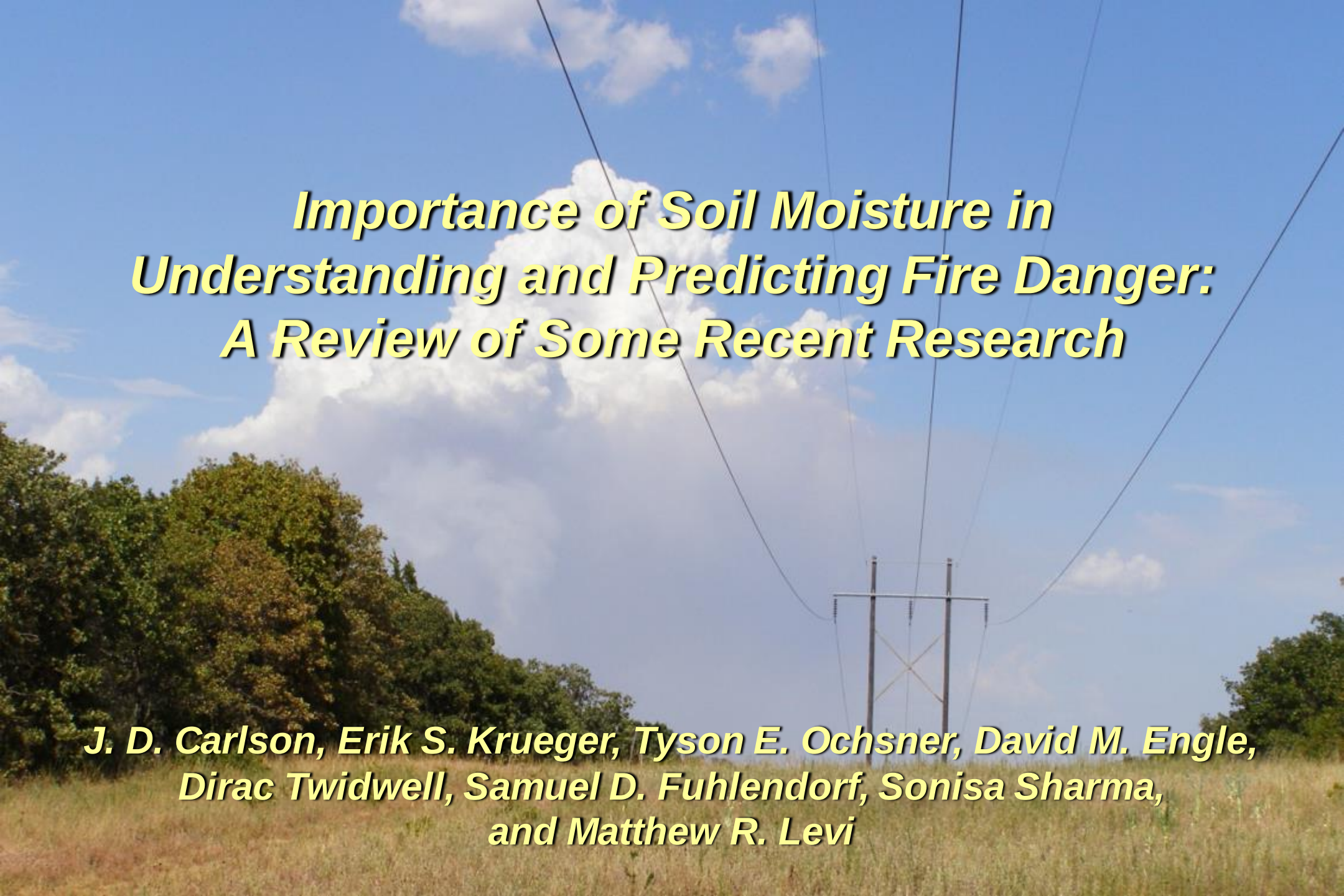

Importance of Soil Moisture in Understanding and Predicting Fire Danger: A Review of Some Recent Research

J. D. Carlson, Erik S. Krueger, Tyson E. Ochsner, David M. Engle, Dirac Twidwell, Samuel D. Fuhlendorf, Sonisa Sharma, and Matthew R. Levi

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REVIEW
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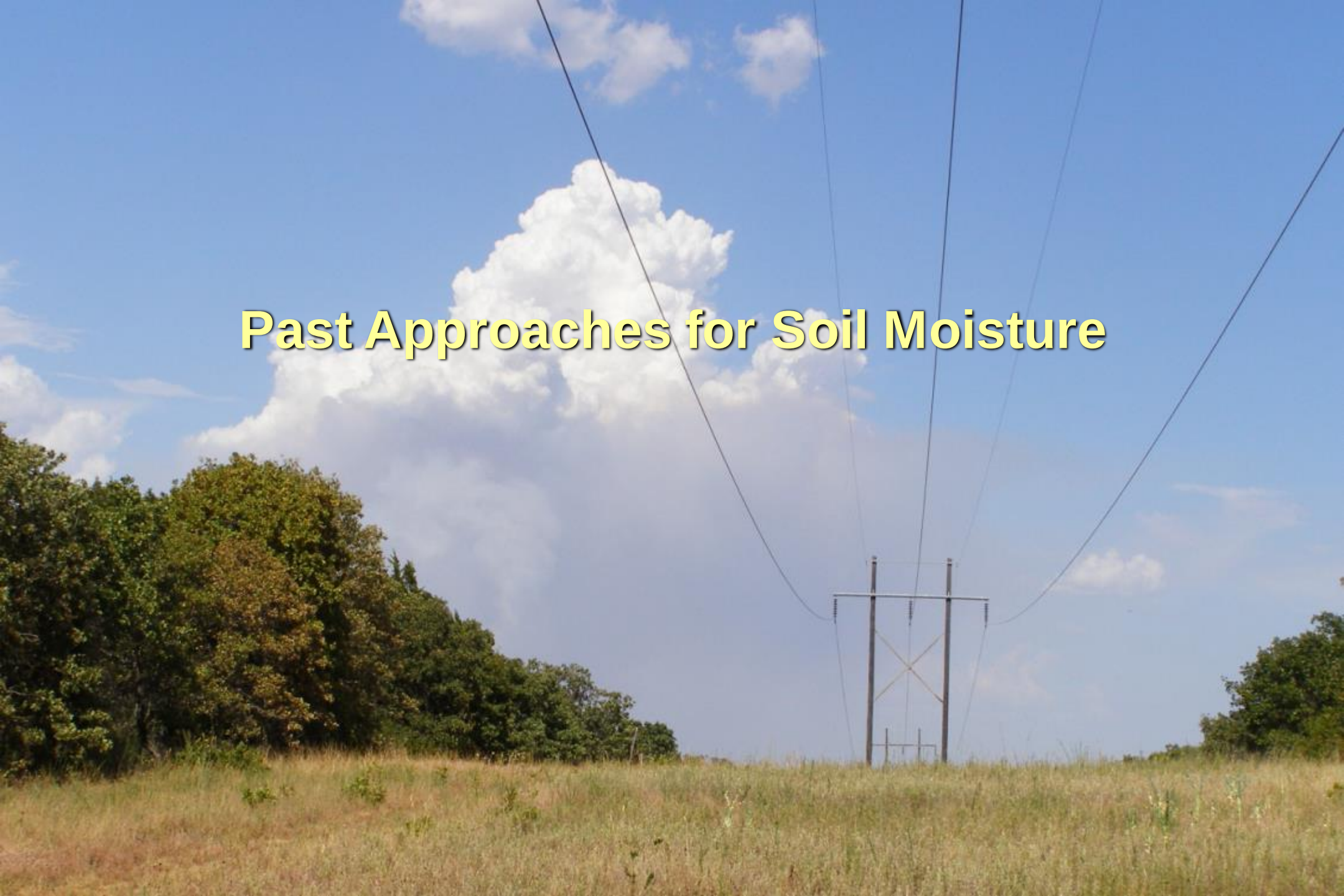
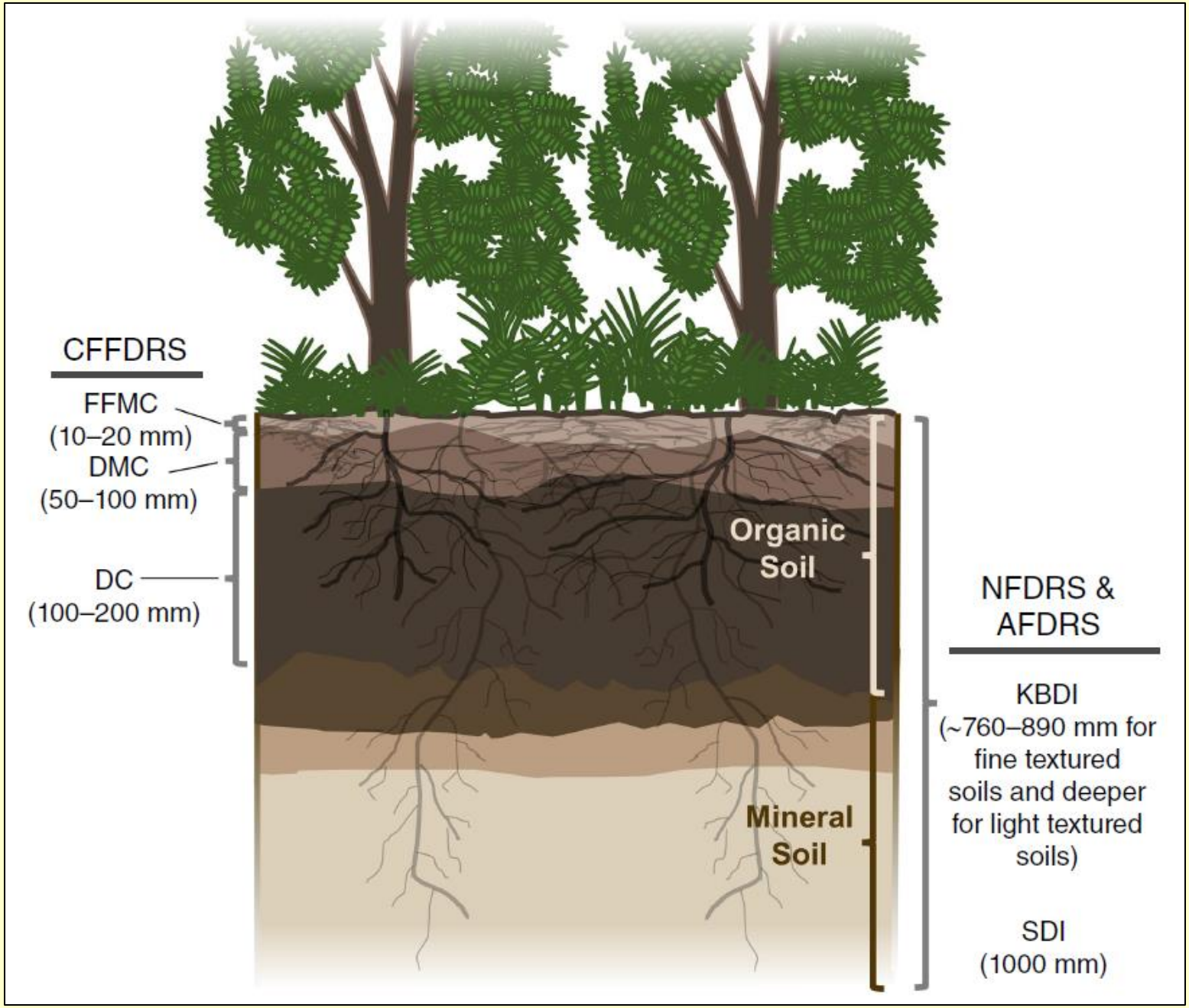
International Journal of WILDLAND FIRE

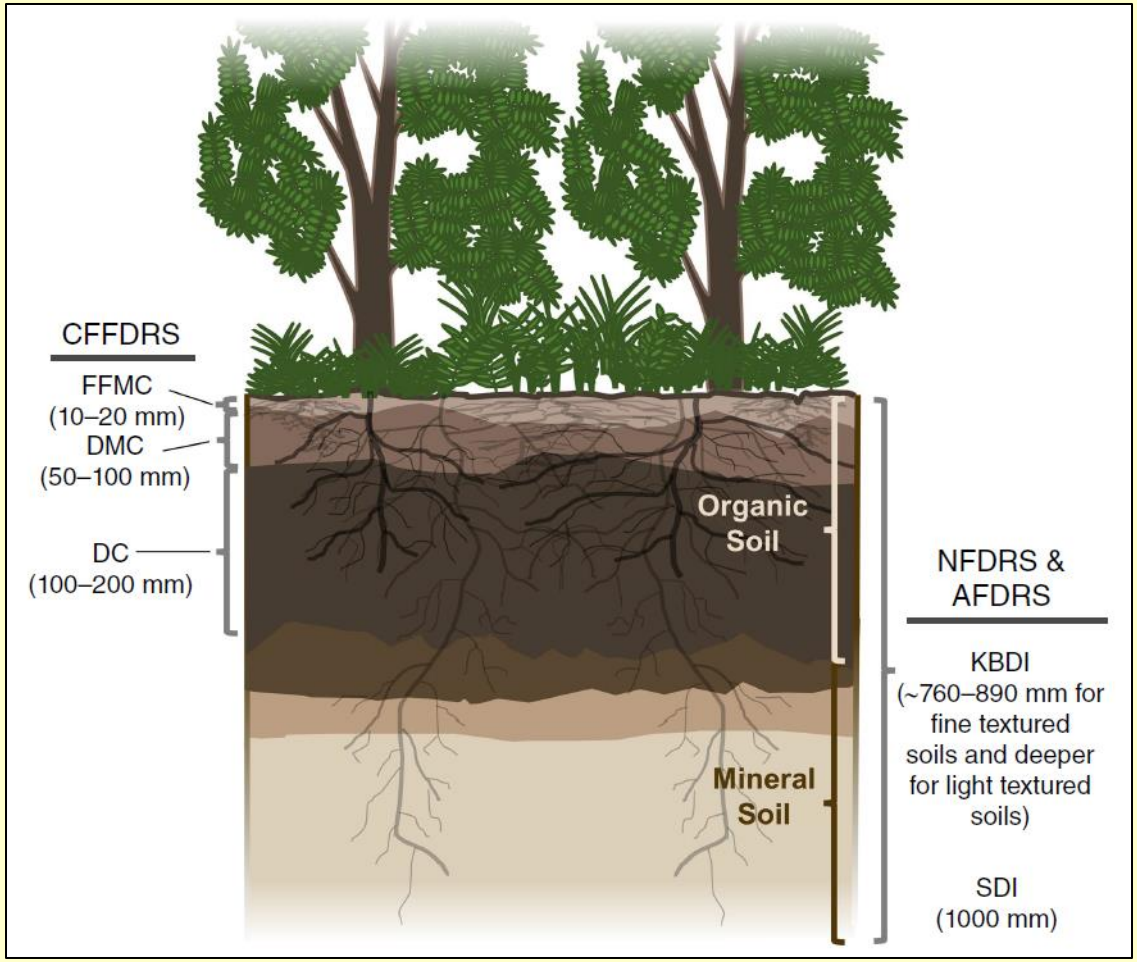
International Association of Wildland Fire

Using soil moisture information to better understand and predict wildfire danger: a review of recent developments and outstanding questions

