Integrated management of **Aphanomyces and Fusarium root rot** in field peas: (3) Impact of crop rotation

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in collaboration with John Rickertsen, NDSU Hettinger Research Extension Center

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FUSARIUM

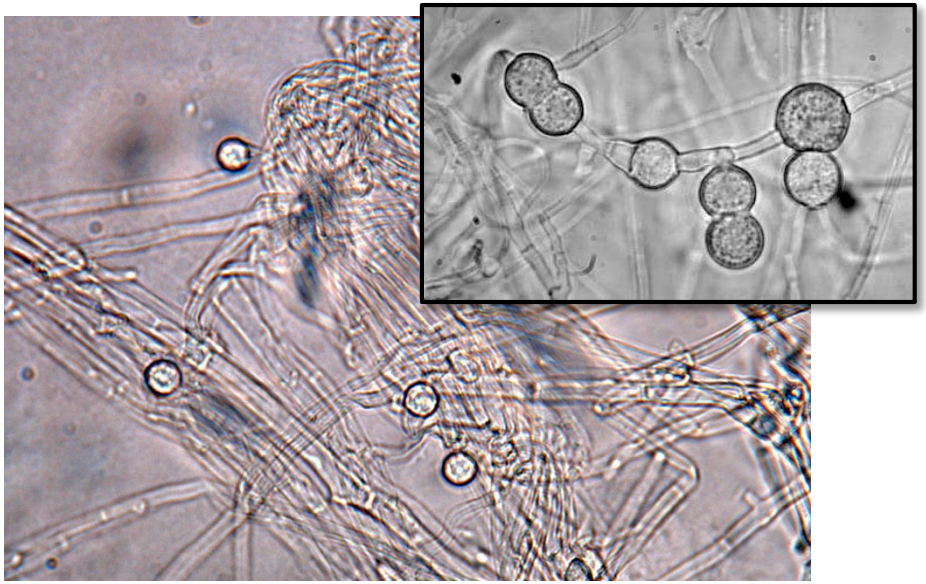
- Reddish-brown to black necrosis

APHANOMYCES

- Diseased tissue initially yellow-brown; later, necrotic
- Cortex often sloughs off when plant is pulled

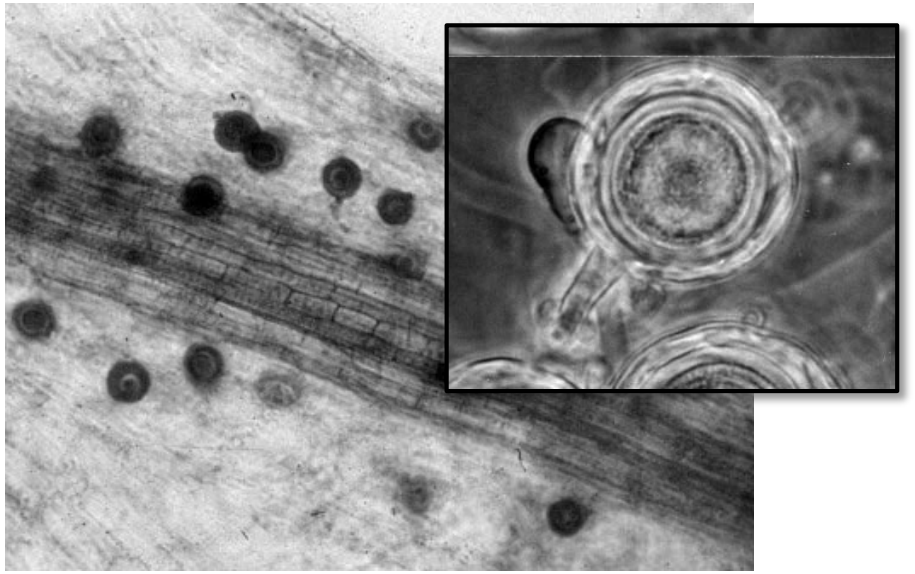
Healthy (left) and diseased (right) lentils (lentil picture courtesy L. Porter, USDA-ARS)

FUSARIUM



- True fungus
- Produces long-term resting structure called ‘chlamydospore’

APHANOMYCES



- A water mold (“oomycete” pathogen)
- Produces long-term resting structure called ‘oospore’

Aphanomyces and Fusarium root rot of field peas:
Long-term crop rotation studies

Research methods:

Study design:

Randomized studies with six replicates (randomized complete block design)

Plots 30 ft x 60 ft at planting, 20 ft x 60 ft at harvest

Row spacing = 7.5 inches

Seeding rate = 330,000 viable seeds/ac

Zero tillage.

- Carrington: zero tillage since the start of the study in 2014
- Hettinger: long-term no-till prior to the start of the study in 2014

Data collection:

Root rot: assessed at early to mid vegetative growth (4-10 nodes) in Carrington and at bloom initiation in Hettinger. The percent of the epicotyl + top 2.5 cm of the tap root diseased; assessed on minimum 50 roots/plot. Roots were collected from a minimum 6 locations per plot outside of the area assessed for yield. Yield was assessed in the middle 20 feet of each 30-foot wide plot. Roots were dug from the first and last 5 feet of the 30-foot width.

Yield: moisture was assessed at harvest and yields are reported at a standard 13.5% moisture

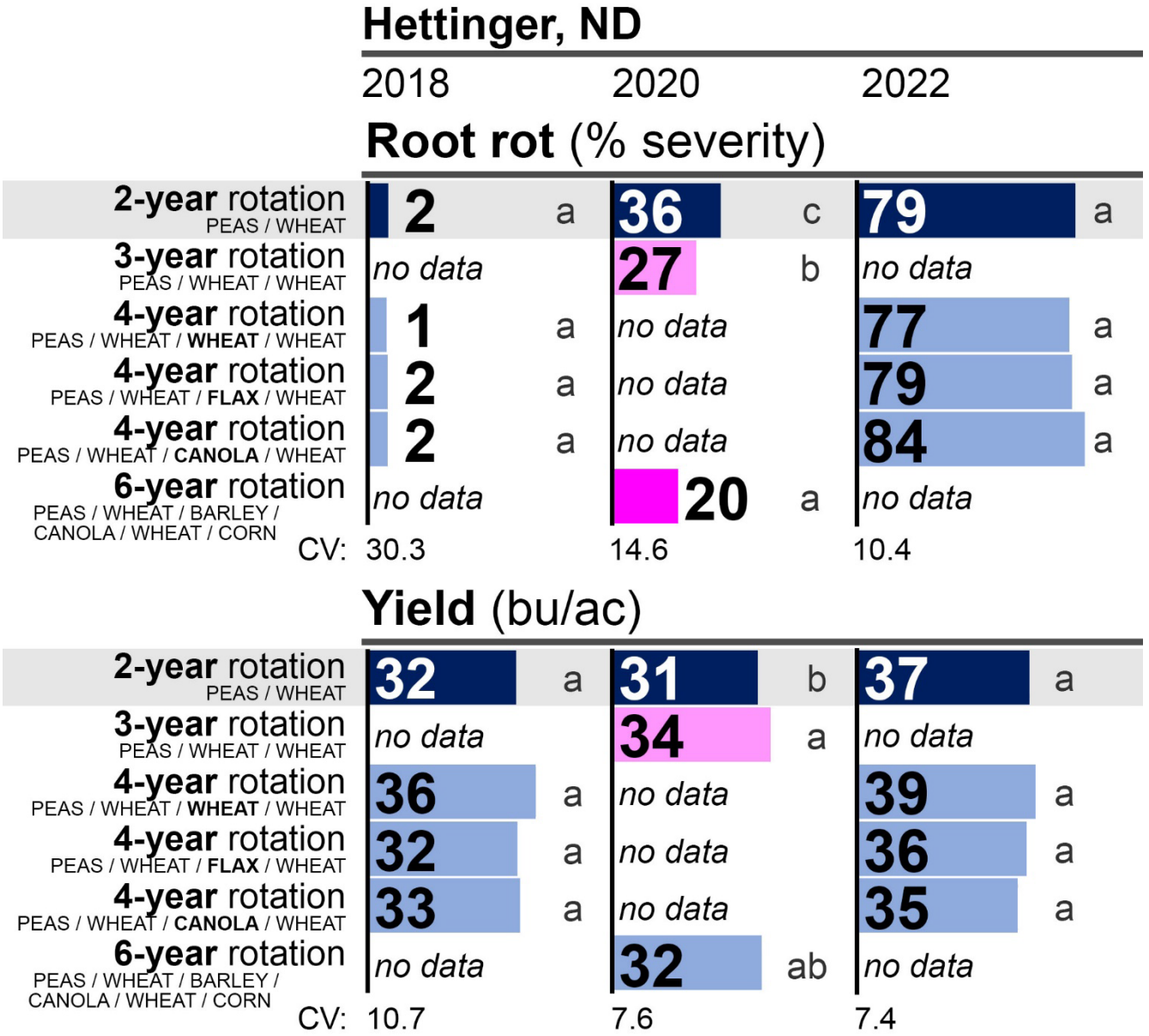
Aphanomyces and Fusarium root rot of field peas: Long-term crop rotation studies

(1) **Field with no prior history of field pea or lentil production** and no problems with pea or lentil root rot when this project was initiated in 2014

HETTINGER:

Use of a 6-year but not a 4-year rotation conferred reductions in root rot.

Root rot pressure was insufficient in 2020 (when 6-year rotation was evaluated) to impact yield.



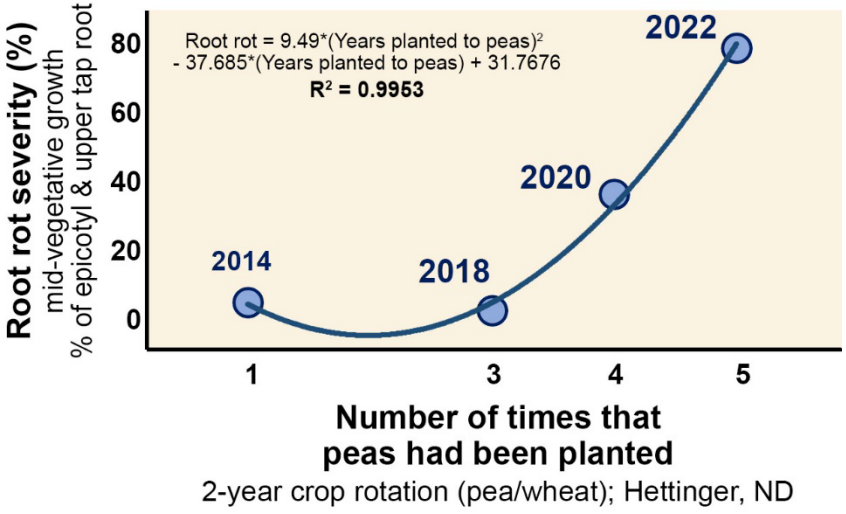
Within-column means followed by different letters are significantly different ($P < 0.05$; Tukey multiple comparison procedure).

Aphanomyces and Fusarium root rot of field peas: Long-term crop rotation studies

(1) **Field with no prior history of field pea or lentil production**
and no problems with pea or lentil root rot when this project was initiated in 2014

HETTINGER:

Root rot severity increased with the number of times peas were seeded to the field.



2-year crop rotation (pea/wheat); Hettinger, ND

Hettinger, ND

Root rot (% severity)

	2018		2020		2022	
2-year rotation PEAS / WHEAT	2	a	36	c	79	a
3-year rotation PEAS / WHEAT / WHEAT	no data		27	b	no data	
4-year rotation PEAS / WHEAT / **WHEAT** / WHEAT	1	a	no data		77	a
4-year rotation PEAS / WHEAT / **FLAX** / WHEAT	2	a	no data		79	a
4-year rotation PEAS / WHEAT / **CANOLA** / WHEAT	2	a	no data		84	a
6-year rotation PEAS / WHEAT / BARLEY / CANOLA / WHEAT / CORN	no data		20	a	no data	
CV:	30.3		14.6		10.4	

Yield (bu/ac)

	2018		2020		2022	
2-year rotation PEAS / WHEAT	32	a	31	b	37	a
3-year rotation PEAS / WHEAT / WHEAT	no data		34	a	no data	
4-year rotation PEAS / WHEAT / **WHEAT** / WHEAT	36	a	no data		39	a
4-year rotation PEAS / WHEAT / **FLAX** / WHEAT	32	a	no data		36	a
4-year rotation PEAS / WHEAT / **CANOLA** / WHEAT	33	a	no data		35	a
6-year rotation PEAS / WHEAT / BARLEY / CANOLA / WHEAT / CORN	no data		32	ab	no data	
CV:	10.7		7.6		7.4	

(1) **Field with no prior history of field pea or lentil production**
and no problems with pea or lentil root rot when this project was initiated in 2014

The results suggest that a 6-year crop rotation may help reduce the buildup of root rot.

- Confirmation will come in the 14th year of this study when peas will be planted to all of the rotation treatments (2- 3-, 4-, and 6-year rotations)

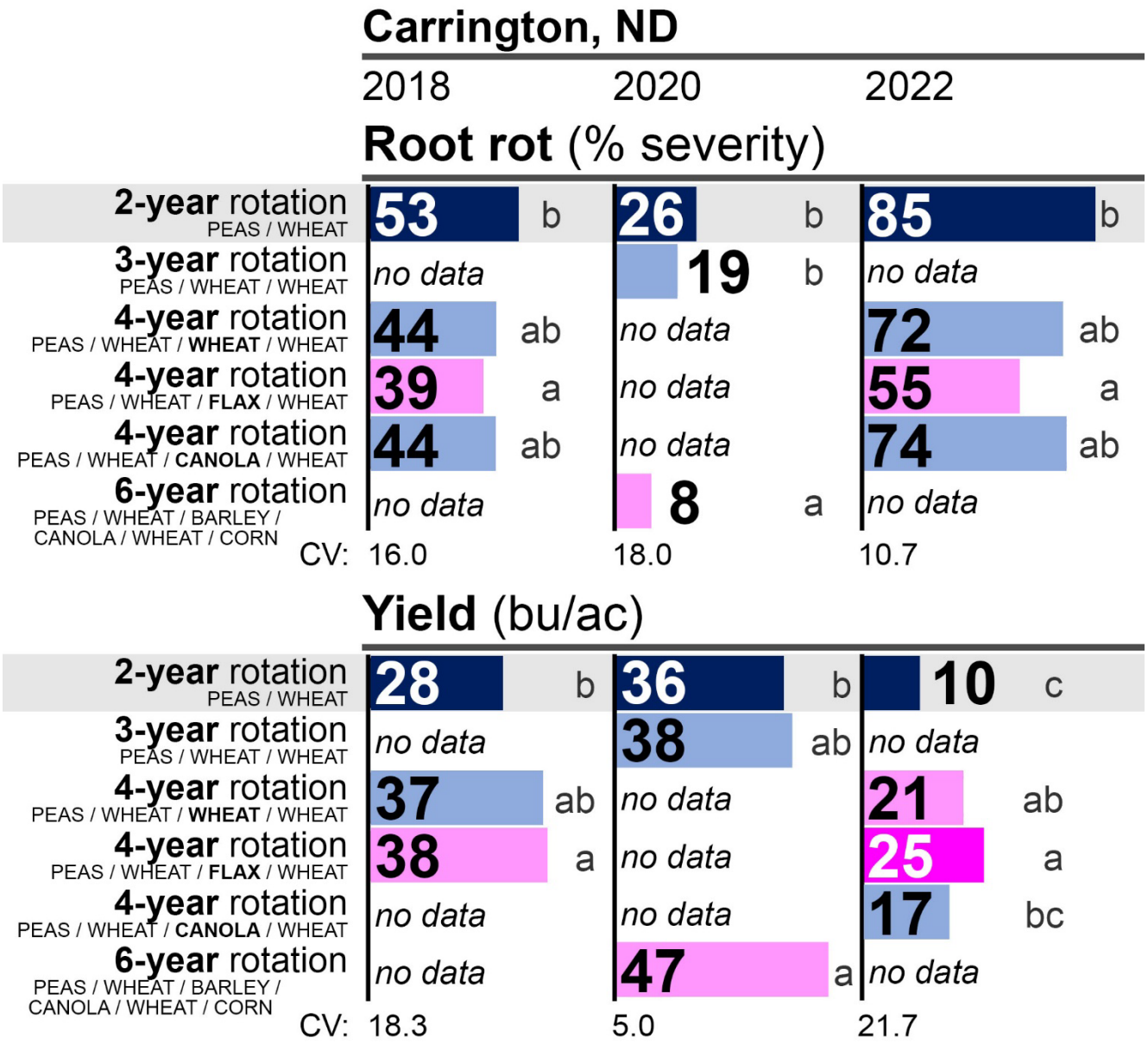
Aphanomyces and Fusarium root rot of field peas: Long-term crop rotation studies

(2) **Field with a long history of field pea production**
and elevated root rot pressure in field peas when this project was initiated in 2014

CARRINGTON:

Use of a 6-year rotation conferred reductions in root rot and commercially acceptable yields.

