852
GOD_15	117	2.41	17	IIs	312	0	398	6-Ene	7.3	AX7822
LLA_15	34	1.70	15	IIIc	172	0	635	12-Dic	4.4	DK7210
LPI_14	109	1.70	31	IIep	266	1	625	19-Dic	6.5	AX878
LPI_15	214	2.44	15	IIep	266	0	682	3-Ene	6.7	DK7310
MJU_14	151	2.63	68	IIc	375	0	462	2-Dic	6.5	DK7010
NJU_14	171	2.60	7	II	292	0	493	7-Dic	6.1	DM2738
NOE_14	356	2.56	47	IIc	375	1	373	14-Dic	5.5	P31Y05
RDO_14	130	1.80	47	IIIc	108	0	481	19-Dic	4.5	DK7210
RSE_15	38	1.86	16	IIIc	154	0	721	16-Dic	5.6	DK7210
SUR_14	162	2.87	62	I	375	1	527	3-Dic	6.5	DOW505

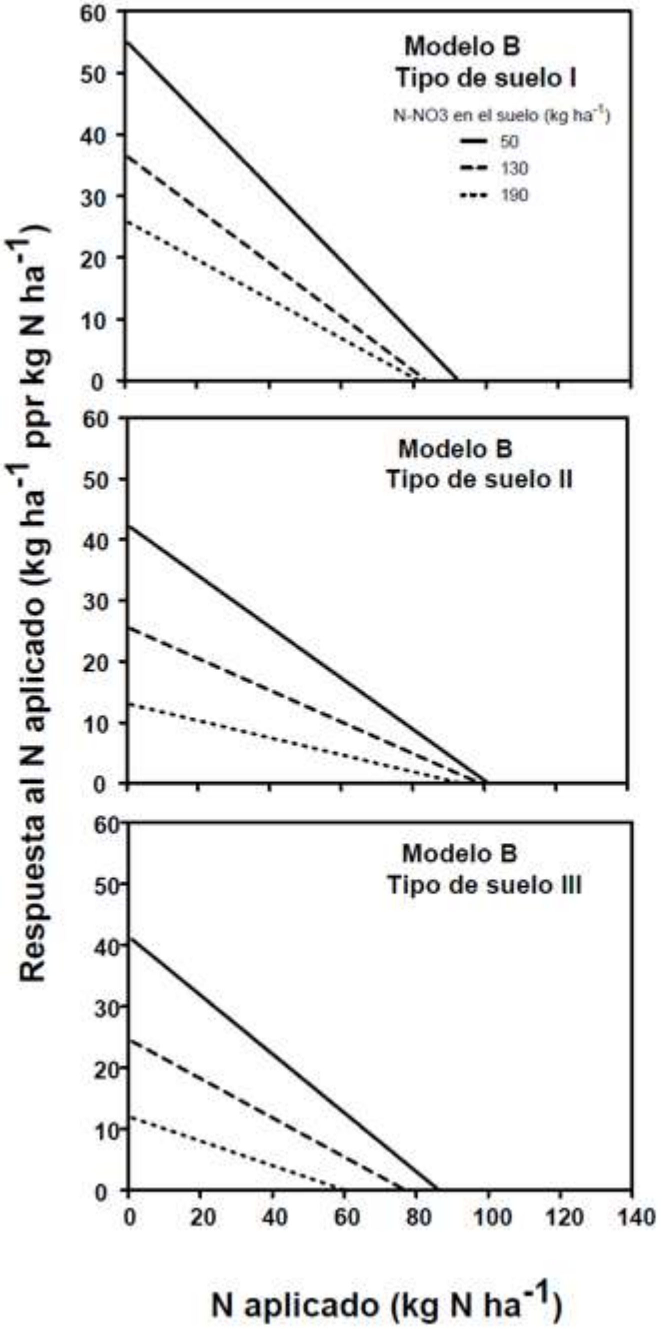
Un segundo análisis nos permitió ver más en detalle algunas cuestiones de respuesta del rendimiento al N aplicado en maíz tardío.



La respuesta depende de:
(i) el tipo de suelo (I, II o III), y
(ii) del N disponible en el suelo.



La respuesta depende de:
(i) el tipo de suelo (I, II o III), y
(ii) del N disponible en el suelo.