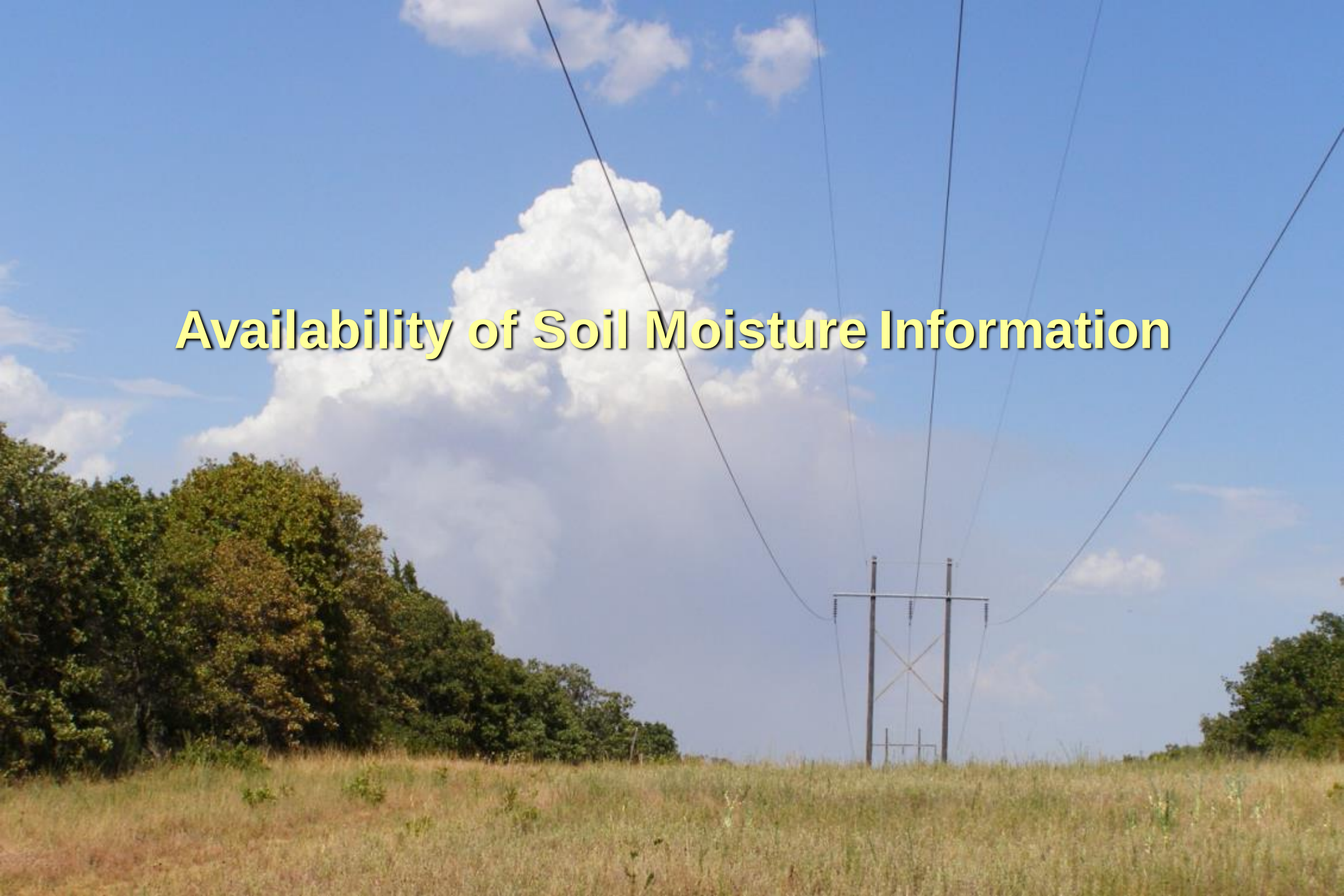
Erik S. Krueger[A,*], Matthew R. Levi[B], Kevin O. Achieng[B,I], John D. Bolten[C], J. D. Carlson[D], Nicholas C. Coops[E], Zachary A. Holden[F], Brian I. Magi[G], Angela J. Rigden[H,§] and Tyson E. Ochsner[A]

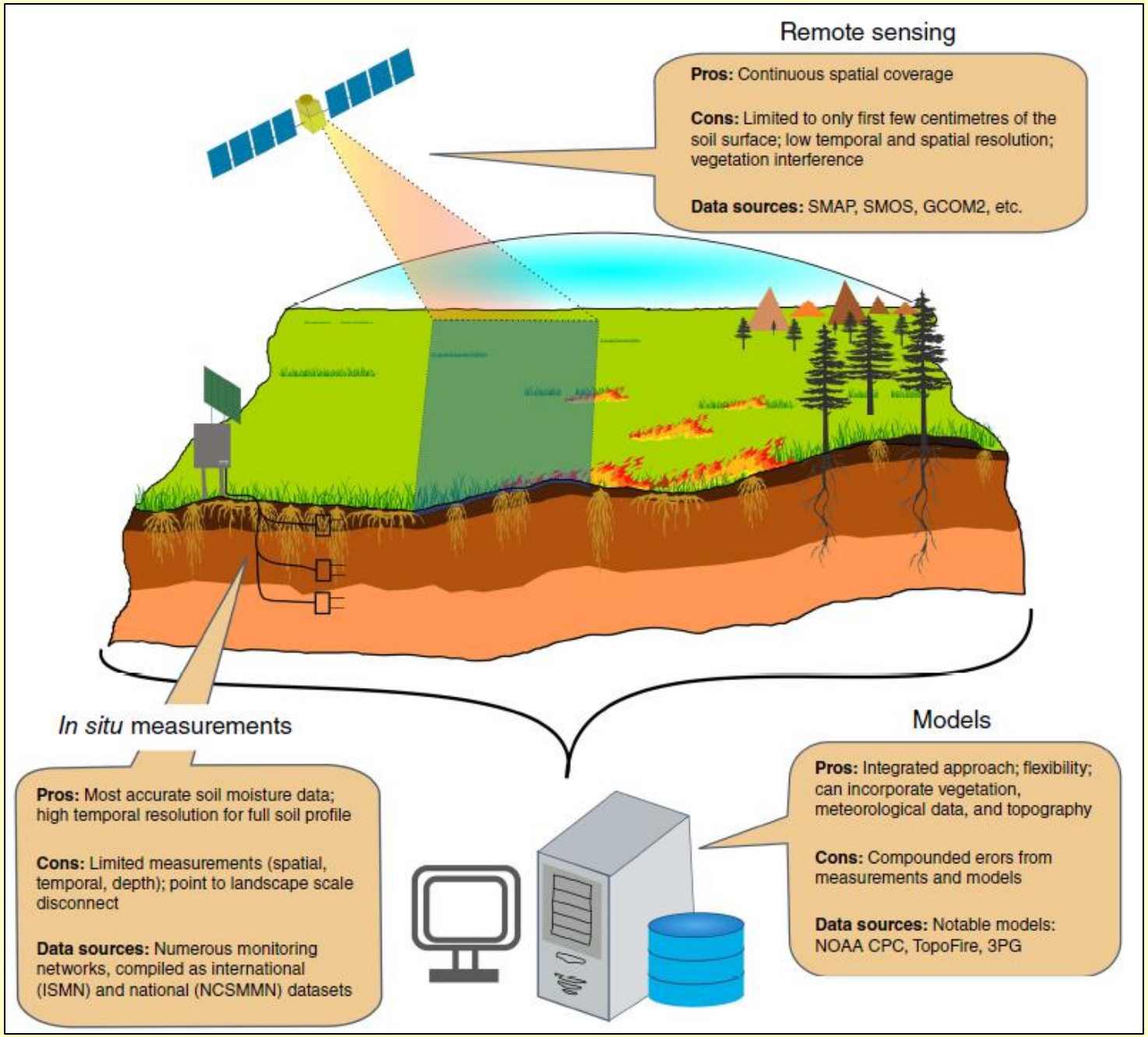

Past Approaches for Soil Moisture

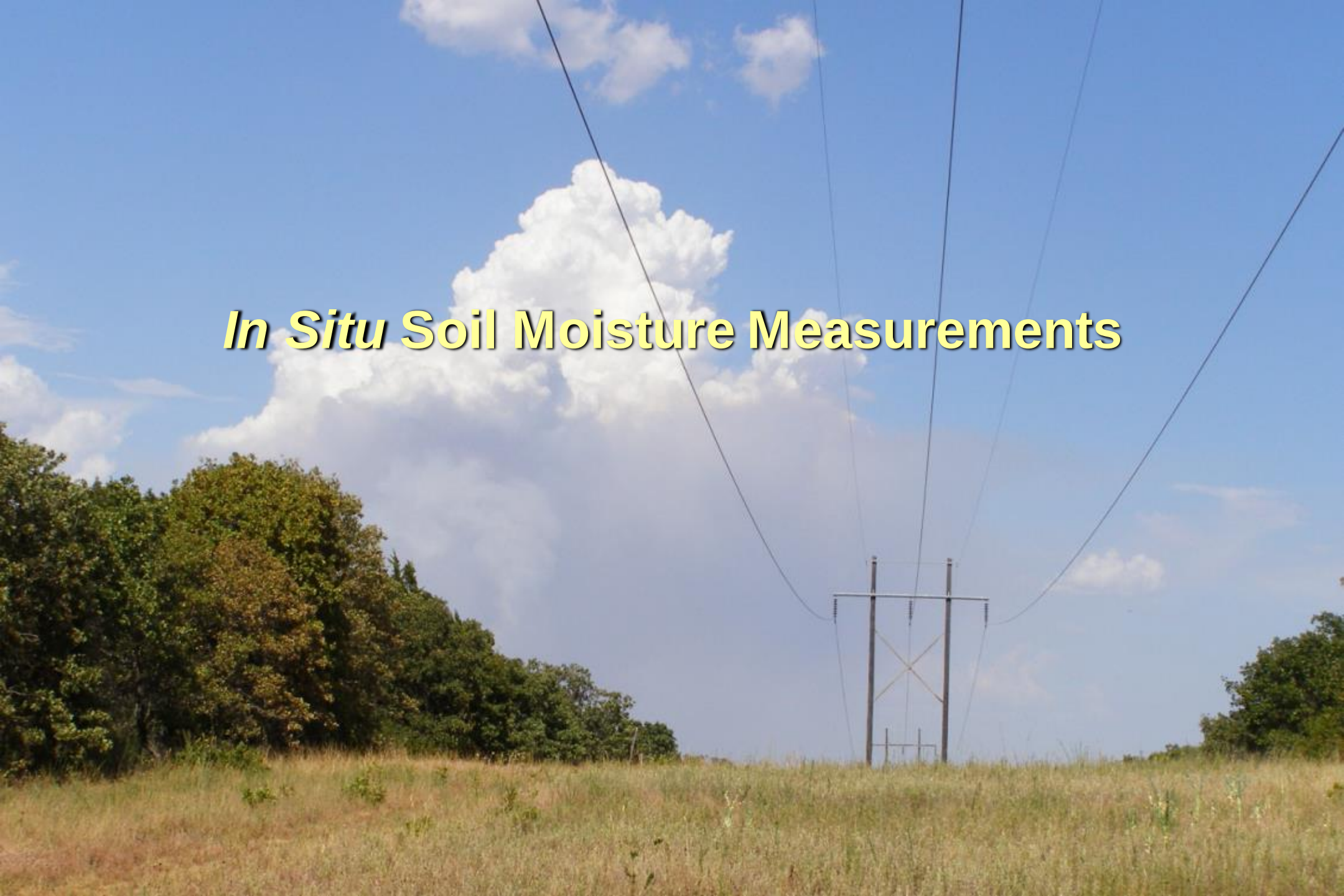

CFFDRS
FFMC
(10–20 mm)
DMC
(50–100 mm)
DC
(100–200 mm)
Organic Soil
Mineral Soil
NFDRS &
AFDRS
KBDI
(~760–890 mm for fine textured soils and deeper for light textured soils)
SDI
(1000 mm)



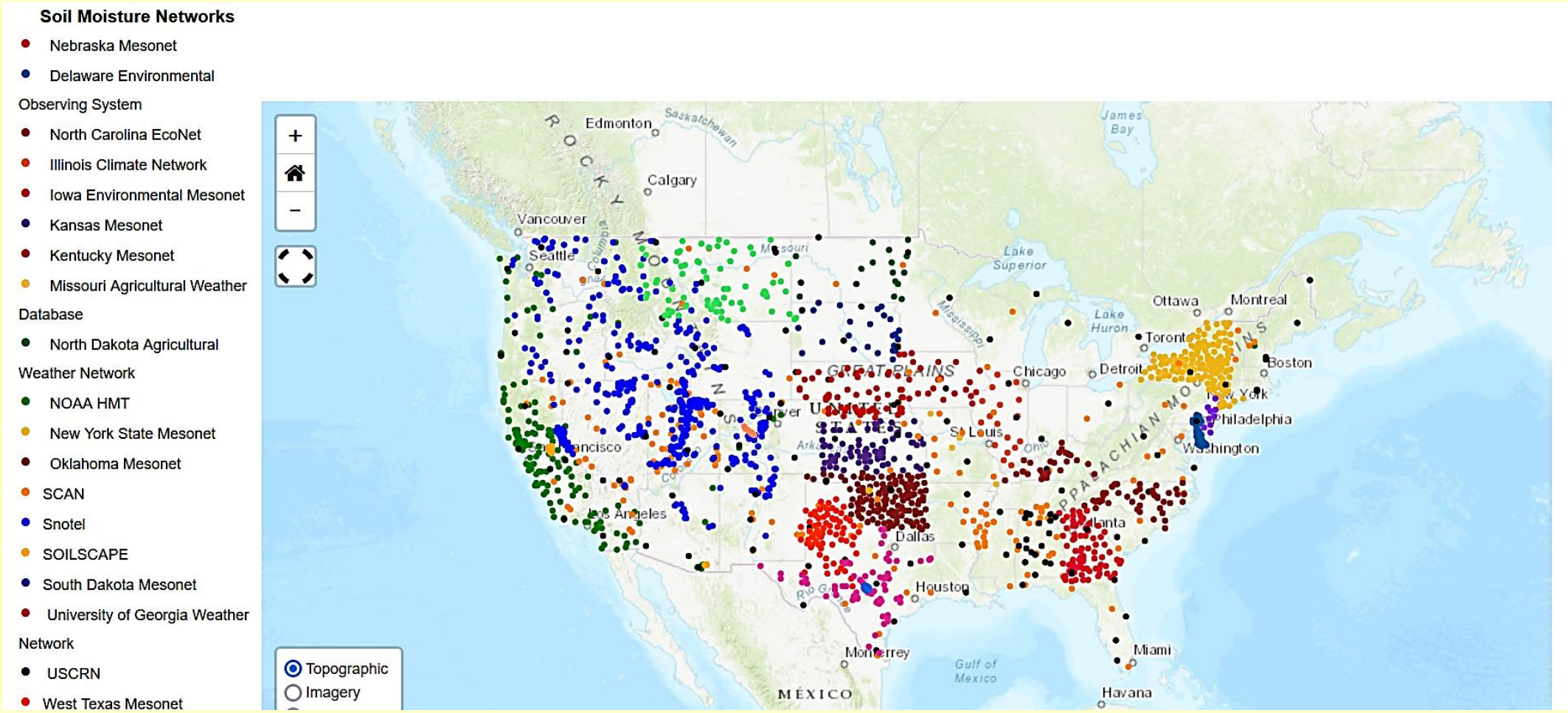
None of these indices use soil moisture from measurements or physically-based hydrologic models, account for physical properties of the soil, or directly account for impacts of overlying vegetation. Instead, moisture content is estimated using simplistic water balance approaches based on weather variables.