The 4-year rotation with wheat and flax conferred reductions in root rot, but yields were not acceptable.



Data represent the average of non-treated and fungicide-treated seed.

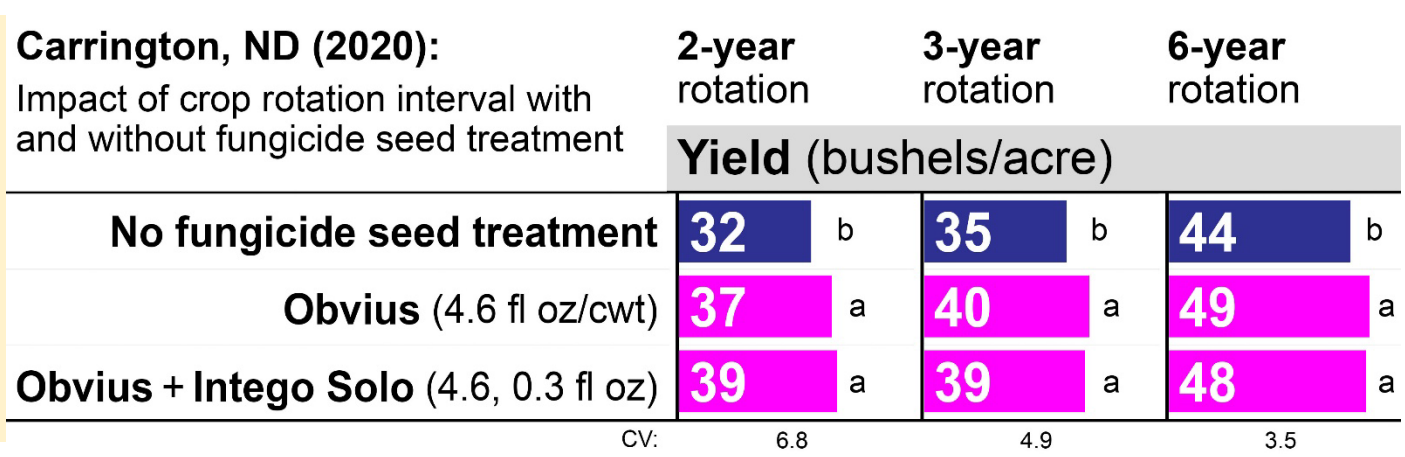
Within-column means followed by different letters are significantly different ($P < 0.05$; Tukey multiple comparison procedure).

Aphanomyces and Fusarium root rot of field peas: Long-term crop rotation studies

(2) **Field with a long history of field pea production**
and elevated root rot pressure in field peas when this project was initiated in 2014

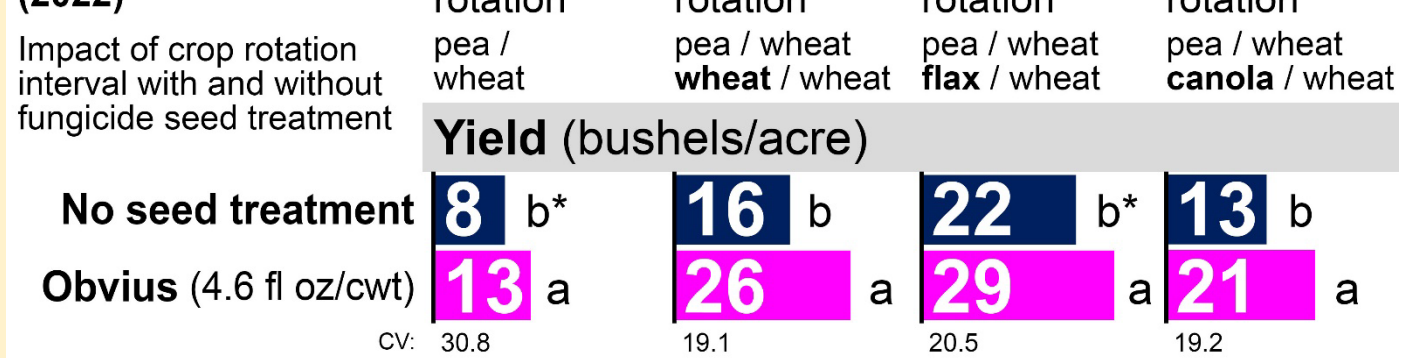
The combined use of **fungicide seed treatment** and **6-year rotation** conferred a 13 to 14 bushel yield increase.

Carrington, ND (2020):
Impact of crop rotation interval with and without fungicide seed treatment



Seed treatment conferred a 7 to 10 bushel yield increase in 4-year rotations but yields were still unacceptable.

Carrington, ND (2022)
Impact of crop rotation interval with and without fungicide seed treatment



The insecticide imidacloprid (Gaucho, 1.6 fl oz/cwt) was applied with the fungicide seed treatment, but no insect pest pressure was observed.

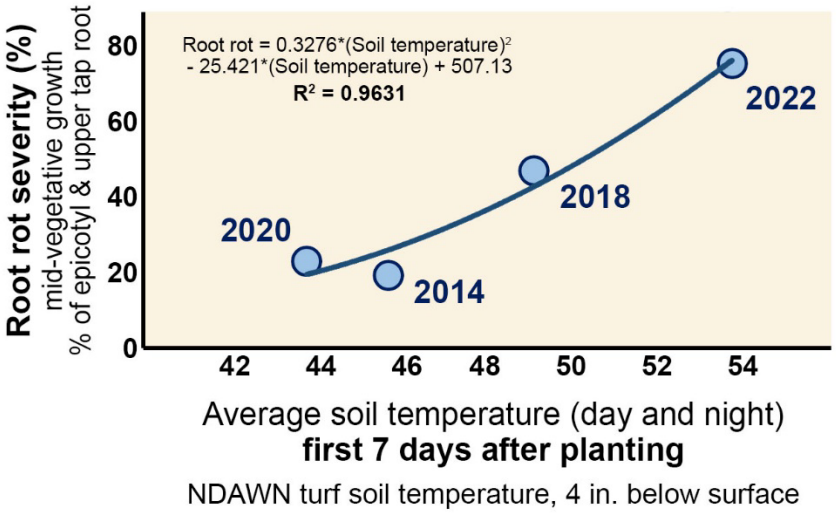
Within-column means followed by different letters are significantly different ($P < 0.05$; Tukey multiple comparison procedure) or ($P < 0.10$) when an asterisk follows one of the letters.

Aphanomyces and Fusarium root rot of field peas: Long-term crop rotation studies

(2) **Field with a long history of field pea production**
and elevated root rot pressure in field peas when this project was initiated in 2014

CARRINGTON:

Root rot severity was closely correlated to soil temperatures in the 7 days after planting.



Carrington, ND

Root rot (% severity)

	2018		2020		2022	
2-year rotation PEAS / WHEAT	53	b	26	b	85	b
3-year rotation PEAS / WHEAT / WHEAT	no data		19	b	no data	
4-year rotation PEAS / WHEAT / **WHEAT** / WHEAT	44	ab	no data		72	ab
4-year rotation PEAS / WHEAT / **FLAX** / WHEAT	39	a	no data		55	a
4-year rotation PEAS / WHEAT / **CANOLA** / WHEAT	44	ab	no data		74	ab
6-year rotation PEAS / WHEAT / BARLEY / CANOLA / WHEAT / CORN	no data		8	a	no data	
CV:	16.0		18.0		10.7	

Yield (bu/ac)

	2018		2020		2022	
2-year rotation PEAS / WHEAT	28	b	36	b	10	c
3-year rotation PEAS / WHEAT / WHEAT	no data		38	ab	no data	
4-year rotation PEAS / WHEAT / **WHEAT** / WHEAT	37	ab	no data		21	ab
4-year rotation PEAS / WHEAT / **FLAX** / WHEAT	38	a	no data		25	a
4-year rotation PEAS / WHEAT / **CANOLA** / WHEAT	no data		no data		17	bc
6-year rotation PEAS / WHEAT / BARLEY / CANOLA / WHEAT / CORN	no data		47	a	no data	
CV:	18.3		5.0		21.7	

Data represent the average of non-treated and fungicide-treated seed.

Within-column means followed by different letters are significantly different ($P < 0.05$; Tukey multiple comparison procedure).

(2) **Field with a long history of field pea production**
and elevated root rot pressure in field peas when this project was initiated in 2014

The results suggest that satisfactory field pea yields can be achieved in fields with severe root rot pressure when a minimum 6-year crop rotation is combined with early planting and use of a fungicide seed treatment.

- Crop rotation, early planting, and fungicide seed treatment each confer partial management of root rot in field peas.
- The combined use of all three tools has an additive effect for root rot management.

Aphanomyces and Fusarium root rot of field peas: Planting date studies conducted across fields **differing** in the **interval since peas were last grown**

Research methods:

Randomized studies with six replicates (randomized complete block with a split-split-plot arrangement, main factor = plant date, sub-factor = variety, sub-sub-factor = seed treatment)

Plots 5 ft x 30 ft at planting, 5 ft x approx. 20 ft at harvest.

Plots consist of 7 rows, each 7.5 inches apart

Seeding rate = 330,000 viable seeds/ac.

Tillage: mixture of direct seeding into previous year's crop (7 studies/year) and full conventional tillage (4 studies/year).

Data collection:

Root rot: assessed at early to mid vegetative growth (4-10 nodes). The percent of the epicotyl + top 2.5 cm of the tap root diseased; assessed on 16, 36, or 50 roots/plot, depending on study and planting date. Half of the roots were collected from each plot end outside of the area assessed for yield.

Wilt: assessed at mid to late pod-fill. A visual estimate of the percent of the plants exhibiting root rot associated wilt symptoms. This was always assessed at a consistent growth stage across field pea varieties within each planting date.

Within each study, every effort was made to assess root rot and wilt at a consistent growth stage across every planting date and every field pea variety.

Yield: moisture was assessed at harvest and yields are reported at a standard 13.5% moisture

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Pathogen diagnostic testing

3 to 4 year rotation

2 to 3 years out of peas

Field:	Field 17	18 north	Field 1	Field Q9D	Average
Last year seeded to peas:	**2021**	**2020**	**2020**	**2020**	
Aphanomyces euteiches (thousand DNA copies/gram of root)					
AAC **Julius**	**13456**	**23709**	**10868**	**62634**	**27667**
AAC **Profit**	**37538**	**23453**	**112343**	**83690**	**64256**
Fusarium oxysporum (thousand DNA copies/gram of root)					
AAC **Julius**	**0**	**0**	**0**	**0**	**0**
AAC **Profit**	**0**	**0**	**0**	**0**	**0**
Fusarium avenaceum (thousand DNA copies/gram of root)					
AAC **Julius**	**92**	**66**	**64**	**244**	**116**
AAC **Profit**	**140**	**171**	**180**	**370**	**215**

Carrington, ND **(2024)**

Diagnostic qPCR testing conducted by the National Agriculture Genotyping Center. Results represent the average across nine qPCR tests per study (bulked samples across replicates 1 and 2, replicates 3 and 4, and replicates 5 and 6 from each of three planting dates). For all fields except 18south and 17, testing was conducted only on non-fungicide treated seed and each of the 9 tests for each variety in each study represents a combined sample of two 1-cm long epicotyl segments, one collected from each of the two experimental replicates bulked within that planting date. For fields 18south and 17, each of the 9 tests for each variety in each study represents the combined sample of 10 1-cm long epicotyl segments, one collected collected from each fungicide seed treatment (non-treated versus four different fungicide seed treatment) and two replicates. The 1-cm long epicotyl segments were collected from a plant with root rot symptoms typical of that plot.

5 to 6 year rotation

4 or 5 years out of peas

Field:	Field Q9A	Q9E west	Average
Last year seeded to peas:	**2019**	**2018**	
Aphanomyces euteiches (thousand DNA copies/gram of root)			
AAC **Julius**	**66052**	**92513**	**79283**
AAC **Profit**	**42345**	**56400**	**49372**
Fusarium oxysporum (thousand DNA copies/gram of root)			
AAC **Julius**	**0**	**0**	**0**
AAC **Profit**	**0**	**0**	**0**
Fusarium avenaceum (thousand DNA copies/gram of root)			
AAC **Julius**	**314**	**1119**	**717**
AAC **Profit**	**127**	**205**	**166**

8 to 11 year rotation

7 to 10 years out of peas

Field Q9F	18 south	Field Q9B	Q9E east	Field Q9G	Average
2016	**2015**	**2015**	**2015**	**2013**	
Aphanomyces euteiches					
3	**19479**	**29061**	**25648**	**21**	**14842**
1	**66357**	**29709**	**35824**	**2**	**26379**
Fusarium oxysporum					
0	**0**	**0**	**0**	**0**	**0**
0	**0**	**0**	**0**	**0**	**0**
Fusarium avenaceum					
1	**267**	**127**	**96**	**0**	**98**
0	**387**	**84**	**249**	**0**	**144**

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Vascular necrosis characteristic of *Fusarium oxysporum* wilt was observed only at low levels

Vascular necrosis

percent of plants with vascular discoloration typical of *F. oxysporum* wilt

	Field 17	Field 18 south	
planting date 1	5-6 nodes	4-5 nodes	
planting date 2	6-8 nodes	6-8 nodes	Combined analysis
planting date 3	7-9 nodes	~5-8 nodes	
AAC **IronHorse**	**1.8** ab	**1.1** a	**1.5** a
AAC **Julius**	**4.4** c	**1.9** a	**3.2** a
ND **Dawn**	**1.6** ab	**0.8** a	**1.2** a
Caphorn	**2.0** ab	**0.9** a	**1.5** a
AAC **Profit**	**3.1** bc	**1.3** a	**2.2** a
LG **Amigo**	**0.9** a	**1.2** a	**1.1** a
F, P>F:	7.01, < 0.0001	0.86, 0.5128	2.64, 0.1552
CV:	130.4	233.4	38.8

Fusarium spp. isolated from vascular tissues at low levels, suggesting low *F. oxysporum* wilt pressure

Fusarium vascular wilt microbiological assay

percent of stem sections with *Fusarium* spp. growing from vascular tissues

	Field 17	Field 18 south	
planting date 1	5-6 nodes	4-5 nodes	
planting date 2	6-8 nodes	6-8 nodes	Combined analysis
planting date 3	7-9 nodes	~5-8 nodes	
AAC **IronHorse**	**6**	**8**	**7** b
AAC **Julius**	**3**	**3**	**3** a
ND **Dawn**	**6**	**5**	**6** ab
Caphorn	**3**	**4**	**4** ab
AAC **Profit**	**3**	**3**	**3** ab
LG **Amigo**	**3**	**5**	**4** ab
F, P>F:			7.65, 0.0217
CV:			17.8

Symptoms characteristic of Fusarium root rot were at moderate severity

Fusarium root rot

% of epicotyl and top 1-inch of tap root with symptoms of Fusarium root rot

	Field 17	Field 18 south	
planting date 1	5-6 nodes	4-5 nodes	
planting date 2	6-8 nodes	6-8 nodes	Combined analysis
planting date 3	7-9 nodes	~5-8 nodes	
AAC **IronHorse**	**19** ab	**10** a	**14** ab
AAC **Julius**	**27** b	**19** b	**23** d
ND **Dawn**	**21** ab	**11** ab	**16** bc
Caphorn	**19** ab	**11** ab	**15** ab
AAC **Profit**	**24** ab	**15** ab	**19** cd
LG **Amigo**	**15** a	**9** a	**12** a
F, P>F:	3.52, 0.0066	3.03, 0.0166	35.70, 0.0006
CV:	58.4	67.5	5.7

Symptoms characteristic of Aphanomyces root rot were at very high severity

Aphanomyces root rot

% of epicotyl and top 1-in. of tap root with symptoms of Aphanomyces root rot

	Field 17	Field 18 south	
planting date 1	5-6 nodes	4-5 nodes	
planting date 2	6-8 nodes	6-8 nodes	Combined analysis
planting date 3	7-9 nodes	~5-8 nodes	
AAC **IronHorse**	**56** ab	**56** a	**56** ab
AAC **Julius**	**48** a	**48** a	**48** a
ND **Dawn**	**53** ab	**53** a	**53** ab
Caphorn	**51** ab	**52** a	**52** ab
AAC **Profit**	**52** ab	**50** a	**51** ab
LG **Amigo**	**62** b	**55** a	**59** b
F, P>F:	3.10, 0.0134	1.26, 0.2934	7.48, 0.0227
CV:	26.4	19.4	3.5

Pathogen diagnostic testing and disease symptom expression

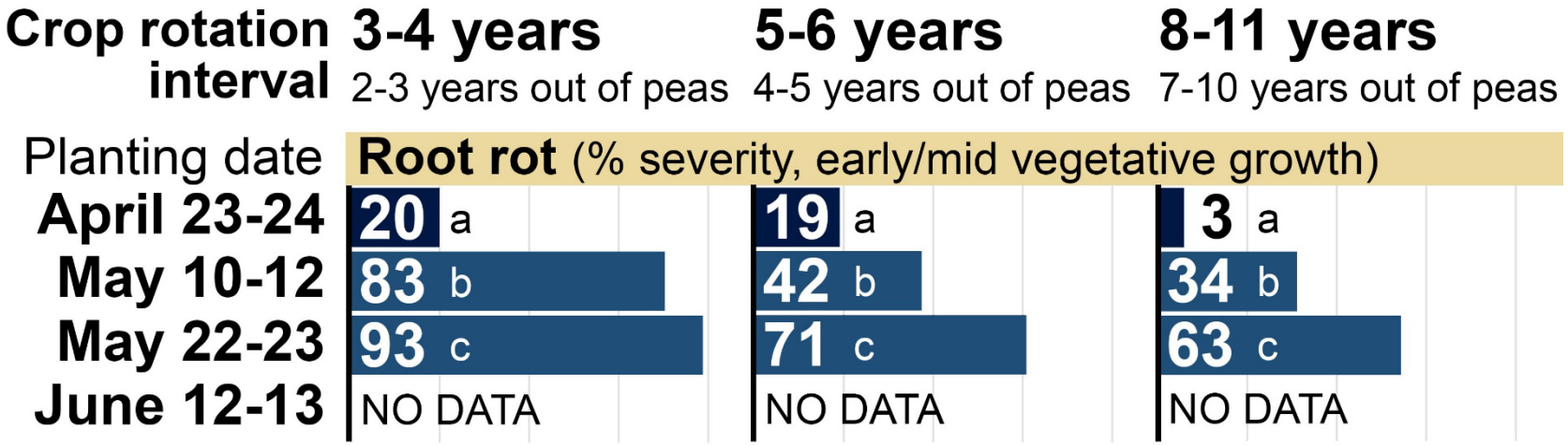
Carrington, ND (2024)

The pathogen diagnostic testing results and disease symptom assessments suggest that:

- Aphanomyces root rot, caused by *Aphanomyces euteiches,* was the predominant contributor to the observed root rot pressure and associated wilt symptoms.
- Fusarium root rot, caused by *Fusarium avenaceum* and presumably other Fusarium species, was a moderate contributor to the observed root rot pressure and associated wilt symptoms.
- Fusarium oxysporum wilt, caused by *F. oxysporum,* was not a significant contributor to the observed wilt symptoms.