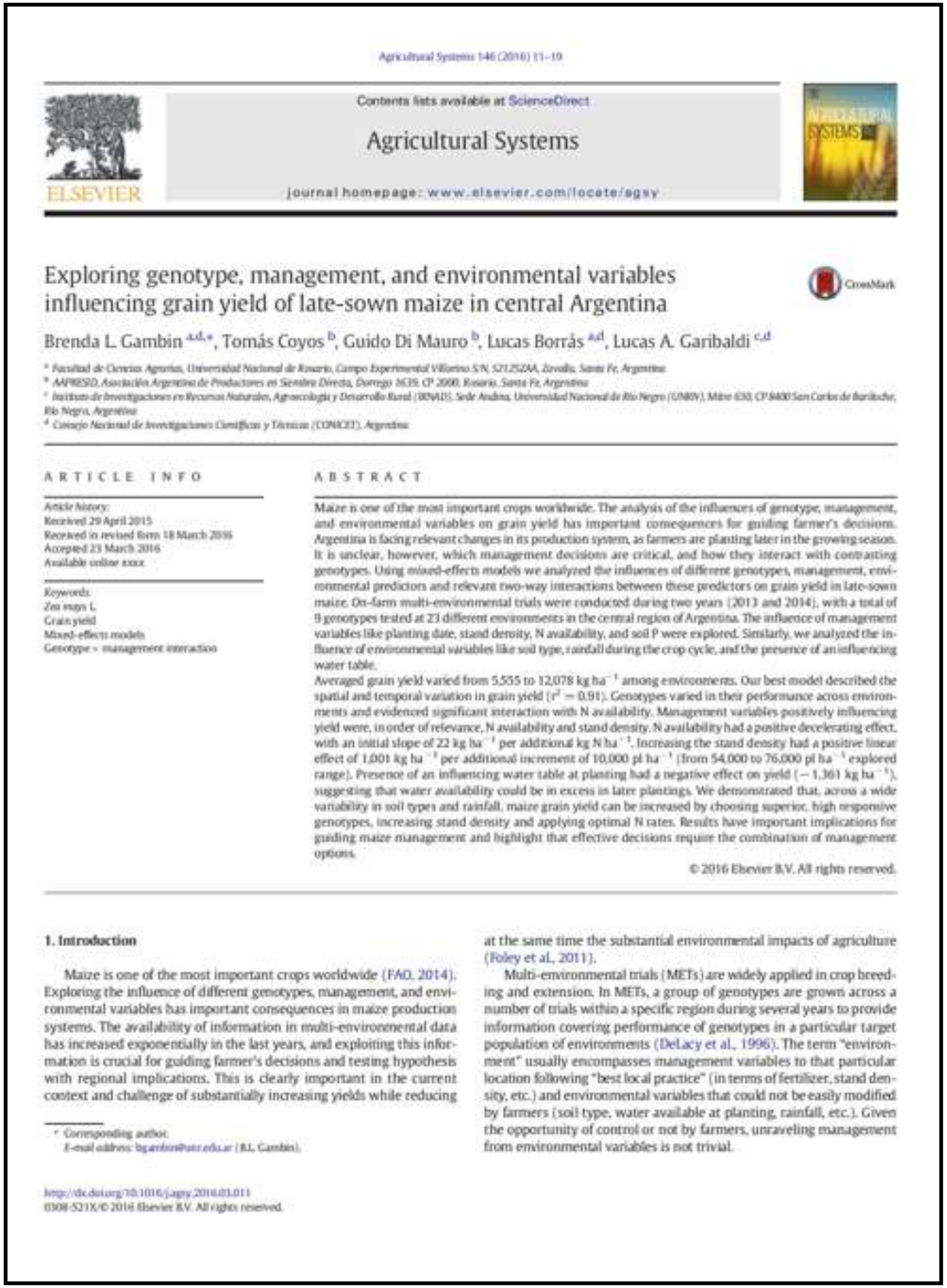
Conclusiones finales:

- **La mejora en rendimiento en la zona núcleo producto del mejoramiento ha sido alrededor de 110-120 kg año^{-1}.**

- **Existe una fuerte interacción entre el genotipo y su manejo, clave para lograr un cultivo exitoso.**
  - **Entre los aspectos a manejar se resaltan densidad y fungicida.**
  - **Si bien los genotipos responden diferencialmente a N, no existen datos para poder predecir esta respuesta diferencial.**

Gracias por la atención !!

