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Is Smoke from Wildfires Affecting Crop Yields?

Indiana CCA Conference

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Introduction

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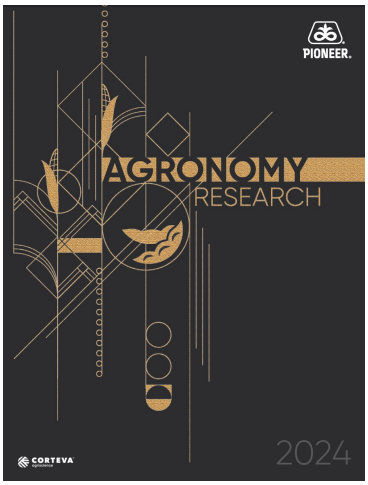
Agronomy Sciences Publications

- Pioneer agronomy library on www.pioneer.com



2024 Pioneer Agronomy Research Summary Book

- Available now on pioneer.com
- Print copies available January 2024

Wildfire Smoke in the Midwest

- Noticeable levels of smoke in the air during summer and fall have now become commonplace
- Wildfire smoke is often most noticeable in the evenings, with hazy red sunsets
- During the day, the smoke creates a persistent cloudy haze in the air, reducing the intensity of direct sunlight and making it more diffuse

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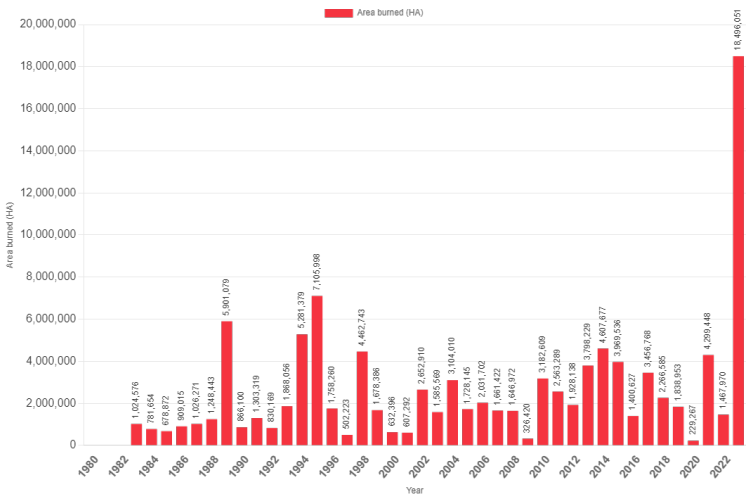
Are Wildfires Getting Worse?

Canadian Wildfires

- Area burned in Canada in 2023 was unprecedented – over 2x any prior year
- Some indication of upward trend in area burned over past 40 years



Total hectares burned by wildland fires in Canada, 1983-2023. Source: Canadian Interagency Forest Fire Centre.

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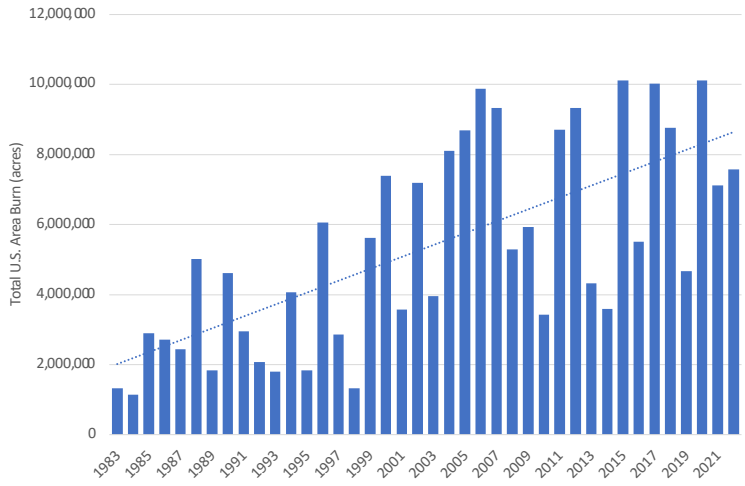
Are Wildfires Getting Worse?

U.S. Wildfires

- Clear increasing trend in total area burned.
- Burned area from wildfires in the U.S. has quadrupled over the past 40 years



Total acres burned by wildland fires in the U.S., 1983-2022. Source: NIFC Wildland Fire Statistics, 2023.

