Response of Crops and Weeds to Climate and CO_2: Threats and Opportunities

National Forum on Climate and Pests, October 4-6, 2016

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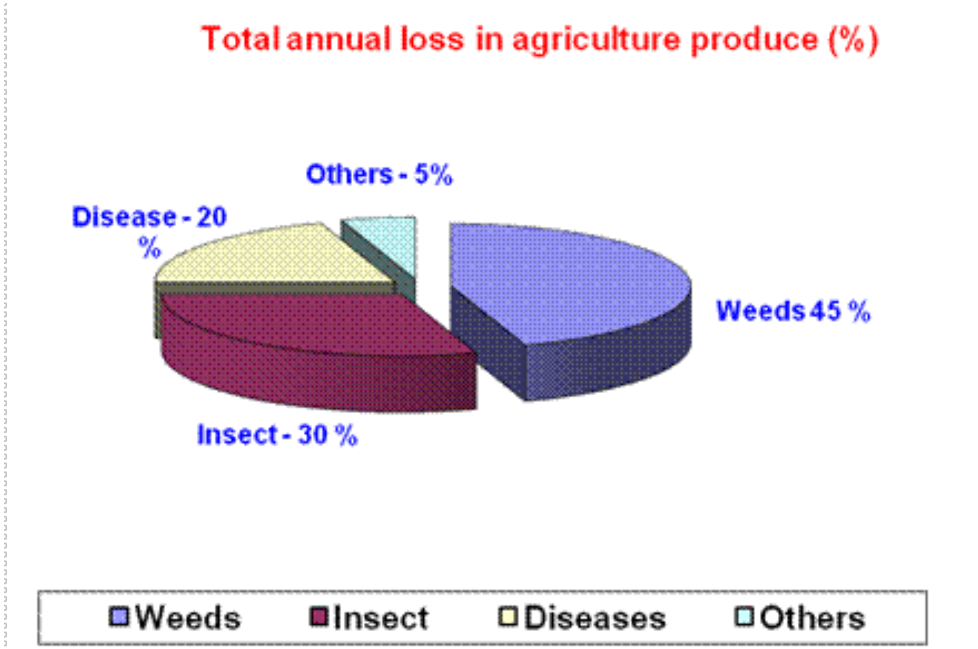
USDA

Agricultural Research Service

Weeds represent the greatest biotic constraint to crop yield.



Best estimates within the United States are a ~10% loss of production associated with weeds, with herbicide application.

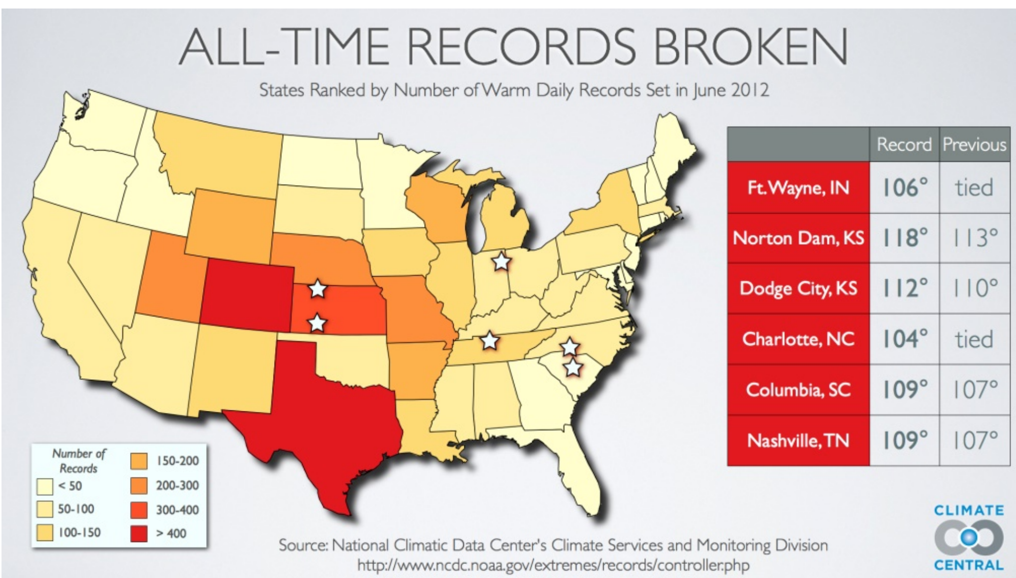
This increases to ~25% with BMP but no herbicide; 100% if no effort is made to control weeds.

Globally, weeds probably represent the greatest biotic restraint to crop production, especially in developing countries. More money is spent on controlling weeds than any other pest threat.