Consultas: lborras@unr.edu.ar



Agricultural Systems 146 (2016) 11–19

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Exploring genotype, management, and environmental variables influencing grain yield of late-sown maize in central Argentina

Brenda L. Gambin [a,d,*], Tomás Coyos [b], Guido Di Mauro [b], Lucas Borrás [a,d], Lucas A. Garibaldi [c,d]

[a] *Facultad de Ciencias Agrarias, Universidad Nacional de Rosario, Campo Experimental Villarino S/N, S2125ZAA, Zavalla, Santa Fe, Argentina*
[b] *AAPRESID, Asociación Argentina de Productores en Siembra Directa, Dorrego 1639, CP 2000, Rosario, Santa Fe, Argentina*
[c] *Instituto de Investigaciones en Recursos Naturales, Agroecología y Desarrollo Rural (IRNAD), Sede Andina, Universidad Nacional de Río Negro (UNRN), Mitre 630, CP 8400 San Carlos de Bariloche, Río Negro, Argentina*
[d] *Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina*

ARTICLE INFO

Article history:
Received 29 April 2015
Received in revised form 18 March 2016
Accepted 23 March 2016
Available online xxxx

Keywords:
Zea mays L.
Grain yield
Mixed-effects models
Genotype × management interaction

ABSTRACT

Maize is one of the most important crops worldwide. The analysis of the influences of genotype, management, and environmental variables on grain yield has important consequences for guiding farmer's decisions. Argentina is facing relevant changes in its production system, as farmers are planting later in the growing season. It is unclear, however, which management decisions are critical, and how they interact with contrasting genotypes. Using mixed-effects models we analyzed the influences of different genotypes, management, environmental predictors and relevant two-way interactions between these predictors on grain yield in late-sown maize. On-farm multi-environmental trials were conducted during two years (2013 and 2014), with a total of 9 genotypes tested at 23 different environments in the central region of Argentina. The influence of management variables like planting date, stand density, N availability, and soil P were explored. Similarly, we analyzed the influence of environmental variables like soil type, rainfall during the crop cycle, and the presence of an influencing water table.

Averaged grain yield varied from 5,555 to 12,078 kg ha^{-1} among environments. Our best model described the spatial and temporal variation in grain yield ($r^2 = 0.91$). Genotypes varied in their performance across environments and evidenced significant interaction with N availability. Management variables positively influencing yield were, in order of relevance, N availability and stand density. N availability had a positive decelerating effect, with an initial slope of 22 kg ha^{-1} per additional kg N ha^{-1}. Increasing the stand density had a positive linear effect of 1,001 kg ha^{-1} per additional increment of 10,000 pl ha^{-1} (from 54,000 to 76,000 pl ha^{-1} explored range). Presence of an influencing water table at planting had a negative effect on yield ($-1,361$ kg ha^{-1}), suggesting that water availability could be in excess in later plantings. We demonstrated that, across a wide variability in soil types and rainfall, maize grain yield can be increased by choosing superior, high responsive genotypes, increasing stand density and applying optimal N rates. Results have important implications for guiding maize management and highlight that effective decisions require the combination of management options.

1. Introduction

Maize is one of the most important crops worldwide (FAO, 2014). Exploring the influence of different genotypes, management, and environmental variables has important consequences in maize production systems. The availability of information in multi-environmental data has increased exponentially in the last years, and exploiting this information is crucial for guiding farmer's decisions and testing hypothesis with regional implications. This is clearly important in the current context and challenge of substantially increasing yields while reducing at the same time the substantial environmental impacts of agriculture (Foley et al., 2011).

Multi-environmental trials (METs) are widely applied in crop breeding and extension. In METs, a group of genotypes are grown across a number of trials within a specific region during several years to provide information covering performance of genotypes in a particular target population of environments (DeLacy et al., 1996). The term "environment" usually encompasses management variables to that particular location following "best local practice" (in terms of fertilizer, stand density, etc.) and environmental variables that could not be easily modified by farmers (soil type, water available at planting, rainfall, etc.). Given the opportunity of control or not by farmers, unraveling management from environmental variables is not trivial.

---

[*] Corresponding author.
E-mail address: bgambin@unr.edu.ar (B.L. Gambin).

http://dx.doi.org/10.1016/j.agsy.2016.03.011
0308-521X/© 2016 Elsevier B.V. All rights reserved.

Factores que determinan el rendimiento en maíz tardío, y ejemplo de interacción N x genotipo.

Pedir copia a:
lborras@unr.edu.ar

Gambín et al.
Agricultural Systems
2016.