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND (2024)

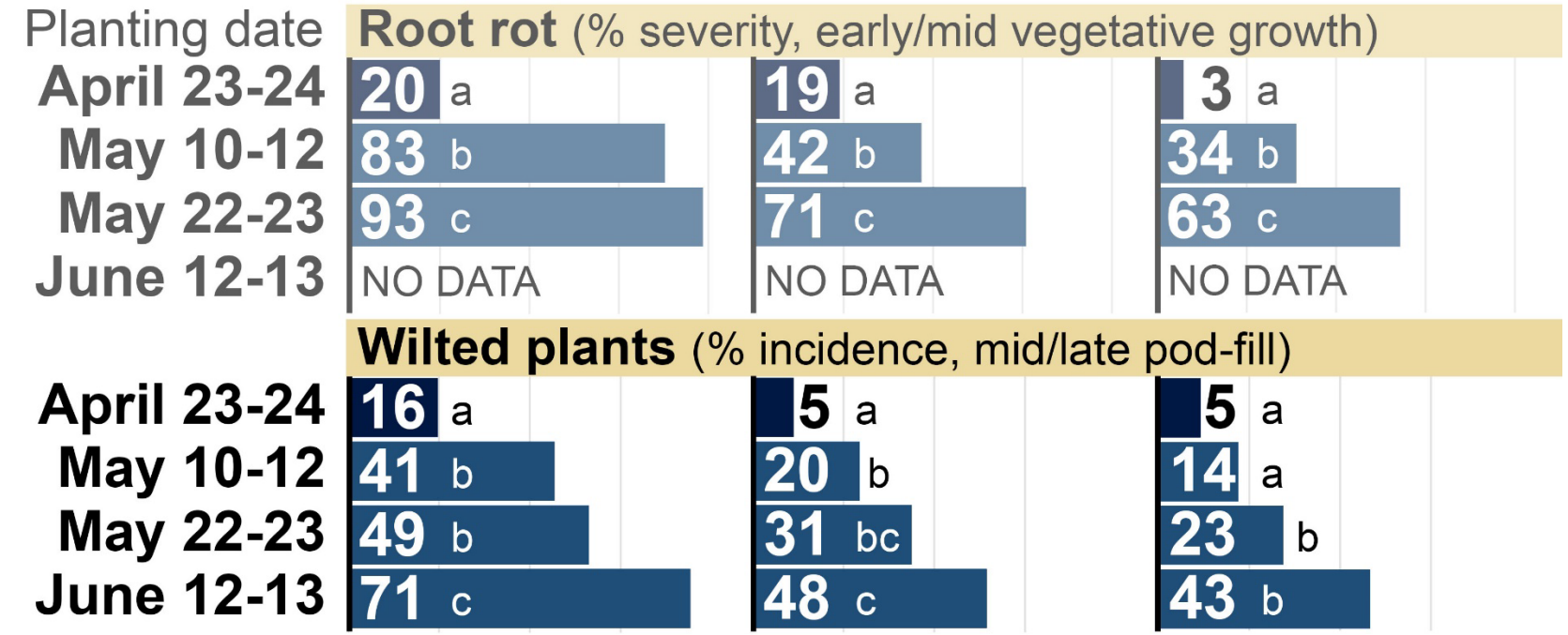


Average across two field pea varieties ('AAC Julius', 'AAC Profit' yellow peas) planted with or without fungicide seed treatment (Obvius, 4.6 fl oz/cwt). Seeding rate = 330,000 viable seeds/ac.

Combined analysis across 11 fields (4 fields with a 3-4 year rotation, 2 fields with a 5-6 year rotation, 5 fields with a 8-11 year rotation) in Carrington, ND (2024).

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND (2024)



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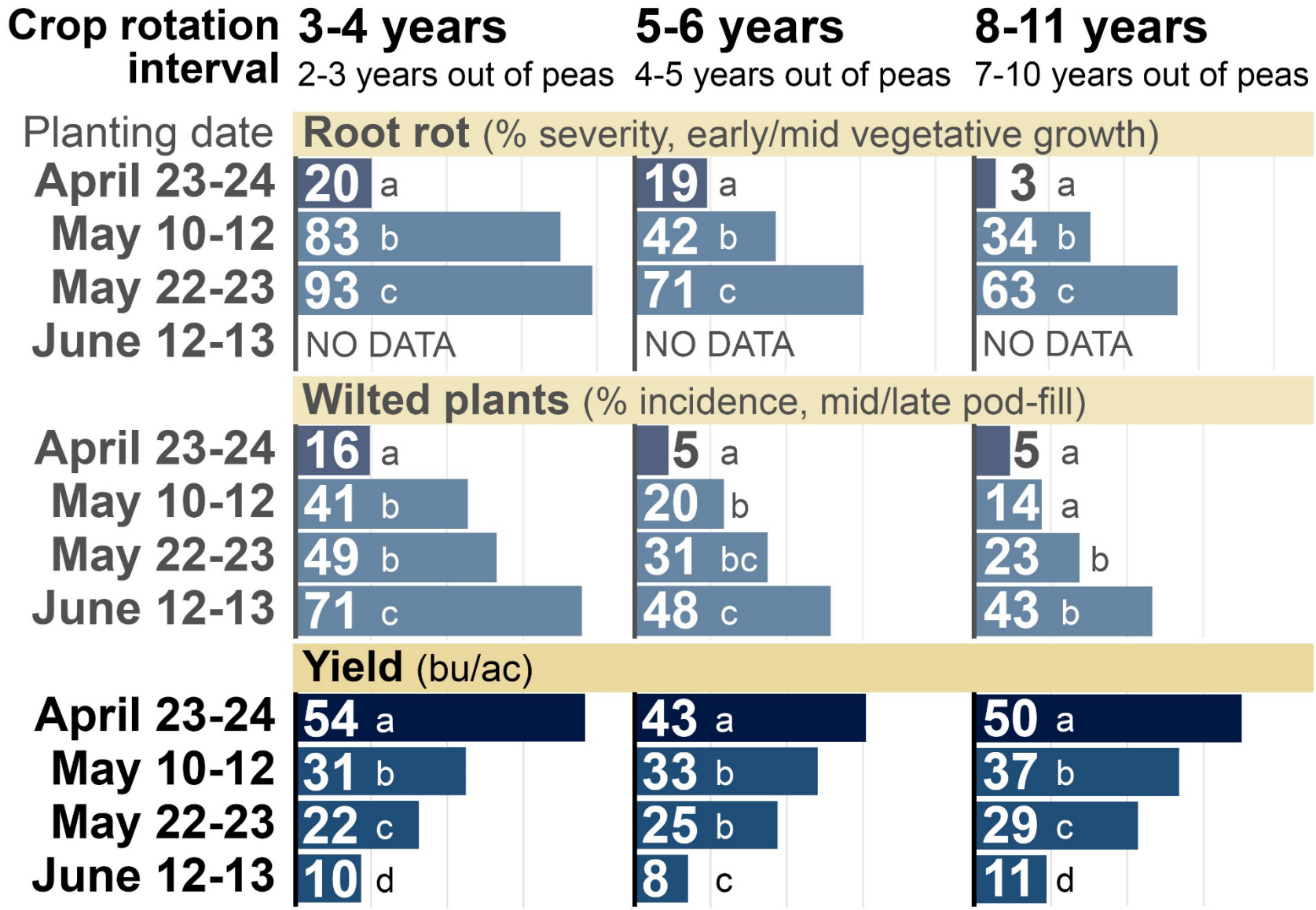
Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND (2024)



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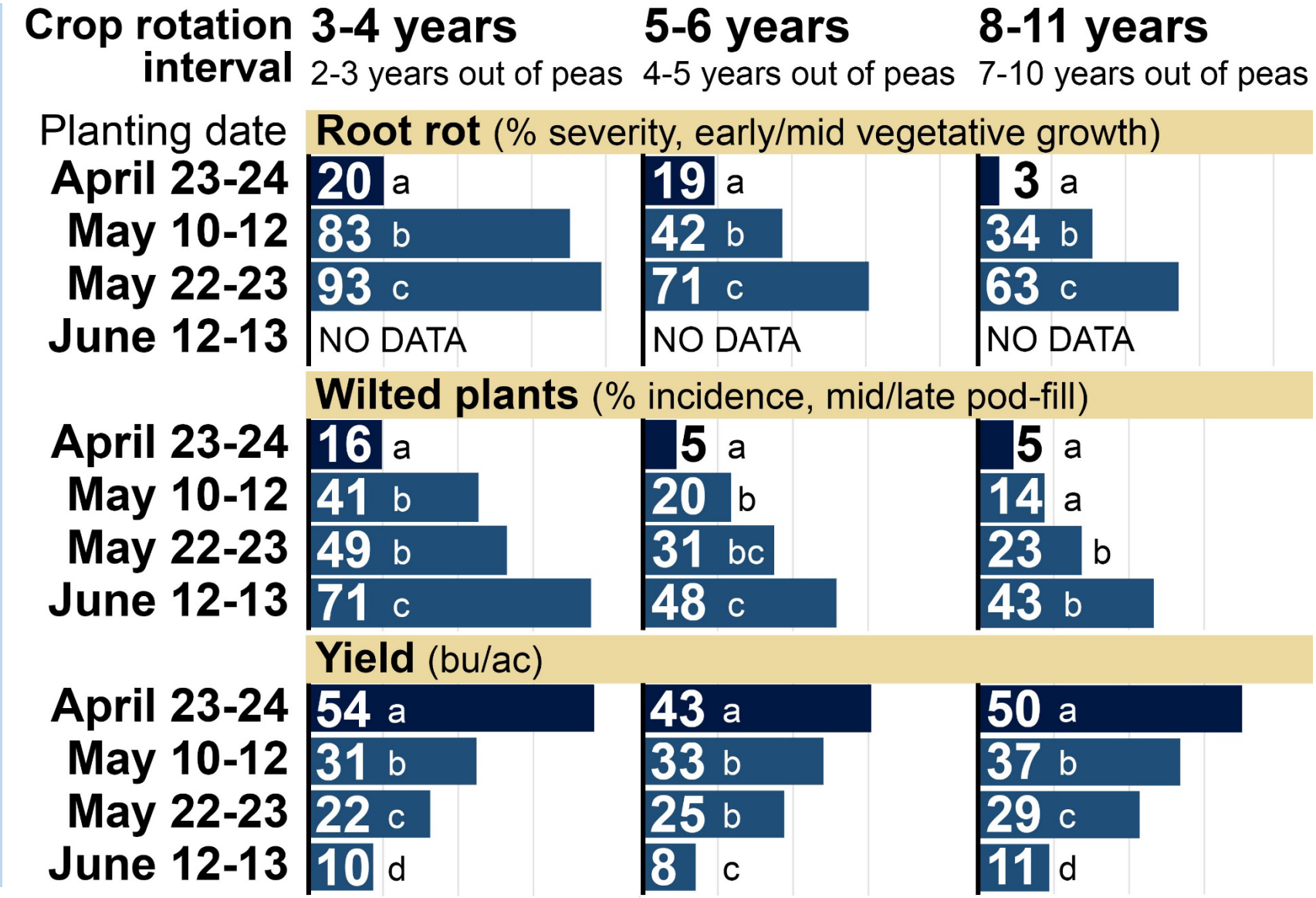
Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND (2024)



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Combined analysis across 11 fields (4 fields with a 3-4 year rotation, 2 fields with a 5-6 year rotation, 5 fields with a 8-11 year rotation) in Carrington, ND (2024).

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND **(2024)**

Circles represent the results from one study.

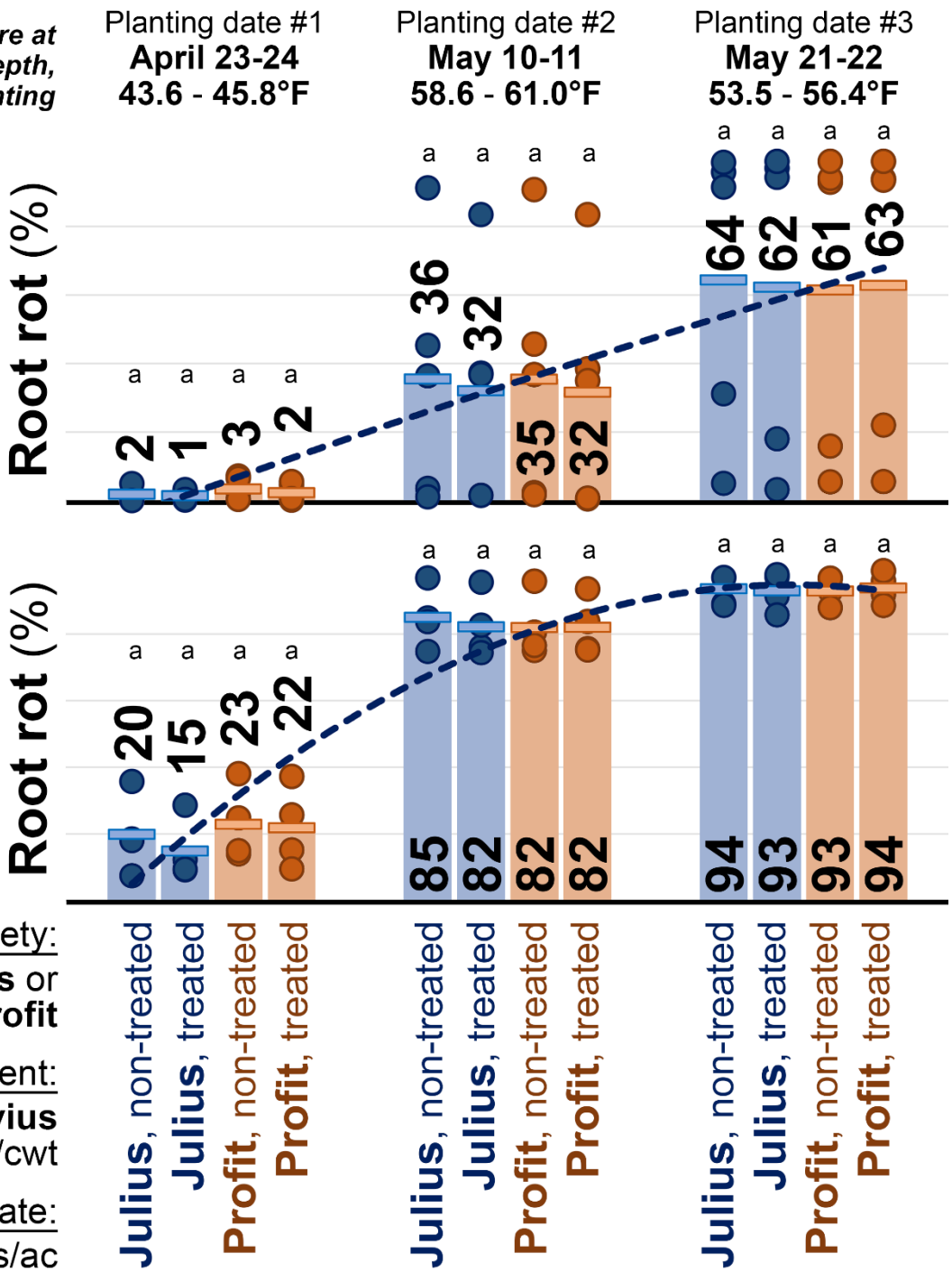
Bars represent the average across studies.