Climate change: Crop/weed Responses

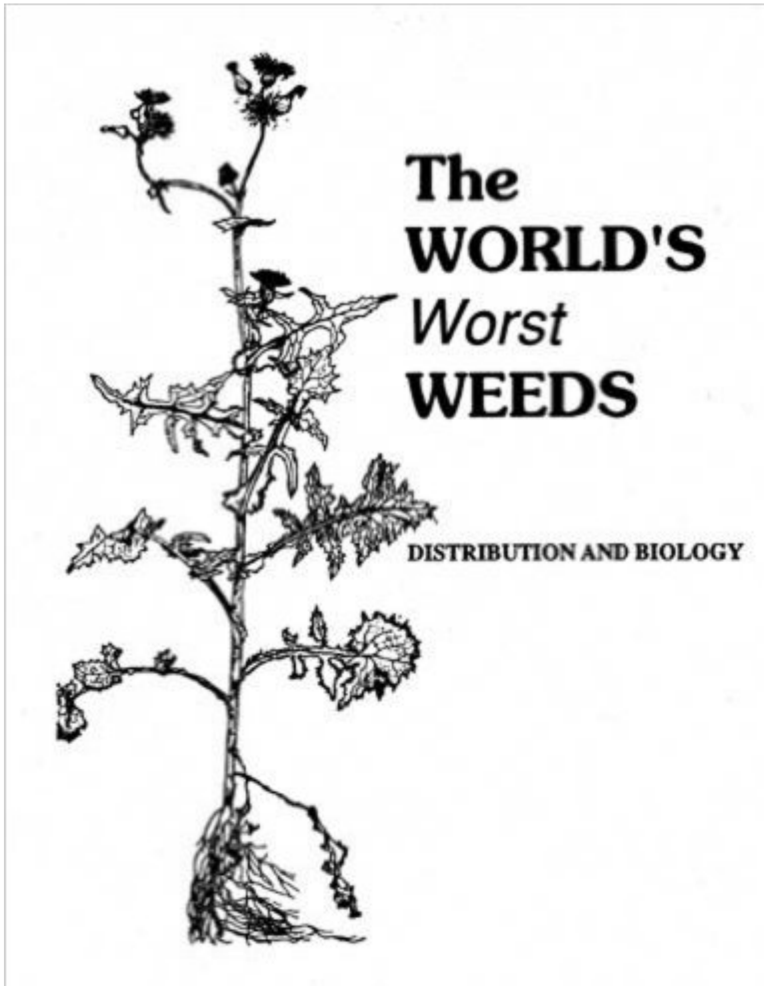
ABIOTIC: Increasing temperatures, but also increasing variation in temperature and precipitation, with more frequent extremes.

BIOTIC: The Increase in CO_2 represents an increase in a basic resource needed for plant growth*



Biotic Response of weeds and crops.

"CO_2 is plant food; that will mean fewer weeds"
WHY?

