Drought-tolerant Germplasm Options for Agriculture

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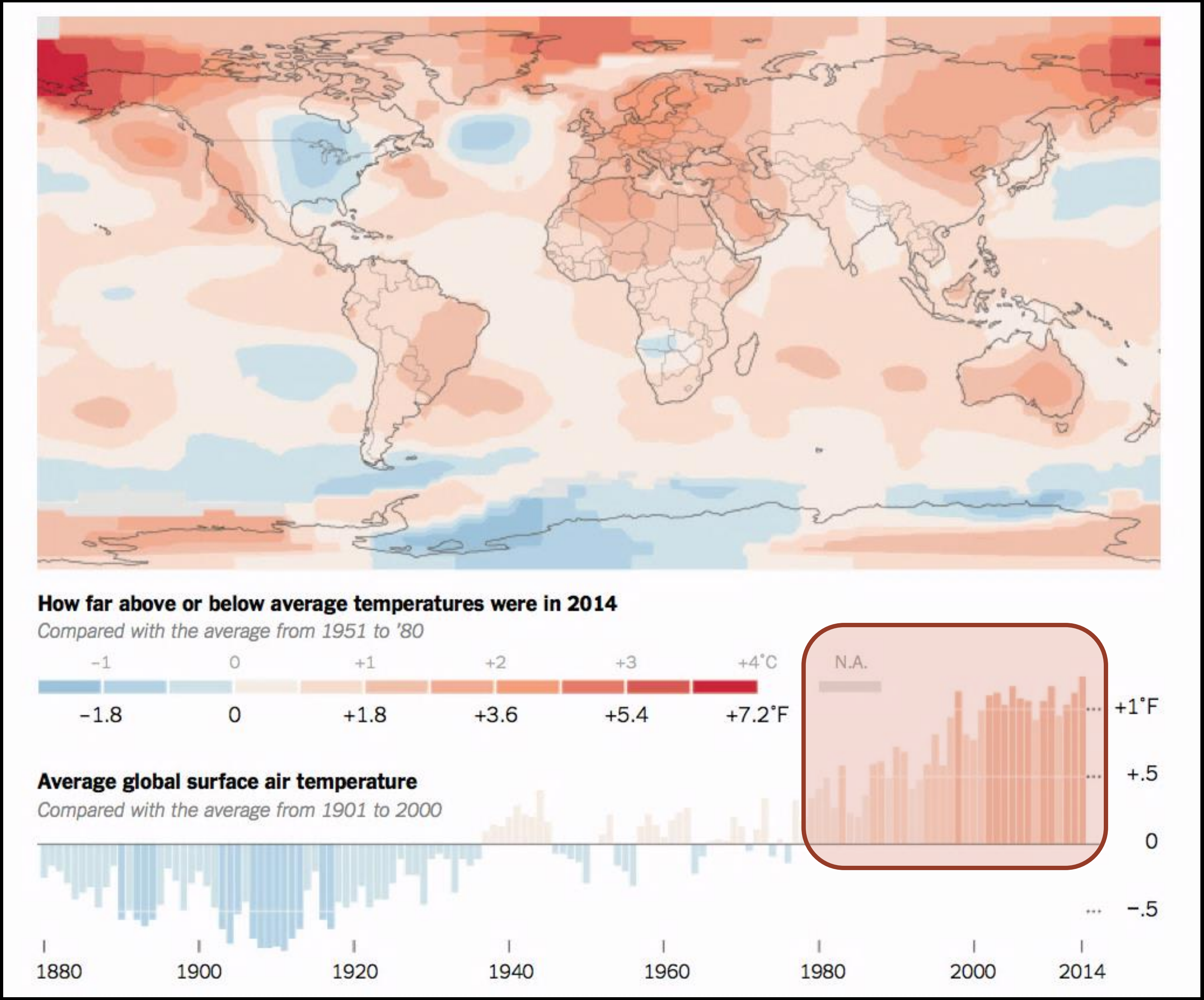
Nevada Agricultural Experiment Station

WAAESD – Charlotte, NC
September 30, 2015

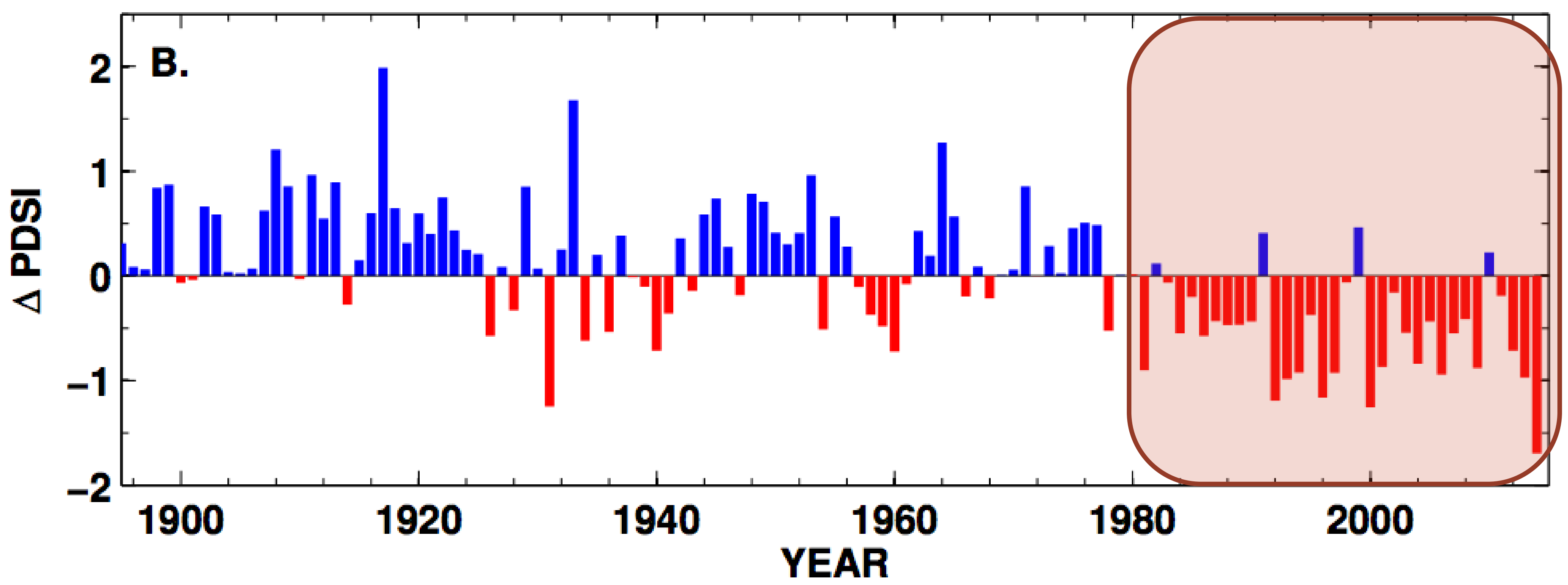
2014: Warmest Year on Record



New York Times Source: NASA; NOAA: 1951-1980 Average (top), 1901-2000 Average (bottom)

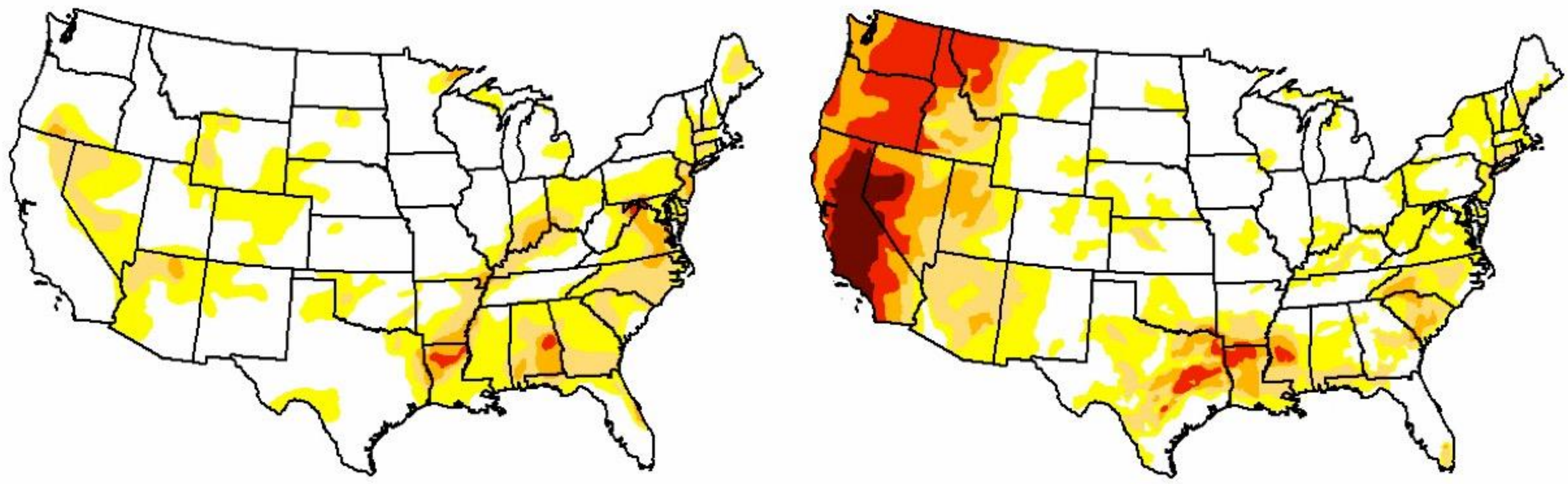
California 2014: Worst Drought in the Last Century

- Change in Palmer Drought Severity Index (ΔPDSI)
- Reduced precipitation (although not unprecedented) and record high temperatures are driving PDSI values more negative (accumulated moisture deficits worst in last 1200 years).



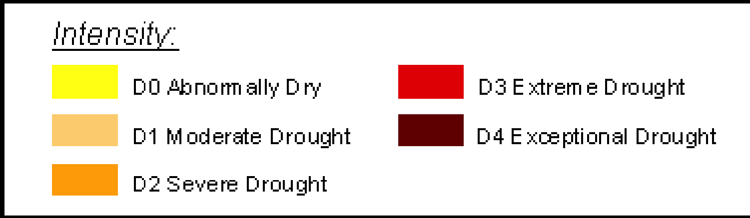
Griffin & Anchukaitus (2014) Geophys. Res. Lett. DOI: 10.1002/2014GL062433

Drought Monitor: 2010 *vs.* 2015



D2 = Crop/pasture losses likely; water shortages common; water restrictions imposed.