Letters denote statistical differences. Within each set of four bars representing the four variety/seed treatment combinations evaluated within each planting date, different letters denote statistically significant differences ($P < 0.05$).

8 to 11 year rotation: combined analysis across four studies.

3 to 4 year rotation: combined analysis across five studies.

Soil temperature at 2-inch seeding depth, first 7 days after planting



Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND **(2024)**

Circles represent the results from one study.

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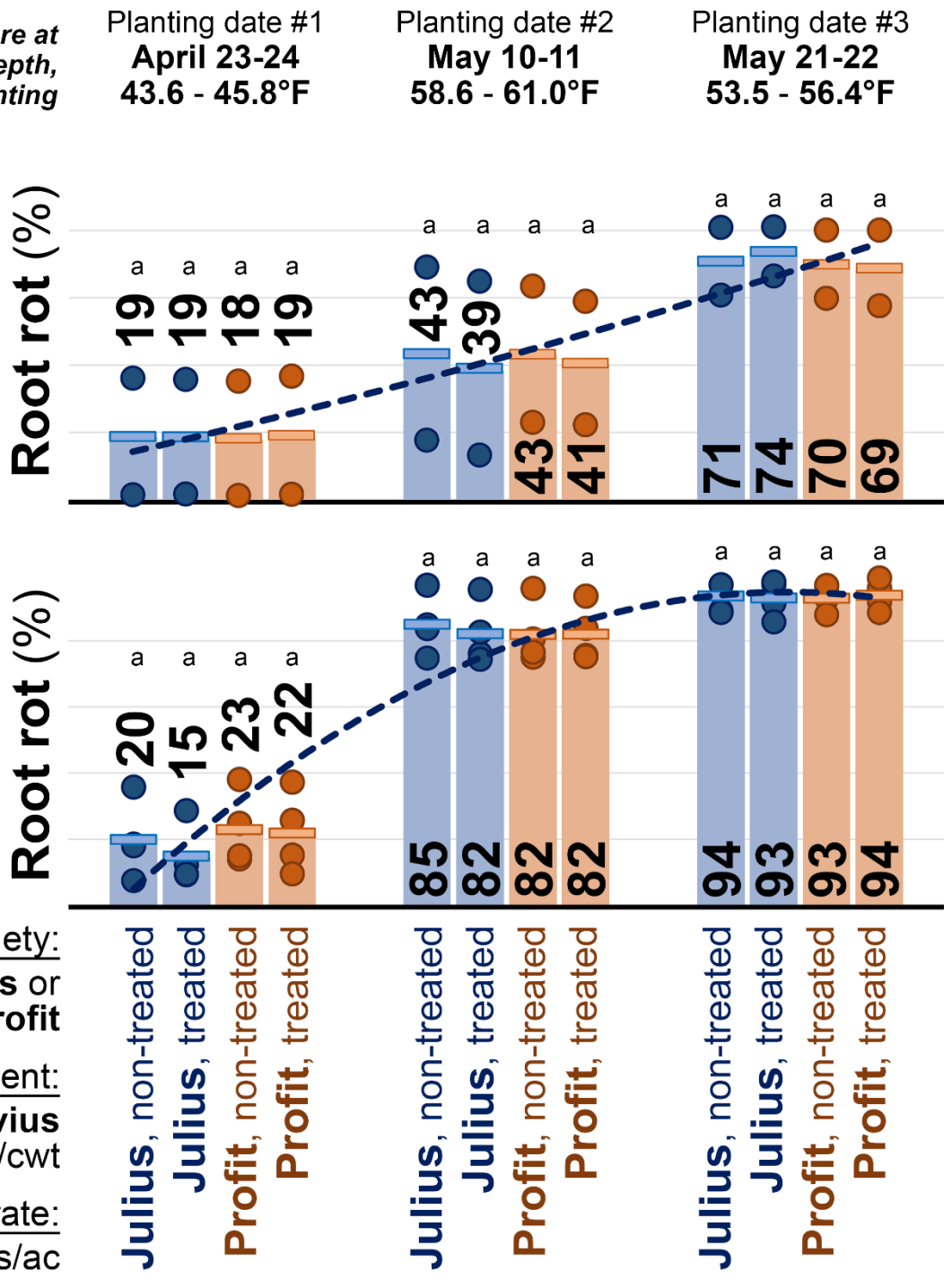
Letters denote statistical differences. Within each set of four bars representing the four variety/seed treatment combinations evaluated within each planting date, different letters denote statistically significant differences ($P < 0.05$).

5 to 6 year rotation: combined analysis across two studies.

3 to 4 year rotation: combined analysis across five studies.

Soil temperature at 2-inch seeding depth, first 7 days after planting



Field pea variety:
AAC Julius or **AAC Profit**

Seed treatment:
Obvius
4.6 fl oz/cwt

Seeding rate:
330,000 seeds/ac

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND
(2024)

Circles represent the results from one study.

Bars represent the average across studies.

Letters denote statistical differences. Within each set of four bars representing the four variety/seed treatment combinations evaluated within each planting date, different letters denote statistically significant differences ($P < 0.05$).

8 to 11 year rotation: combined analysis across four studies.

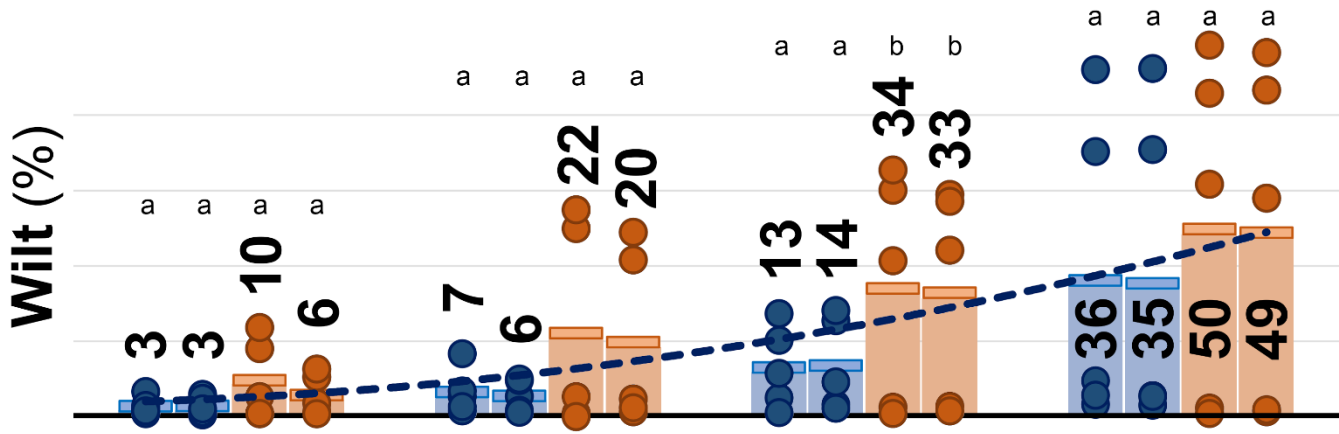
3 to 4 year rotation: combined analysis across five studies.

Soil temperature at 2-inch seeding depth, first 7 days after planting

Planting date #1	Planting date #2	Planting date #3	Planting date #4
April 23-24	**May 10-11**	**May 21-22**	**June 12-13**
43.6 - 45.8°F	**58.6 - 61.0°F**	**53.5 - 56.4°F**	**65.2 - 67.6°F**

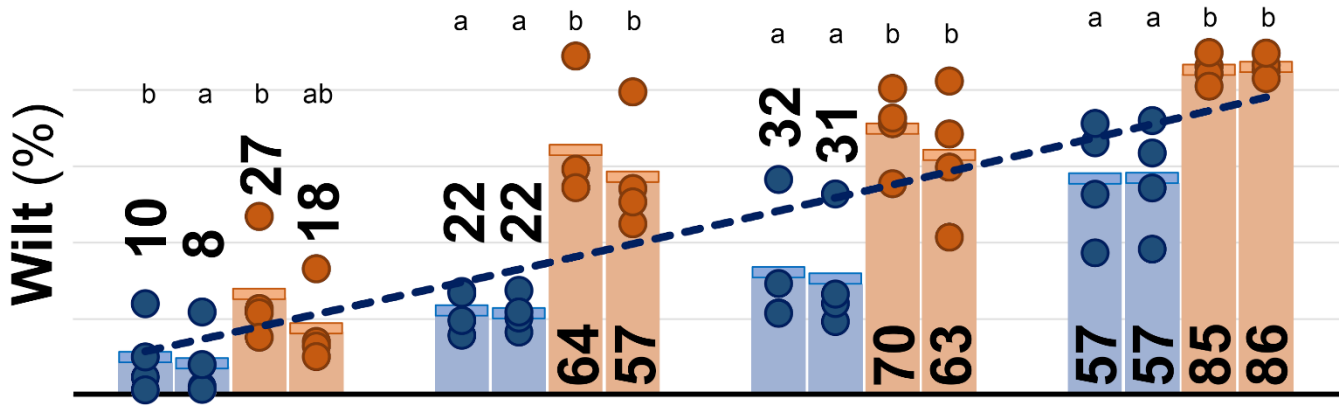
8-11 year rotation

7 to 10 years out of peas



3-4 year rotation

2 or 3 years out of peas



Field pea variety:
AAC Julius or **AAC Profit**

Seed treatment:
Obvius
4.6 fl oz/cwt

Seeding rate:
330,000 seeds/ac

Julius, non-treated
Julius, treated
Profit, non-treated
Profit, treated

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND
(2024)

Circles represent the results from one study.

Bars represent the average across studies.

Letters denote statistical differences. Within each set of four bars representing the four variety/seed treatment combinations evaluated within each planting date, different letters denote statistically significant differences ($P < 0.05$).

5 or 6 year rotation: combined analysis across two studies.

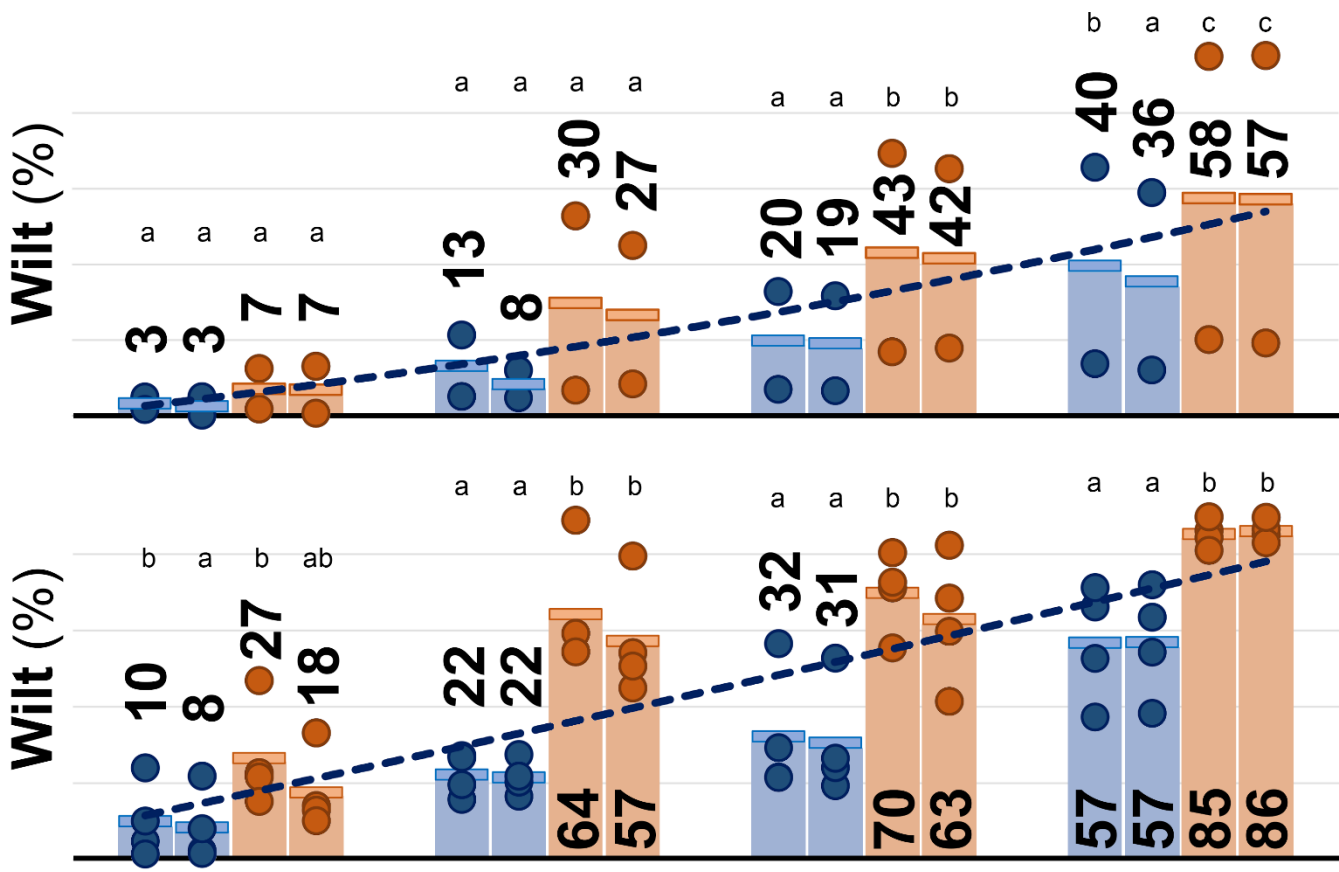
3 to 4 year rotation: combined analysis across five studies.

Soil temperature at 2-inch seeding depth, first 7 days after planting

Planting date #1	Planting date #2	Planting date #3	Planting date #4
April 23-24	**May 10-11**	**May 21-22**	**June 12-13**
43.6 - 45.8°F	**58.6 - 61.0°F**	**53.5 - 56.4°F**	**65.2 - 67.6°F**

5-6 year rotation

4 or 5 years out of peas



3-4 year rotation

2 or 3 years out of peas

Field pea variety:
AAC Julius or **AAC Profit**

Seed treatment:
Obvius
4.6 fl oz/cwt

Seeding rate:
330,000 seeds/ac

Julius, non-treated
Julius, treated
Profit, non-treated
Profit, treated

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND
(2024)

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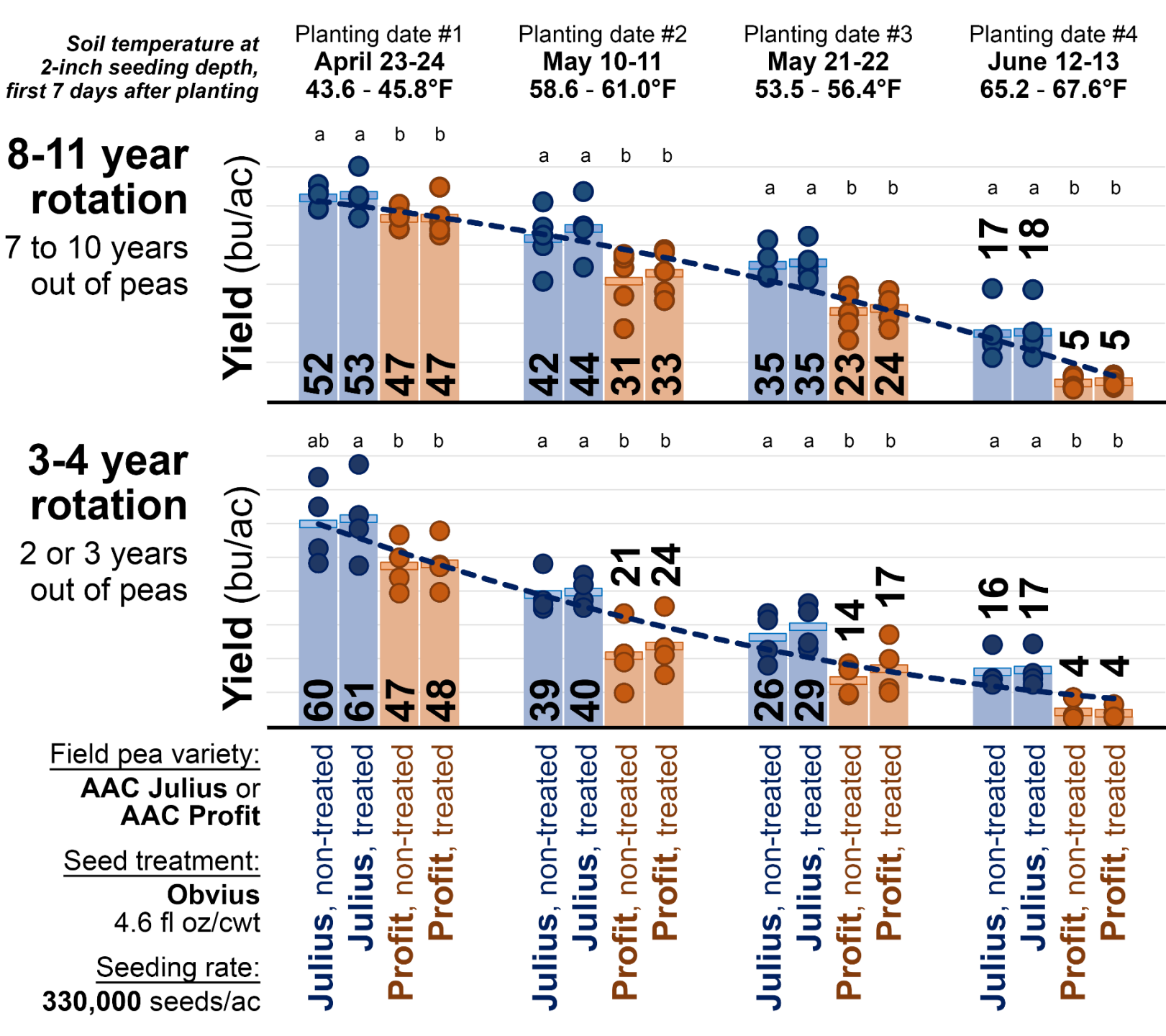
8 to 11 year rotation: combined analysis across four studies.