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Why are Wildfires Getting Worse?

1. Poor Forest Management

- Fire is a natural part of forest ecosystems, but regulatory hurdles prevent prescribed burning and other forms of preventative management
- Result = buildup of combustible fuel and elevated fire risk

2. Climate Change

- Hotter, drier climate is conducive to larger and more frequent fires

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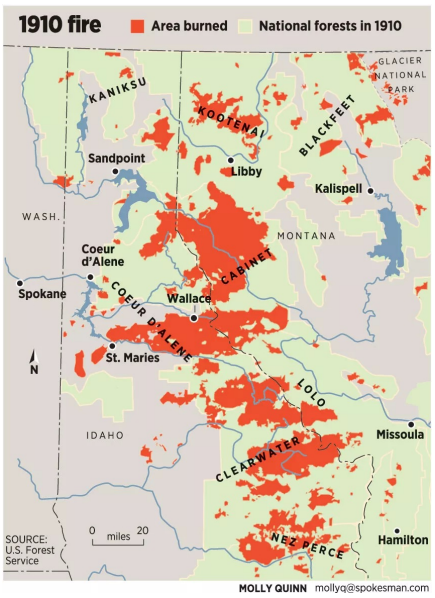
"The Big Burn" - 1910

- Massive wildfire in August of 1910
- Preceded by extremely dry conditions in winter 1909 through spring 1910
- Burned over 3 million acres, mostly in northern Idaho and western Montana
- Several towns destroyed
- 87 fatalities



"The Big Burn" - Legacy

- This single event shaped U.S. forest management policy for decades to come
- U.S. Forest Service founded a few years earlier in 1905
- "10 a.m. policy" - Put 'em out, put 'em all out, and put 'em all out fast
- Three consecutive Forest Service Chiefs were personally involved in fighting the Big Burn (1920-1939)

Thinking Like a Mountain, About Fire – Tom Tidwell, U.S. Forest Service Chief, Big Burn Centennial Commemoration, Boise, ID — May 22, 2010

Preventative Fire Management

- Important role of fire in natural ecosystems is now widely recognized, but acting on that knowledge can be difficult
- Growth of populations in wildland-urban interface
- Resistance to controlled burning from private land-owners and local communities
- Cumulative effects of decades of suppression-focused management
- Recent California drought has added to fuel load
- Limited effectiveness of active forest management

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Climate Change

The increase in fire activity over the past 20 years has largely been driven by climate change (Abatzoglou and Kolden 2013)

- Increased temperatures and lower precipitation during the fire season
- Lengthening of the fire season due to higher spring and fall temperatures
- Earlier snowmelt
- Reduced river flows

All of these factors have contributed to make fuel loads in forests drier and more combustible (Overpeck and Udall, 2020)

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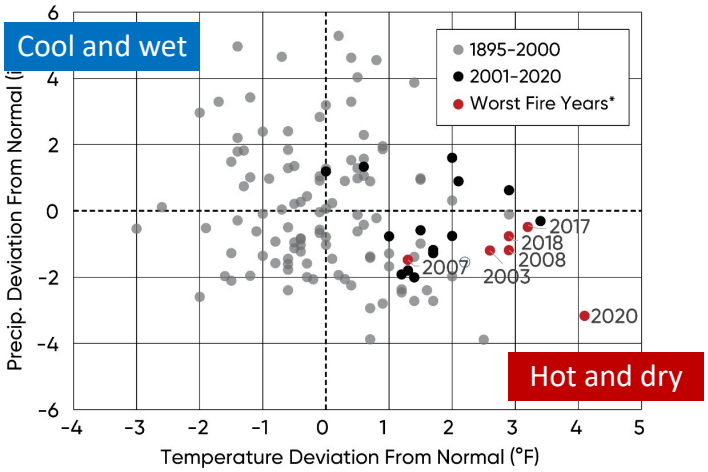
Climate Effects on California Wildfires

- Average fire season temperatures have exceeded the 20th Century average every year since 2004
- The worst wildfire years in California – years in which over 1 million acres burned – have all been years with above-average temperature and below-average precipitation



California temperature and precipitation deviation from average from July-November of each year, 1895-2020. * Over 1 million acres burned.