D4 = “Exceptional and widespread pasture/crop losses; shortages of water in reservoirs, streams, and wells creating water emergencies”



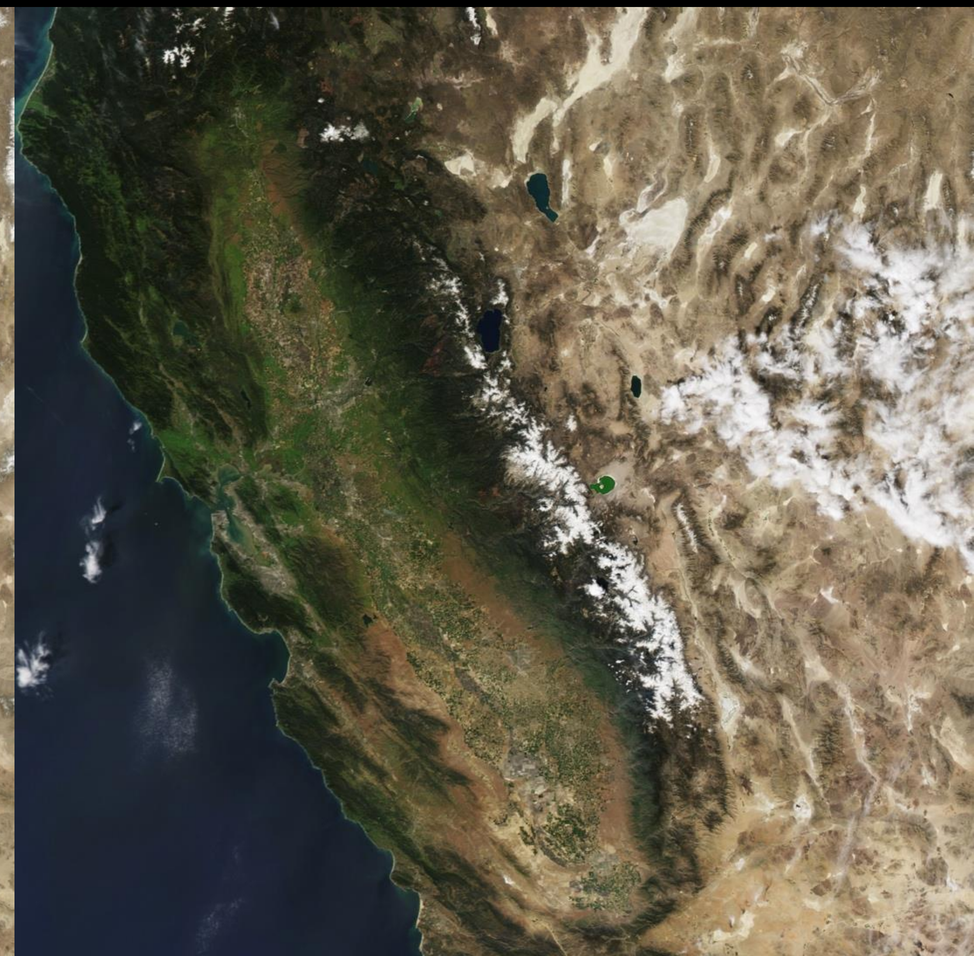
Source: http://droughtmonitor.unl.edu/

Sierra Snowpack: 2010 *vs.* 2015

- **2015 lowest recorded snowpack (6% of average) in last century**

March 27, 2010

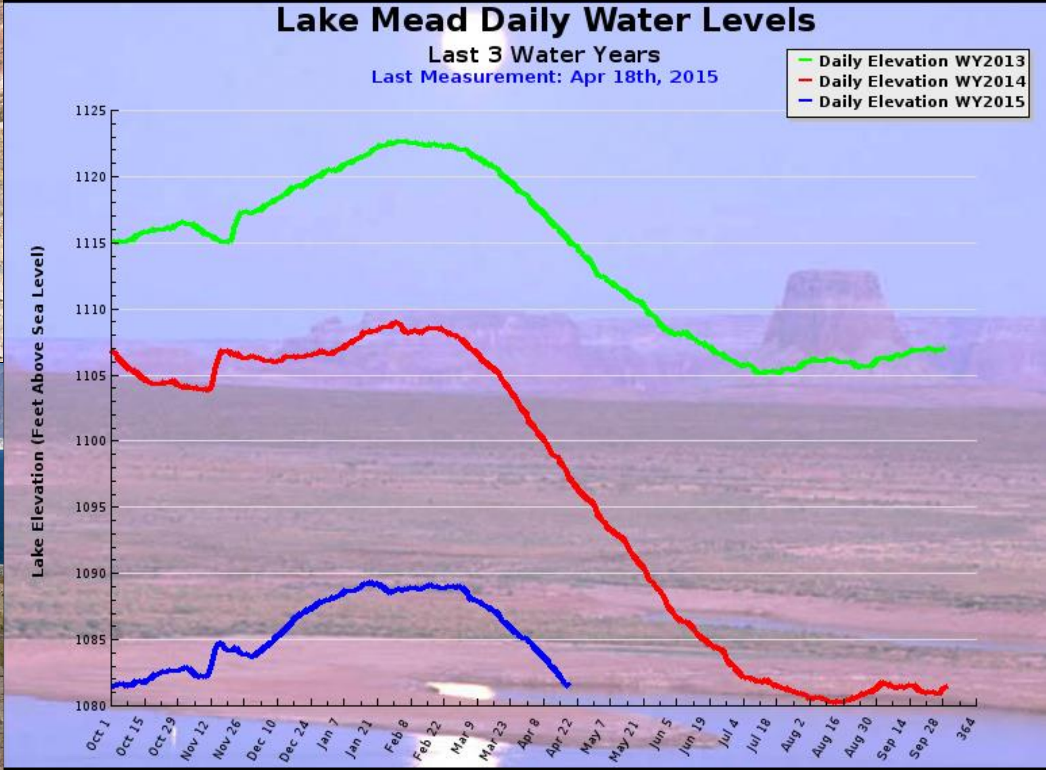
March 29, 2015



Source: NASA Earth Observatory. Credit: Jesse Allen

Lake Mead Drops to All Time Low

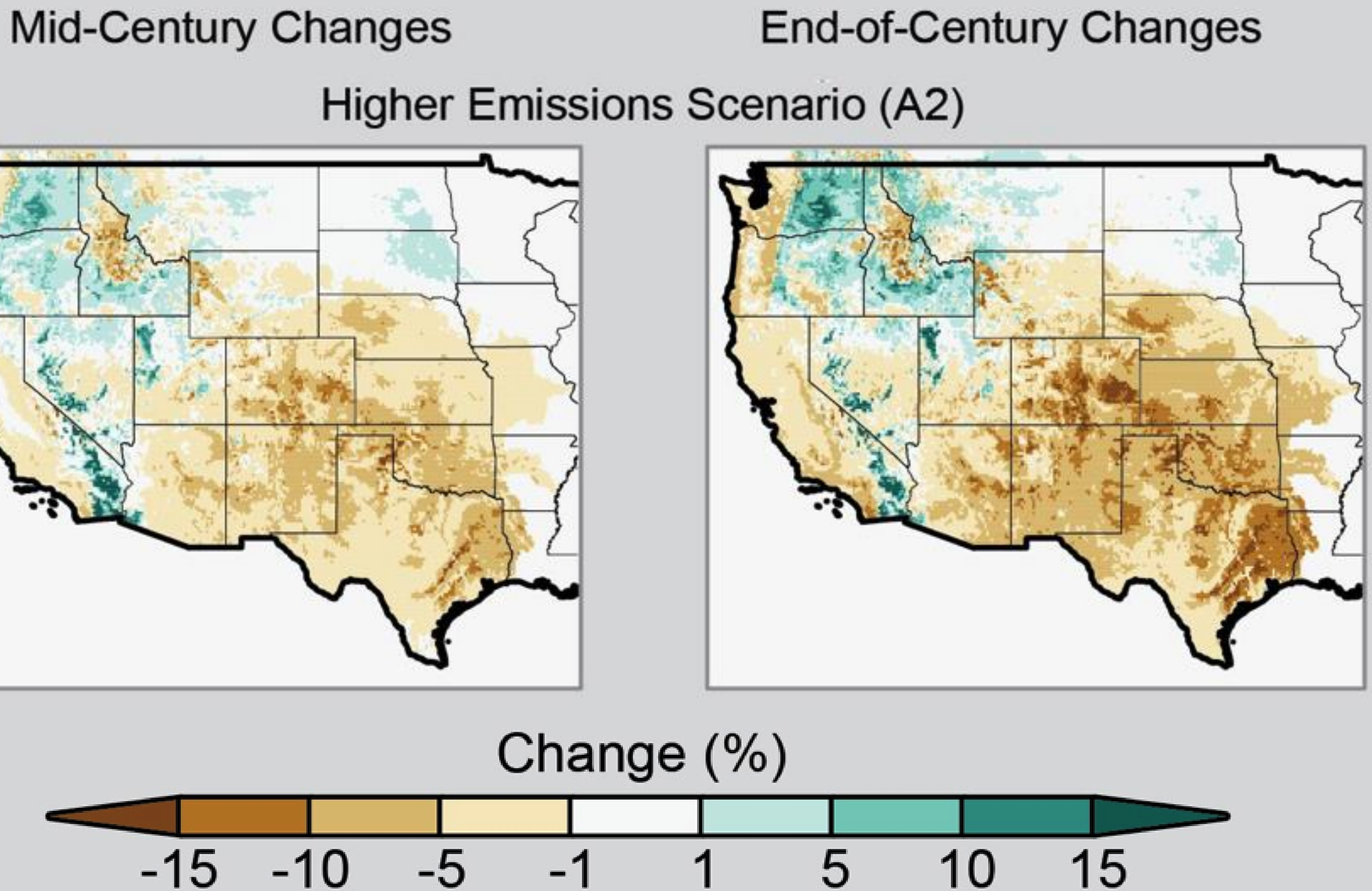
- 1080 ft. level is lowest level since construction in 1930s (full pool = 1,229 ft.).
- LVWA is spending $1.5 billion to add water intake pipes at 850 ft.