Site-Specific Covariates Affecting Yield Response to Nitrogen of Late-Sown Maize in Central Argentina

Tomás Coyos, Lucas Borrás, and Brenda L. Gambin*

ABSTRACT

Optimizing fertilizer rates is a common problem in modern agriculture. Frequently used response models ignore basic statistical assumptions and do not allow quantifying the effects of variables influencing yield response to fertilizer, generating uncertainty in fertilizer rate recommendations. We used linear mixed-effects models to explore maize (*Zea mays* L.) yield response to applied nitrogen (N) in late sowings, and we tested different predictors for explaining yield responses across sites. Data included yield response trials to applied N at 17 different environments (combination site × year) with four to five N rates replicated twice in each trial. The best model (Model A) that included significant effect of N rate applied, sowing date, and soil N-NO_3 at sowing described grain yield variations with high accuracy ($R^2 = 0.93$). Another best model (Model B) showed that soil type as additional variable affected significantly yield response to applied N. The final model indicated that the overall response across sites was characterized by a linear coefficient of 67 kg grain ha^{-1} per additional kg N ha^{-1} applied and a quadratic coefficient of −0.37 kg grain ha^{-1} per additional kg N ha^{-1} applied. Across all sites, soil N-NO_3 at sowing (explored range from 34 to 356 kg N ha^{-1}) explained 46% of the variability in the linear yield response to applied N. We proposed a method and generated statistical models with site specific covariates that can help optimize farmers' decisions on the use of optimal N fertilizer rates.

Core Ideas

- We used linear mixed effects models to explore maize yield response to applied N.
- Final models accurately described the observed data ($R^2 = 0.93$).
- Best models indicated that yield response to applied N depended on soil N and soil type.
- Information is useful to optimize management decisions on N fertilizer rates.
- Resulting models are better than traditional ones based on ordinary least squares.

OPTIMIZING FERTILIZER rates is a common agricultural objective, currently aggravated by the negative environmental effects of excess fertilizer. The present challenge to increase yields while reducing the environmental impacts of agriculture (Foley et al., 2011) demands adequate response models for fertilizer applications. This is particularly true for N, a major plant nutrient.

The most widely used method for estimating N fertilizer needs is based on conducting so-called yield response trials. This method consists on applying a wide range of N rates in individual plots, measuring the yield at each applied N rate, and fitting a response model. Commonly used response models include a quadratic response, Mitscherlich curve, linear or quadratic responses followed by a plateau at high fertilizer rates, a logistic response, among others (Cerrato and Blackmer, 1990). All too often, individual plot yield data versus fertilizer rates from different sites and years are pooled together. The simple approach is to fit a response function to all the data using ordinary least squares (Monbiela et al., 1981; Saín and Jauregui, 1993; Pagani et al., 2008; Salvagiotti et al., 2011; Díaz Valdez et al., 2014). This provides a simple model for determining fertilizer rates at regional level.

Mentioned models, although widely used for their simplicity, have several limitations. When databases include large spatial and temporal variability, correlation coefficients are often low (Kim et al., 2008). This can be attributed to large variability in soil N supply, variable N losses related to mechanisms like leaching, volatilization, or denitrification, or yield limitations due to other factors like water availability, among others (Kyveryga et al., 2013). Typically, the easiest solution is to subjectively remove extreme data or extreme response trials, reducing the possibility to find any rational explanation for those particular cases. This increases the uncertainty to N recommendations.

These models also have important statistical limitations, as they ignore the correlations that probably exist between the responses of different plots at the same site or within the same year (Wallach, 1995). Ignoring assumptions might result in inefficient parameter estimators (Zuur et al., 2009). Mixed-effects models (also called hierarchical or multilevel models) are statistical tools to deal with these common limitations. However,

Published in Agron. J. 110:1–10 (2018)
doi:10.2134/agronj2017.09.0520
Supplemental material available online

T. Coyos, AAPRESID, Asociación Argentina de Productores en Siembra Directa, Dorrego 1639, CP 2000, Rosario, Santa Fe, Argentina; L. Borrás, B.L. Gambin, Instituto de Investigaciones en Ciencias Agrarias de Rosario (IICAR, CONICET), Campo Experimental Villarino S/N, S2125ZAA, Zavalla, Santa Fe, Argentina. Received 7 Sept. 2017. Accepted 18 Feb. 2018. *Corresponding author (bgambin@unr.edu.ar; gambin@iicar-conicet.gob.ar).

Abbreviations: AIC, Akaike's information criterion; PCV, proportional change in variance; REML, restricted maximum likelihood.

Variables que afectan la respuesta del rendimiento al agregado de N en maís tardío.

Pedir copia a:
lborras@unr.edu.ar

Coyos et al.
Agronomy Journal
2018.