Availability of Soil Moisture Information

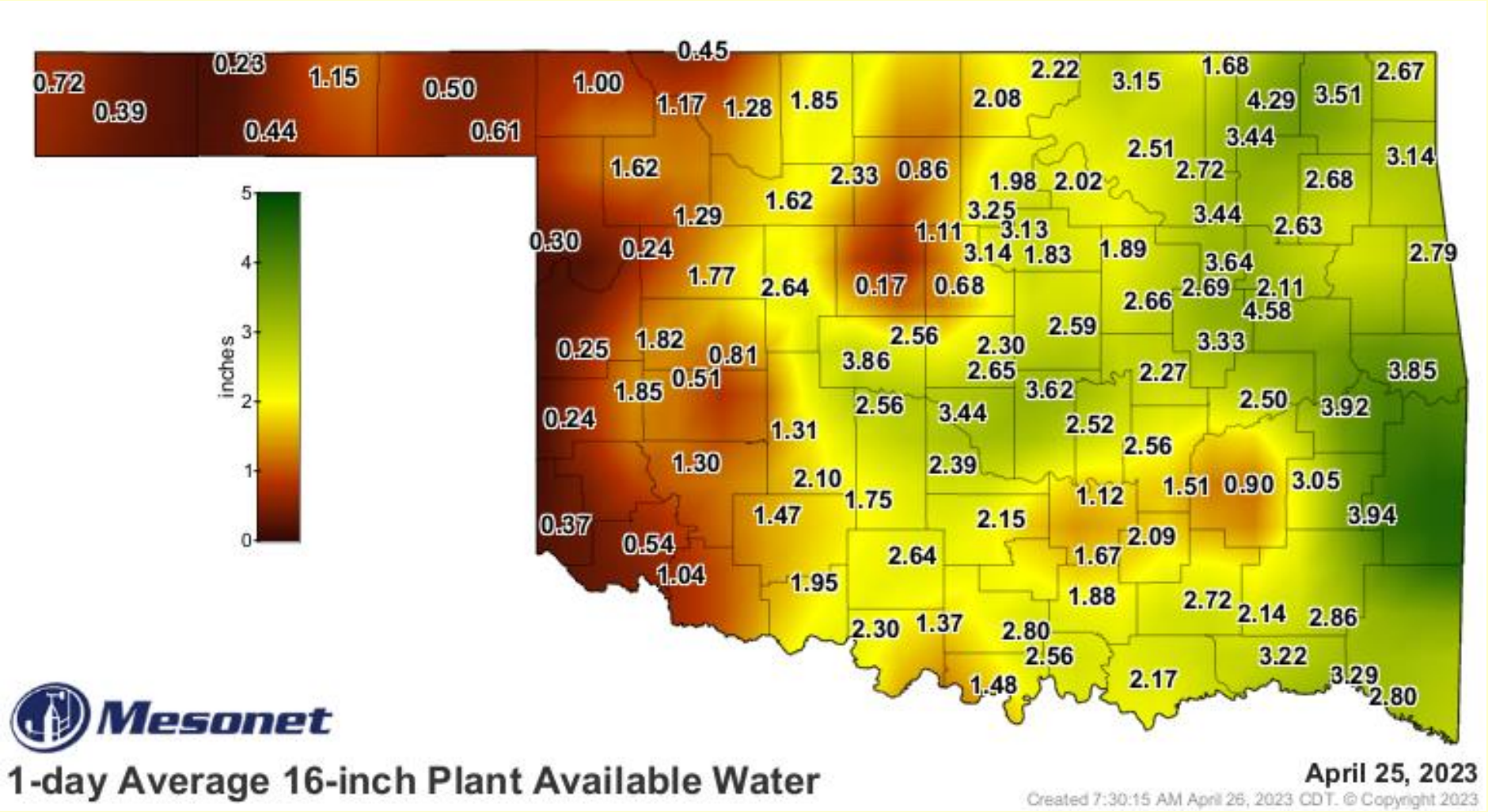

Remote sensing
Pros: Continuous spatial coverage
Cons: Limited to only first few centimetres of the soil surface; low temporal and spatial resolution; vegetation interference
Data sources: SMAP, SMOS, GCOM2, etc.
In situ measurements
Pros: Most accurate soil moisture data; high temporal resolution for full soil profile
Cons: Limited measurements (spatial, temporal, depth); point to landscape scale disconnect
Data sources: Numerous monitoring networks, compiled as international (ISMN) and national (NCSMMN) datasets
Models
Pros: Integrated approach; flexibility; can incorporate vegetation, meteorological data, and topography
Cons: Compounded erors from measurements and models
Data sources: Notable models: NOAA CPC, TopoFire, 3PG


In Situ Soil Moisture Measurements

National Soil Moisture Network

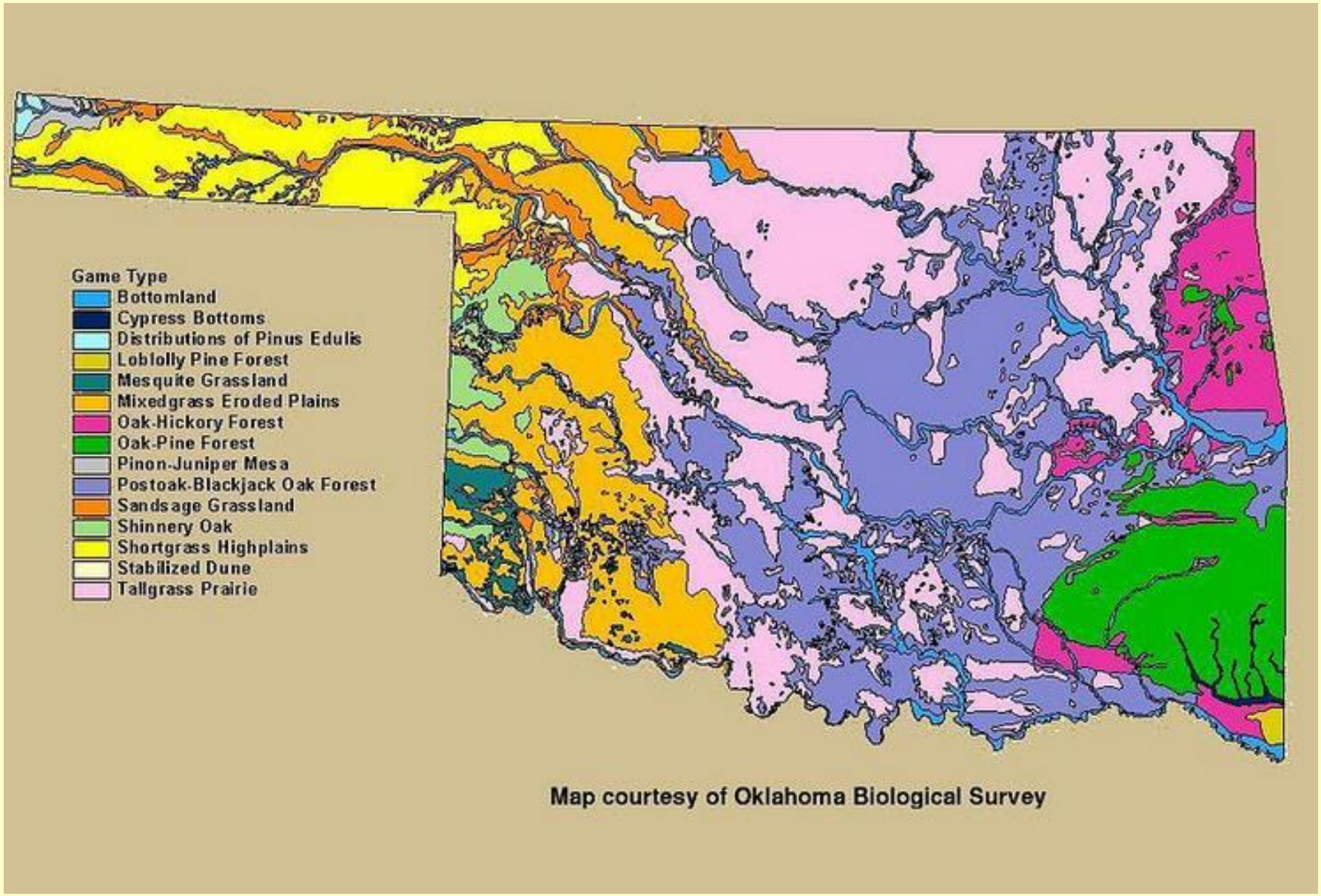


Oklahoma Mesonet

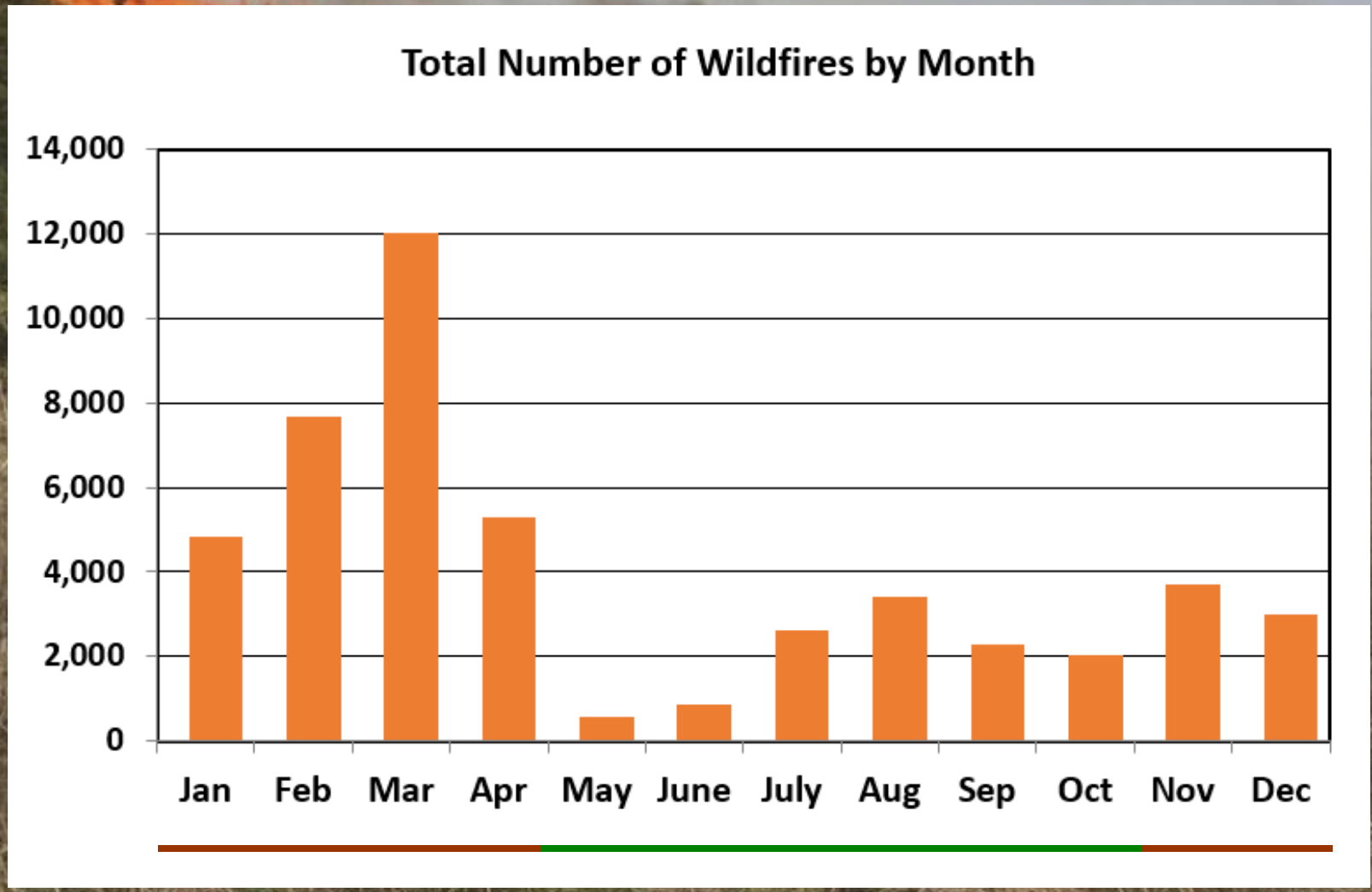


Background to Research: Oklahoma Fuels and Wildfire Climatology

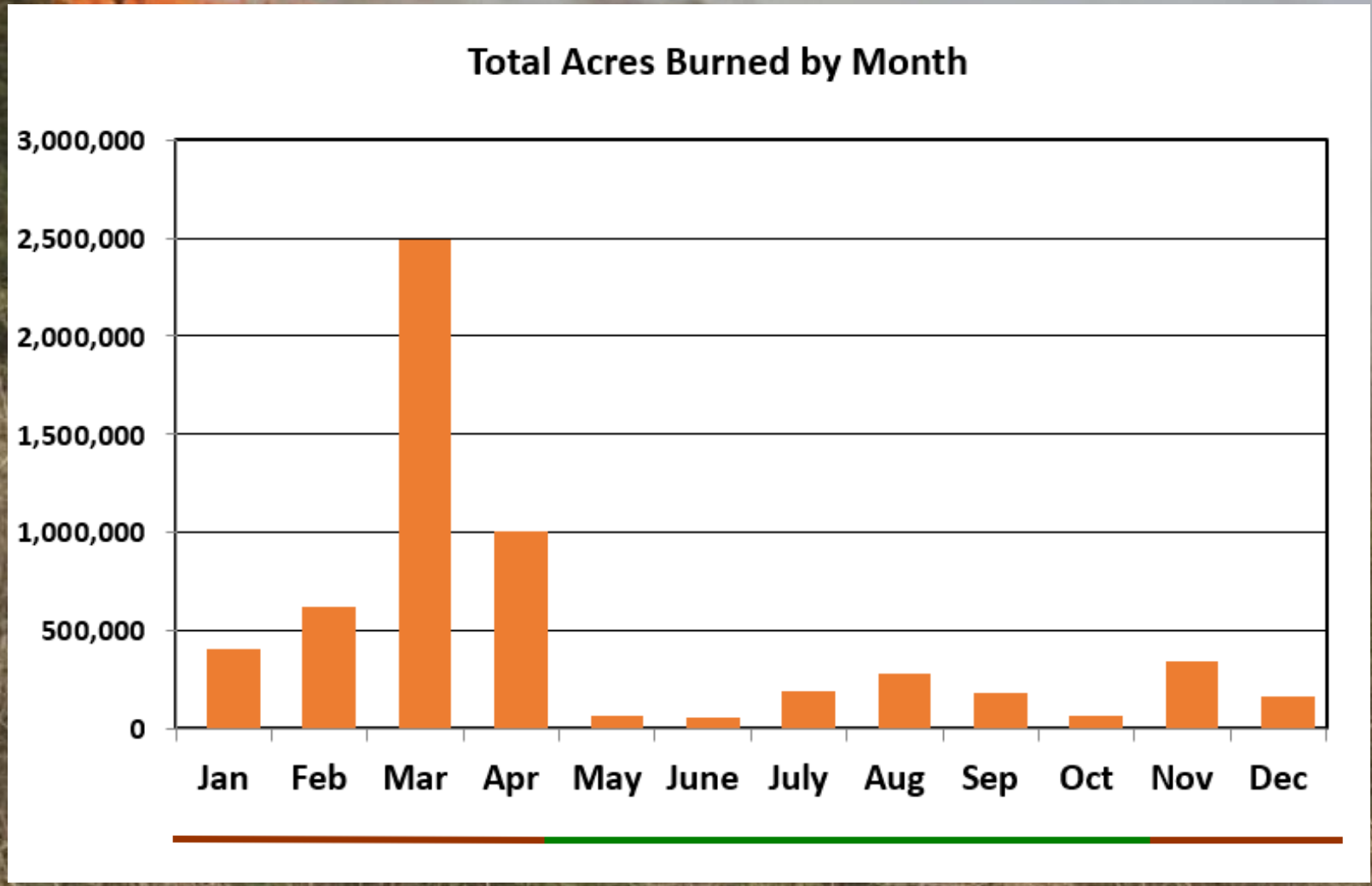
Distribution of Wildland Fuels in Oklahoma



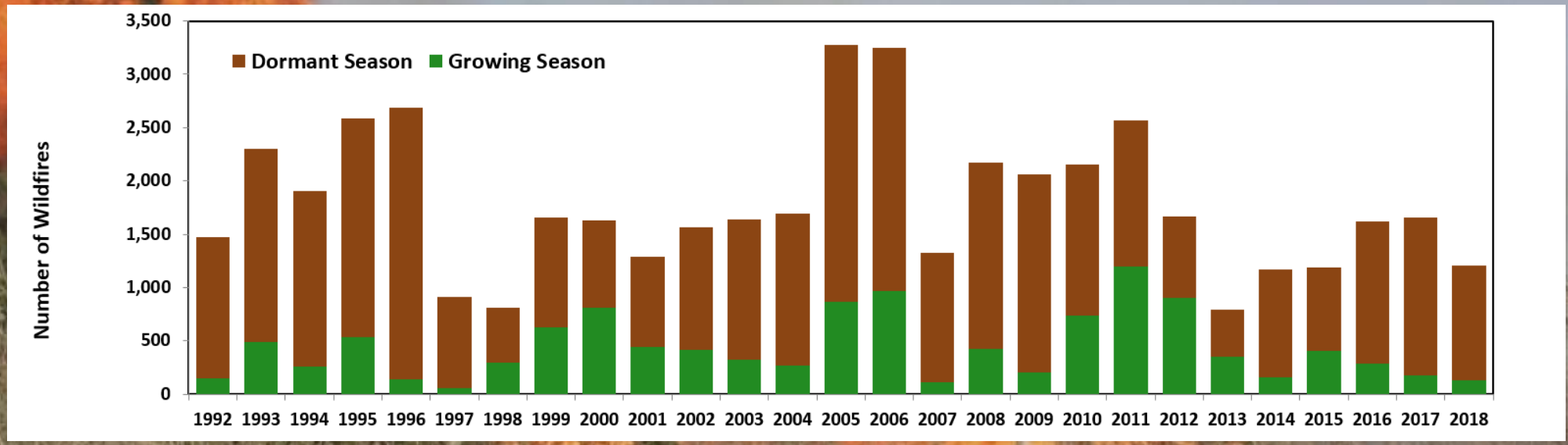
Oklahoma Wildfire Monthly Climatology
(48,212 wildfires from 1992-2018)