Lake Mead, NV http://zimbio.com and http://thepoog.com

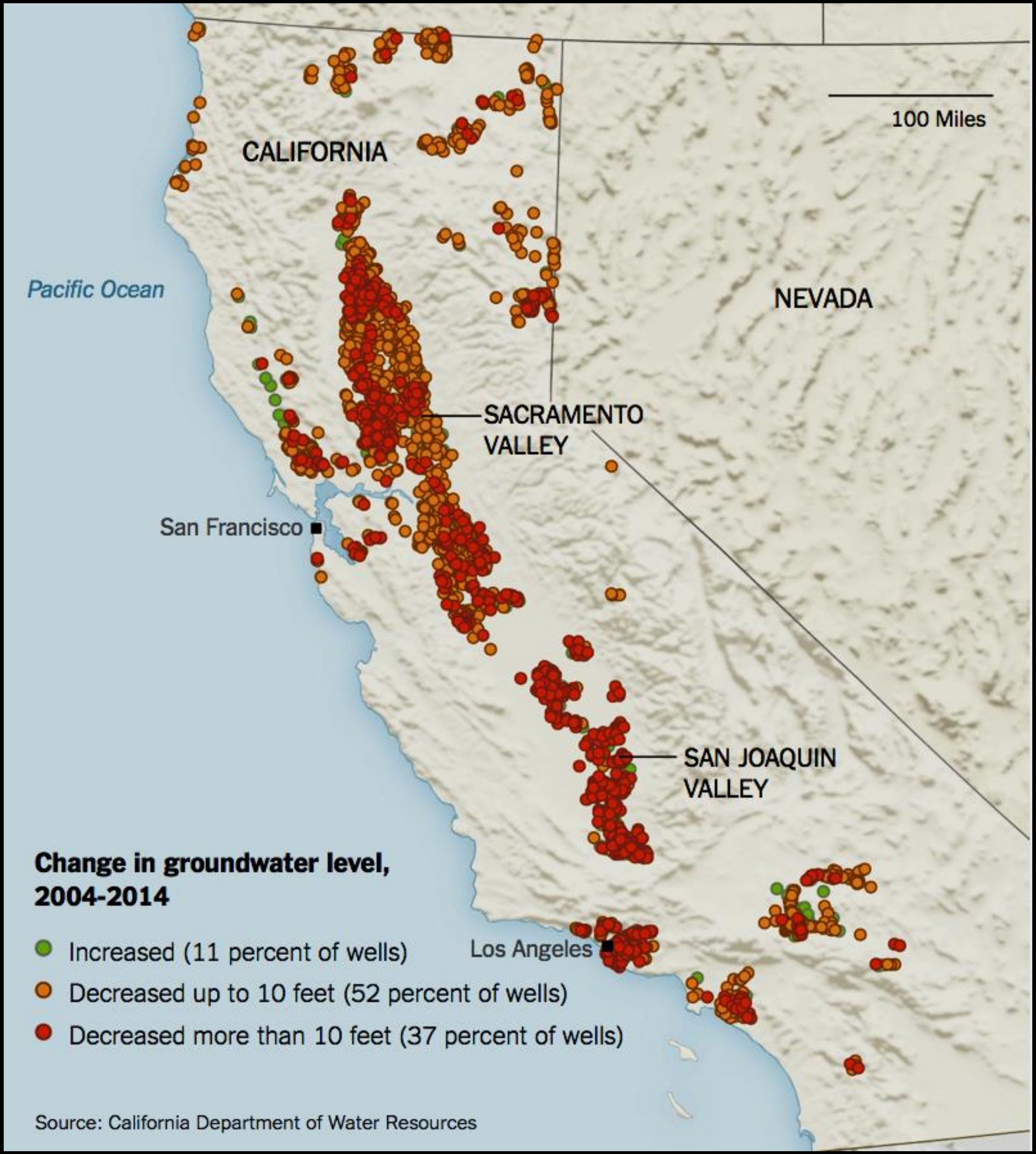
Lake Mead, NV http://Graphs.water-data.com/lakemead

Predicted Soil Drying Trends in the Future



Source: NOAA/NCDC

Groundwater Depletion: California



New York Times Source: California Department of Water Resources: 2004-2014

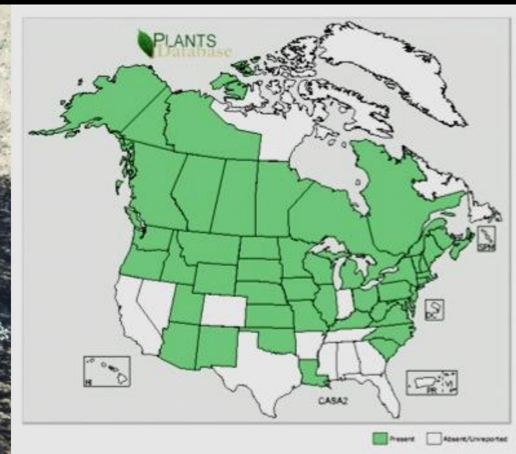
How can we make better use of our limited water resources?

Alternative crops with improved drought tolerance and water-use efficiency…

Drought-tolerant Germplasm Options

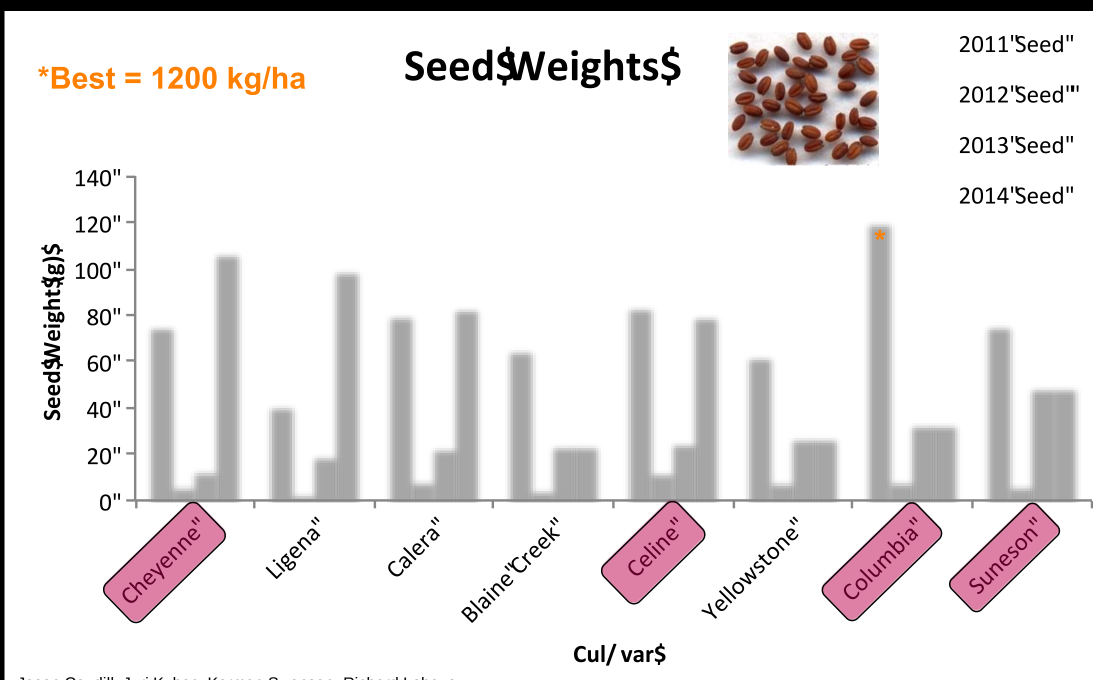
- *Camelina*
- *Sporobolus*
- Gumweed
- Rabbitbrush
- *Agave*
- *Opuntia*

Drought-tolerant Germplasm *Options: Camelina*



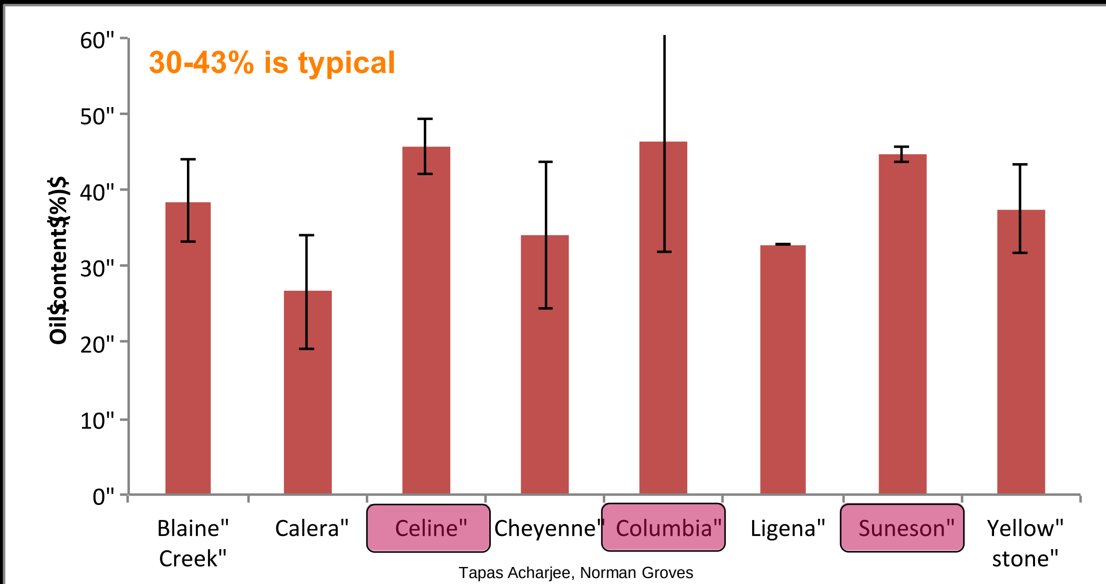
http://plants.usda.gov/; USDA-NRCS PLANTS Database

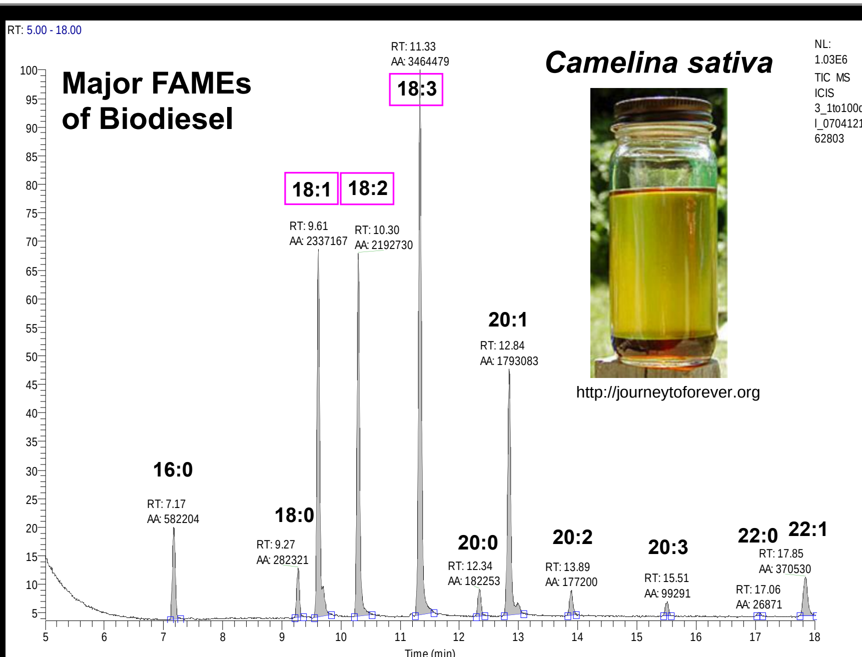
False flax (*Camelina sativa*)



- Generally more drought and salt tolerant than canola
- Requires low water (400 mm) and fertilizer inputs
- Inexpensive to grow (~$80/ha)
- Rapid growth cycle (85-100 days)
- Can be winter seeded; rotation or intercrop
- Oilseed production: 1,200 kg/ha

Drought-tolerant Germplasm *Options: Camelina*





- High seed oil content: 30-47% oil
- Predominantly C18:1 (oleic), C18:2 (linoleic), and C18:3 (α-linolenic) fatty acids
- Suitable for biodiesel; Oil rich in polyunsaturated fatty acids
- Meal contains 45-47% crude protein, 10-11% fiber
- Erucic acid (C22:1) and glucosinolate contents should be reduced to improve edible oil quality

Drought-tolerant Germplasm *Options: Camelina*

- Analysis of transgenic *C. sativa (*Celine) P_{SARK}::IPT with improved drought tolerance and delayed leaf senescence.