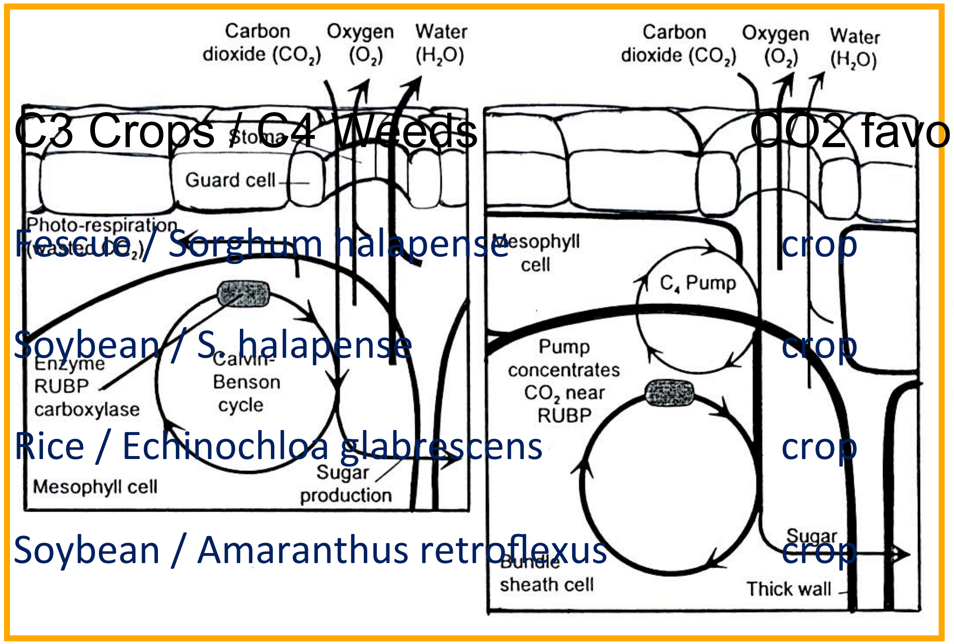


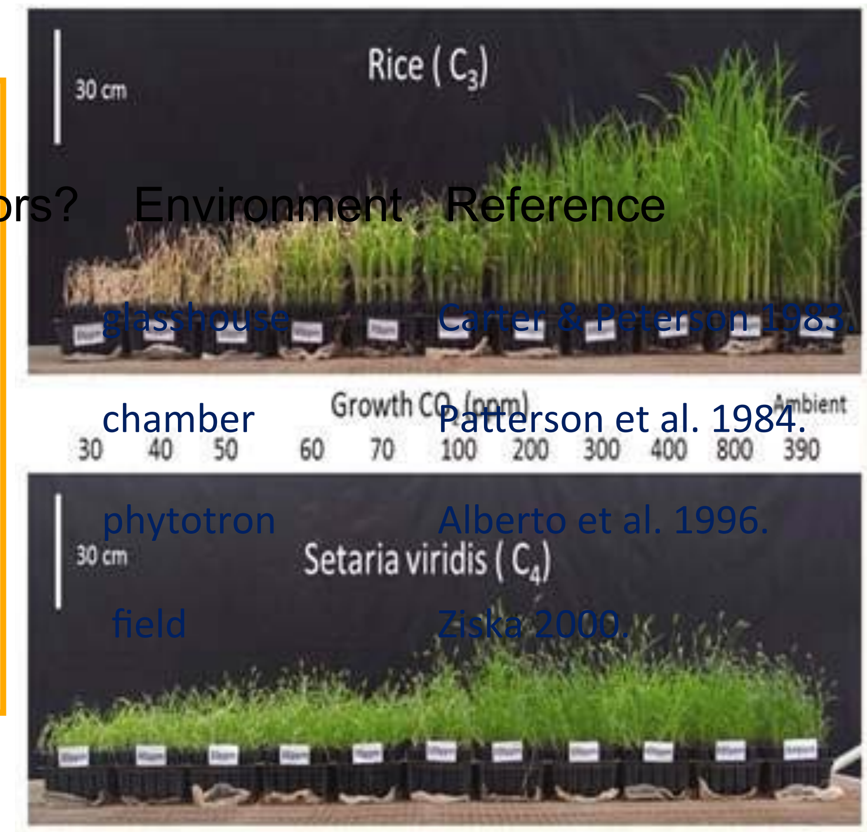
- First systematic attempt to evaluate globally the serious or significant weed problems in agriculture.
- Based on input from weed scientists from 100 countries around the world.
- Focus is on global agriculture and "worst" weeds.

- Observations: Many crops had the C3 photosynthetic pathway, while many weeds had the C4 photosynthetic pathway.

Biotic Response

“CO_2 is plant food; that will mean fewer weeds”
WHY?





C3 Crops / C4 Weeds	CO2 favors?	Environment	Reference
Fescue / Sorghum halapense	crop	glasshouse	Carter & Peterson 1983.
Soybean / S. halapense	crop	chamber	Patterson et al. 1984.
Rice / Echinochloa glabrescens	crop	phytotron	Alberto et al. 1996.
Soybean / Amaranthus retroflexus	crop	field	Ziska 2000.

- Paradigm: Because weeds are less responsive to CO2 than crops, weed competition will decline as will crop losses as CO2 increases.

The Problem with Paradigms: They change.

	Holm (1977)	Current
Corn	Cyperus rotundus (C4)	Albutilon theophrasti (C3)
	Digitaria sanguinalis (C4)	Ipomea spp. (C3)
	Echinochloa crus-galli (C4)	Albutilon theophrasti (C3)
	Sorghum halapense (C4)	Ambrosia trifida (C3)
	Portulaca oleracea (C4)	Amaranth spp. (C4)
	Cynodon dactylon (C4)	Chenopodium album (C3)
Soybean	Eleusine indica (C4)	Ipomea spp. (C3)
	Echinochloa colonum (C4)	Setaria spp. (C4)
	Cyperus rotundus (C4)	Amaranthus spp. (C4)
	Echinochloa crus-galli (C4)	Albutilon theophrasti (C3)
		Chenopodium album (C3)
Wheat	Avena fatua (C3)	Cirsium arvense (C3)
	Polygonum convolvulus (C3)	Convolvulus arvensis (C3)
	Chenopodium alba (C3)	Avena fatua(C3)
	Convolvulus arvensis (C3)	Bromus tectorum (C3)

Turns out, "worst" changes with time.

Reality: Both C3 and C4 Crops compete with C3 and C4 weeds.
On average, a given crop competes with 8-10 weeds.

Paradigm shifts

Amaranthus retroflexus **(C_4)**	**Soybean**	**Crop**	**Field**	**Ziska, 2000**
Amaranthus retroflexus **(C_4)**	**Sorghum**	**Weed**	**Field**	**Ziska, 2003**
Chenopodium album **(C_3)**	**Soybean**	**Weed**	**Field**	**Ziska, 2000**
Taraxacum officinale **(C_3)**	**Lucerne**	**Weed**	**Field**	**Bunce 1995**
Albutilon theophrasti **(C_3)**	**Sorghum**	**Weed**	**Field**	**Ziska, 2003**
Taraxacum **and** ***Plantago*** **(C_3)**	**Grasses**	**Weed**	**Field**	**Potvin and Vasseur, 1997**

C3 Crops / C4 Weeds	CO_2+	Crop or Weed?	Reference
Rice / Barnyardgrass	CO_2+temperature	Weed	Alberto et al. 1996.
Tomato / Pigweed	CO_2+drought	Weed	Valerio et al. 2011.
Rice / Barnyardgrass	CO_2+ N deficit	Weed	Zhu et al. 2008.