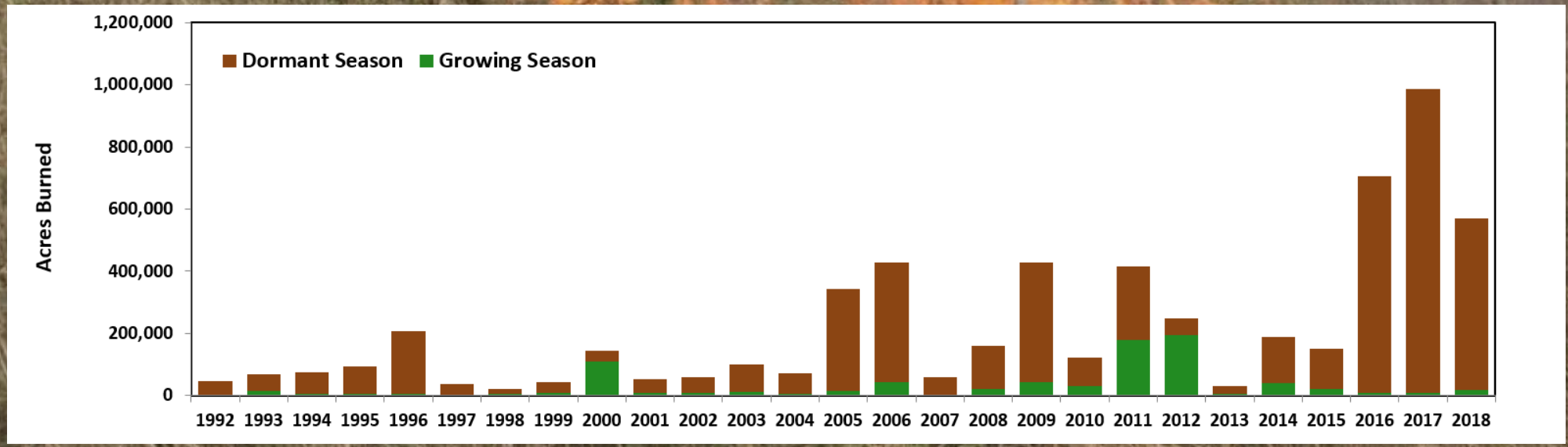


Oklahoma Wildfire Monthly Climatology
(48,212 wildfires from 1992-2018)



Oklahoma Wildfires by Year (1992-2018)





Review of Past Research in Oklahoma
(Soil Moisture and Fire Danger)

Soil Moisture (FAW)

- Mesonet soil moisture sensors at 5, 25 cm
- Integrated water content: 0-40 cm soil layer
- Volumetric Water Content (VWC)
- Fraction of Available Water (FAW)
- Normally, 0 <= FAW <= 1

$$FAW = (VWC - VWC_{wp}) / (VWC_{fc} - VWC_{wp})$$

ratio of measured plant available water to the
maximum plant available water capacity of the soil


EMPIRICAL Evidence for the
Importance of Soil Moisture to Fire Danger
(Wildfires)

Wildfires by Size Class

(Soil Science Society of America Journal, 2015)

- 38,419 Oklahoma wildfires (2000-2012)
- Individual fires linked to nearest Mesonet station data on day of ignition
- Five fire size classes
- Dormant (Nov-Apr) and growing (May-Oct) seasons