Source: NOAA National Centers for Environmental Information

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Sources of Ignition

- The large majority of wildfires nationwide are human caused
- *However,* fires in the Western U.S. that burn large areas tend to be lightning caused (Prestemon et al., 2013)
- 77% of burned area in boreal forests globally associated with lightning ignition (Janssen et al., 2023)

Table 2—Fire causes, reported average annual ignitions, reported average annual area burned, and percentage shares of fires by causes, using combined data from the U.S. Department of the Interior and the Forest Service, U.S. Department of Agriculture, January 2000–December 2008

Cause	Average annual ignitions reported	Average annual area burned reported, acres	Percentage share of reported ignitions	Percentage share of reported area burned
Natural/Lightning	10,874	5,496,235	45.34	79.90
Campfire	1,964	179,338	8.19	2.61
Smoking	418	22,387	1.74	0.33
Fire Use/Debris Burning	1,538	100,971	6.41	1.47
Incendiary/Arson	2,969	268,962	12.38	3.91
Equipment (Use)	1,338	246,804	5.58	3.59
Railroad	117	14,193	0.49	0.21
Juveniles/Children [a]	1,063	20,464	4.43	0.30
Miscellaneous and unknown [b]	3,704	529,313	15.44	7.69

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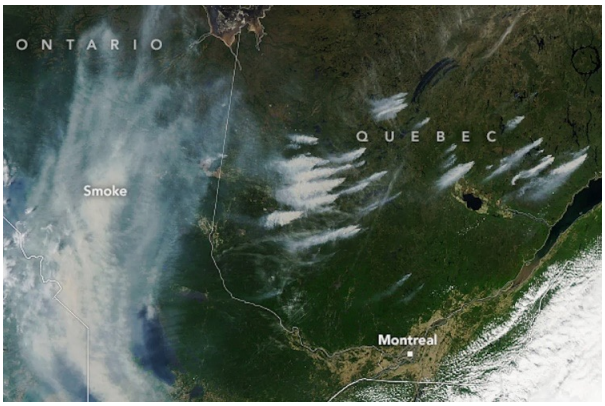
Lightning-Caused Fires

- Lightning was a major factor in Canadian wildfires in 2023 and California fires in 2020.
- Environmental conditions preceding and following thunderstorms determine whether the fire smolders and burns out or explodes into a major conflagration
- Frequency of lightning increasing with rising global temperatures (Janssen et al., 2023, Pérez-Invernón et al., 2023)



Smoke from wildfires in Quebec; June 3, 2023. Lightning strikes from a storm system can ignite numerous fires in an area that will then all flare up at the same time when conditions turn hot and dry. Image: NASA Earth Observatory

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Future Outlook

Combustible fuel	↑	Buildup of fuel Impacts of California drought
Sources of ignition	↑	Increase in lightning frequency
Favorable conditions	↑↑	Increased temperatures, lower precip., lengthening of the fire season, earlier snowmelt, reduced river flows

Wildfire smoke is likely to be an ongoing or worsening issue.

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Impact of Wildfire Smoke

- The increase in wildfire activity has led to a substantial increase in the number of days each year impacted by smoke in the air.
- Effects of wildfire smoke extend far beyond the immediate vicinity of the fires, with increases observed throughout the U.S. (Burke et al., 2021).

Central Iowa. July 31, 2021.

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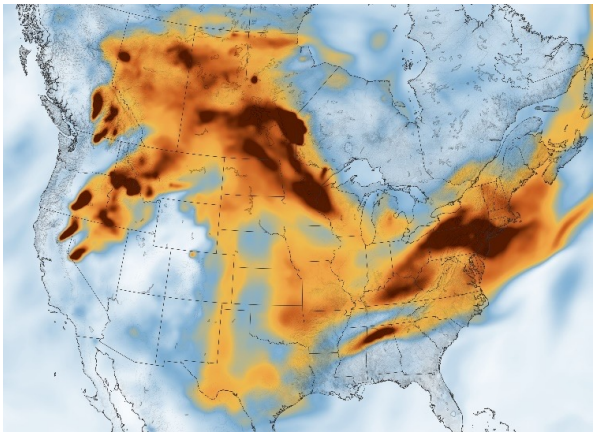
Impact of Wildfire Smoke

- At high altitudes, the smoke can travel with jet stream winds across the continent (NASA, 2017).
- Pockets of concentrated smoke can sometimes occur far from the fires that generated it



Smoke concentration in the atmosphere over North America from fires in the Western U.S. and Canada, July 21, 2021. Source: NASA Earth Observatory.