3 to 4 year rotation: combined analysis across five studies.



Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND
(2024)

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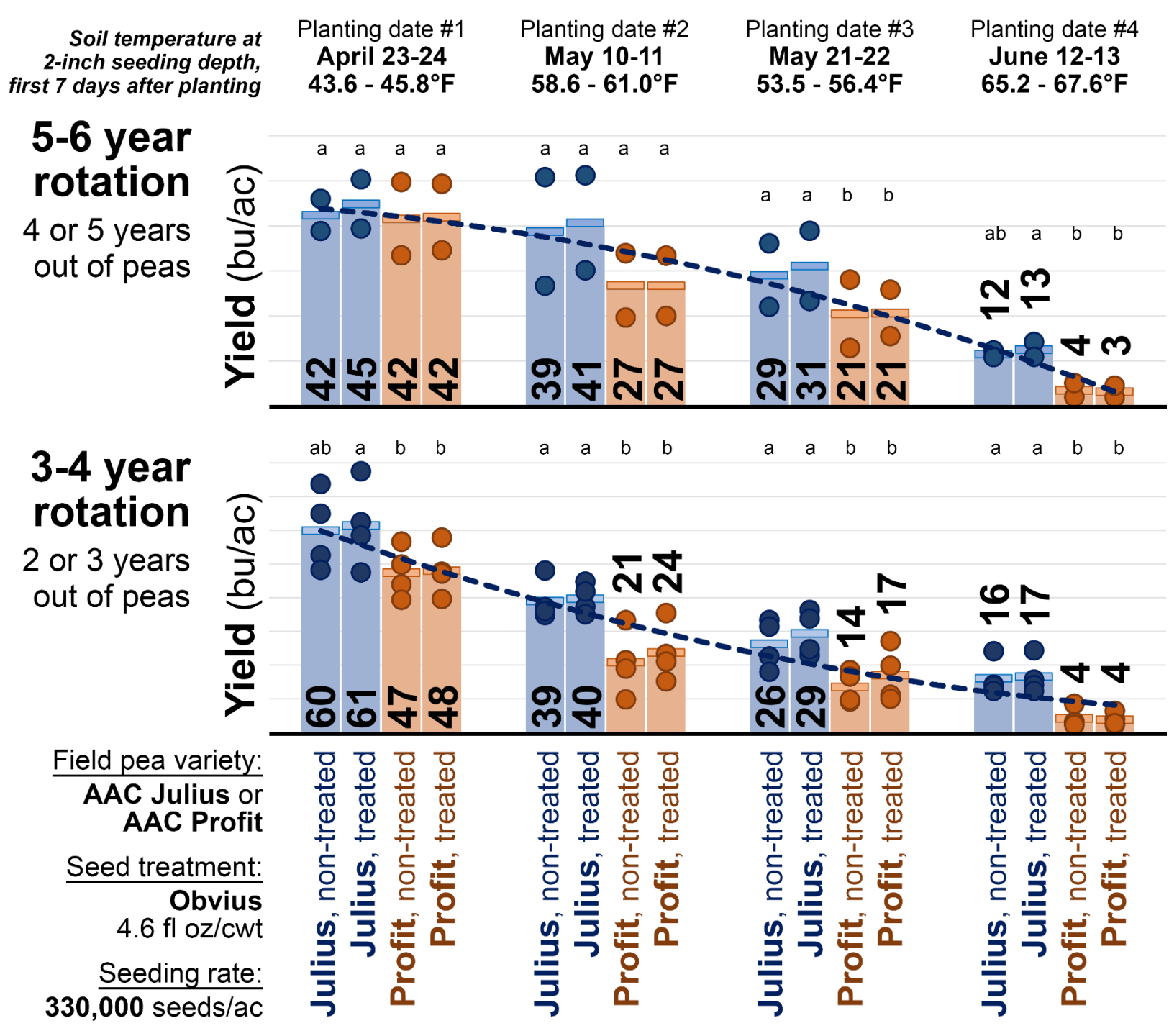
Bars represent the average across studies.

Letters denote statistical differences. Within each set of four bars representing the four variety/seed treatment combinations evaluated within each planting date, different letters denote statistically significant differences ($P < 0.05$).

5 or 6 year rotation: combined analysis across two studies.

3 to 4 year rotation: combined analysis across five studies.



Planting date studies conducted **across fields differing in crop rotation interval**
Carrington, ND (2024)

For fields with elevated Aphanomyces root rot pressure, the results suggest:

- When crop rotations are tight, field pea variety selection and planting date are critically important for achieving commercially acceptable field pea yields.
- A minimum five- to six-year rotation may confer flexibility with field pea variety selection when planting early.
- A minimum five- to six-year rotation may confer moderate flexibility with planting date (up to 2 to 2.5 weeks after reaching target 43-49°F soil temperature) when planting an Aphanomyces tolerant variety.

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND (2023)

Diagnostic qPCR testing conducted by the National Agriculture Genotyping Center. Results represent the average across four qPCR tests per study (one per planting date). Each test represents a combined sample of six 1-cm long epicotyl segments, one collected from each of the six experimental replicates within each planting date. The 1-cm long epicotyl segments were collected from a plant with root rot symptoms typical of that plot. Testing was only conducted on plants grown from non-treated seed (no fungicide seed treatment).

Pathogen diagnostic testing — 3 to 4 year rotation

2 or 3 years out of peas

Field:	Field Q9D	F18 north	Field 1	F18 north	Field Q9A	Average
Last year seeded to peas:	2020	2020	2020	2019	2019	
Aphanomyces euteiches (thousand DNA copies/gram of root)						
AAC **Julius**	38558	16818	154627	10670	319	44198
AAC **Profit**	40581	10563	120633	957	47422	44031
Fusarium oxysporum (thousand DNA copies/gram of root)						
AAC **Julius**	0	1.9	0	0	5.0	1.4
AAC **Profit**	0	0	0	0	0	0
Fusarium avenaceum (thousand DNA copies/gram of root)						
AAC **Julius**	0	0	0	0	0	0
AAC **Profit**	0	0	0	0	0	0

Pathogen diagnostic testing — 5 to 7 year rotation

4 or 6 years out of peas

Field:	Q9E west	Field Q9F	Average
Last year seeded to peas:	2018	2016	
Aphanomyces euteiches (thousand DNA copies/gram of root)			
AAC **Julius**	17290	0	8645
AAC **Profit**	72670	0	36335
Fusarium oxysporum (thousand DNA copies/gram of root)			
AAC **Julius**	0	1.6	0.8
AAC **Profit**	0	0	0
Fusarium avenaceum (thousand DNA copies/gram of root)			
AAC **Julius**	0	0	0
AAC **Profit**	0	0	0

8 to 10 year rotation

7 to 9 years out of peas

Field Q9B	F18 south	Q9E east	Field Q9G	Average
2015	2015	2015	2013	
Aphanomyces euteiches				
47830	25260	10616	0	20926
37114	751	110068	0	36983
Fusarium oxysporum				
0	0	0	4.8	1.2
0	0	0	0	0
Fusarium avenaceum				
0	0	0	0	0
0	0	0	0	0

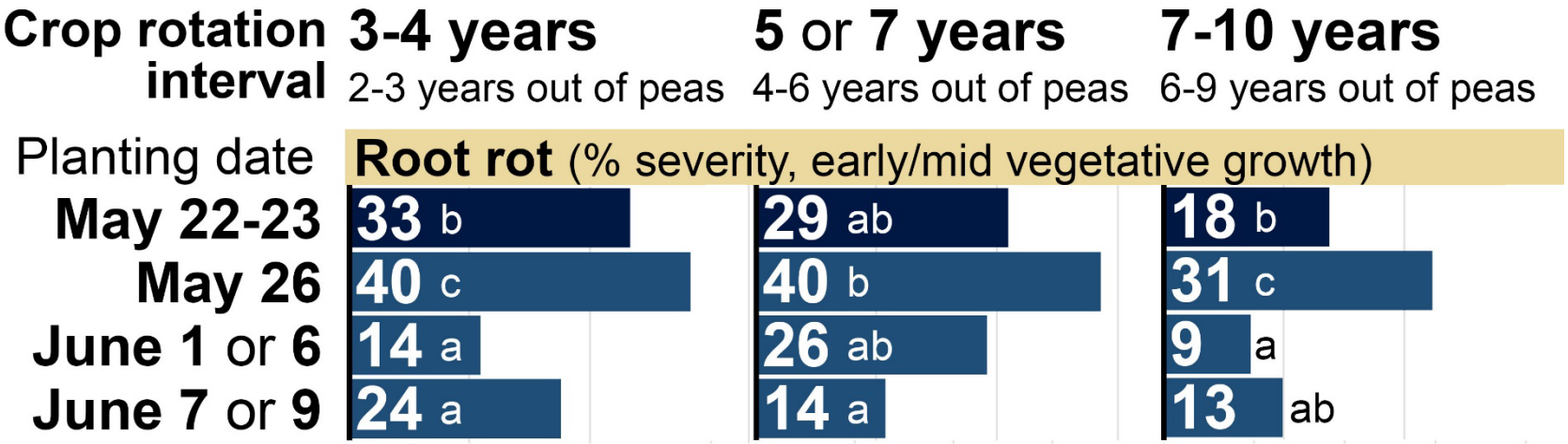
Pathogen diagnostic testing
Carrington, ND (2023)

The pathogen diagnostic testing results and disease symptom assessments suggest that:

- Aphanomyces root rot, caused by *Aphanomyces euteiches,* was the predominant contributor to the observed root rot pressure and associated wilt symptoms.
- Fusarium root rot, caused by various Fusarium species, was likely a moderate contributor to the observed root rot pressure and associated wilt symptoms. *Fusarium avenaceum* was not detected, but some strains of *F. oxysporum* cause root rot in peas. Other other species of Fusarium (not tested) also cause Fusarium root rot in peas.
- Fusarium oxysporum wilt, caused by *F. oxysporum,* was not a significant contributor to the observed wilt symptoms.

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND (2024)

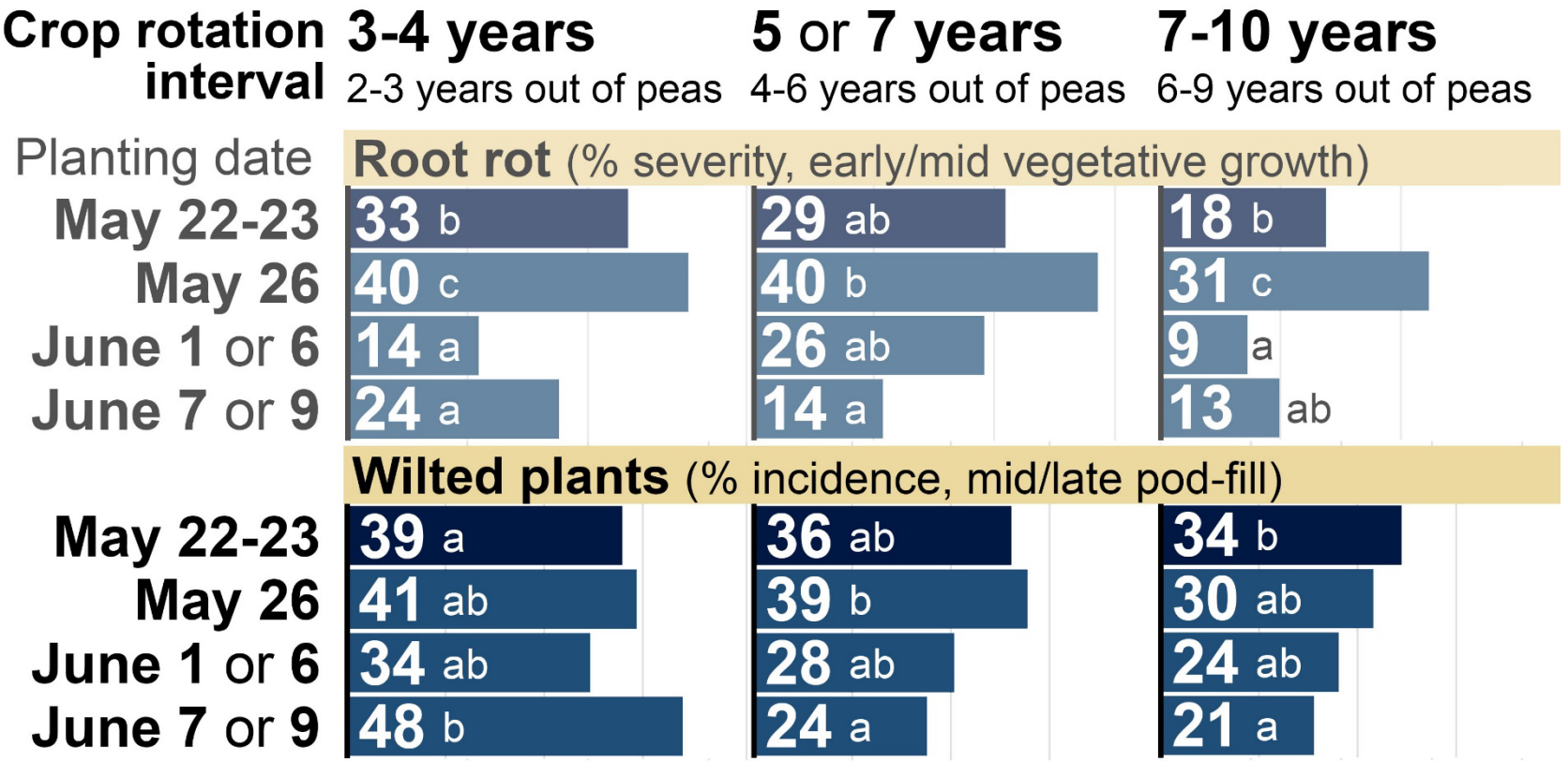


Average across two field pea varieties ('AAC Julius', 'AAC Profit' yellow peas) planted with or without fungicide seed treatment (Obvius, 4.6 fl oz/cwt). Seeding rate = 330,000 viable seeds/ac.

Combined analysis across 11 fields (4 fields with a 3-4 year rotation, 2 fields with a 5 or 7 year rotation, 5 fields with a 7-10 year rotation) in Carrington, ND (2023).