Dormant Season Wildfires

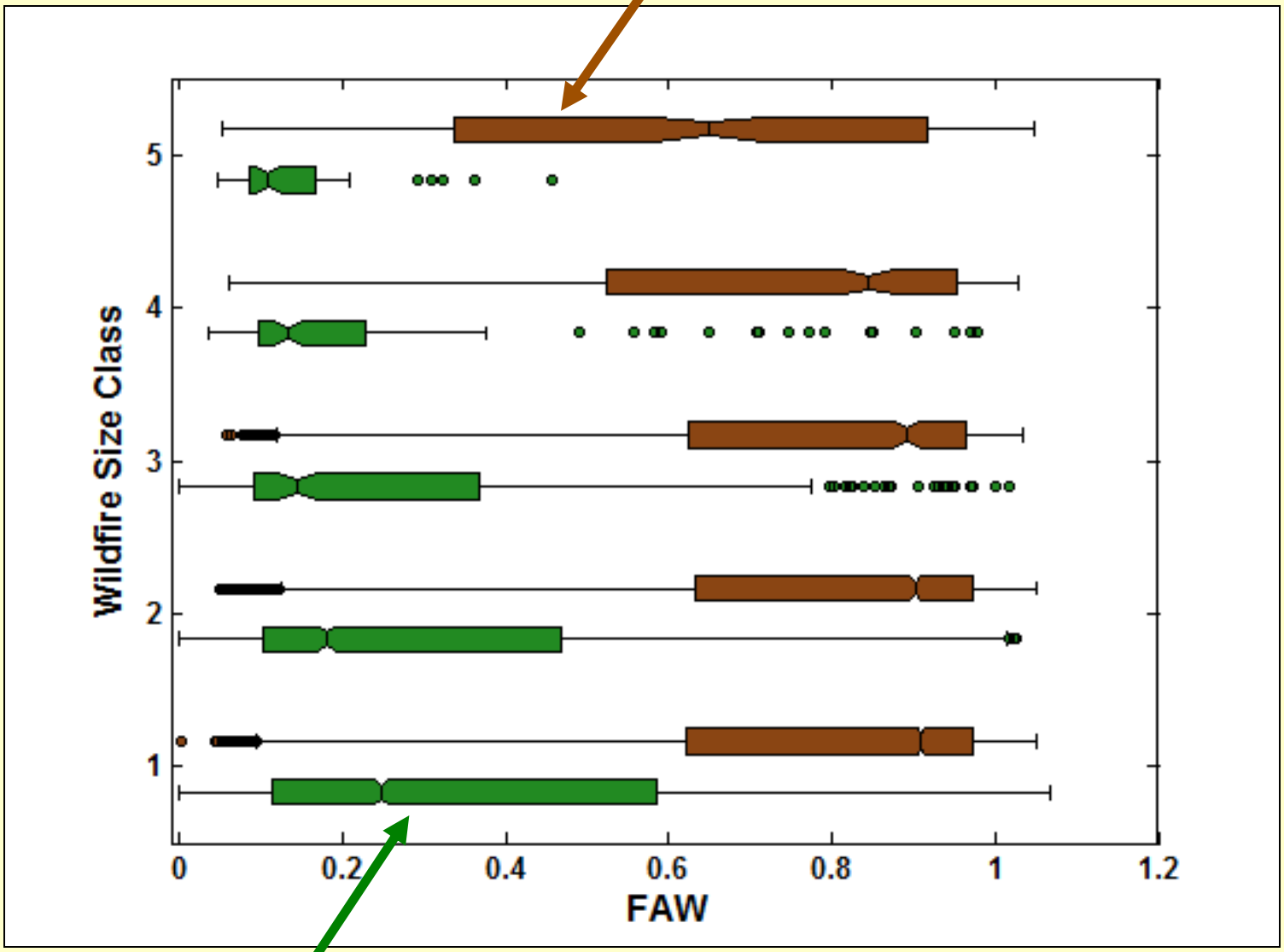
>= 1000 acres

300-1000 acres

100-300 acres

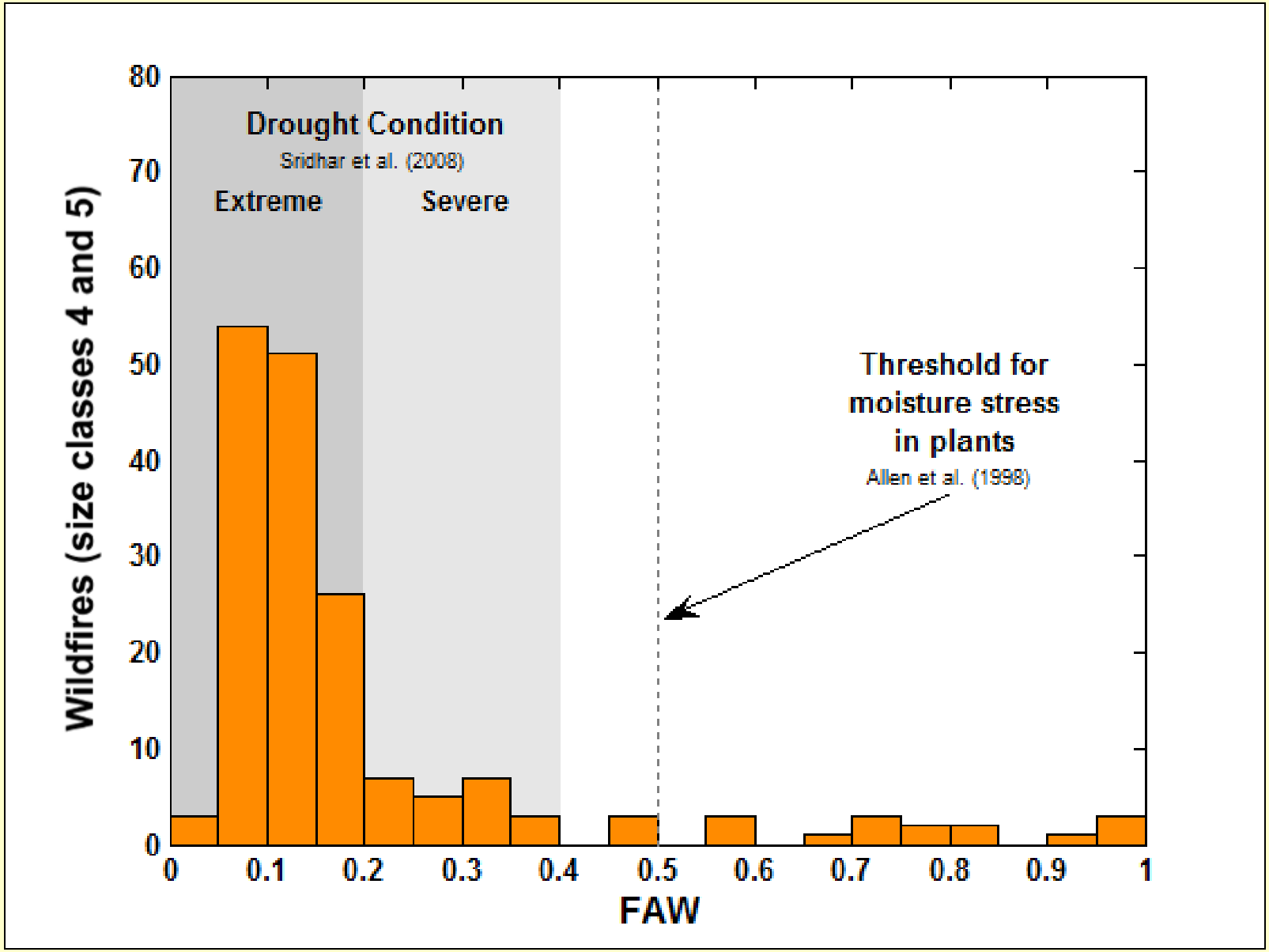
10-100 acres

< 10 acres



Growing Season Wildfires

Growing Season Wildfires >= 300 Acres

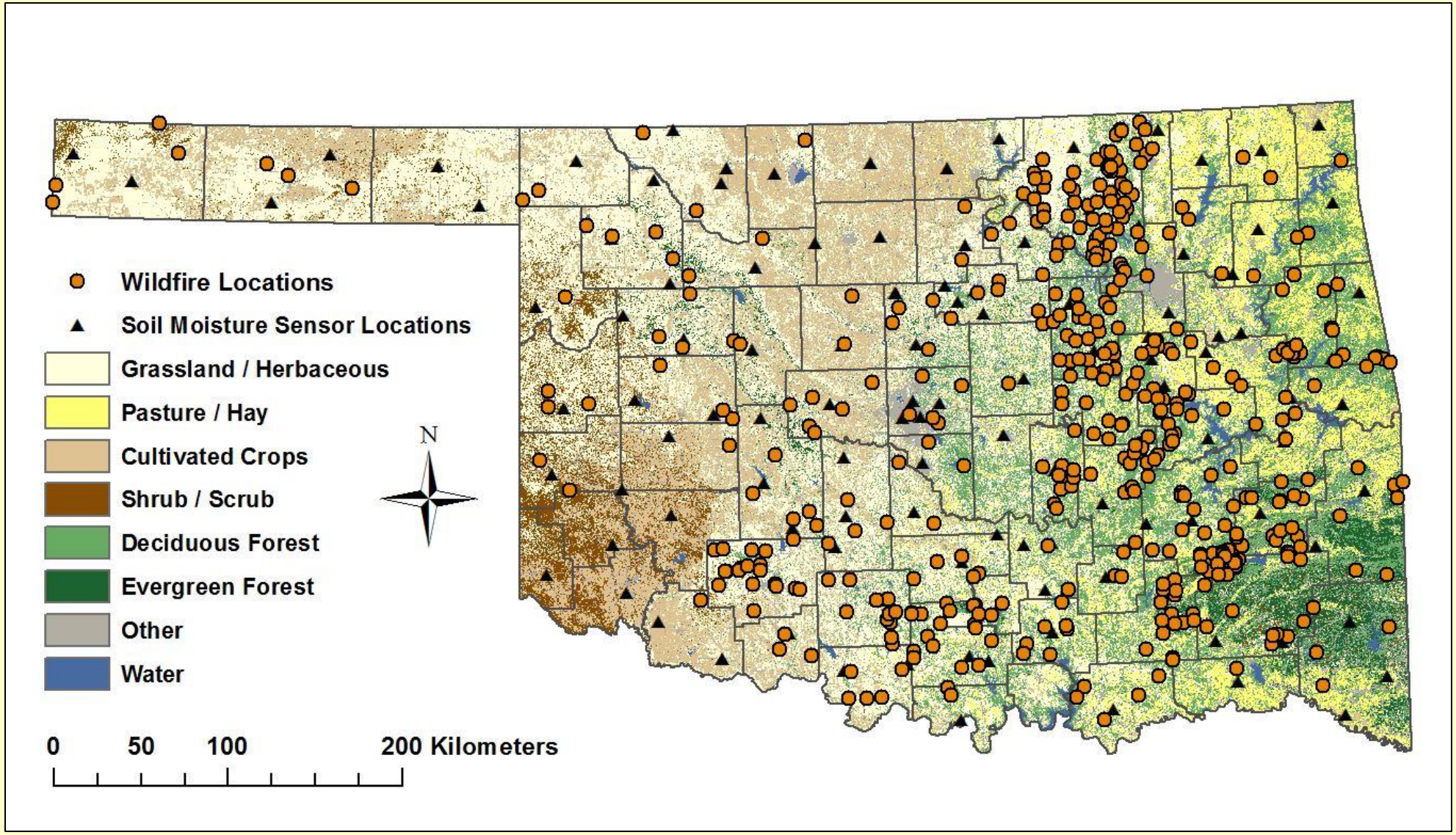


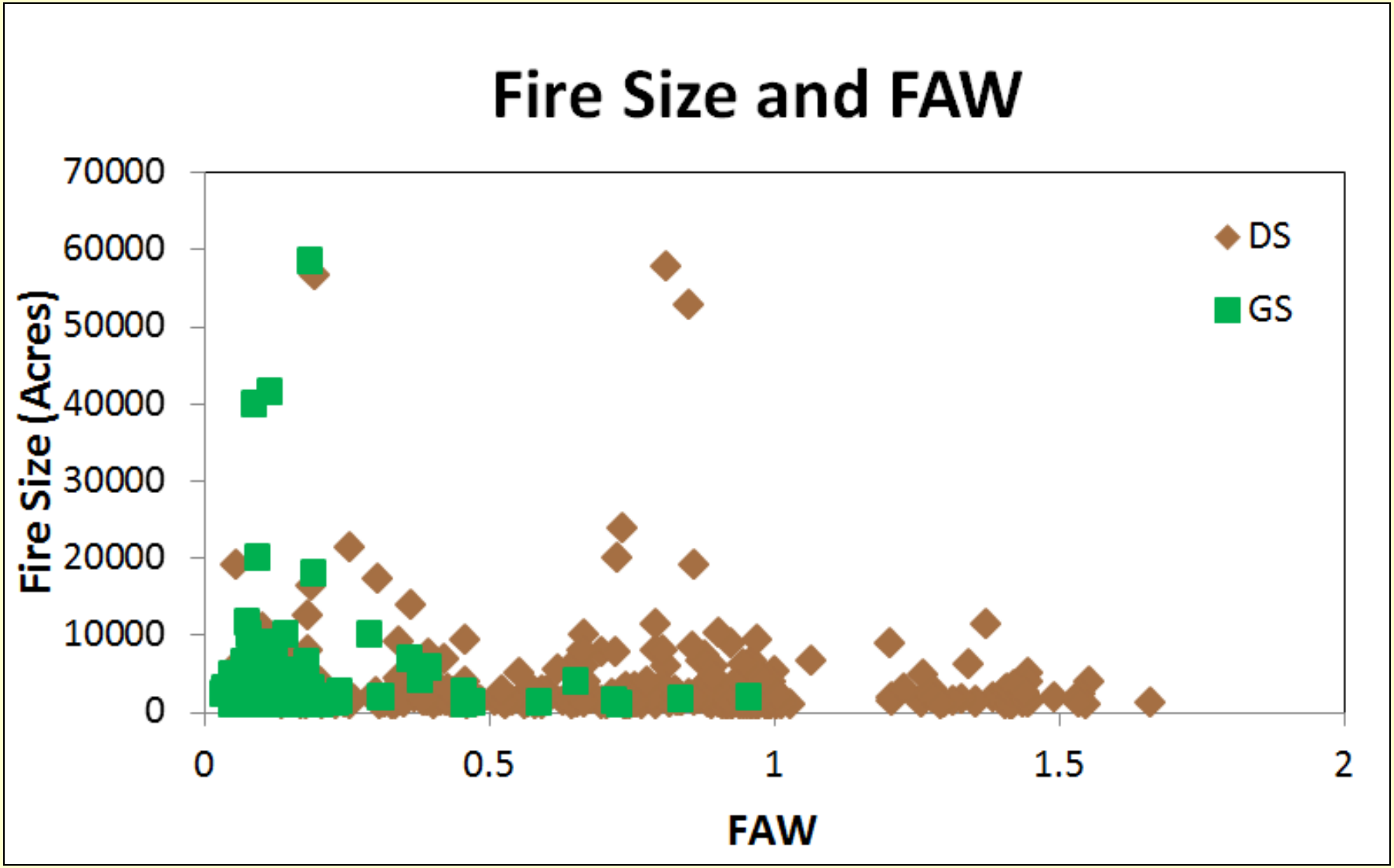
Large Wildfires

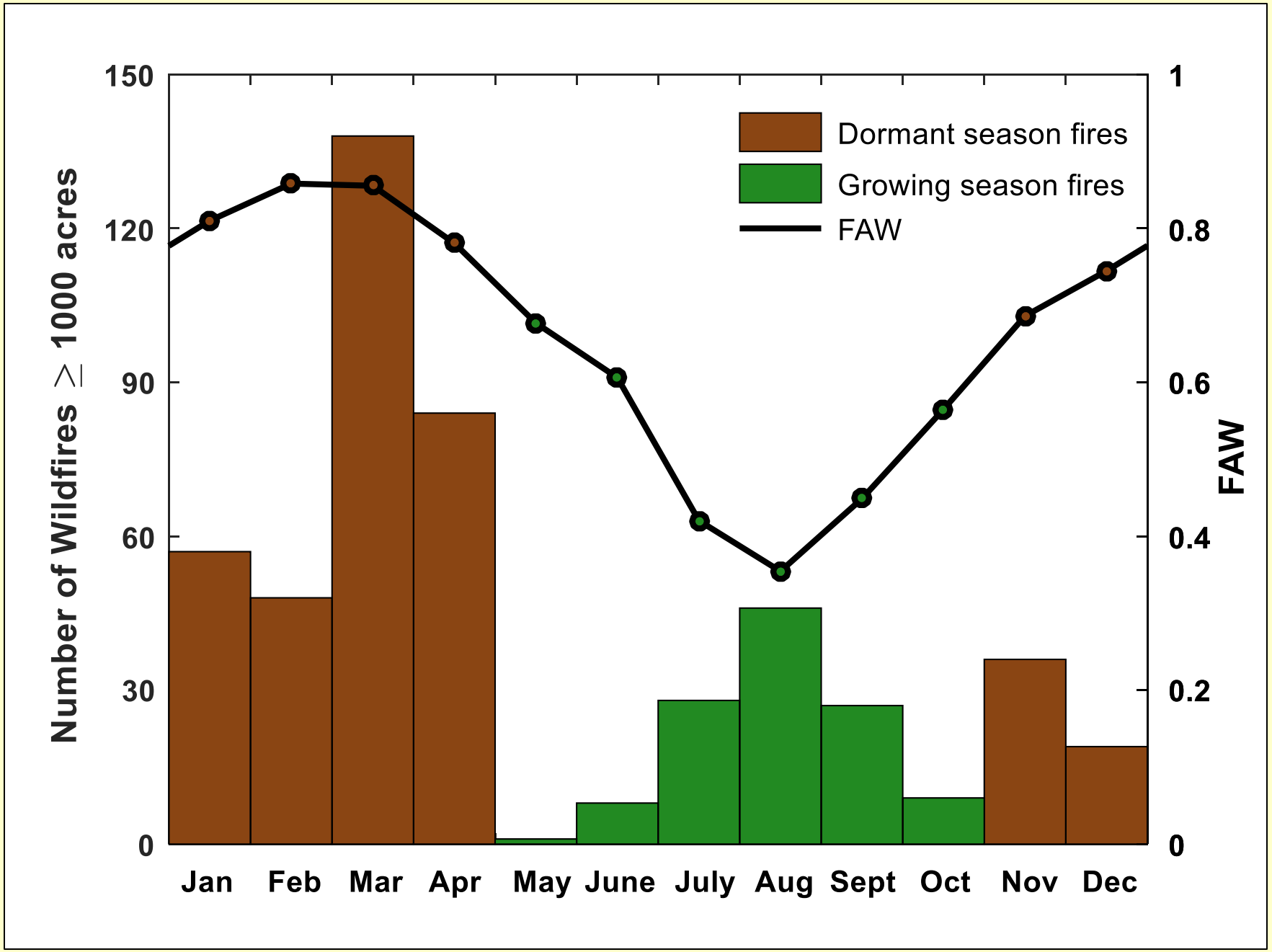
(International Journal of Wildland Fire, 2016)

- 501 Oklahoma wildfires >= 1000 acres (2000-2012)
- Individual fires linked to nearest Mesonet station data on day of ignition
- Dormant (Nov-Apr) and growing (May-Oct) seasons

Location of Wildfires and Soil Moisture Sensors Used in Research Study




Fire Size and FAW
70000
60000
50000
40000
30000
20000
10000
0
Fire Size (Acres)
0
0.5
1
1.5
2
FAW
DS
GS


Number of Wildfires ≥ 1000 acres
150
120
90
60
30
0
1
0.8
0.6
0.4
0.2
0
FAW
Dormant season fires
Growing season fires
FAW
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

Large Multi-Day 2011 Growing Season Wildfires

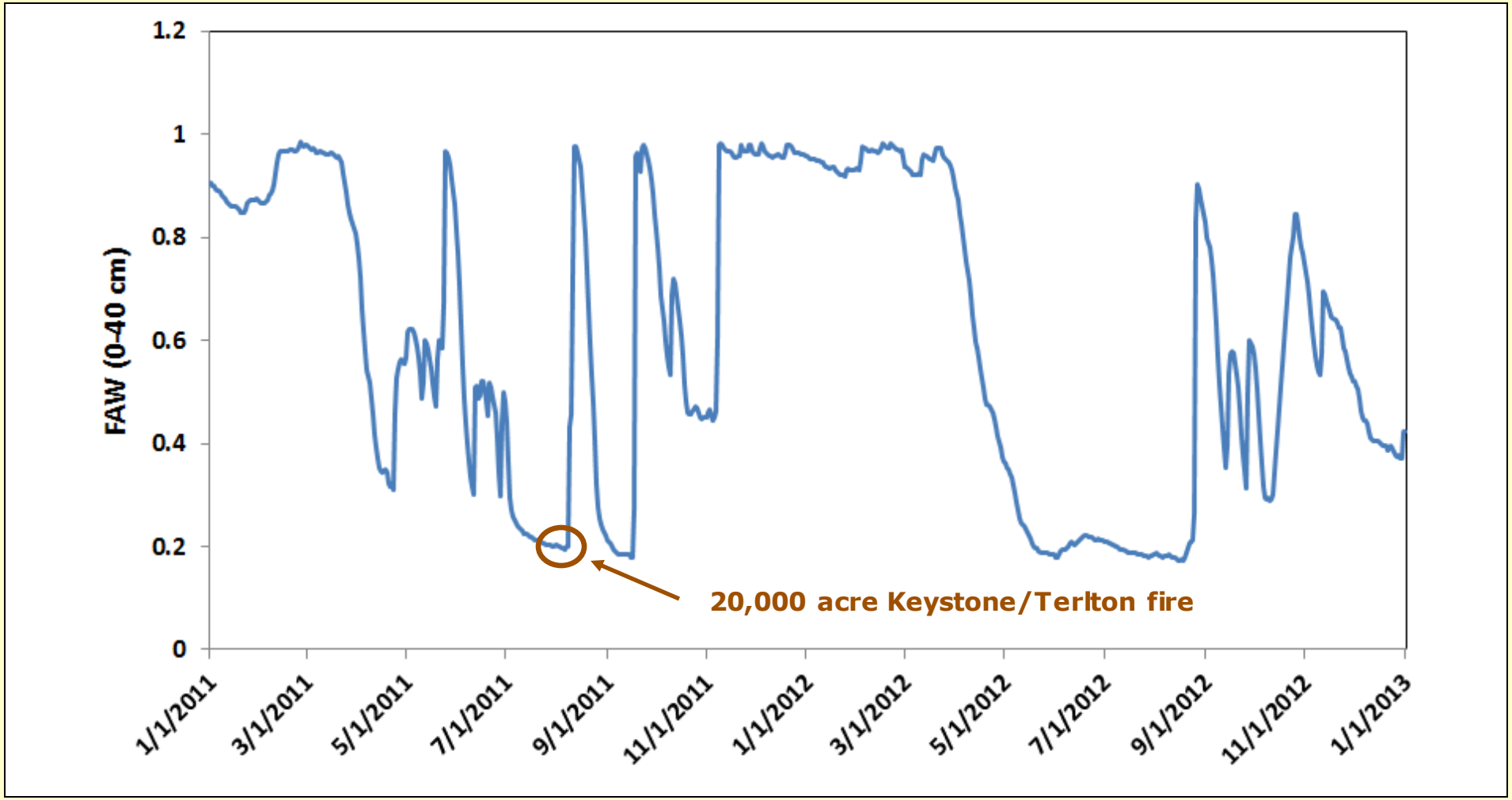
Keystone/Terlton Complex

August 5-10, 2011

20,129 acres (8146 ha)

Fraction of Available Water (FAW)

(Oilton site)



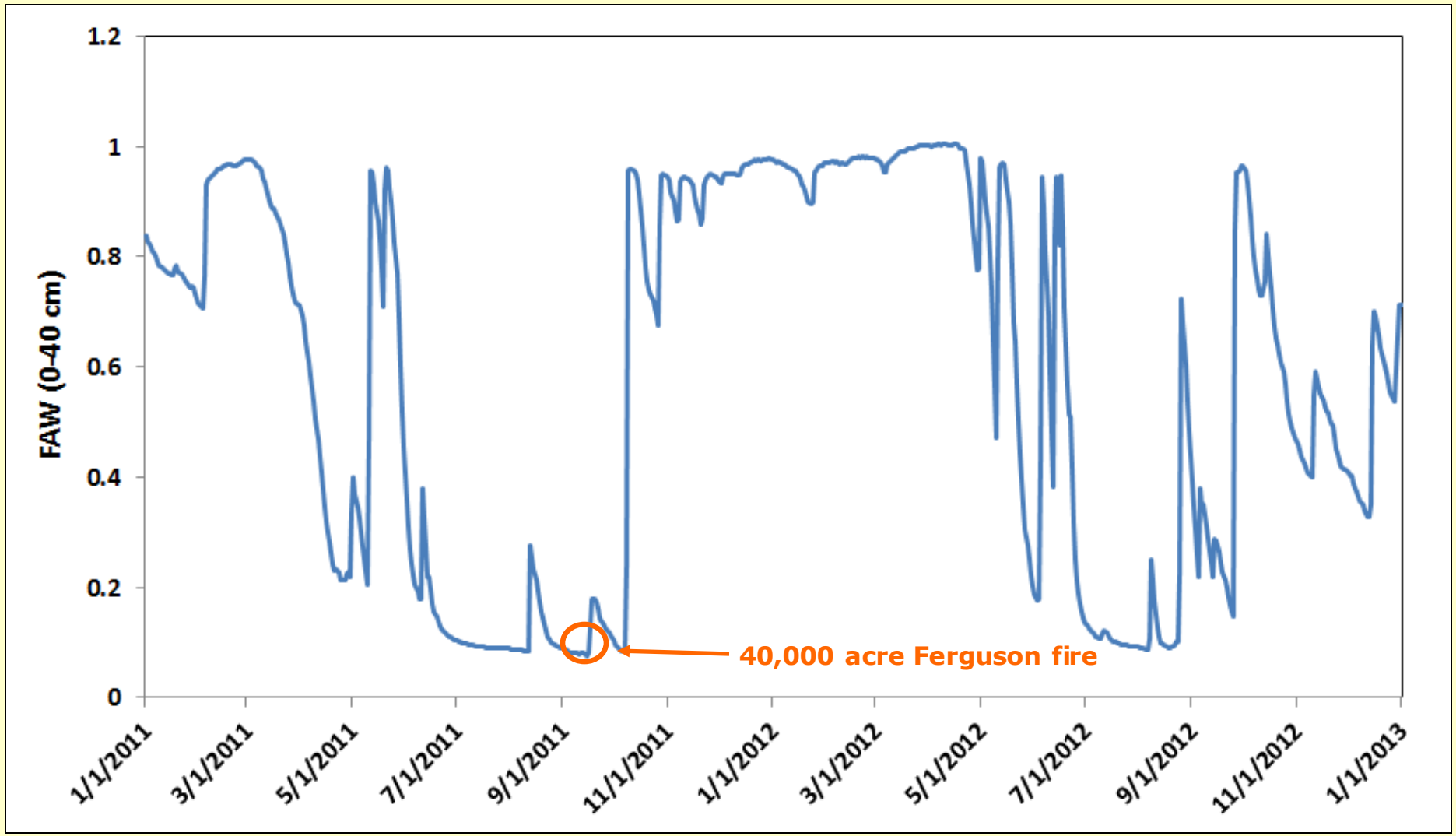
Ferguson Fire

September 1-10, 2011

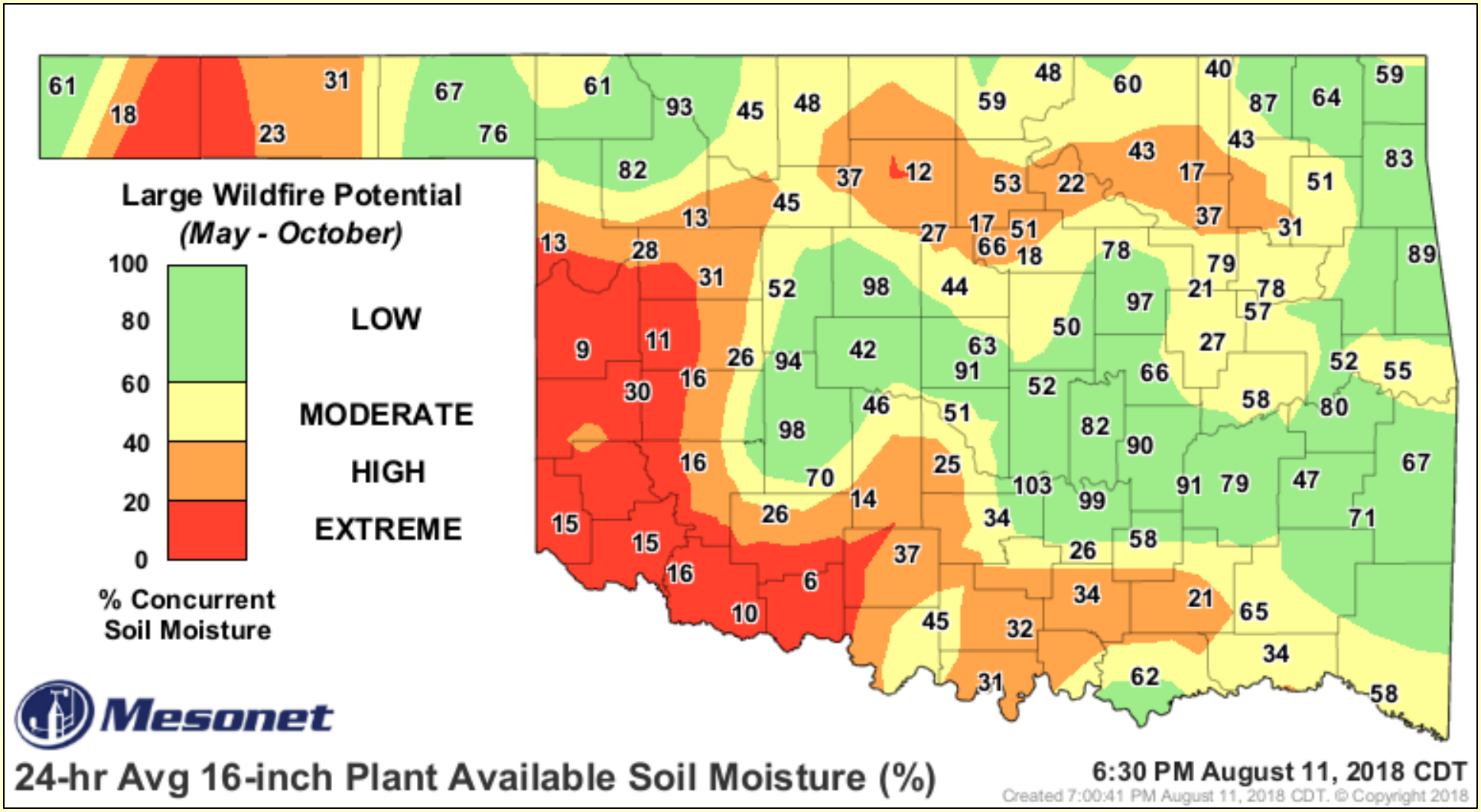
39,907 acres (16,150 ha)