Wild-type

P_{SARK}::IPT

28 days optimal growth conditions

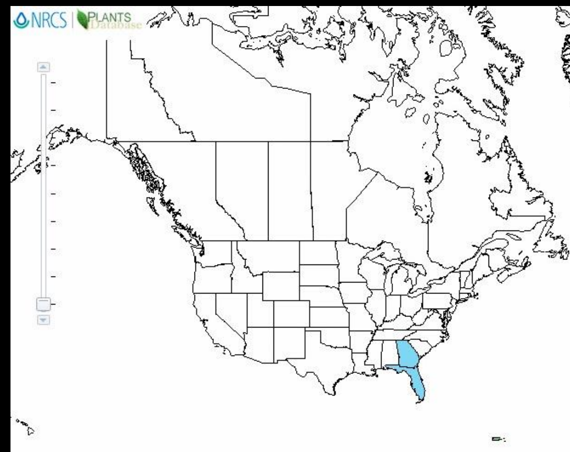
Water-deficit stress for 14-20 days

Rewater

Assess drought tolerance performance

James Davis

Drought-tolerant Germplasm *Options: Sporobolus*



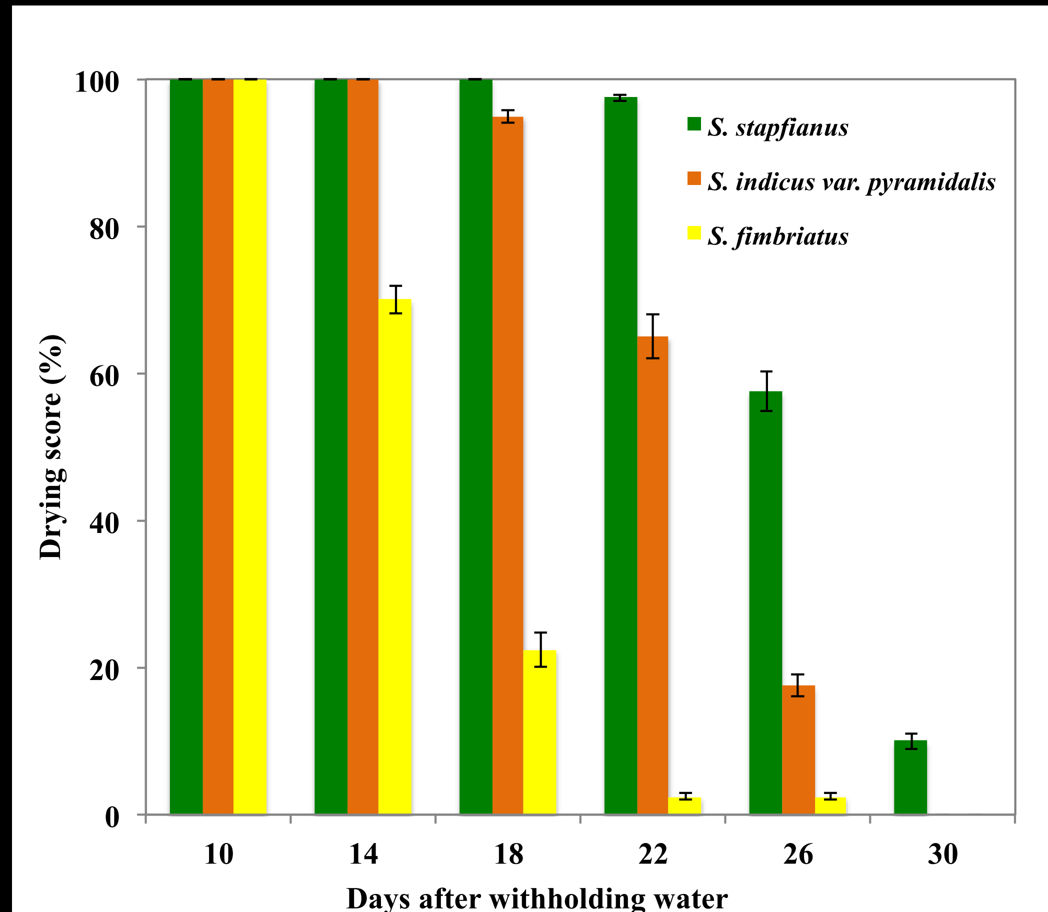
http://plants.usda.gov/; USDA-NRCS PLANTS Database.

West Indian Dropseed (*Sporobolus indicus pyrimidalis*)

- *S. stapfianus (Poacea)* DT native to South Africa, Kenya, Somalia, Nigeria, and Ethiopia
- Survives complete desiccation, resurrects within hours

- ***S. indica cv.pyrimidalis*** desiccation sensitive DS sister species introduced to FL, GA
- *S. fimbriatus* desiccation sensitive DS sister species
- Potential as low-water input forage grasses

Chronic Water-deficit Stress: Drying Scores



2 month old plants; *n* = 40 per species; *n* = 120 total

- After day 22 of withholding water, 5% of *S. fimbriatus survived,* in contrast, 99% of *S. stapfianus* were still green (do not die -> enter dry state).

Yobi et al., 2013

Sporobolus: 2008 & 2009 Field Trials

S. fimbriatus (3) *S. pyrimidalis* (2) *S. stapfianus* (1)

2	1	3
2	3	1
1	2	3

3	1	2
1	3	2
1	2	3

3	2	1
3	2	1
3	2	1

3	1	2
1	2	3
3	1	2

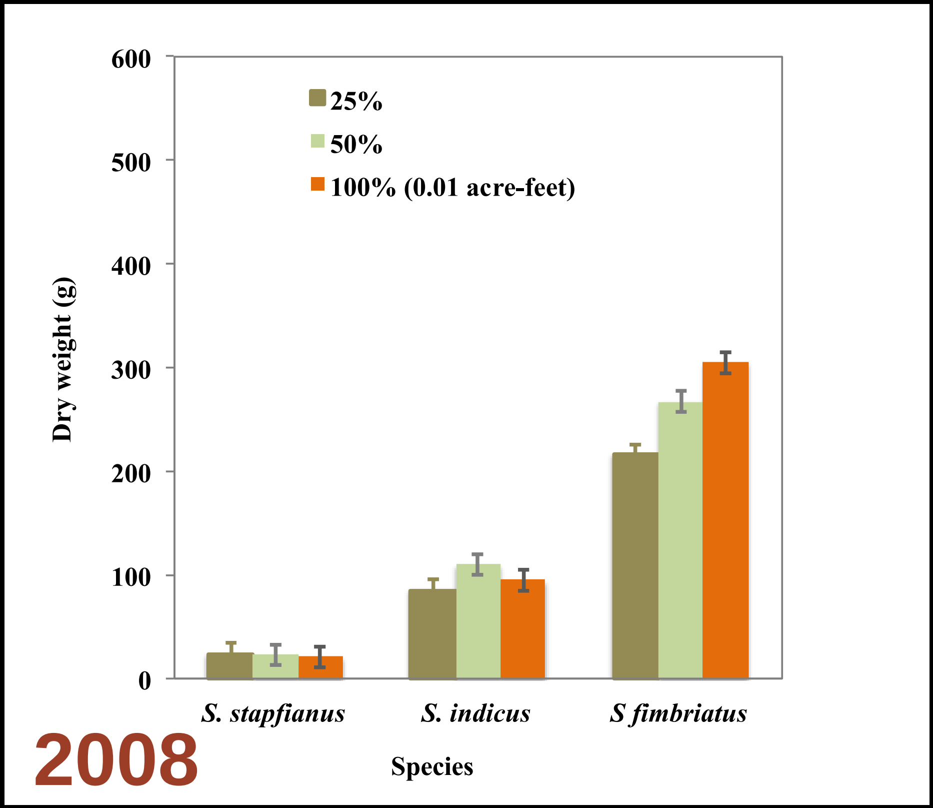
1	3	2
1	3	2
3	1	2

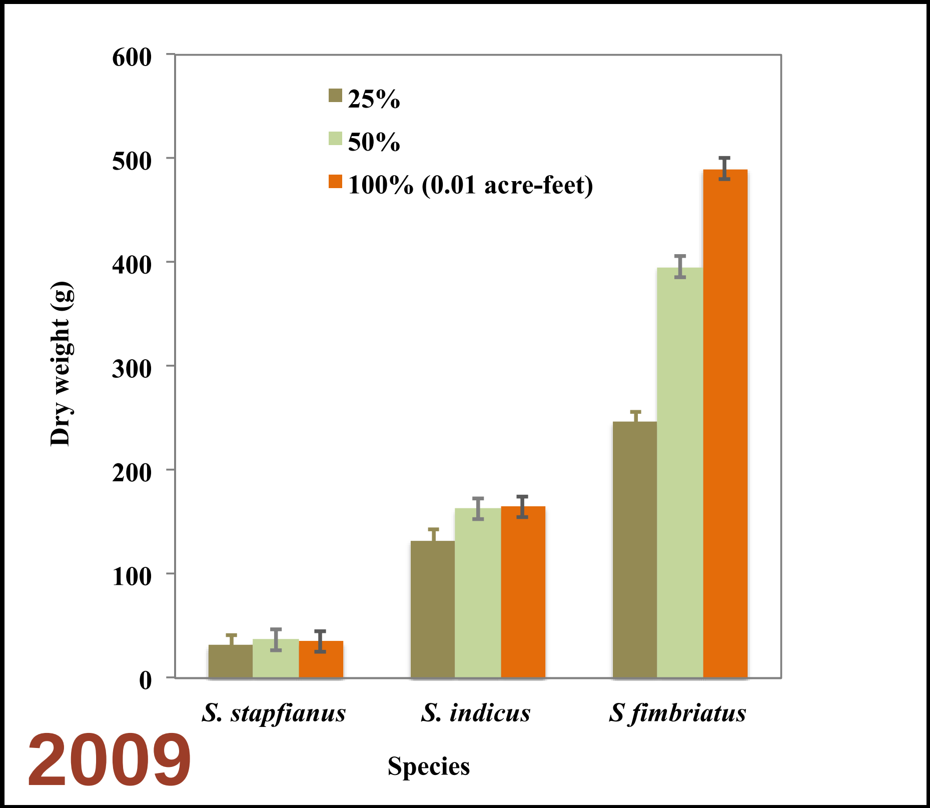
1	2	3
3	1	2
2	1	3

Irrigation Regime: 0.1 acre ft (dark blue) *0.05 acre ft* (blue) *0.025 acre ft* (light blue)