Worst?

Often the "worst" weed may be a wild, weedy relative of the crop.

Rice Yield Loss from Heavy, Season-Long Weed Interference

Weed Species	**Yield Loss, %**
Red rice	82
Barnyardgrass	70
Bearded sprangletop	36
Amazon sprangletop	35
Broadleaf signalgrass	32
Ducksalad	21
Hemp sesbania	19
Spreading dayflower	18
Northern jointvetch	17
Eclipta	10

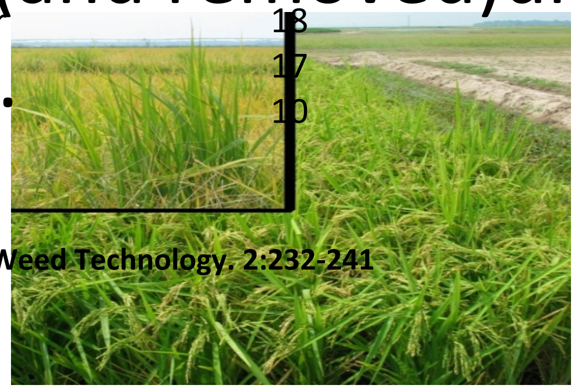
R. J. Smith, Jr. 1988. Weed Technology. 2:232-241

Why Worst?

1. Pre-adapted to the same abiotic conditions as the crop.
2. Difficult to identify; may not be recognized as a weed (and removed) until damage has been done.

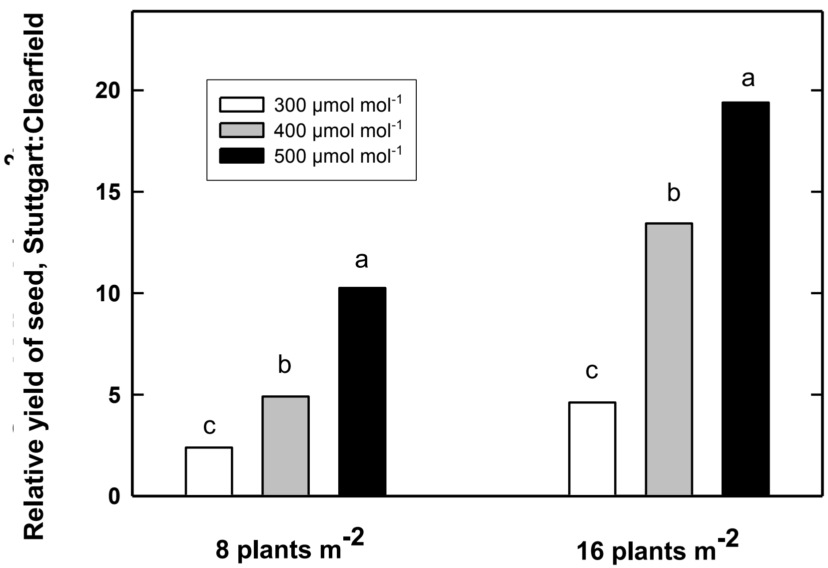






Biotic Response

Wild vs. cultivated crop A new Paradigm?



Weeds, especially "worst" weeds, respond more to a resource change (e.g. CO2) than the crop. As such, crop losses are likely to increase, not decrease with higher [CO2].

Clearfield Rice, Management

Clearfield® rice is a chemical mutant that confers tolerance to imazethapyr herbicides.

Before the advent of this technology, there were no effective options to control red rice in conventional white rice.

There is a small amount of outcrossing (~.3%) between red rice and cultivated rice. Outcrossing is based on floral synchronicity, spatial proximity and genetic compatibility.

HYPOTHESIS: CAN CO_2 EFFECT OUTCROSSING RATES AND THE TRANSFER OF HERBICIDE RESISTANCE?

Clearfield 161, planted with Stuttgart red rice at ratio of 7:1 for three CO2 concentrations, 300, 400 and 600 ppm (beginning, end of 20th century, IPCC 21st century prediction), using growth chambers.

And?