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND (2024)



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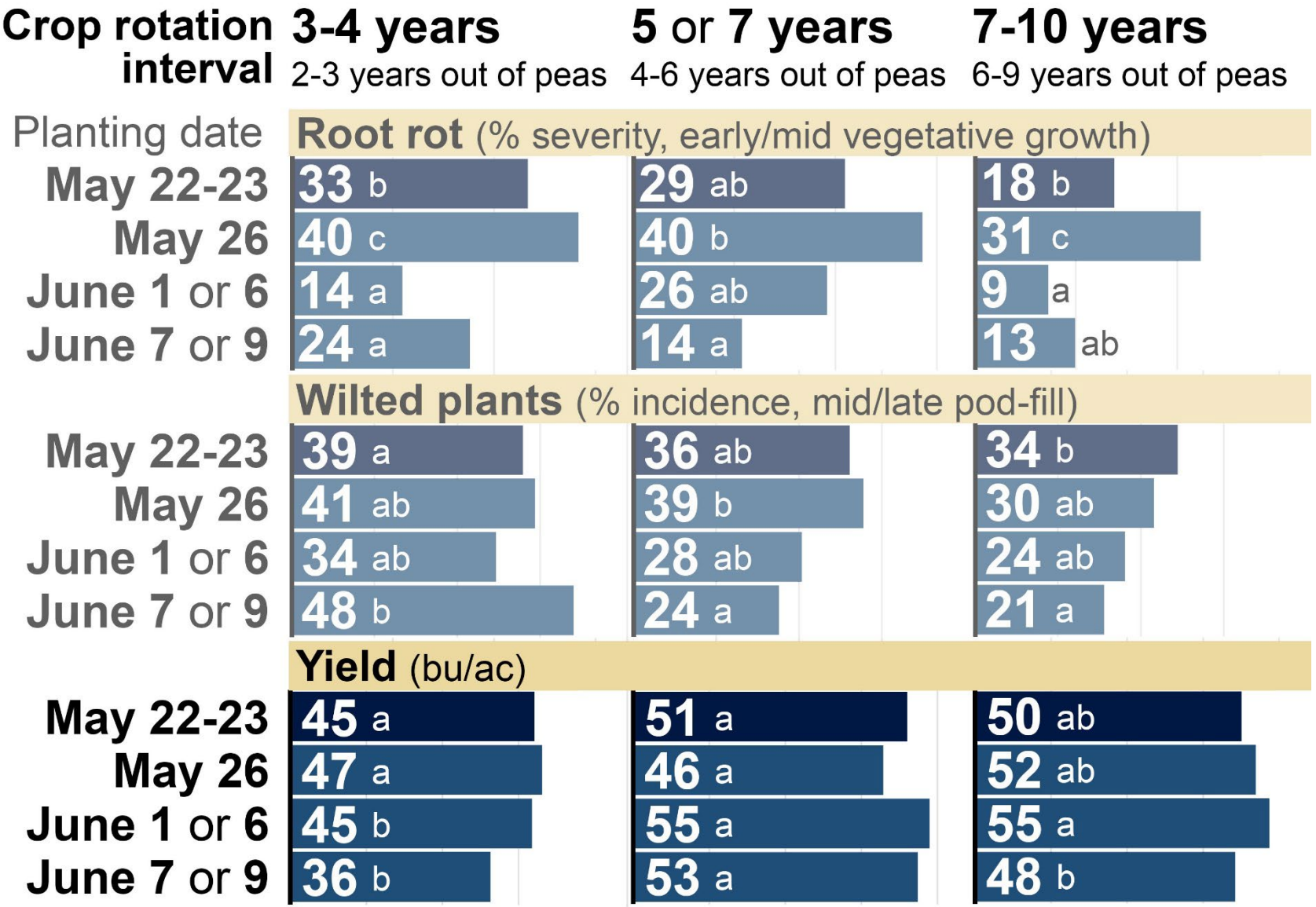
Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND (2024)



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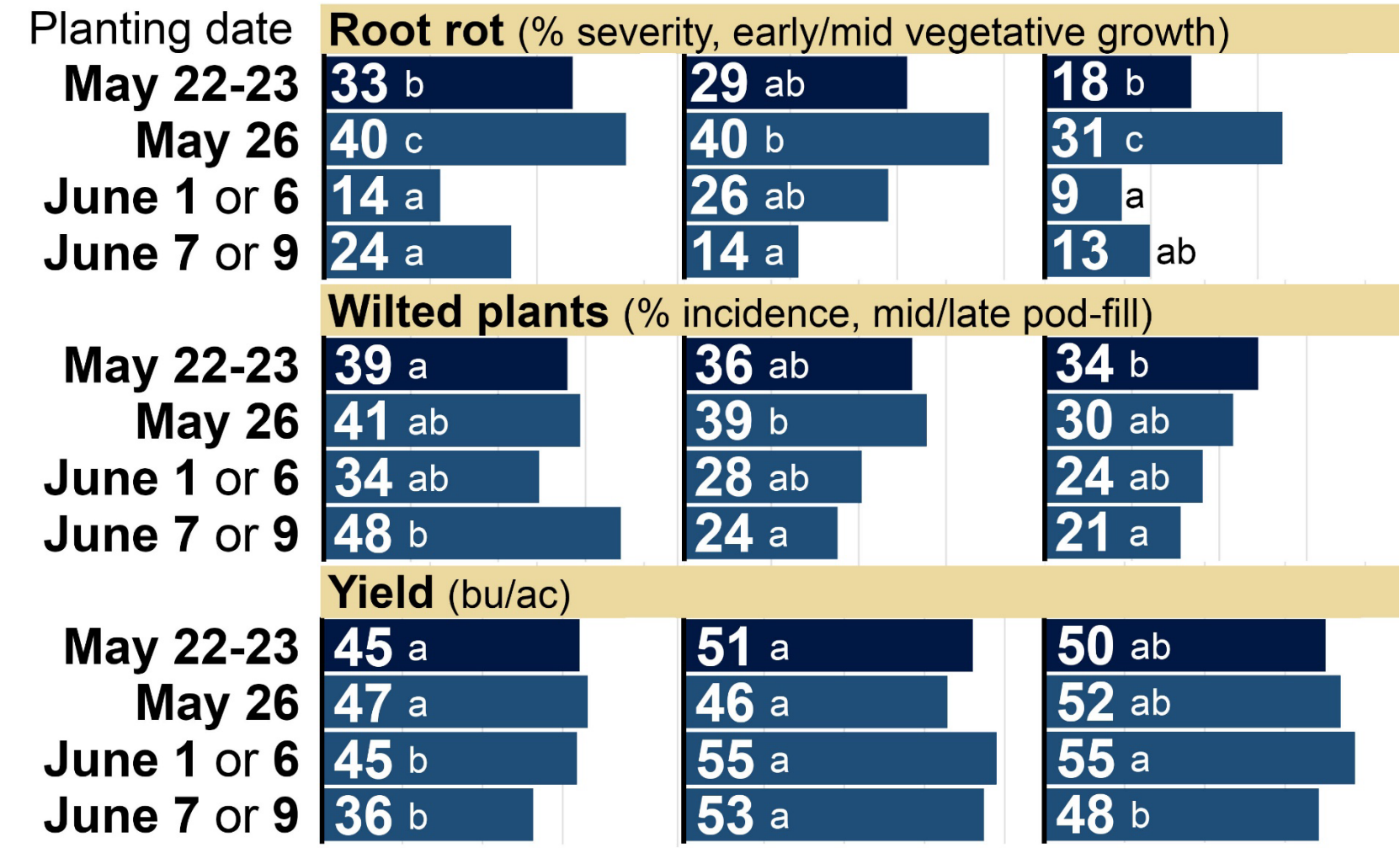
Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND (2024)



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Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND
(2023)

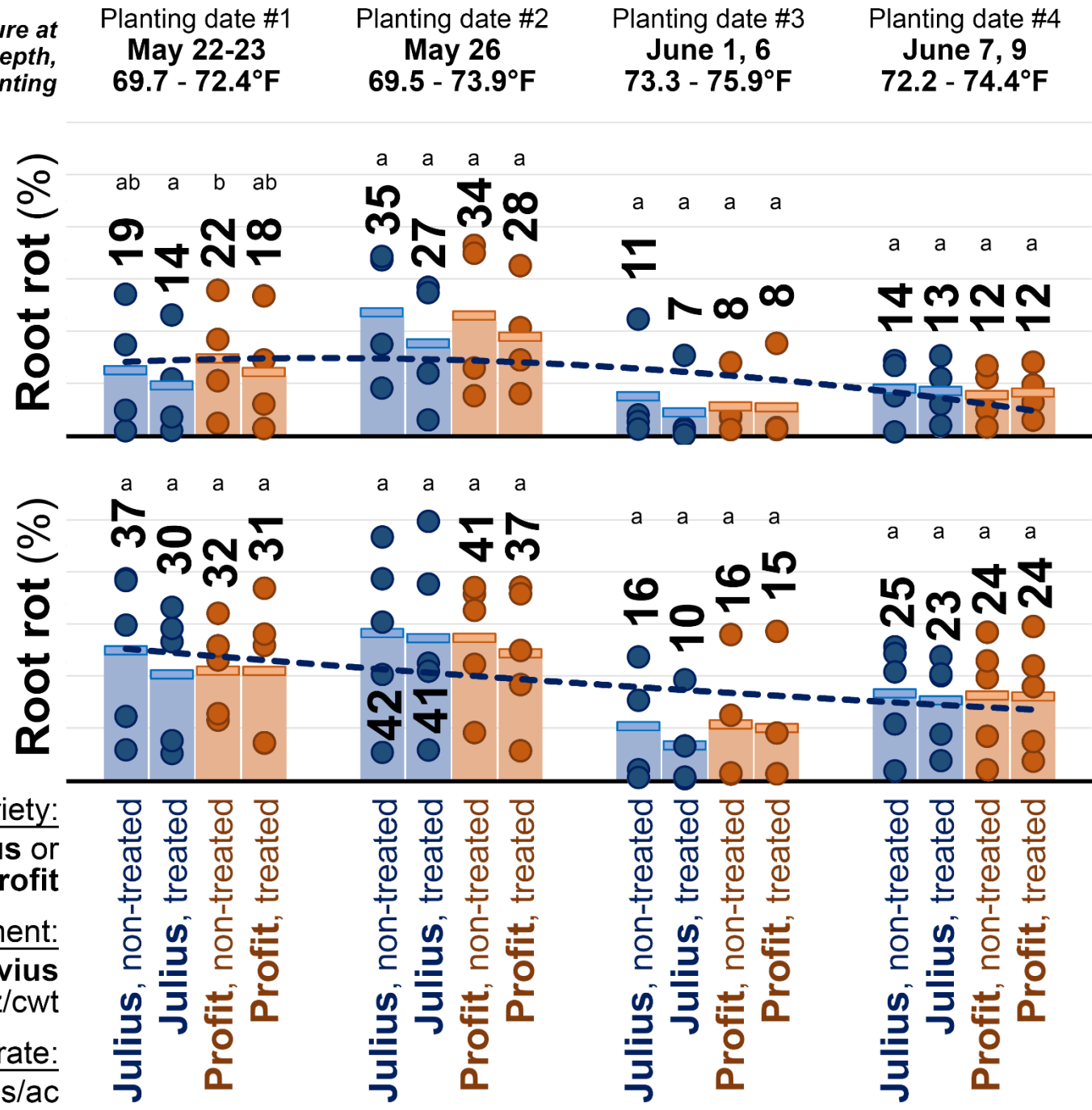
Circles represent the results from one study.

Bars represent the average across studies.

Letters denote statistical differences. Within each set of four bars representing the four variety/seed treatment combinations evaluated within each planting date, different letters denote statistically significant differences ($P < 0.05$).

8 to 10 year rotation: combined analysis across five studies.

3 to 4 year rotation: combined analysis across four studies.



Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND
(2023)

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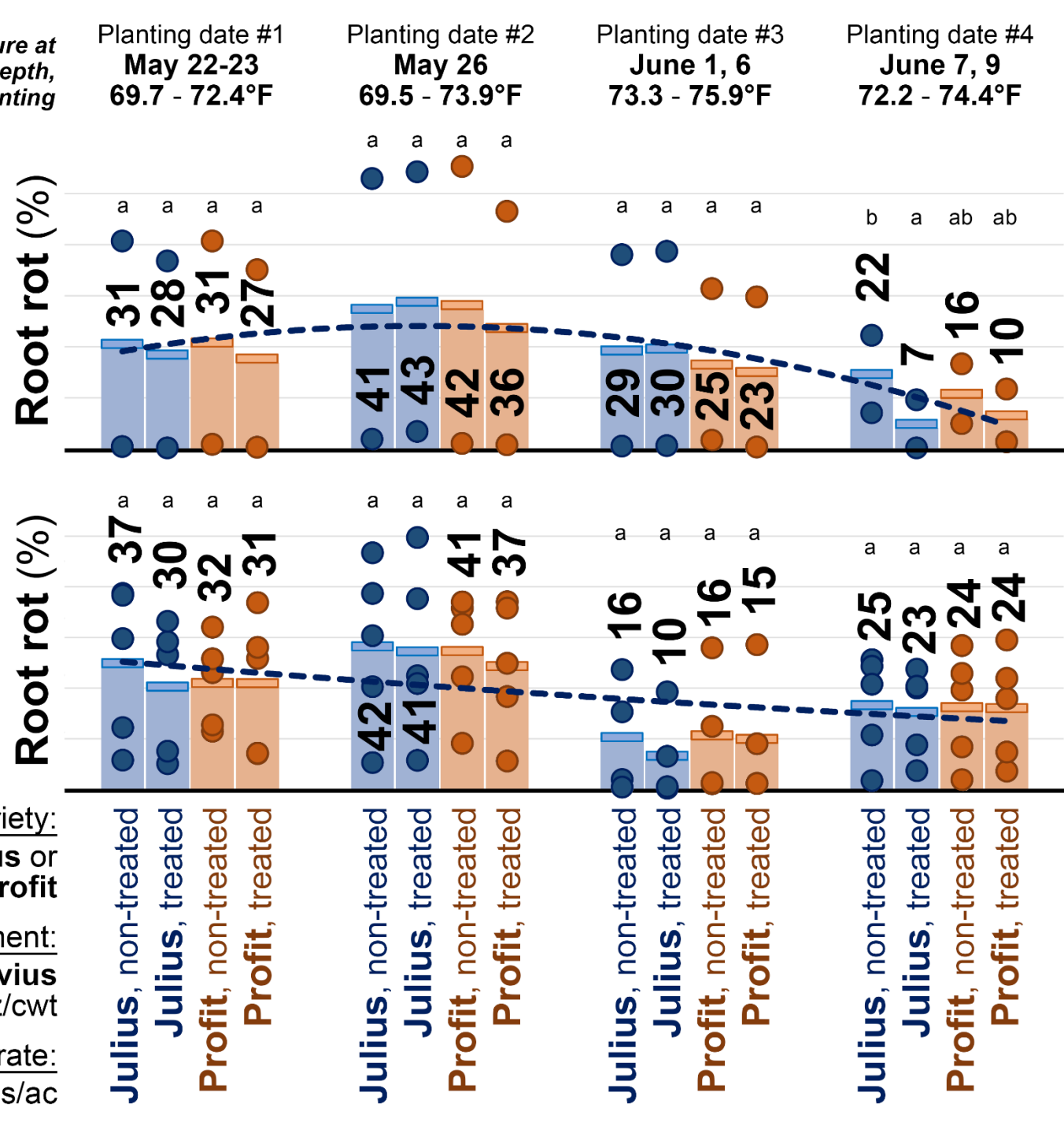

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND
(2023)

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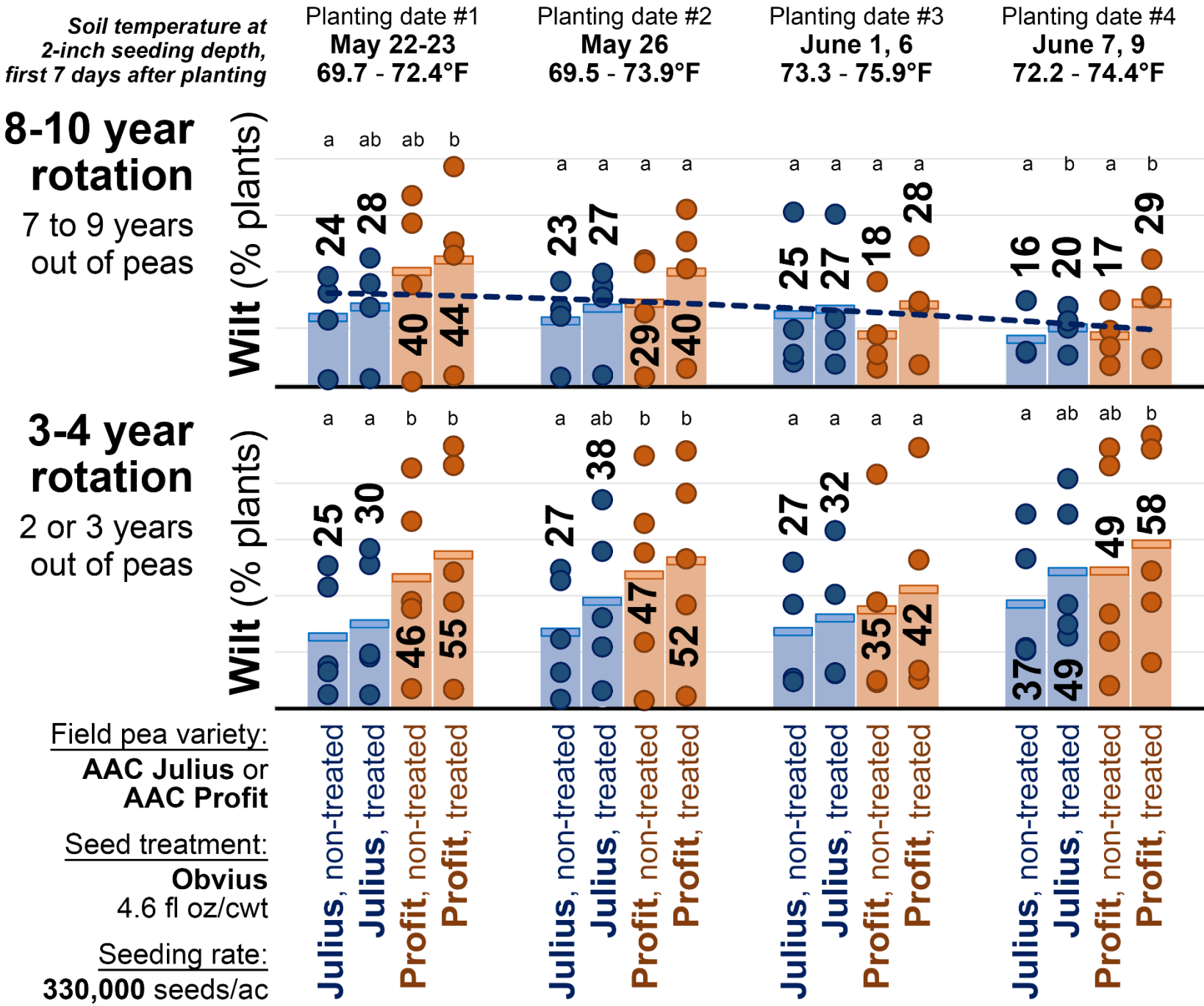

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND
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8 to 10 year rotation: combined analysis across five studies.