Yobi et al., 2013

Biomass Production: Dry weight





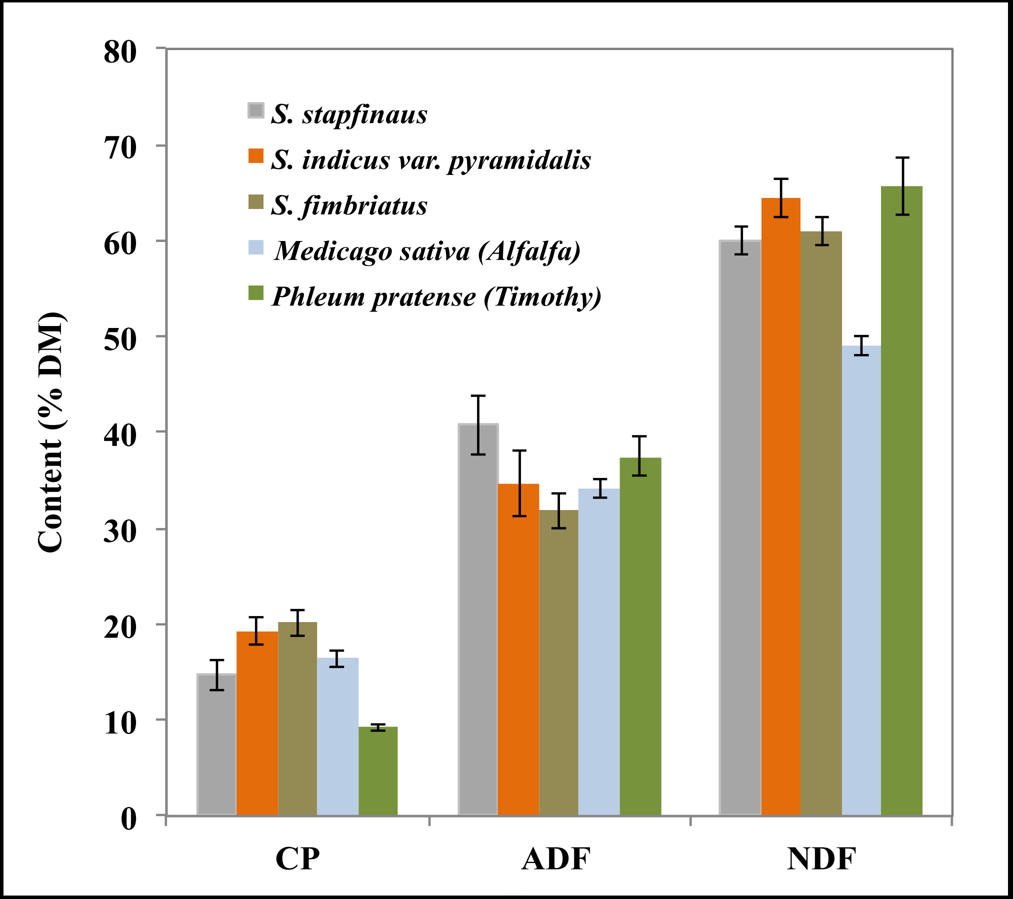
- Biomass production: *S. stapfianus* << *S. indicus* < *S. fimbriatus.* do not increase biomass production in response to increasing water inputs.
- Require 500-fold less water than the commonly used forages such as alfalfa (0.01 *vs* 5 acre-feet).

Yobi et al., 2013

Drought-tolerant Germplasm *Options: Sporobolus*

- *Sporobolus* species tested have mineral and forage qualities comparable to other forage grasses and alfalfa, but can be grown with far less water.

- *Sporobolus stapfianus* can be used as a low-water input and drought-durable ornamental landscape clump grass for arid areas.

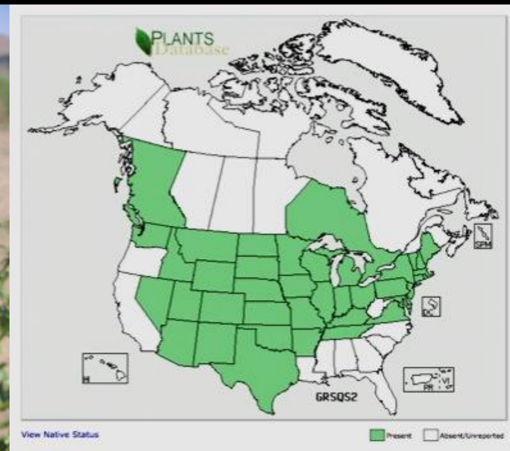


- Interspecific *Sporobolus* hybrids might provide intermediate biomass producing genotypes with the DT trait.

Yobi et al., 2013

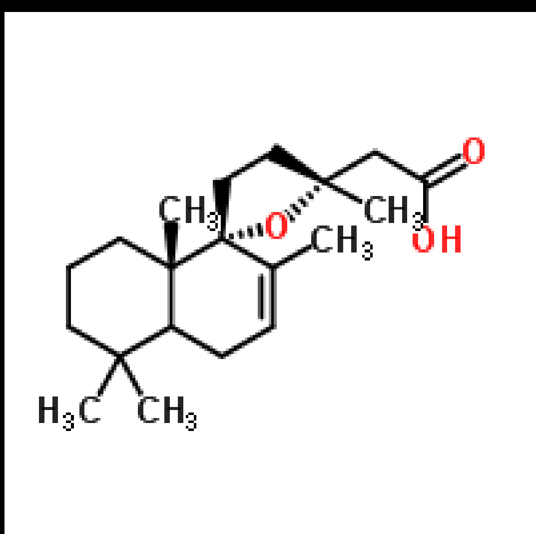
Drought-tolerant Germplasm Options: *Gumweed*

Photo credit: Glenn Miller



http://plants.usda.gov/; USDA-NRCS PLANTS Database.

Gumweed (*Grindelia squarosa*)



Grindelic acid

Photo credit: Glenn Miller

- Native species that requires little water and fertilizer inputs
- Vegetative and floral tissues contain 11-13% “biocrude” resin by dry weight
- Hydrocarbons are C_{20} grindelic acid plus (55% by weight in the biocrude) plus other C_{10-20} terpenoids.
- Biocrude resin production: 900-1200 kg/ha (used as B20).

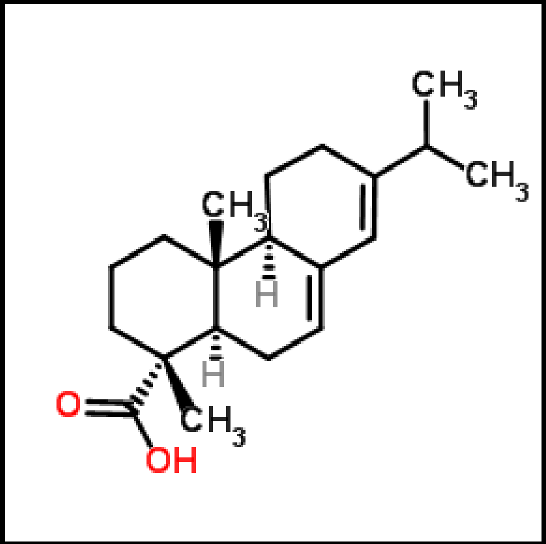
Glenn Miller

Drought-tolerant Germplasm Options: *Gumweed*

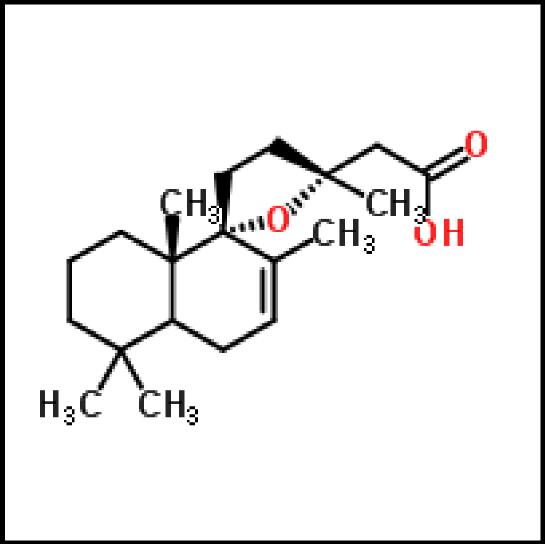
- Gumweed can provide a substitute for abietic acid (wood resin) as grindelic acid has a similar structure.

- Abietic acid is in high demand for making paper, ester gums, and various paints, varnishes, and lacquers and is currently derived from tree stumps (mostly imported).

- Distillation of extract (acid extract of gumweed over alumina) converts 50% to highly branched, high-energy, C_{15} two-ring hydrocarbons that are suitable for use as a jet fuel.