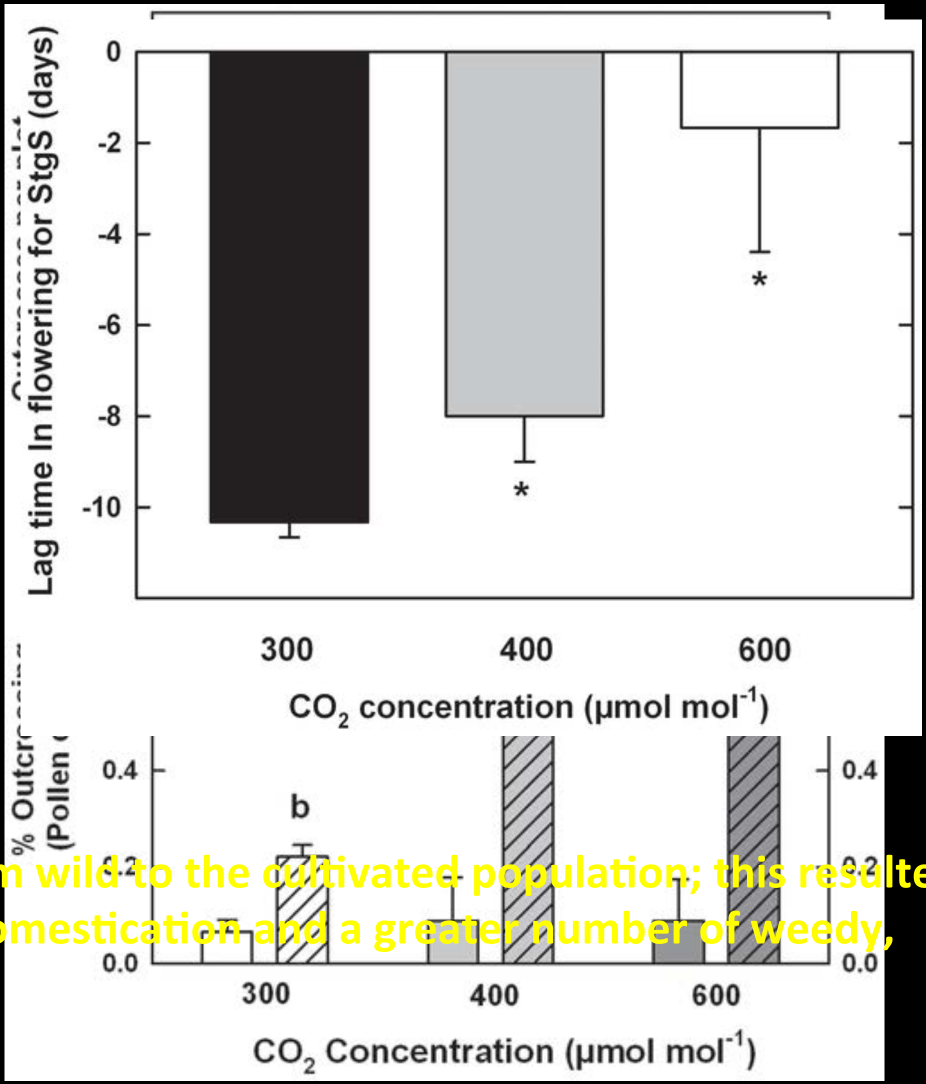
Resultant seed was planted in Arkansas. As Clearfield rice crosses at low rates with red rice any herbicide-resistant hybrids could be confirmed using DNA fingerprinting.

300 ppm CO2, CL-161 female

600 ppm CO2, CL-161 female

And?

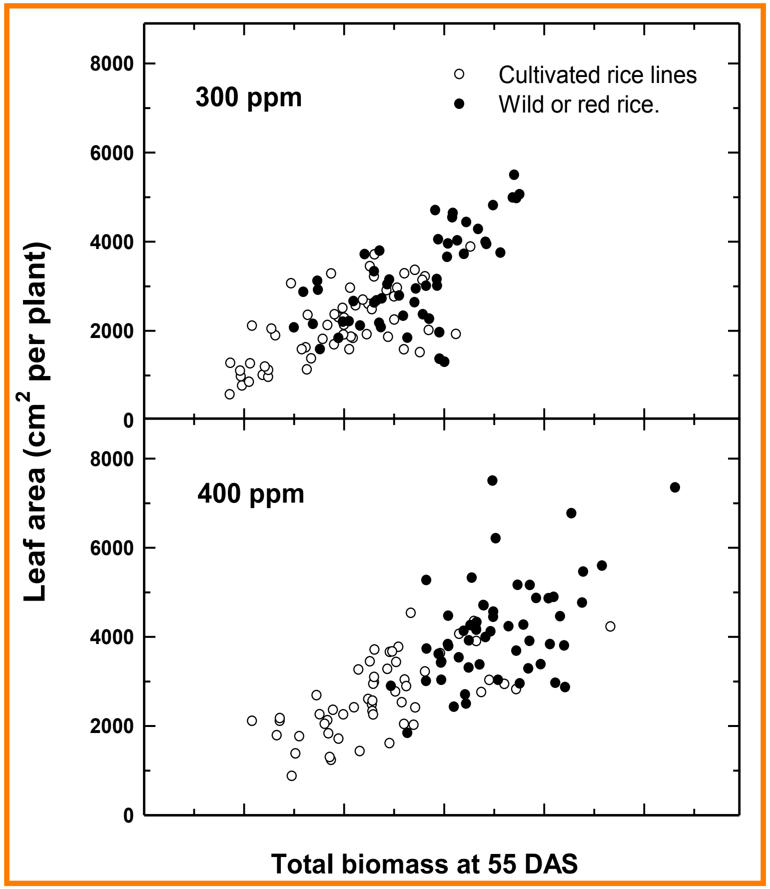
Percent outcrossing and outcrosses per plot for the pollen donor as detected in cultivated and wild rice populations in the field plots.