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Effects on Sunlight

Reduced Sunlight Intensity

- Smoke reflects a portion of incoming sunlight, reducing the amount available to plants
- Since plants depend on sunlight to carry out photosynthesis, any reduction in light is potentially detrimental to crop productivity
- C4 plants are more susceptible to reductions in solar radiation

Increased Diffusion of Light

- Wildfire smoke can significantly increase the diffuse fraction of photosynthetically active radiation (PAR)
- Can benefit plants by increasing their light use efficiency

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Complex and Interacting Effects

- Reduced total solar radiation is likely to be negative in most circumstances
- Increased diffusion of solar radiation could potentially be positive for crop growth
- Any benefit derived from increased diffuse radiation could be negated if the reduction in total solar radiation is too great
- Reduction in solar radiation can reduce surface temperatures, which may be good, bad, or neutral depending on the timing and circumstances
- If a crop is suffering through a period of drought stress, a temporary moderation of daytime temperatures may be helpful
- If a crop is running behind in its development due to below-normal GDU accumulation, further reductions in temperature from wildfire smoke will likely make things worse

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Impacts of Reduced Solar Radiation

Reductions in yield can be dramatic

- Studies that have included shade treatments that reduce light by 50% or more during grain fill have seen corn yield drop by more than half

Percent corn yield reduction associated with three different levels of shading (15%, 30%, and 50%) for two hybrids at three different plant densities (Yang et al., 2019).

Density (plants/acre)	Hybrid 1			Hybrid 2		
	15%	30%	50%	15%	30%	50%
	yield reduction (%)					
30,400	NS*	NS	35	13	19	50
42,500	NS	19	42	15	25	55
48,500	NS	24	51	14	29	64

* Not significant at α=0.05

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Impacts of Reduced Solar Radiation

Timing and intensity matter

- The more solar radiation is reduced, the greater the effect on yield
- Reductions in solar radiation during silking and grain fill have a much greater impact than the same level of reduction prior to silking (Liu and Tollenaar, 2009; Reed et al., 1988)

Effect of shade treatment timing on corn yield (Liu and Tollenaar, 2009.)

Shade Period[1]	Yield Reduction (%)
4 weeks pre-silking[a]	3.2% NS
3 weeks at silking[b]	12.6% **
3 weeks post-silking[c]	21.4% **

[1] Weeks relative to silking: [a] -5 to -1, [b] -1 to +2, [c] +2 to +5. Shading treatments reduced solar radiation by 55%

NS=not significant, **= highly significant, (α=0.05)

Effects of a 70% shade treatment applied at different timings on corn pollination and ear length in a 2021 Pioneer Agronomy study (Emmert, 2021).

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Impacts of Reduced Solar Radiation

Effects can vary by hybrid and plant density

- Yang et al. (2019) findings:
- Greater yield reductions at higher plant densities
- Two hybrids compared in the study differed in their response to reduced light levels

Percent corn yield reduction associated with three different levels of shading (15%, 30%, and 50%) for two hybrids at three different plant densities (Yang et al., 2019).

Density (plants/acre)	Hybrid 1			Hybrid 2		
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30,400	NS*	NS	35	13	19	50
42,500	NS	19	42	15	25	55
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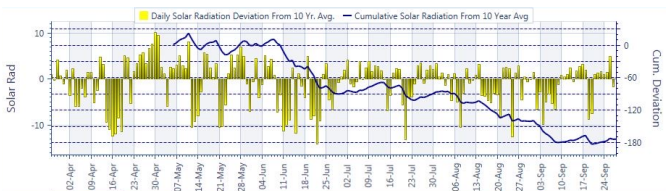
* Not significant at α=0.05