Abietic acid (wood rosin)



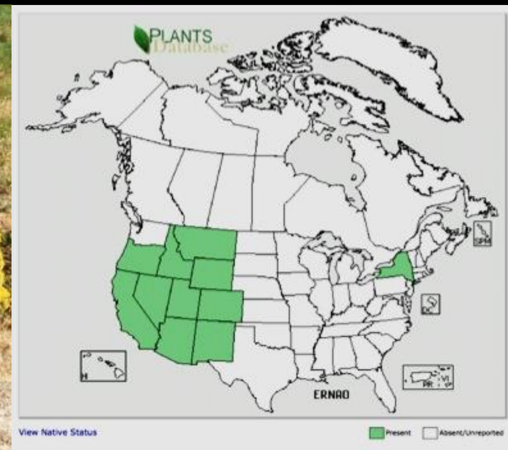
Grindelic acid

Jet fuel

Glenn Miller

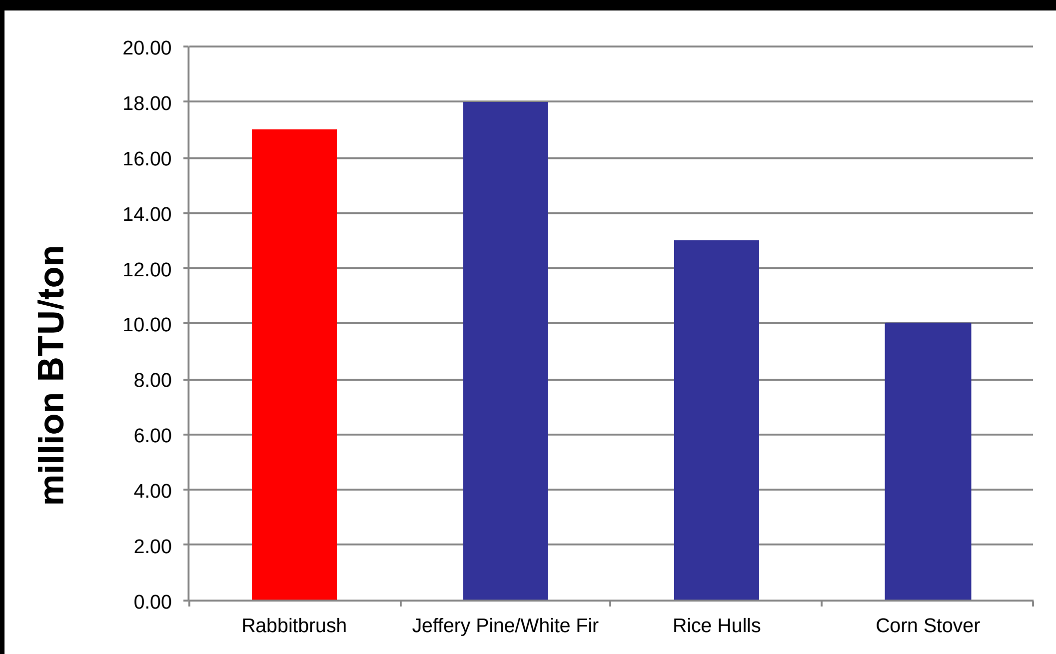
Drought-tolerant Germplasm Options: *Rabbitbrush*

Photo credit: John Cushman



http://plants.usda.gov/; USDA-NRCS PLANTS Database.

Rabbitbrush (*Ericameria nauseosa*)



- **Native species that requires little water and fertilizer inputs**
- **Produces 40 Mg/ha dry biomass; High energy content ~17 M BTU/Mg**
- **Vegetative and floral tissues contain 20% resin by dry weight**
- **Hydrocarbons are C_{5-20}** terpenoids.
- Biocrude resin production: 2600 L/ha (used as B20).

David Shintani

Drought-tolerant Germplasm Options: *Rabbitbrush*

- Rabbitbrush shoots contain 2-6% rubber by dry weight

- High molecular weight rubber comparable to Guayule and Hevea
  (RB 995,800 dal; Guayule 1,143,000 dal; Hevea 1,143,000 dal)

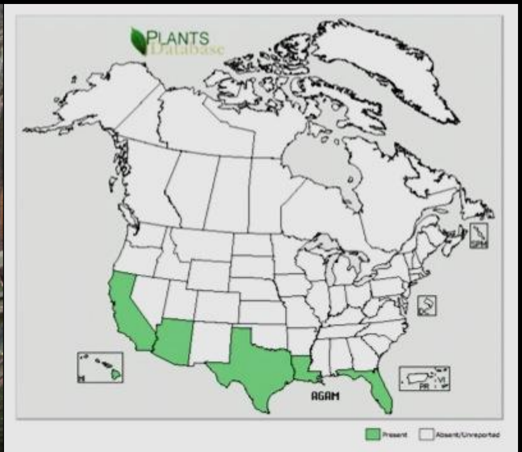
- Good thermostability
  (Plasticity Retention Index: RB 73; Guayule 77.1; Hevea 60)

- Excellent hypoallergenic qualities
  (mg protein/g rubber : RB = ~6.0; Guayule = ~6.7; Hevea; ~13,350)

Rabbitbrush rubber

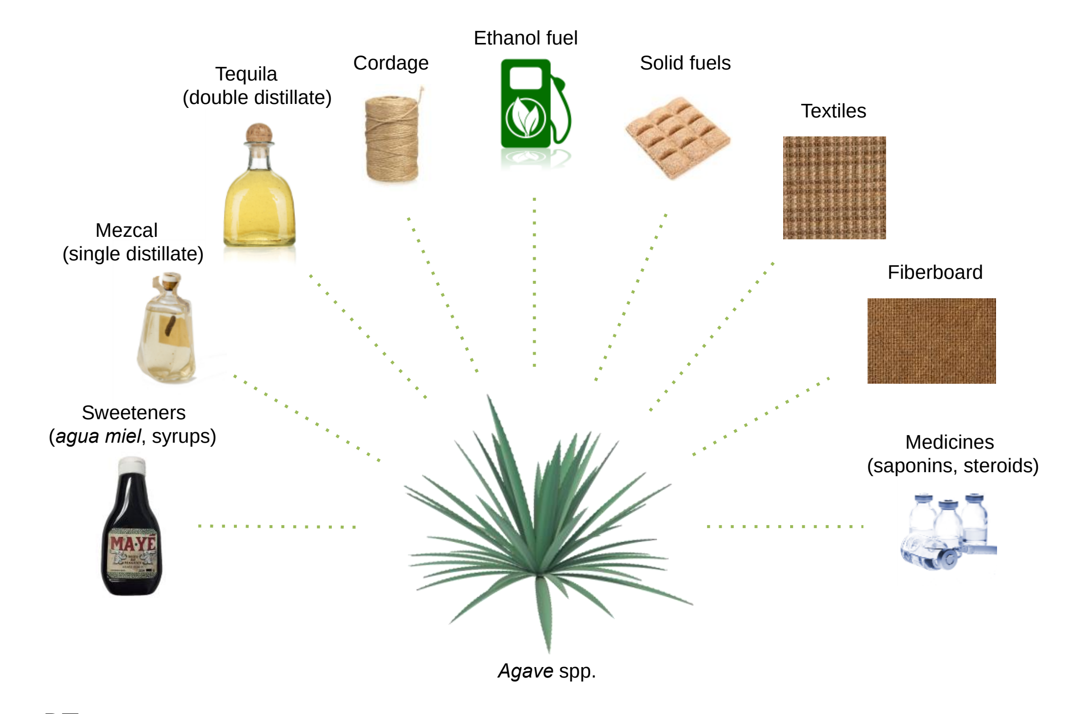
David Shintani

Drought-tolerant Germplasm Options: *Agave*



http://plants.usda.gov/; USDA-NRCS PLANTS Database.

Agave (*Agave americana*)



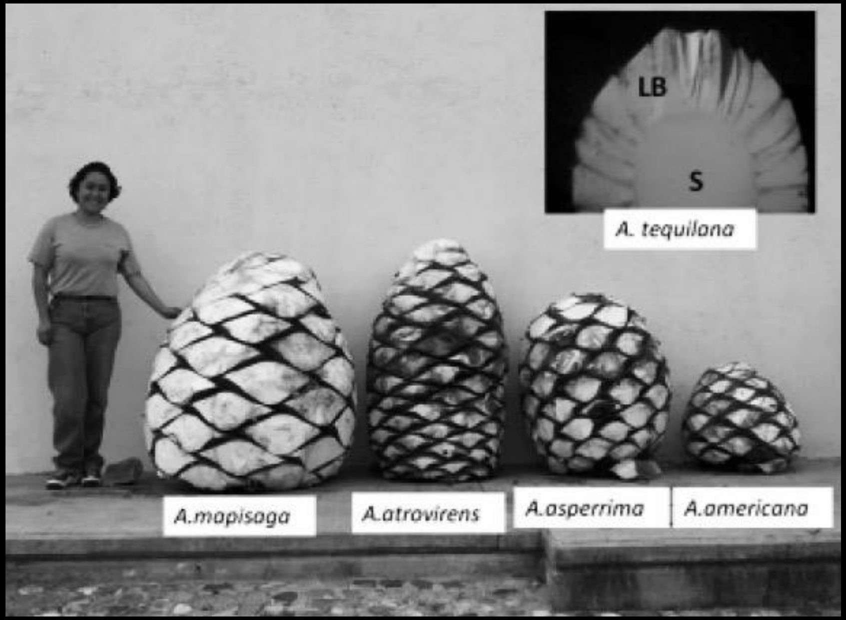
- Water inputs only 20% of traditional crops
- High biomass producers (10-34 Mg/ha/year)
- Leaves and stems contain fermentable sugars with low lignin content for ethanol production
- Various uses

Cushman et al., (2015) J. Exp. Bot.

Drought-tolerant Germplasm Options: *Agave*

- *Agave* worldwide cultivation >500,000 ha (low input, 5-8 year life cycle)
- Large Agave species used for alcoholic beverage production (27-38% sugar leaves/stems)
- Ethanol production well developed:
  - ✓ 14,000 l ha^{-1} (1246 gal ac^{-1}) ethanol plus
  - ✓ 33,650 l ha^{-1} (3598 gal ac^{-1}) cellulosic ethanol (bagasse waste products)

Agave tequilana



Simpson et al., 2011 Global Change Biology: Bioenergy 3: 25-36.