Crop Ecology & Physiology

Genotypic Differences among Argentinean Maize Hybrids in Yield Response to Stand Density

Fernando Hernández, Agustina Amelong, and Lucas Borrás*

ABSTRACT

Maize (*Zea mays* L.) stand density selection is an important management practice because yield is maximized at a particular optimum value. Optimum stand density (OSD) varies across environments, and many have argued that current commercial genotypes differ in their optimum stand density for a similar environment. We tested this concept by planting 11 Argentinean commercial genotypes from four seed companies at a range of stand densities (1, 8, and 16 plants m^{-2}) in two environments. Genotypes differed in their yield response to changes in stand density, and their OSD varied from 7.3 to 11.9 plants m^{-2}. Yield of tested genotypes was similar at the lowest stand density but different at the highest density, indicating no differences in potential yield per plant but significant differences in crowding tolerance. When using a crop growth and biomass partitioning framework for understanding kernel set differences among genotypes in their response to stand density, hybrids differed in most measured traits, showing differential strategies for coping with stress tolerance. Under high stand density conditions, genotypic strategies for avoiding barrenness were key for hybrid tolerance to crowding stress. We conclude that stand density management needs to take into account not only the environment but also the specific genotype, especially under high density management systems.

Maize grain yield has a parabolic response to stand density changes, and there is an optimum stand density that maximizes yield (Echarte et al., 2000; Sangoi et al., 2002; Sarlangue et al., 2007). This is widely known by crop managers, physiologists, and breeders; together with the concept that this optimum stand density varies with the environment (e.g., N and water availability). Better environments have maximum yields at higher stand densities (Al-Kaisi and Yin, 2003). This creates a need to decide which stand density is needed at each environment (Reeves and Cox, 2013; Van Roekel and Coulter, 2011, 2012; Robles et al., 2012). Recently, however, many have argued that stand density management also needs to consider the specific genotype because commercial hybrids differ in their optimum stand density for similar environments (Sarlangue et al., 2007).

Maize grain yield response to stand density changes is usually dissected in two components, potential yield per plant and tolerance to crowding stress. The last component has been successfully enhanced by breeding and is responsible for most yield improvements (Russell, 1991; Tollenaar and Wu, 1999; Duvick and Cassman, 1999; Sangoi et al., 2002; Duvick et al., 2004; Tokatlidis and Koutroubas, 2004; O'Neill et al., 2004). There is evidence that the first component, potential yield per plant, has increased (Ci et al., 2011; Luque et al., 2006) or not altered at all (Duvick and Cassman, 1999; Duvick et al., 2004; Tollenaar and Wu, 1999; Sangoi et al., 2002). It is accepted that greater crowding tolerance of modern genotypes allows using higher stand densities when compared to older ones (Tollenaar et al., 1994; Tollenaar and Wu, 1999; Duvick et al., 2004; Lee and Tollenaar, 2007). This has steadily increased the stand density farmers are using. Sarlangue et al. (2007) found differences in optimum stand density when current commercial genotypes with different canopy structure and maturity were compared, short-season hybrids showed reduced plant size and higher optimum stand densities.

At the individual plant level yield is mostly correlated to changes in kernel number per plant (KNP; Andrade et al., 1999; Vega et al., 2001). The number of established kernels depends on the accumulation of ear biomass (EB) around the flowering period and in the efficiency this biomass is used for setting kernels (Fig. 1A). The accumulation of EB depends on total plant growth (plant growth rate around flowering, PGR; Otegui and Bonhomme, 1998; Andrade et al., 1999) and in the partitioning of this plant biomass to the developing ear (Vega et al., 2001; Echarte et al., 2004; Fig. 1B).

Facultad de Ciencias Agrarias, Universidad Nacional de Rosario, S2125ZAA Zavalla, Prov. de Santa Fe, Argentina. Received 6 Apr. 2014). *Corresponding author (lborras@unr.edu.ar).

Published in Agron. J. 106:2316–2324 (2014)
doi:10.2134/agronj14.0183

Abbreviations: C_{EB}, curvature of ear biomass accumulated at 15 days after anthesis vs. plant growth rate around flowering; C_{KN}, curvature of kernel number per plant vs. ear biomass accumulated at 15 days after anthesis; CVPGR, coefficient of variation of plant growth rate around flowering; EB, ear biomass accumulated at 15 days after anthesis; IS_{EB}, initial slope of plant growth rate around flowering vs. ear biomass accumulated at 15 days after anthesis; IS_{KN}, initial slope of kernel number per plant vs. ear biomass accumulated at 15 days after anthesis; KNP, kernel number per plant; OSD, optimum stand density; PGR, plant growth rate around flowering; PGR_b, base plant growth rate for ear biomass accumulation.

Interacciones genotipo x densidad y diferencias en densidad óptima en genotipos comerciales Argentinos.

Pedir copia a:
lborras@unr.edu.ar

Hernández et al.
Agronomy Journal
2014.