Impacts of Reduced Solar Radiation

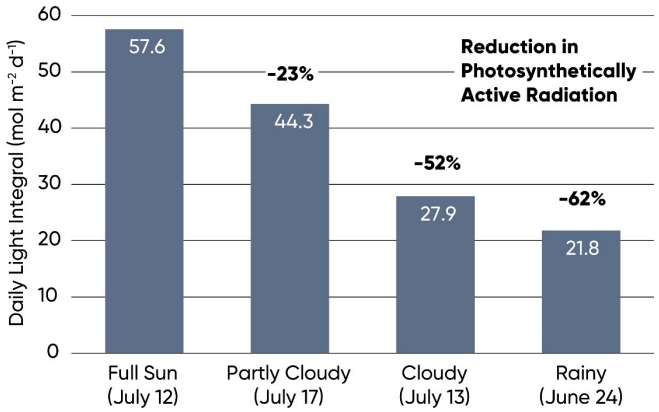
Reduced solar radiation can also affect stalk quality

- Severe stalk rots and lodging have often been observed in association with prolonged periods of low solar radiation during grain fill



How Much Does Wildfire Smoke Reduce Solar Radiation?

- Effects of cloud cover on PAR
- Partly cloud = ~25% reduction



Daily PAR received in Johnston, IA under sunny, cloudy, and rainy conditions on four different days during summer of 2015.

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How Much Does Wildfire Smoke Reduce Solar Radiation?

2018 Study in the California Central Valley (Hemes et al., 2020)

- Total PAR was reduced by 3.6% on average due to wildfire smoke
- Diffuse fraction increased by over 34% during the study period (mid-July – August)
- Predicted effect on corn was a 2.5% *increase* in photosynthesis, as the positive effect of more diffuse PAR exceeded the negative effect of reduced total PAR
- However, under the smokiest conditions observed during the study period, photosynthesis was predicted to decline by over 8%

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How Much Does Wildfire Smoke Reduce Solar Radiation?

- California study on lake ecosystems found that wildfire smoke over a 55-day period in 2018 reduced PAR by 11% (Scordo et al., 2021).
- Ohio State found 6-7% reduction in PPFD in 2021 (smoky) compared to 2017-2020 (not smoky).

Daily average photosynthetic photon flux density in Wood County, Ohio (Lindsey et al., 2021).

Year	June	July
	— µmol/m²/s —	
2021	679	694
2017 to 2020	730	738
Difference	**-7%**	**-6%**

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Effects on Solar Radiation and Crop Yield

Is wildfire smoke affecting crops through its effects on solar radiation? **Yes**

***Could* it cause reductions in yield?** **Yes**

***Has* it caused reductions in yield?** **Probably not**

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Direct Effects of Ground-Level Smoke

- The Canadian wildfires of 2023 brought increased attention to the direct impacts of ground-level smoke on living organisms (Londo et al., 2023)

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What is in Wildfire Smoke?

- Largest component of smoke is water vapor
- Other constituents include carbon dioxide, carbon monoxide, and nitrogen oxides
- Fine particulate matter ($PM_{2.5}$) is the main cause of the visible haze of smoke that reflects and scatters sunlight
- Thousands of different chemical compounds can be contained in small amounts within the particulate and gaseous fractions
- Compounds contained in wildfire smoke can undergo reactions in the atmosphere, changing the composition of the smoke over time

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Components Harmful to Plants

- Particulate matter, ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) are all components of wildfire smoke that are known to be harmful to plants
- All four have been shown to reduce yields in corn and soybeans
- A 2021 study estimated that the presence of these pollutants in the atmosphere has reduced yields of corn and soybean in the U.S. by roughly 5% over the past 20 years (Lobell and Burney, 2021).
- *However*, these pollutants can come from a variety of sources other than wildfire smoke;
- Additional contribution from wildfire smoke large enough to impact yield?

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Ozone

- Ground-level ozone is very harmful to plants, causing more damage to plants than all other air pollutants combined (USDA ARS, 2016)
- Ozone (O_3) is most commonly known for the naturally occurring ozone layer in the upper atmosphere that shields Earth from harmful ultraviolet radiation
- Ozone is a strong oxidant and damages plants by entering stomata and oxidizing (burning) plant tissue
- Formed when pollutants, mainly nitrogen oxides and volatile organic compounds, react in the atmosphere in the presence of sunlight
- Corn and soybean are both susceptible to yield loss from ozone pollution (McGrath et al., 2015)

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How Does Smoke Affect Ground Level Air Quality?

- The smokiest day of 2023 at the Corteva Agriscience research farm at Johnston, IA was June 28
- How much was air quality impacted?