Drought-tolerant Germplasm Options: *Agave*

- *Agave* worldwide cultivation >500,000 Ha

- Large Agave species used for fiber production:
  - *A. sisalana* (sisal) 246 x 10^3 Mg
  - *A. fourcroydes* (henequin) 22 x 10^3 Mg

Agave sisalana

Sisal fibers

Drought-tolerant Germplasm Options: *Agave*

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Cite this: *Energy Environ. Sci.*, 2011, **4**, 3110

www.rsc.org/ees

ANALYSIS

Life cycle energy and greenhouse gas analysis for agave-derived bioethanol

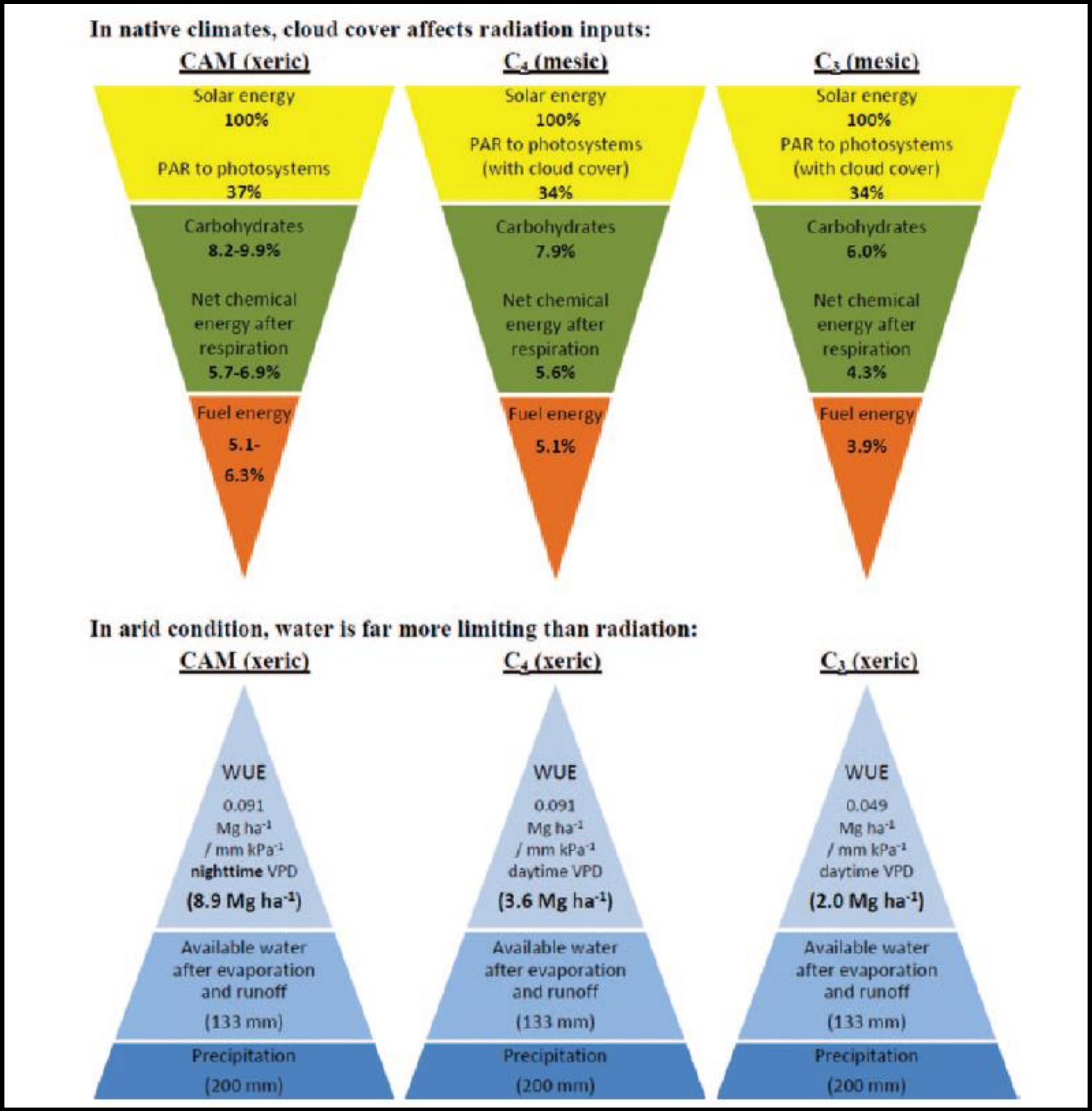
Xiaoyu Yan,*[a] Daniel K. Y. Tan,[bc] Oliver R. Inderwildi,[a] J. A. C. Smith*[b] and David A. King[a]

Received 29th January 2011, Accepted 24th June 2011
DOI: 10.1039/c1ee01107c

"Life cycle energy and greenhouse gas (GHG) analysis of agave-derived ethanol … suggests that ethanol derived from agave is likely to be superior, or at least comparable to that from corn, switchgrass, and sugarcane, in terms of the energy balance and GHG balances…ethanol output and … net GHG offset "

Yan et al., 2011 Energy Environ. Sci. 4: 3110.

Drought-tolerant Germplasm Options: *Agave*

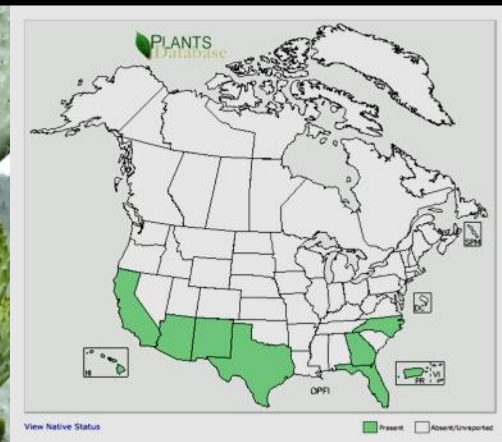


- Under native conditions, CAM (*Agave*) species have comparable fuel energy content to C_4 bioenergy crops.
- Under arid, water-limiting conditions, *Agave* has yield potentials that are 147% greater than C_4 species.

Davis et al. 2014 J. Exp. Bot 65:3471-3478.

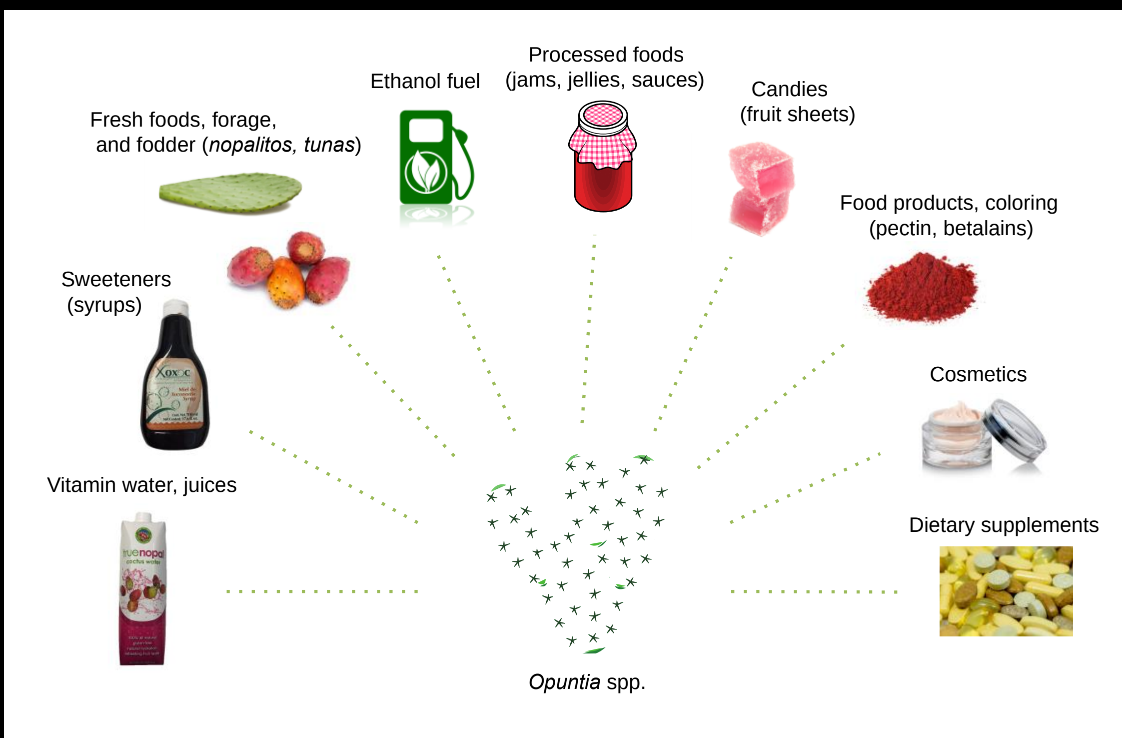
Drought-tolerant Germplasm Options: *Opuntia*

Photo credit: J.S. Peterson @ USDA-NRCS PLANTS Database



http://plants.usda.gov/; USDA-NRCS PLANTS Database.

Prickly Pear Cactus (*Opuntia ficus-indica*)



- Water inputs only 20% of traditional crops
- High biomass producers (10-47 Mg/ha/year)
- Leaves and fruits are edible by humans/livestock and fermentable for ethanol and biogas production
- Various uses

Cushman et al., (2015) J. Exp. Bot.

Drought-tolerant Germplasm Options: *Opuntia*

- *Opuntia* worldwide cultivation >1,000,000 ha

- Large *Opuntia* species used for food as young cladodes (nopalitos) and fruits (tunas) and forage



Paterson **et al., (2008)** Trop. Plant Biol. 1**: 3-19**

Drought-tolerant Germplasm Options: *Opuntia*

World J Microbiol Biotechnol
DOI 10.1007/s11274-014-1745-6

ORIGINAL PAPER

Opuntia ficus-indica cladodes as feedstock for ethanol production by *Kluyveromyces marxianus* and *Saccharomyces cerevisiae*

Olukayode O. Kuloyo · James C. du Preez · Maria del Prado García-Aparicio · Stephanus G. Kilian · Laurinda Steyn · Johann Görgens

- Separate hydrolysis & fermentation (SHF) and simultaneous saccharification (enzymatic hydrolysis) and fermentation (SSF) conditions tested.
- Only 2.6% ethanol yield; 4% needed for economic viability.
- Low fermentable sugar (Glu, Gal, Fru, Man) content limits commercial viability.

Kuloyo et al., 2014 World J. Microbiol. Biotechnol.