Fraction of Available Water (FAW)

(Medicine Park site)



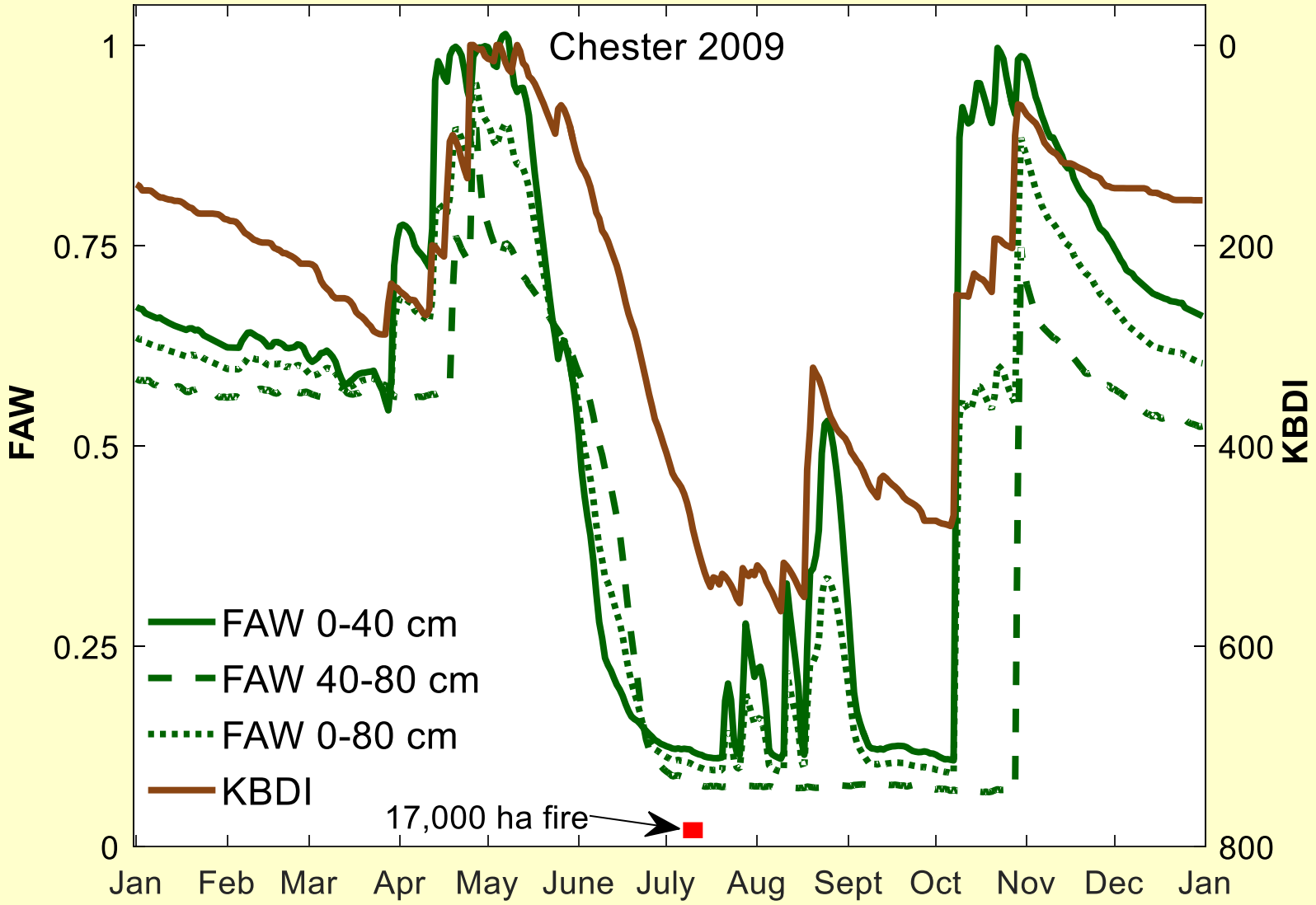
Stand-Alone Soil Moisture Product on OK-FIRE

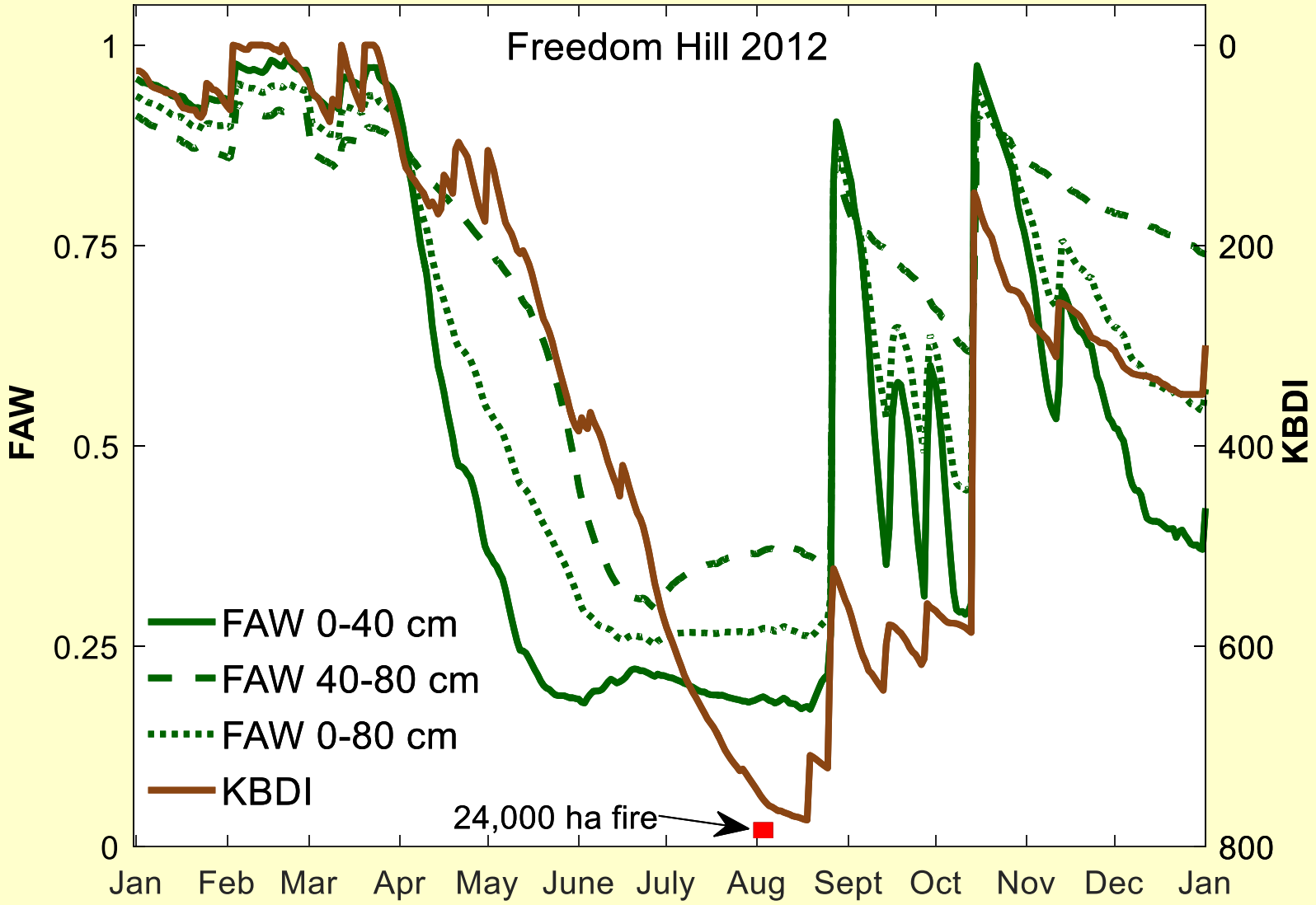


FAW versus KBDI

(Soil Science Society of America Journal, 2017)

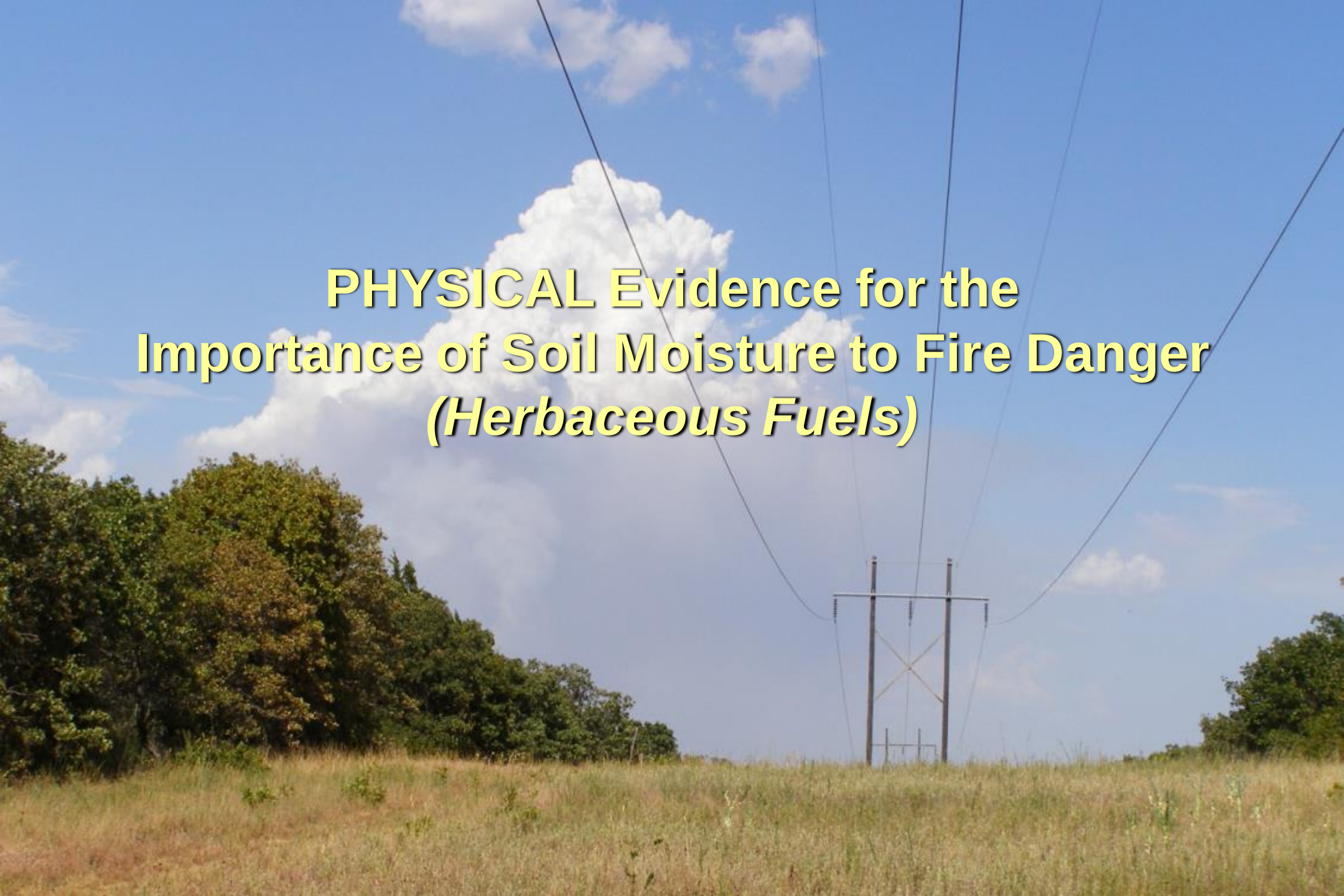
- 501 Oklahoma wildfires >= 1000 acres (2000-2012)
- Individual fires linked to nearest Mesonet station data on day of ignition
- Dormant (Nov-Apr) and growing (May-Oct) seasons

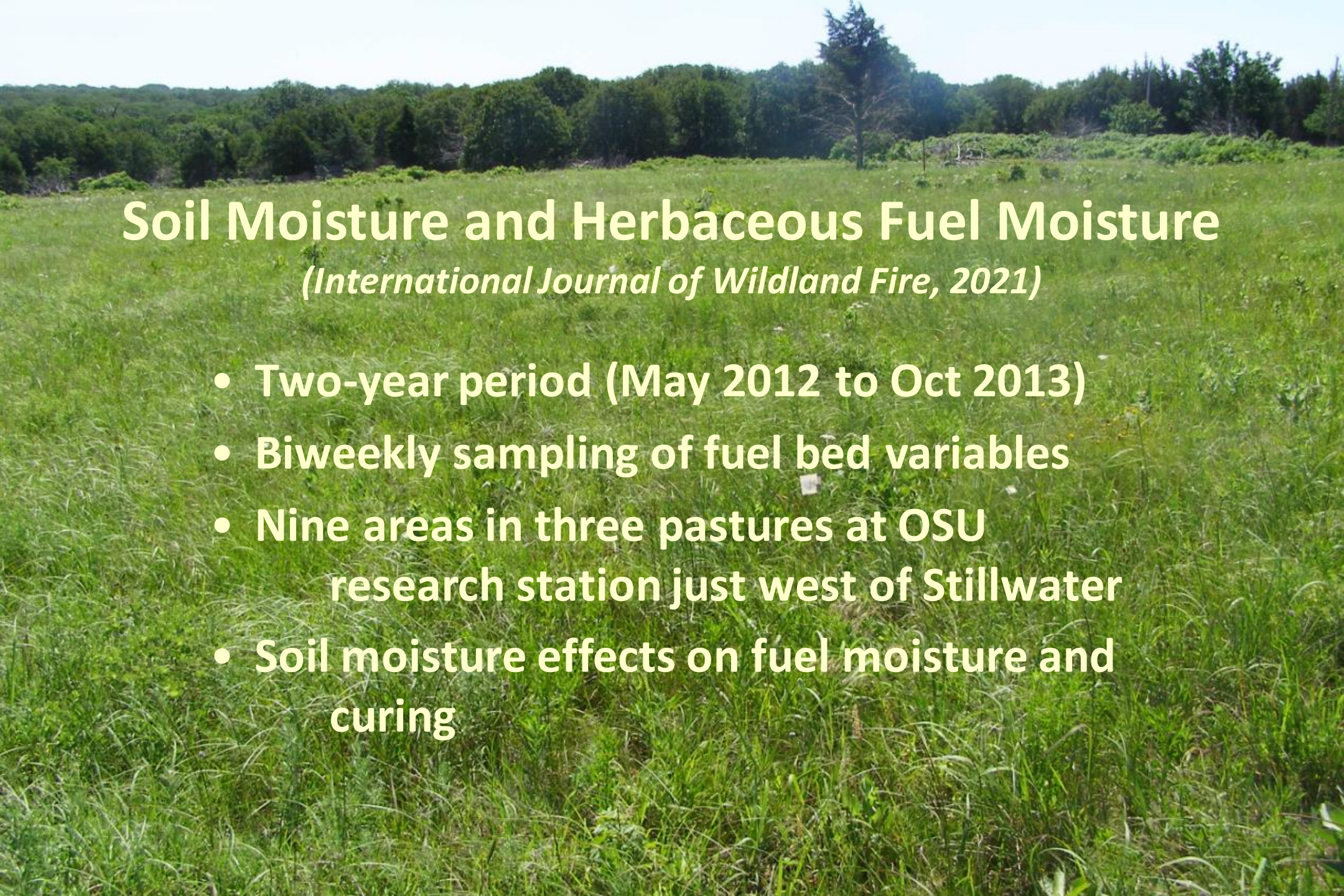

Chester 2009
FAW
KBDI
1
0.75
0.5
0.25
0
0
200
400
600
800
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
FAW 0-40 cm
FAW 40-80 cm
FAW 0-80 cm
KBDI
17,000 ha fire