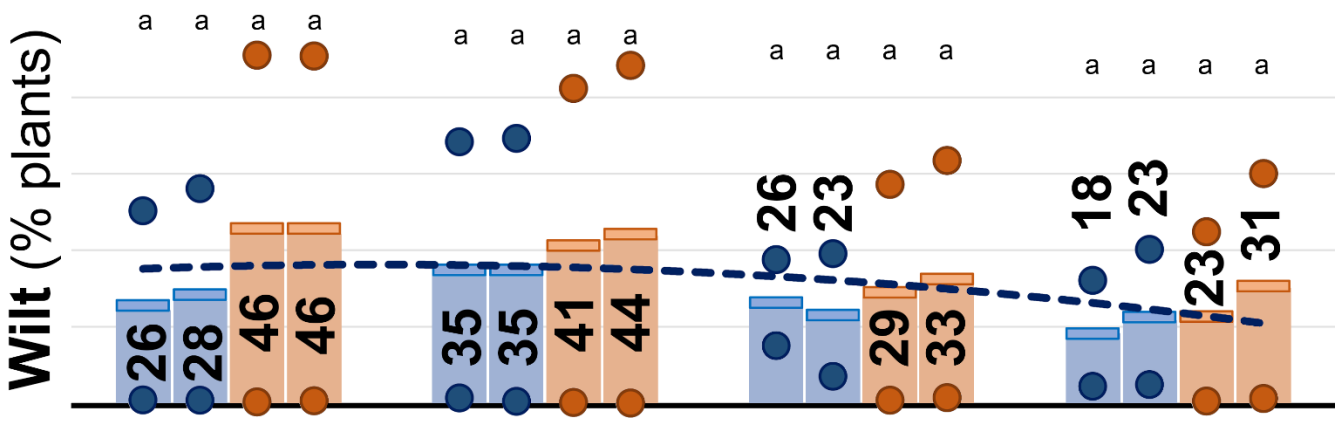
5 or 7 year rotation: combined analysis across two studies.

Soil temperature at 2-inch seeding depth, first 7 days after planting

Planting date #1	Planting date #2	Planting date #3	Planting date #4
May 22-23	**May 26**	**June 1, 6**	**June 7, 9**
69.7 - 72.4°F	**69.5 - 73.9°F**	**73.3 - 75.9°F**	**72.2 - 74.4°F**

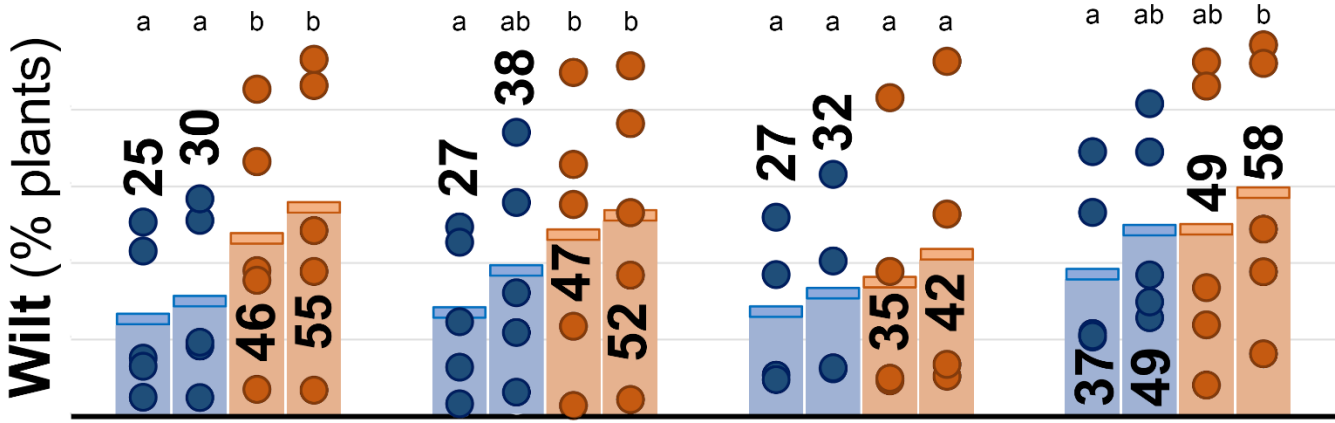
5-7 year rotation

4 or 6 years out of peas



3-4 year rotation

2 or 3 years out of peas



Field pea variety:
AAC Julius or **AAC Profit**

Seed treatment:
Obvius
4.6 fl oz/cwt

Seeding rate:
330,000 seeds/ac

Julius, non-treated
Julius, treated
Profit, non-treated
Profit, treated

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Carrington, ND
(2023)

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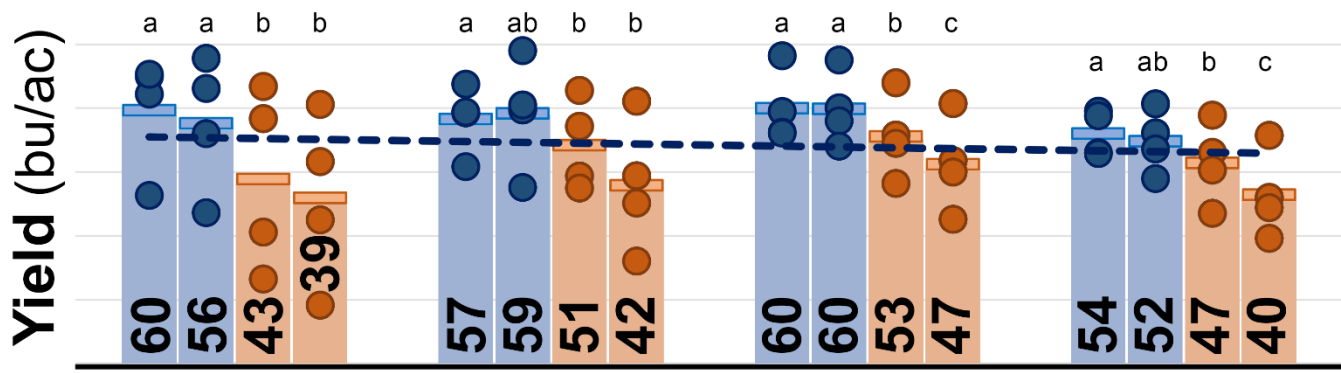
69.7 - 72.4°F	**69.5 - 73.9°F**	**73.3 - 75.9°F**	**72.2 - 74.4°F**

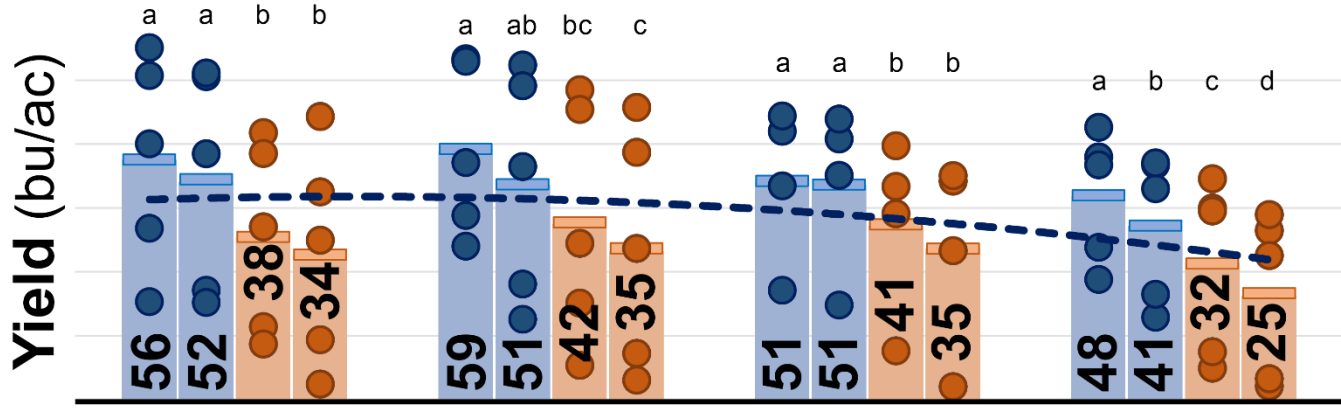
8-10 year rotation

7 to 9 years out of peas



3-4 year rotation

2 or 3 years out of peas



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Profit, treated

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Planting date #1	Planting date #2	Planting date #3	Planting date #4
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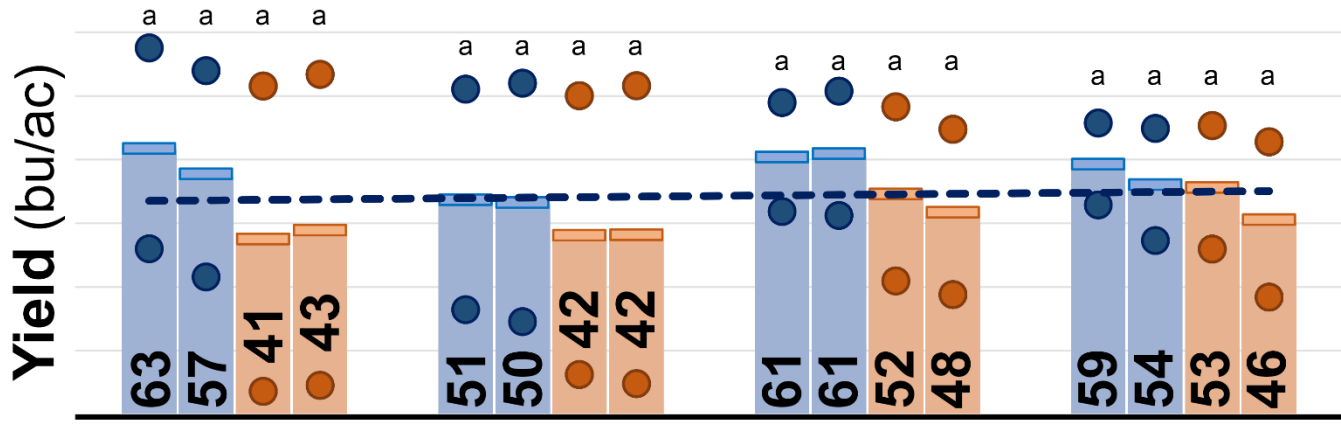
5-7 year rotation

4 or 6 years out of peas



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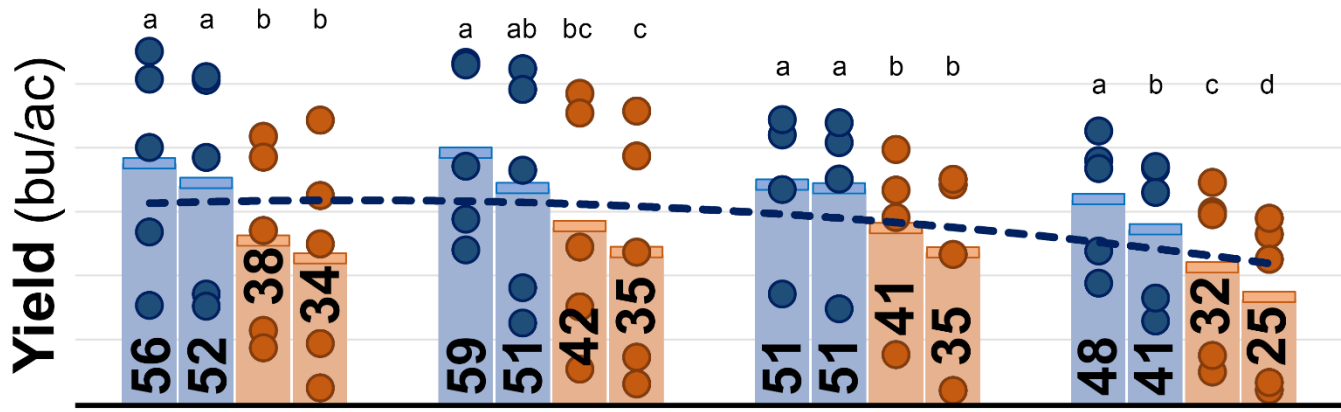
2 or 3 years out of peas



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Seeding rate:
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Julius, non-treated
Julius, treated
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Profit, treated

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Planting date studies conducted **across fields differing in crop rotation interval**
Carrington, ND (2023)

For fields with elevated Aphanomyces root rot pressure, the results suggest:

- When early planting is not possible, losses to Aphanomyces root rot can be sharply mitigated through crop rotation (minimum 4-5 years out of peas) and field pea variety selection

Planting date studies conducted in fields with nearly identical crop rotation histories
Carrington, ND (2023-2024)

- All of the planting date studies were conducted on fields that are utilized for foundation seed increase. Some were conducted on fields predominantly utilized for foundation seed increase and occasionally utilized for small-plot research.
- Two fields had the same field pea rotation history except for a moderate-size footprint within each field where peas were grown in small-plot studies one year.
- Planting date studies were conducted on top of the footprint where peas were grown in small-plot studies several years prior and in the portion of the field where peas had only been grown for foundation seed increase.
- The studies had identical cropping history except for the one year where the previous small-plot studies had been conducted.