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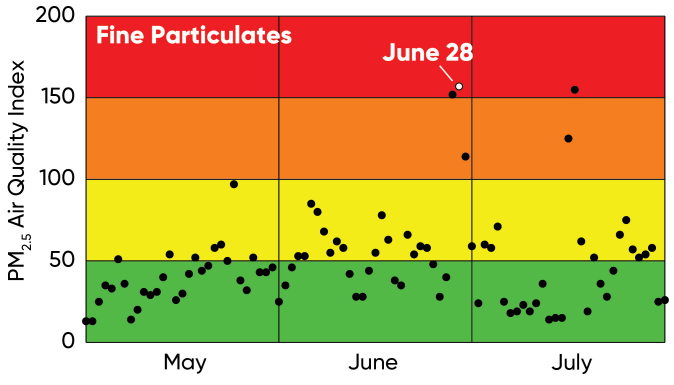
How Does Smoke Affect Ground Level Air Quality?

- Clear spike of $PM_{2.5}$ level into unhealthy range

Air Quality Index (0-500 Scale)

	0-50	Good
	51-100	Moderate
	101-150	Unhealthy for Sensitive Groups
	151-200	Unhealthy
	201-300	Very Unhealthy
	301 and up	Hazardous



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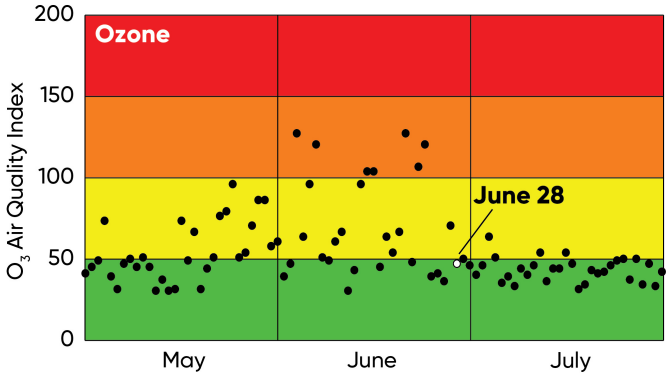
How Does Smoke Affect Ground Level Air Quality?

- No effect on ozone level

Air Quality Index (0-500 Scale)

0-50	Good
51-100	Moderate
101-150	Unhealthy for Sensitive Groups
151-200	Unhealthy
201-300	Very Unhealthy
301 and up	Hazardous



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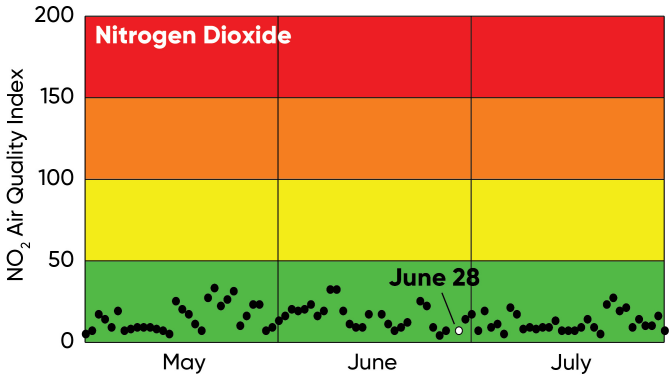
How Does Smoke Affect Ground Level Air Quality?

- No effect on nitrogen dioxide level

Air Quality Index (0-500 Scale)

0-50	Good
51-100	Moderate
101-150	Unhealthy for Sensitive Groups
151-200	Unhealthy
201-300	Very Unhealthy
301 and up	Hazardous



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Effects of Smoke on Crops

Is wildfire smoke affecting crops through its effects on solar radiation?	Yes
Could it cause reductions in yield?	Yes
Has it caused reductions in yield?	Probably not
Are direct phytotoxic effects of ground-level smoke likely to negatively impact crops?	**Probably not**

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Conclusions

- It's plausible that heavy and persistent wildfire smoke cover could impact crop productivity
- It seems unlikely that the smoky conditions experienced over the past few years have had a significant impact on yields in most areas
- Reductions in solar radiation have been temporary and relatively minor, analogous to a slight increase in the density of cloud cover
- Direct phytotoxic effects of ground-level smoke are not likely to be significant
- Wildfires are likely to increase in frequency and intensity in the coming years
- Effects on wildfire smoke on both agricultural and natural ecosystems will continue to be an active area of research

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