Freedom Hill 2012
FAW
KBDI
1
0.75
0.5
0.25
0
0
200
400
600
800
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
FAW 0-40 cm
FAW 40-80 cm
FAW 0-80 cm
KBDI
24,000 ha fire

For the 10 largest wildfires in our study:

- FAW provided an average of 10 days earlier warning time than KBDI
- The average warning time before wildfire occurrence using FAW was 29 days


PHYSICAL Evidence for the
Importance of Soil Moisture to Fire Danger
(Herbaceous Fuels)

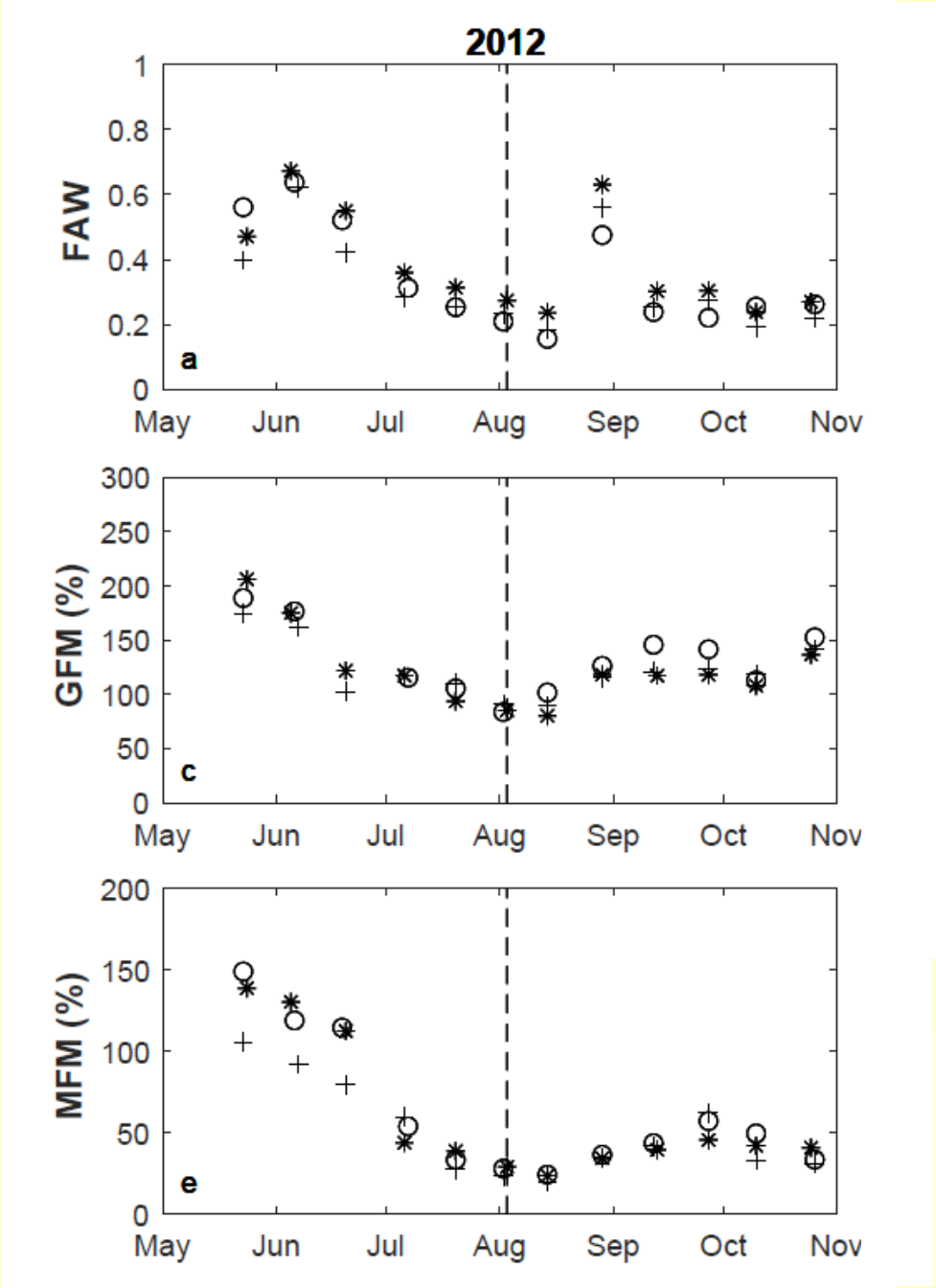


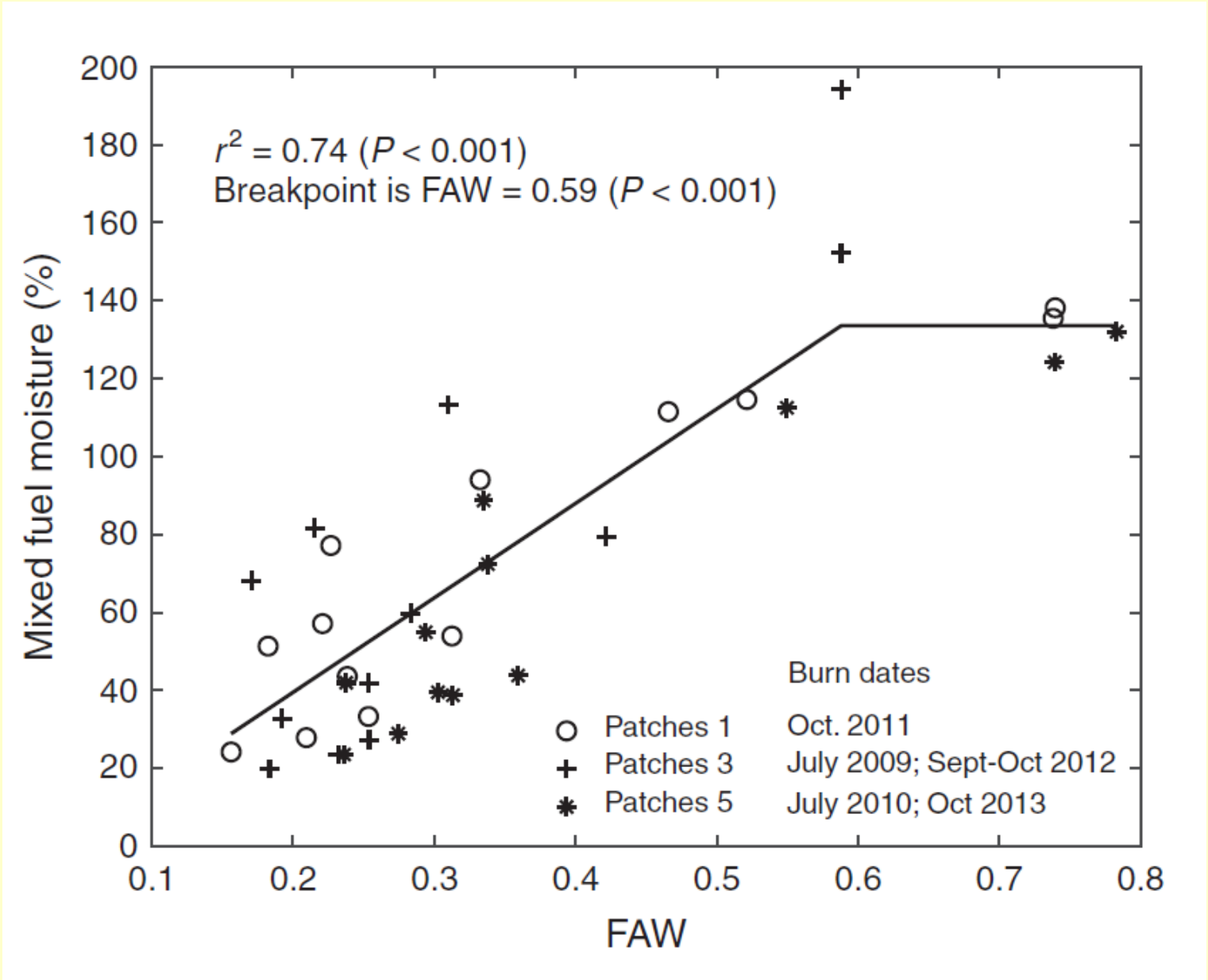
Soil Moisture and Herbaceous Fuel Moisture

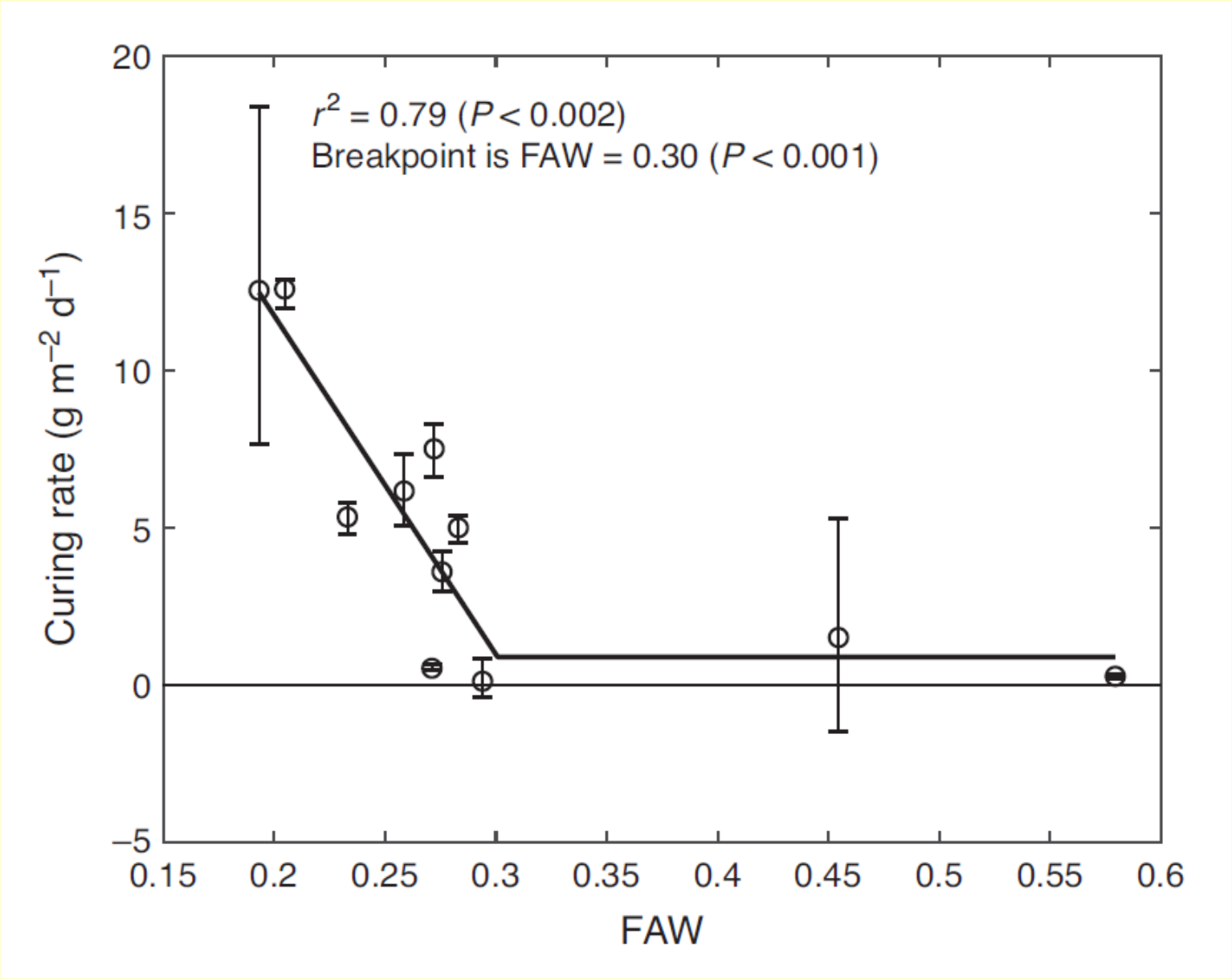
(International Journal of Wildland Fire, 2021)

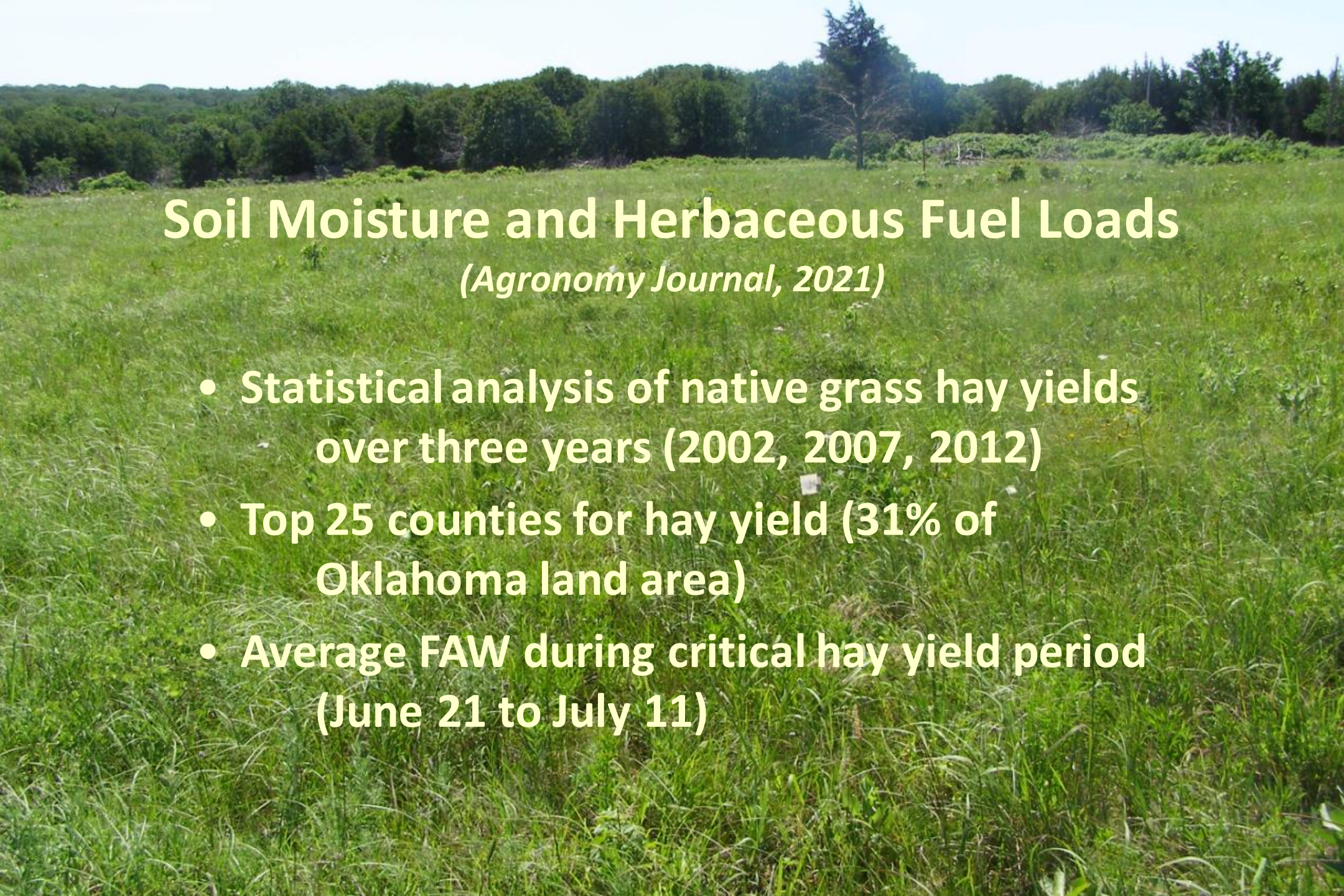
- Two-year period (May 2012 to Oct 2013)
- Biweekly sampling of fuel bed variables
- Nine areas in three pastures at OSU research station just west of Stillwater
- Soil moisture effects on fuel moisture and curing

Wildfires burned 34,600 ha in the vicinity of the research site during August 2-5.




r^2 = 0.74 (P < 0.001)
Breakpoint is FAW = 0.59 (P < 0.001)
Mixed fuel moisture (%)
FAW
0
20
40
60
80
100
120
140
160
180
200
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Burn dates
Patches 1 Oct. 2011
Patches 3 July 2009; Sept-Oct 2012
Patches 5 July 2010; Oct 2013