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Fields with a shared history of field peas except for one year

Carrington (2023-2024)

	MODERATE CROP ROTATION INTERVAL (2-3 years out of peas)				EXTENDED CROP ROTATION INTERVAL (7-8 years out of peas)			
Field	F18 north	F18 north	F18 north	**Combined analysis**	F18 south	F18 south	**Combined analysis**	
Year	2023	2023	2024		2023	2024		
Last year seeded to peas:	**2020**	**2019**	**2020**	2-3 years out of peas	**2015**	**2015**	7-8 years out of peas	
Years out of peas:	**2**	**3**	**3**		**7**	**8**		
Aphanomyces euteiches (thousand DNA copies/gram of root)								
AAC **Julius**	**16818**	**10670**	diagnostic testing in progress		**25260**	diagnostic testing in progress		
AAC **Profit**	**10563**	**957**			**751**			
Fusarium oxysporum (thousand DNA copies/gram of root)								
AAC **Julius**	**1.9**	**0**	diagnostic testing in progress		**0**	diagnostic testing in progress		
AAC **Profit**	**0**	**0**			**0**			
Root rot severity (%, early/mid vegetative growth)								
AAC **Julius**	50 a	34 a	63 a	**49** a	5 a	66 a	**35** a	
AAC **Profit**	47 a	34 a	63 a	**48** a	7 a	67 a	**37** a	
Wilted plants (% of plants, mid/late pod-fill)								
AAC **Julius**	57 a	59 a	20 b	**45** a	25 a	33 a	**29** a	
AAC **Profit**	79 b	91 b	56 a	**75** b	38 b	54 b	**46** a	
Yield (bu/ac)								
AAC **Julius**	31 a	26 a	37 b	**31** a	45 a	35 a	**40** a**	
AAC **Profit**	11 b	9 b	23 a	**14** b	30 b	24 b	**27** b	

ROOT ROT
25%
reduction

WILT
38%
reduction

YIELD
47%
increase

Average across peas grown from non-treated seed and **seed treated with fungicide seed treatment** (Obvius @ 4.6 fl oz/cwt)
Average across four planting dates: May 22, May 26, June 1, and June 7 (2023); April 23, May 11, May 21, and June 13 (2024)
Means followed by different letters are significantly different ($P < 0.05$ unless followed by two asterisks, in which case $P < 0.10$)

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

Fields with a shared history of field peas except for one year; Carrington (2023-2024)

	MODERATE CROP ROTATION INTERVAL (4-5 years out of peas)			EXTENDED CROP ROTATION INTERVAL (7-8 years out of peas)		
Field Year	Q9E west 2023	Q9E west 2024	**Combined analysis**	Q9E east 2023	Q9E east 2024	**Combined analysis**
Last year seeded to peas:	**2018**	**2018**	4-5 years out of peas	**2015**	**2015**	7-8 years out of peas
Years out of peas:	**4**	**5**		**7**	**8**	
Aphanomyces euteiches (thousand DNA copies/gram of root)						
AAC **Julius**	**17290**	diagnostic testing in progress		**10616**	diagnostic testing in progress	
AAC **Profit**	**72670**			**110068**		
Fusarium oxysporum (thousand DNA copies/gram of root)						
AAC **Julius**	**0**	diagnostic testing in progress		**0**	diagnostic testing in progress	
AAC **Profit**	**0**			**0**		
Root rot severity (%, early/mid vegetative growth)						
AAC **Julius**	55 a	62 a	**58** a	29 a	45 a	**37** a
AAC **Profit**	50 a	60 a	**55** a	28 a	45 a	**36** a
Wilted plants (% of plants, mid/late pod-fill)						
AAC **Julius**	49 a	29 a	**39** a	40 a	28 a	**34** a
AAC **Profit**	72 b	56 b	**64** b	41 a	52 b	**47** a
Yield (bu/ac)						
AAC **Julius**	38 a	26 a	**32** a	58 a	40 a	**49** a**
AAC **Profit**	19 b	18 b	**18** a	46 b	26 a	**36** b

ROOT ROT 35% reduction

WILT 22% reduction

YIELD 69% increase

Average across peas grown from non-treated seed and **seed treated with fungicide seed treatment** (Obvius @ 4.6 fl oz/cwt)
Average across four planting dates: May 22, May 26, June 1, and June 7 (2023); April 23, May 11, May 21, and June 13 (2024)
Means followed by different letters are significantly different ($P < 0.05$ unless followed by two asterisks, in which case $P < 0.10$)

Planting date studies conducted in fields with nearly identical crop rotation histories
Carrington, ND (2023-2024)

For fields with elevated Aphanomyces root rot pressure, the results suggest:

- The use of an extended crop rotation interval (in this case, 7-8 years) and field pea variety selection are both useful tools for sharply reducing losses to Aphanomyces root rot.

3-year crop rotation (2 years out of peas):
Early planting, variety selection, and seed treatment were critical

Carrington, ND (2024)

Study #1 Field 17

		Planting date #1		Planting date #2		Planting date #3		Planting date #4	
	Date:	**April 23-24**		**May 10**		**May 22**		**June 12-13**	
	soil temperature:	**45.2°F**		**60.3°F**		**56.4°F**		**67.6°F**	
average soil temp. at seeding depth in the 1st 7 days after planting		**Wilted plants** (%)	**Yield** (bu/ac)	**Wilted plants** (%)	**Yield** (bu/ac)	**Wilted plants** (%)	**Yield** (bu/ac)	**Wilted plants** (%)	**Yield** (bu/ac)
		80-97% pods fully filled	13.5% moisture	75-90% pods fully filled	13.5% moisture	85-100% pods fully filled	13.5% moisture	40-85% pods fully filled	13.5% moisture
Field pea variety	**Fungicide seed treatment**								
AAC IronHorse	Non-treated seed	3 a*	69 a*	18 a*	42 a*	30 a*	38 a*	55 a*	14 b*
AAC IronHorse	Obvius, 4.6 fl oz/cwt	2 a	85 a	13 a	50 a	25 a	44 a	58 a	14 b
AAC IronHorse	Obvius, 4.6 fl oz/cwt + Relenya, 0.4 fl oz/cwt	3 a	85 a	17 a	54 a	24 a	37 a	59 a	13 b
AAC IronHorse	Vibrance Total, 5 fl oz/cwt	3 a	77 a	15 a	50 a	23 a	45 a	44 a	17 a
AAC IronHorse	Vibrance Total, 5 fl oz + Trebuset, 0.614 fl oz/cwt	3 a	73 a	12 a	50 a	23 a	42 a	37 a	19 a
	CV:	47.1	14.6	36.1	14.1	28.8	20.4	59.8	13.3
AAC Julius	Non-treated seed	10 a*	74 a*	27 a*	36 a*	57 a*	18 a*	71 b*	12 bc*
AAC Julius	Obvius, 4.6 fl oz/cwt	8 a	77 a	22 a	42 a	53 a	25 a	72 b	12 bc
AAC Julius	Obvius, 4.6 fl oz/cwt + Relenya, 0.4 fl oz/cwt	10 a	80 a	26 a	41 a	57 a	19 a	72 b	12 c
AAC Julius	Vibrance Total, 5 fl oz/cwt	8 a	87 a	23 a	44 a	47 a	25 a	65 ab	16 ab
AAC Julius	Vibrance Total, 5 fl oz + Trebuset, 0.614 fl oz/cwt	6 a	83 a	20 a	45 a	45 a	26 a	58 a	17 a
	CV:	44.8	10.9	25.6	19.0	19.0	31.8	11.2	17.5
ND Dawn	Non-treated seed	10 b*‡	73 a*	41 a*	31 b*	44 a*	29 a*	58 a*	15 a*
ND Dawn	Obvius, 4.6 fl oz/cwt	5 a	79 a	39 a	41 a	47 a	27 a	62 a	14 a
ND Dawn	Obvius, 4.6 fl oz/cwt + Relenya, 0.4 fl oz/cwt	6 ab	74 a	38 a	38 ab	46 a	28 a	65 a	13 a
ND Dawn	Vibrance Total, 5 fl oz/cwt	5 a	77 a	29 a	43 a	36 a	32 a	59 a	17 a
ND Dawn	Vibrance Total, 5 fl oz + Trebuset, 0.614 fl oz/cwt	5 a	79 a	31 a	42 a	36 a	33 a	58 a	18 a
	CV:	20.8	7.1	23.2	14.5	30.8	24.6	17.8	20.9
Caphorn	Non-treated seed	20 b*	67 a*	78 c*	23 a*	78 ab*	10 ab*	84 a*	4 a*
Caphorn	Obvius, 4.6 fl oz/cwt	9 ab	71 a	64 b	25 a	73 ab	10 ab	88 a	4 a
Caphorn	Obvius, 4.6 fl oz/cwt + Relenya, 0.4 fl oz/cwt	9 ab	78 a	68 bc	24 a	83 b	8 b	84 a	3 a
Caphorn	Vibrance Total, 5 fl oz/cwt	8 a	74 a	54 a	26 a	73 ab	13 ab	89 a	4 a
Caphorn	Vibrance Total, 5 fl oz + Trebuset, 0.614 fl oz/cwt	8 a	72 a	53 a	32 a	65 a	16 a	76 a	6 a
	CV:	60.9	9.9	11.0	27.3	10.6	36.4	17.6	59.8
AAC Profit	Non-treated seed	47 b*	50 b*	89 b*	10 c*	80 b*	10 a*	90 ab*	2 b*
AAC Profit	Obvius, 4.6 fl oz/cwt	33 ab	47 b	80 ab	15 abc	82 b	10 a	90 ab	3 b
AAC Profit	Obvius, 4.6 fl oz/cwt + Relenya, 0.4 fl oz/cwt	33 ab	51 b	83 ab	14 bc	86 b	8 a	91 b	2 b
AAC Profit	Vibrance Total, 5 fl oz/cwt	28 a	70 a	80 ab	20 ab	76 ab	9 a	88 ab	3 a
AAC Profit	Vibrance Total, 5 fl oz + Trebuset, 0.614 fl oz/cwt	24 a	59 ab	69 a	21 a	63 a	16 a	78 a	5 a
	CV:	29.2	14.7	10.4	25.0	10.2	38.2	8.3	33.7
LG Amigo	Non-treated seed	72 b*	27 a*	96 b*	6 b*	95 b*	4 a*	66 a*	4 a*
LG Amigo	Obvius, 4.6 fl oz/cwt	51 a	37 a	88 b	8 ab	88 b	9 a	65 a	5 a
LG Amigo	Obvius, 4.6 fl oz/cwt + Relenya, 0.4 fl oz/cwt	60 ab	30 a	91 b	6 b	95 b	6 a	59 a	6 a
LG Amigo	Vibrance Total, 5 fl oz/cwt	52 ab	39 a	83 ab	10 ab	86 b	6 a	66 a	6 a
LG Amigo	Vibrance Total, 5 fl oz + Trebuset, 0.614 fl oz/cwt	56 ab	39 a	68 a	12 a	66 a	8 a	59 a	9 a
	CV:	19.9	26.5	10.2	38.4	9.5	61.0	11.8	39.7

Seeding rate = 330,000 viable seeds/ac Row spacing = 7.5 inches

9-year crop rotation (8 years out of peas):
Penalty to delayed planting more modest; more flexibility on varieties with early planting

Carrington, ND (2024)

Study #2 Field 18 south

average soil temp. at seeding depth in the 1st 7 days after planting

		Planting date #1		Planting date #2		Planting date #3		Planting date #4	
		Date: **April 23**		**May 12**		**May 22**		**June 12**	
		soil temperature: **45.8°F**		**58.6°F**		**55.3°F**		**67.0°F**	
		Wilted plants (%)	**Yield** (bu/ac)	**Wilted plants** (%)	**Yield** (bu/ac)	**Wilted plants** (%)	**Yield** (bu/ac)	**Wilted plants** (%)	**Yield** (bu/ac)
Field pea variety	**Fungicide seed treatment**	85-100% pods fully filled	13.5% moisture	70-100% pods fully filled	13.5% moisture	85-100% pods fully filled	13.5% moisture	78-100% pods fully filled	13.5% moisture
AAC IronHorse	Non-treated seed	3 a*	62 a*	6 a*	47 a*	7 a*	45 a*	78 a*	21 b*
AAC IronHorse	Obvius, 4.6 fl oz/cwt	1 a	69 a	6 a	43 a	7 a	45 a	73 a	24 ab
AAC IronHorse	Obvius, 4.6 fl oz/cwt + Relenya, 0.4 fl oz/cwt	2 a	68 a	8 a	44 a	9 a	46 a	77 a	21 b
AAC IronHorse	Vibrance Total, 5 fl oz/cwt	2 a	65 a	4 a	44 a	6 a	44 a	73 a	25 ab
AAC IronHorse	Vibrance Total, 5 fl oz + Trebuset, 0.614 fl oz/cwt	1 a	65 a	3 a	45 a	5 a	45 a	69 a	25 a
	CV:	62.8	7.9	58.6	9.8	35.2	7.0	12.5	11.2
AAC Julius	Non-treated seed	3 a*	55 a*	17 b*	31 a*	20 a*	32 b*	92 a*	17 c*
AAC Julius	Obvius, 4.6 fl oz/cwt	5 a	60 a	10 ab	34 a	28 a	31 b	92 a	18 bc
AAC Julius	Obvius, 4.6 fl oz/cwt + Relenya, 0.4 fl oz/cwt	6 a	57 a	13 ab	33 a	24 a	32 b	92 a	17 bc
AAC Julius	Vibrance Total, 5 fl oz/cwt	2 a	58 a	7 a	35 a	19 a	35 ab	86 a	20 ab
AAC Julius	Vibrance Total, 5 fl oz + Trebuset, 0.614 fl oz/cwt	1 a	61 a	7 a	35 a	21 a	38 a	85 a	23 a
	CV:	113.7	6.6	46.6	14.1	28.4	8.5	6.8	9.7
ND Dawn	Non-treated seed	5 a*	49 a*	14 a*	36 a*	21 a*	32 b*	93 ab*	19 b*
ND Dawn	Obvius, 4.6 fl oz/cwt	2 a	59 a	11 a	40 a	13 a	39 a	94 b	19 b
ND Dawn	Obvius, 4.6 fl oz/cwt + Relenya, 0.4 fl oz/cwt	2 a	59 a	13 a	42 a	15 a	38 ab	94 b	18 b
ND Dawn	Vibrance Total, 5 fl oz/cwt	3 a	55 a	15 a	34 a	17 a	37 ab	88 ab	24 a
ND Dawn	Vibrance Total, 5 fl oz + Trebuset, 0.614 fl oz/cwt	3 a	59 a	10 a	37 a	11 a	39 ab	88 a	25 a
	CV:	96.0	11.6	44.4	13.9	40.4	11.2	4.2	12.2
Caphorn	Non-treated seed	14 a*	58 a*	34 a*	28 a*	36 b*	26 b*	94 b*	9 b*
Caphorn	Obvius, 4.6 fl oz/cwt	13 a	58 a	24 a	32 a	30 ab	30 ab	88 ab	12 ab
Caphorn	Obvius, 4.6 fl oz/cwt + Relenya, 0.4 fl oz/cwt	19 a	56 a	25 a	33 a	30 ab	28 b	94 ab	10 b
Caphorn	Vibrance Total, 5 fl oz/cwt	14 a	58 a	26 a	31 a	24 ab	31 ab	84 ab	12 b
Caphorn	Vibrance Total, 5 fl oz + Trebuset, 0.614 fl oz/cwt	14 a	57 a	23 a	34 a	21 a	34 a	82 a	16 a
	CV:	39.0	7.6	25.9	14.5	26.7	11.0	8.7	17.5
AAC Profit	Non-treated seed	24 b*	50 a*	55 b*	19 c*	65 b*	16 c*	99 a*	4 b*
AAC Profit	Obvius, 4.6 fl oz/cwt	13 ab	55 a	42 ab	26 b	57 ab	18 bc	97 a	5 ab
AAC Profit	Obvius, 4.6 fl oz/cwt + Relenya, 0.4 fl oz/cwt	20 ab	51 a	41 ab	23 bc	63 b	17 c	99 a	4 b
AAC Profit	Vibrance Total, 5 fl oz/cwt	11 ab	54 a	33 a	26 b	47 a	23 ab	95 a	6 ab
AAC Profit	Vibrance Total, 5 fl oz + Trebuset, 0.614 fl oz/cwt	9 a	53 a	30 a	30 a	42 a	24 a	96 a	7 a
	CV:	42.6	7.4	19.9	14.3	16.6	13.8	2.9	32.8
LG Amigo	Non-treated seed	28 a*	12 b*	44 b*	10 a*	61 b*	7 b*	92 ab*	5 bc*
LG Amigo	Obvius, 4.6 fl oz/cwt	22 a	19 a	38 ab	10 a	59 b	8 ab	92 ab	5 bc
LG Amigo	Obvius, 4.6 fl oz/cwt + Relenya, 0.4 fl oz/cwt	22 a	21 a	36 ab	10 a	68 b	7 b	96 b	5 c
LG Amigo	Vibrance Total, 5 fl oz/cwt	16 a	23 a	24 a	11 a	57 b	10 ab	86 a	7 b
LG Amigo	Vibrance Total, 5 fl oz + Trebuset, 0.614 fl oz/cwt	14 a	21 a	24 a	12 a	37 a	11 a	86 a	10 a
	CV:	63.7	16.2	24.9	17.7	17.1	21.4	6.6	18.3

Seeding rate = 330,000 viable seeds/ac Row spacing = 7.5 inches

Aphanomyces and Fusarium root rot of field peas: Impact of crop rotation interval

For fields with elevated Aphanomyces and Fusarium root rot pressure, the results suggest:

- Crop rotation helps manage Aphanomyces and Fusarium root rot in field peas.
- Crop rotation provides partial management of the Aphanomyces and Fusarium root rot complex and must be combined with other tools – field pea variety selection, planting date, and fungicide seed treatment – to achieve satisfactory disease management.
- A minimum five- to six-year rotation may confer flexibility with field pea variety selection when planting early.
- A minimum five- to six-year rotation may confer moderate flexibility with planting date (up to 2 to 2.5 weeks after reaching target 43-49°F soil temperature) when planting an Aphanomyces tolerant variety.

Integrated management of **Aphanomyces and Fusarium root rot** in field peas: (3) Impact of crop rotation interval

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