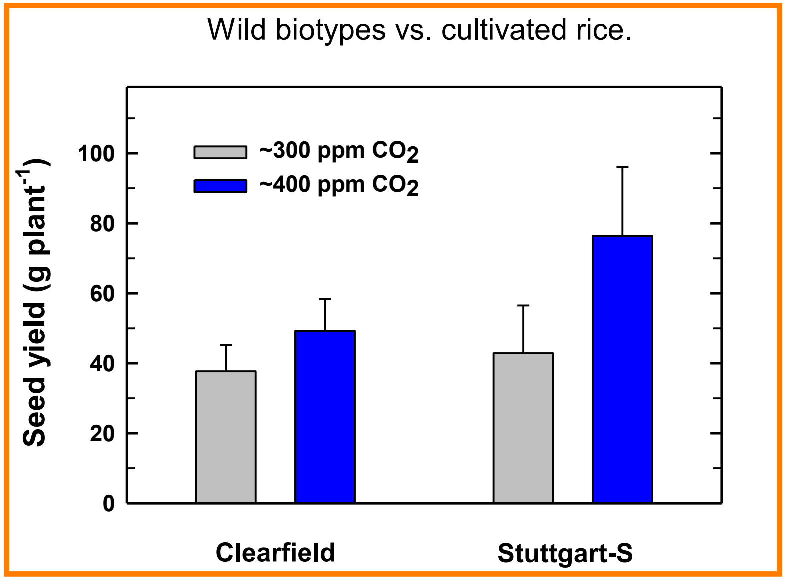


The direction of outcrossing was from wild to the cultivated population; this resulted in a subsequent increase in rice dedomestication and a greater number of weedy, herbicide-resistant hybrid progeny

Why the difference in biotic response between wild and cultivated?

A comparison of wild and cultivated rice lines.





Suggestion that there has been selection by nature for increased sensitivity to recent changes in atmospheric carbon dioxide; in contrast to artificial selection.

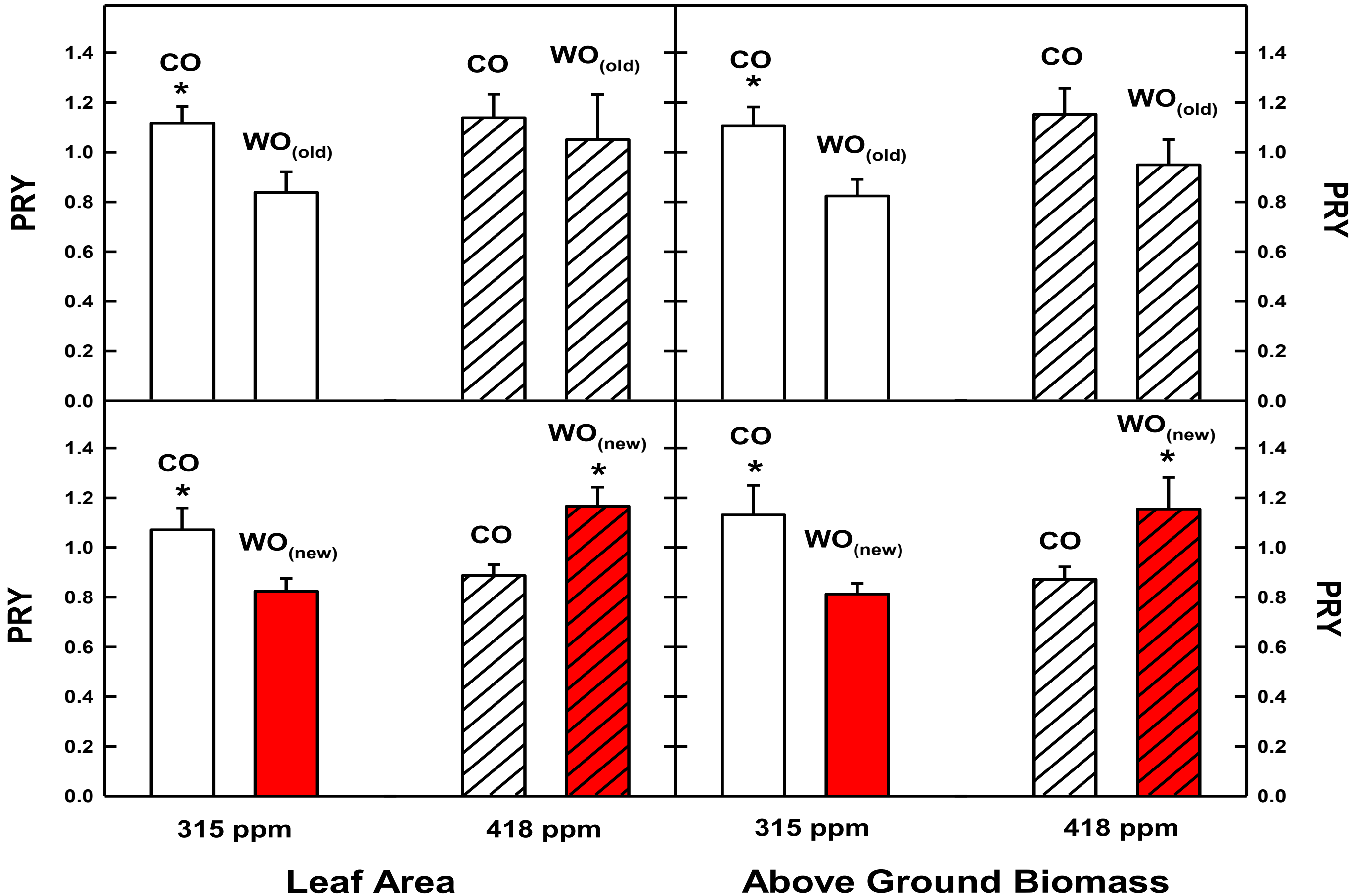
Can recent increases in CO_2 be a selection factor in weed biology and competitive performance?