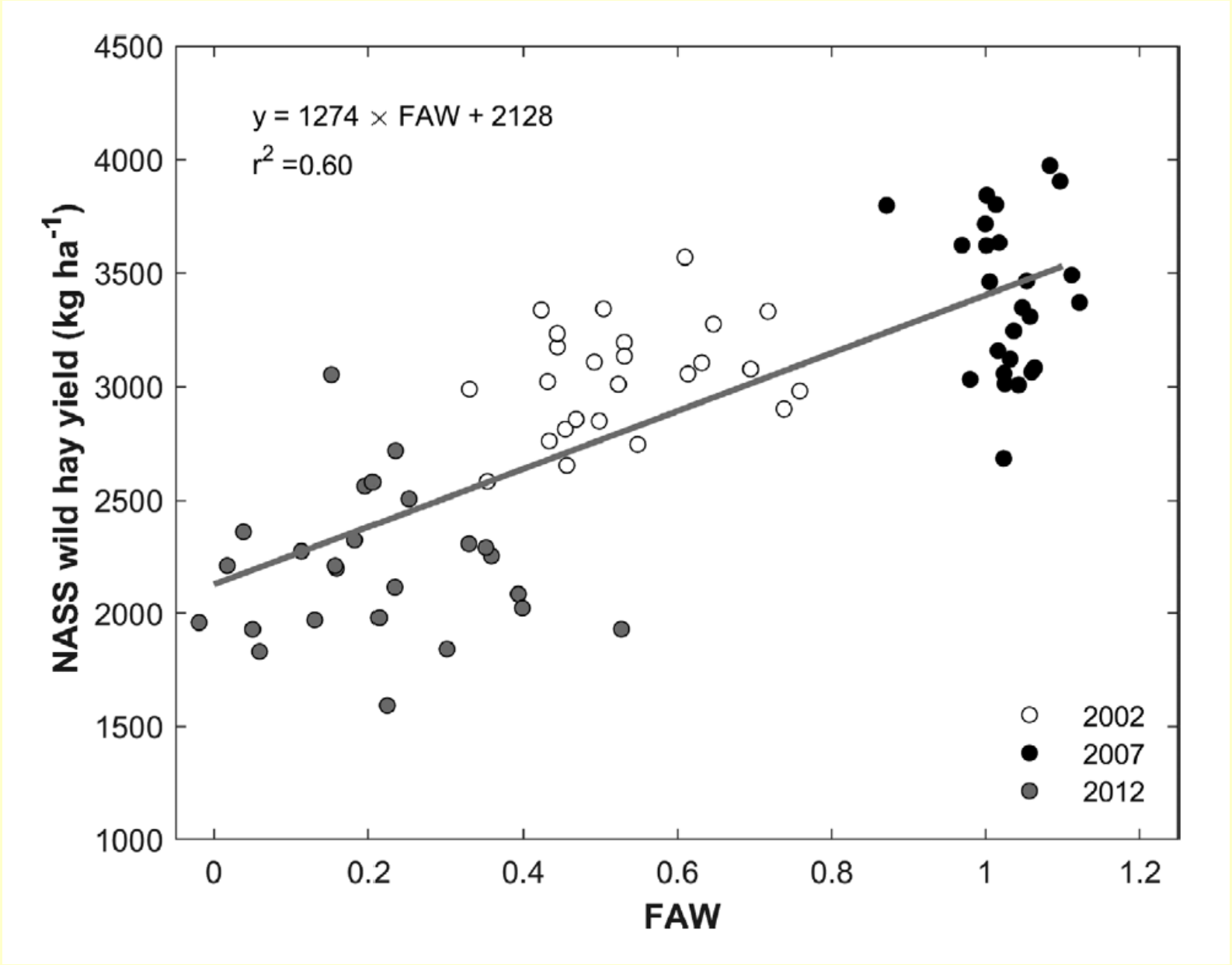

r^2 = 0.79 (P < 0.002)
Breakpoint is FAW = 0.30 (P < 0.001)
Curing rate (g m^{-2} d^{-1})
FAW
20
15
10
5
0
−5
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6

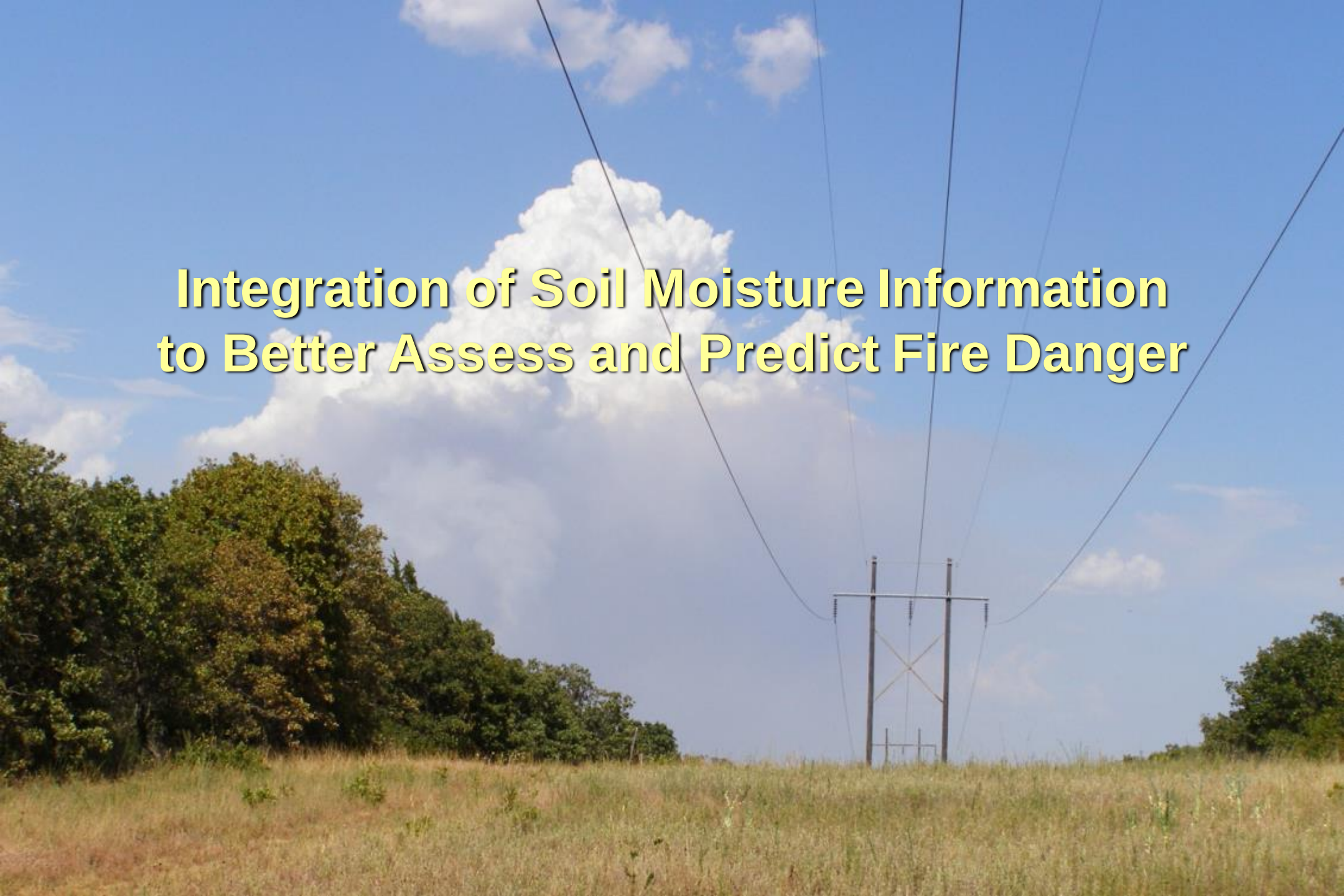


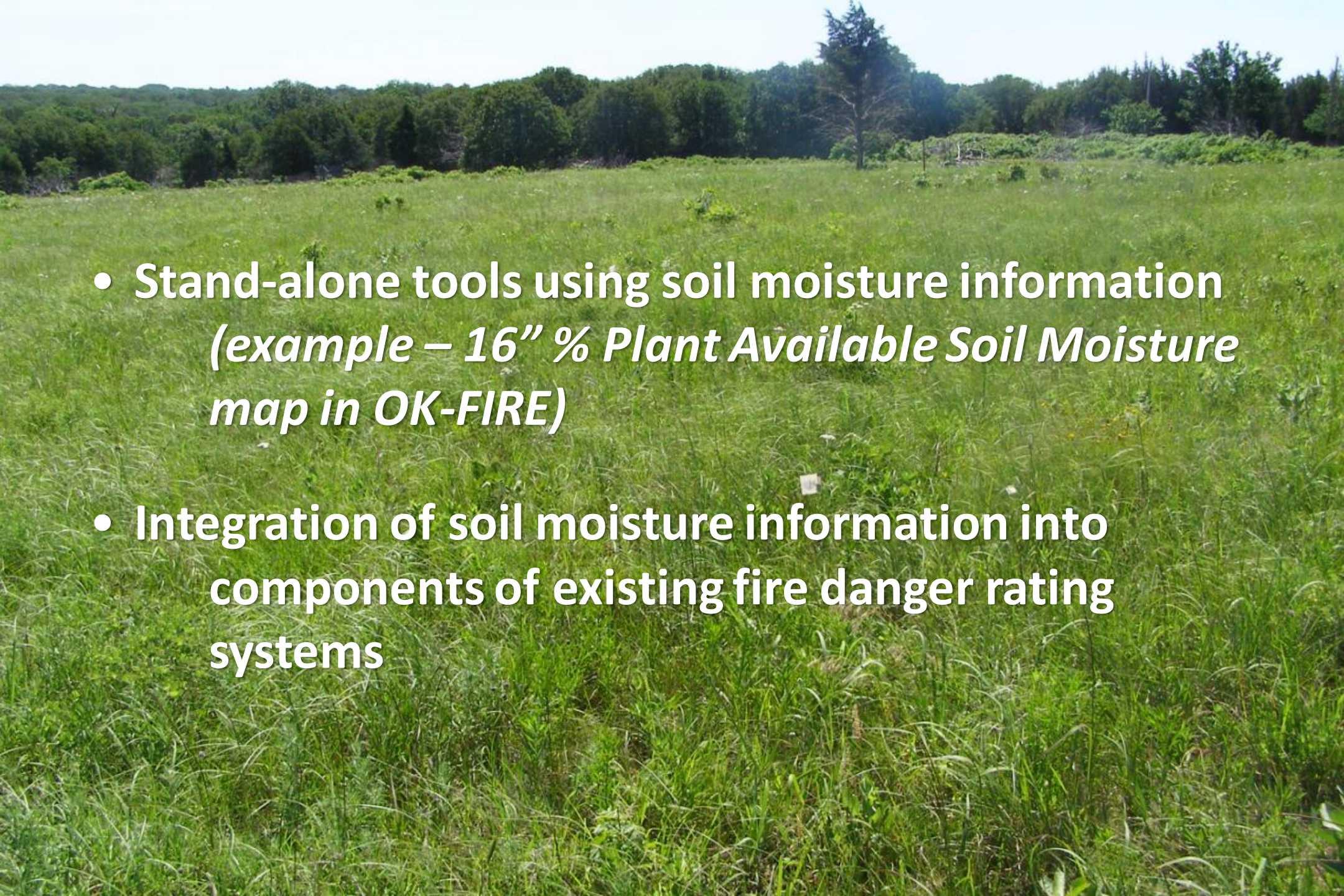
Soil Moisture and Herbaceous Fuel Loads

(Agronomy Journal, 2021)

- Statistical analysis of native grass hay yields over three years (2002, 2007, 2012)
- Top 25 counties for hay yield (31% of Oklahoma land area)
- Average FAW during critical hay yield period (June 21 to July 11)


y = 1274 × FAW + 2128
r2 =0.60
NASS wild hay yield (kg ha-1)
FAW
4500
4000
3500
3000
2500
2000
1500
1000
0
0.2
0.4
0.6
0.8
1
1.2
2002
2007
2012

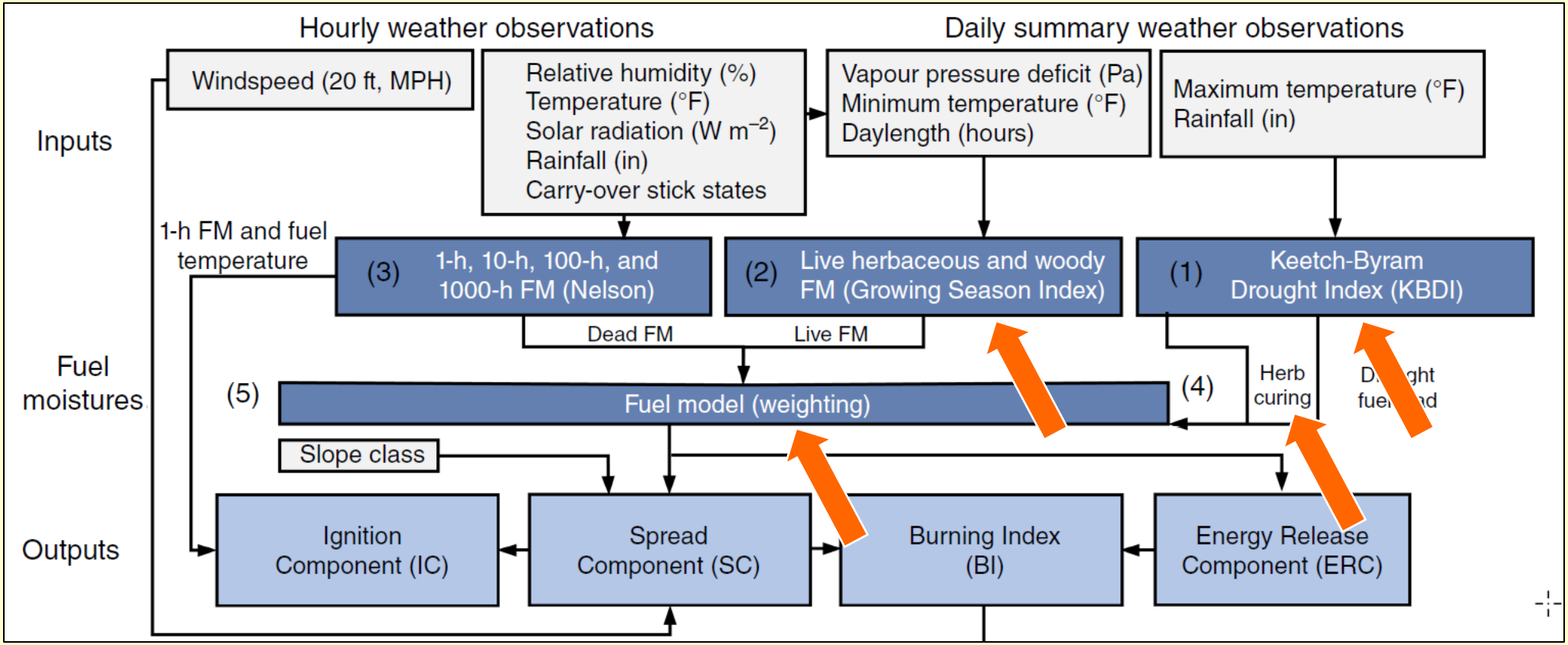

Integration of Soil Moisture Information
to Better Assess and Predict Fire Danger



- **Stand-alone tools using soil moisture information *(example – 16” % Plant Available Soil Moisture map in OK-FIRE)***

- **Integration of soil moisture information into components of existing fire danger rating systems**

NFDRS 2016


Hourly weather observations
Daily summary weather observations
Inputs
Windspeed (20 ft, MPH)
Relative humidity (%)
Temperature (°F)
Solar radiation (W m−2)
Rainfall (in)
Carry-over stick states
Vapour pressure deficit (Pa)
Minimum temperature (°F)
Daylength (hours)
Maximum temperature (°F)
Rainfall (in)
1-h FM and fuel temperature
(3) 1-h, 10-h, 100-h, and 1000-h FM (Nelson)
(2) Live herbaceous and woody FM (Growing Season Index)
(1) Keetch-Byram Drought Index (KBDI)
Dead FM
Live FM
Fuel moistures
(5)
Fuel model (weighting)
(4)
Herb curing
Slope class
Outputs
Ignition Component (IC)
Spread Component (SC)
Burning Index (BI)
Energy Release Component (ERC)


Final Thoughts


Thank You!
Questions?