1965, ~319 ppm CO_2
WO_{old}

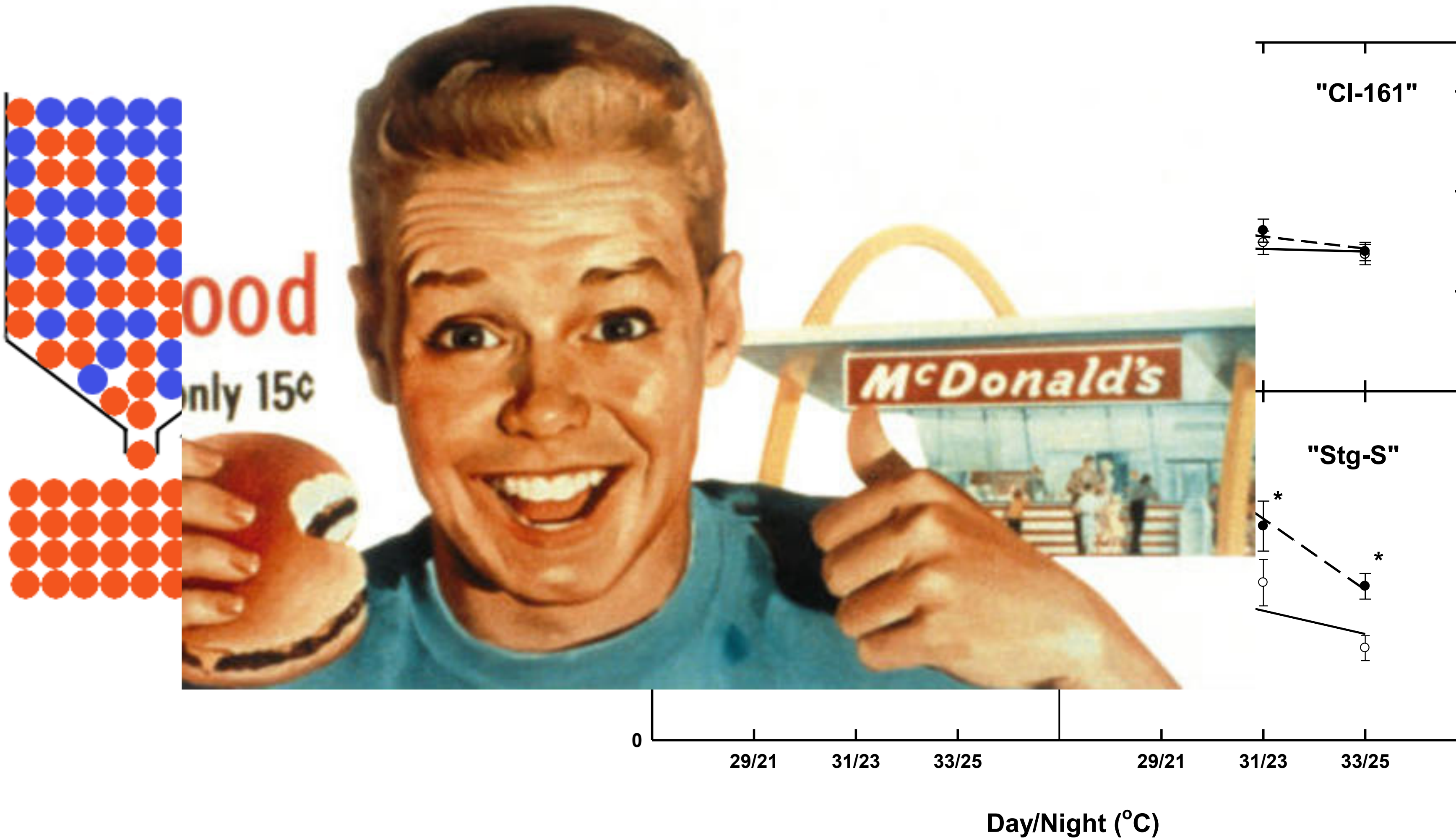
2013, ~395 ppm CO_2
WO_{new}

Clintland 64, Cultivated Oat

CO2 and Selection

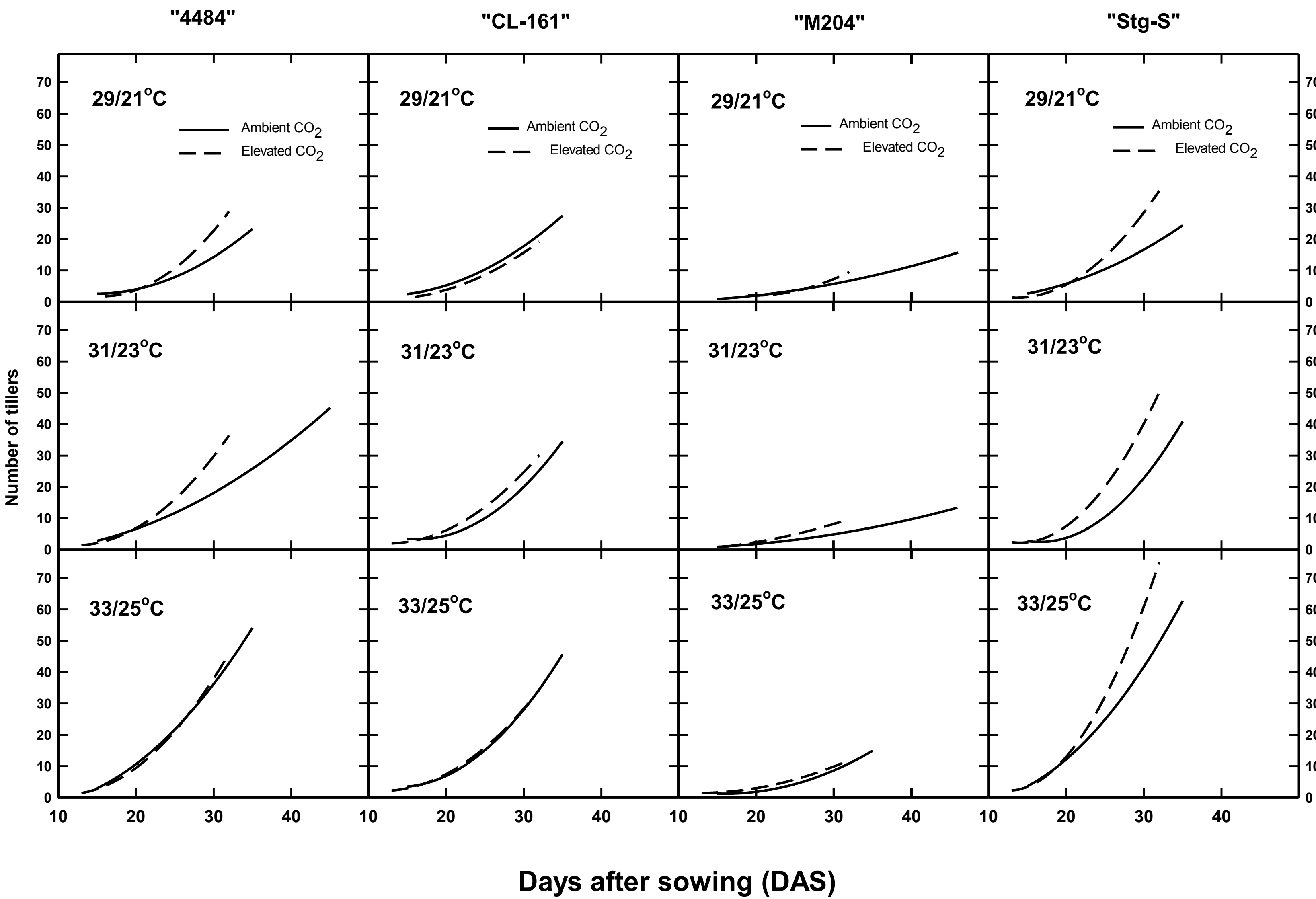


Why are weeds adapting to CO_2 and not crops?



How are weeds adapting?

What characteristics are associated with greater increases in seed yield as CO2 increases?



Let me Sum Up.

There is no basis for assuming that as CO_2 rises, or as climate changes, that weeds will be less of a threat for crop production based on photosynthetic pathway. Preliminary evidence suggests that weeds may impose greater limitations on crop production.

The worst weeds, often wild relative of the crop, may be better able to adapt to the increase in CO_2 and/or temperature associated with future conditions. This adaptation may include, but is not limited to, increased gene transfer from wild to Cultivated lines, increased herbicide resistance and enhanced adaptation to CO_2.

?

However, adaptation among wild, weedy lines may serve as a means to enhance adaptation of cultivated lines, especially cereal lines, to increase production as CO_2 increases. We may be able to learn from our weedy “cousins”.