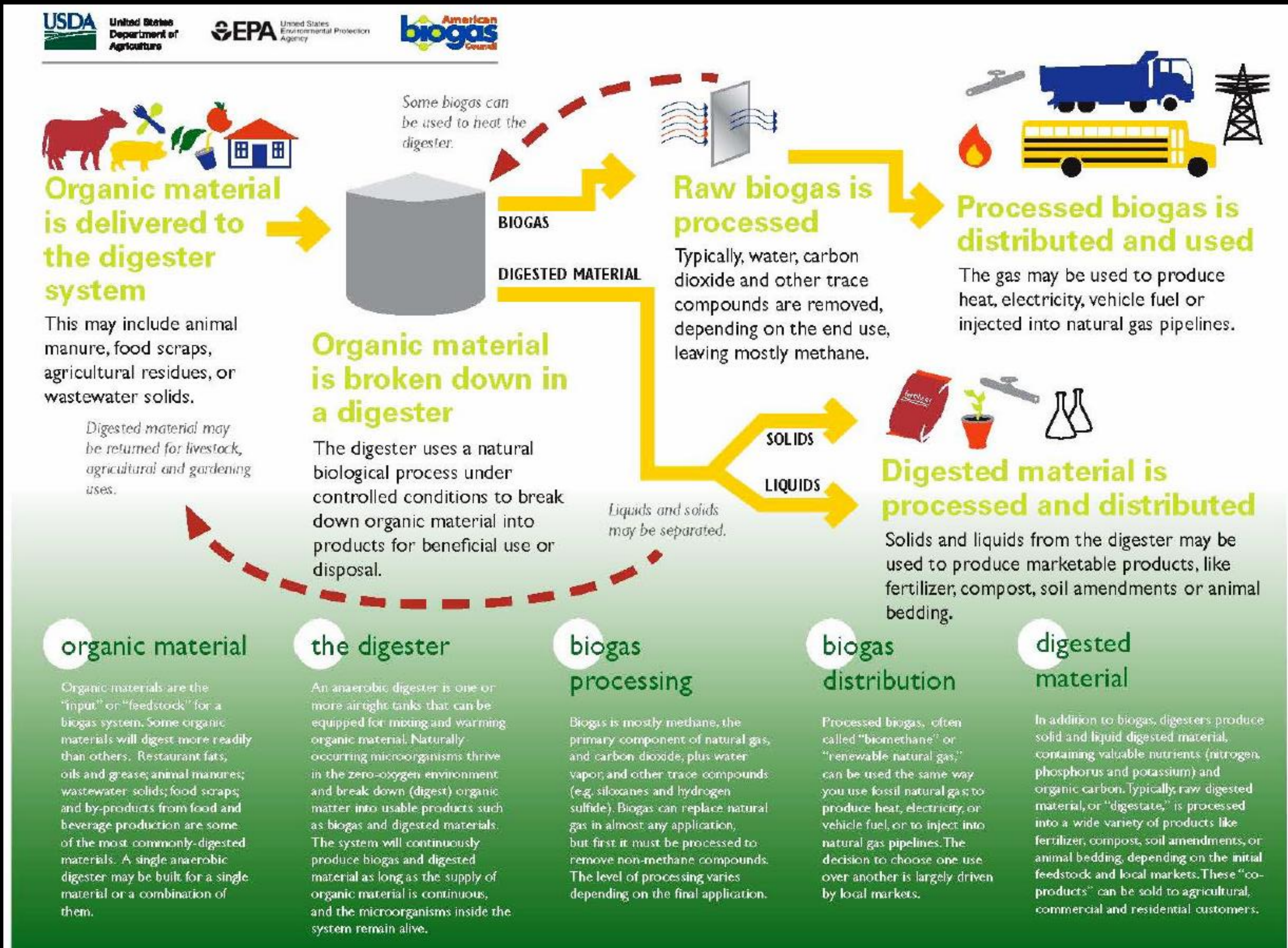
Drought-tolerant Germplasm Options: *Opuntia*

- Prickly pear “spears” added as the sole carbon source using minimal media.
- Soil consortium of microbes resulted in hydrolysis within 5 days.
- More complete release of fermentable sugar should improve utility as a biofuel feedstock.

Soil Consortium | Control

Brian Fox Lab (Univ. Wisconsin)

Biogas Opportunities Roadmap (2014)



Drought-tolerant Germplasm Options: *Opuntia*

- *Opuntia* plantation in Chile for biogas production.

Photo credit: Rodrigo Wayland Morales, Elqui Global Energy, La Serena, Chile

CAM Bioenergy Crops: *Opuntia & Euphorbia*

Fig. 2 Ten-month-old *Opuntia ficus-indica* in Laikipia, Kenya (photo credit George Francis).

Opuntia ficus-indica

Fig. 3 *Euphorbia tirucalli* under test in Laikipia, Kenya (photo credit George Francis).

Euphorbia tirucalli

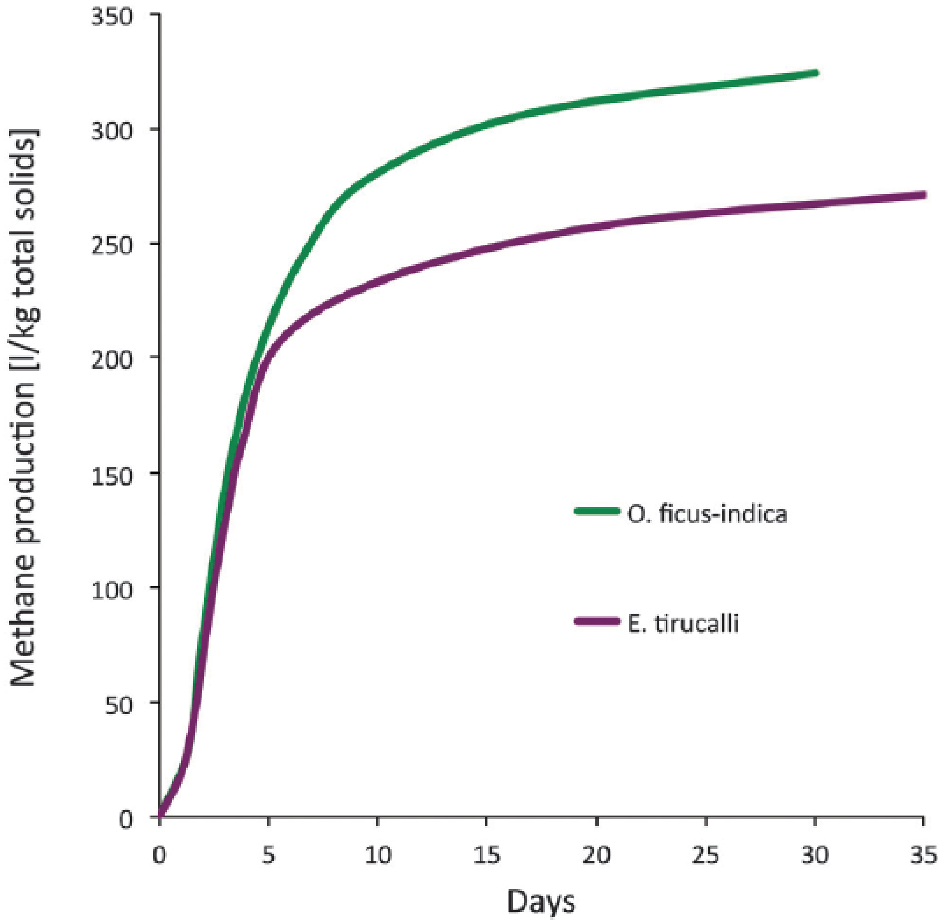


Fig. 6 Digestion rate of *Opuntia ficus-indica* and *Euphorbia tirucalli* grown in Laikipia, Kenya.[46]

Mason et al., 2015 Energy & Environmental Science

CAM Bioenergy Crops: *Opuntia & Euphorbia*

Energy & Environmental Science

ROYAL SOCIETY OF CHEMISTRY

ANALYSIS

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Cite this: DOI: 10.1039/c5ee00242g

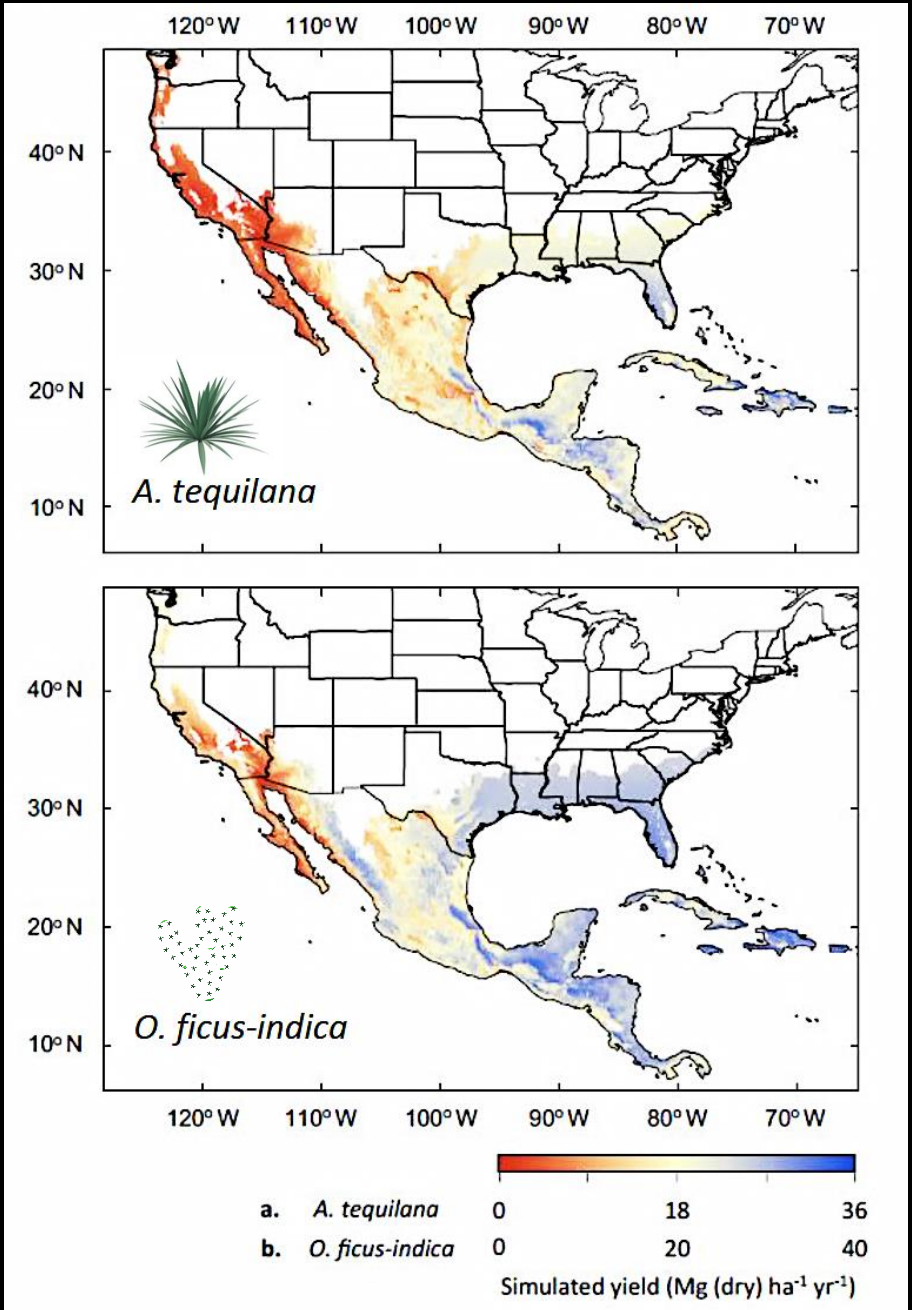
The potential of CAM crops as a globally significant bioenergy resource: moving from 'fuel or food' to 'fuel and more food'†

P. Michael Mason,*[ab] Katherine Glover,[b] J. Andrew C. Smith,[c] Kathy J. Willis,[d] Jeremy Woods[e] and Ian P. Thompson[a]

- *Opuntia ficus-indica* and *Euphorbia tirucalli* are highly drought-tolerance CAM bioenergy crops that can be grown on semi-arid lands.
- Anaerobic digestion of biomass to produce biogas.
- Global power generation = 5 PW h per year; 100-380 M ha or 4-15% of potential land area (2.5 B ha total semi-arid lands).

Mason et al., 2015 Energy & Environmental Science

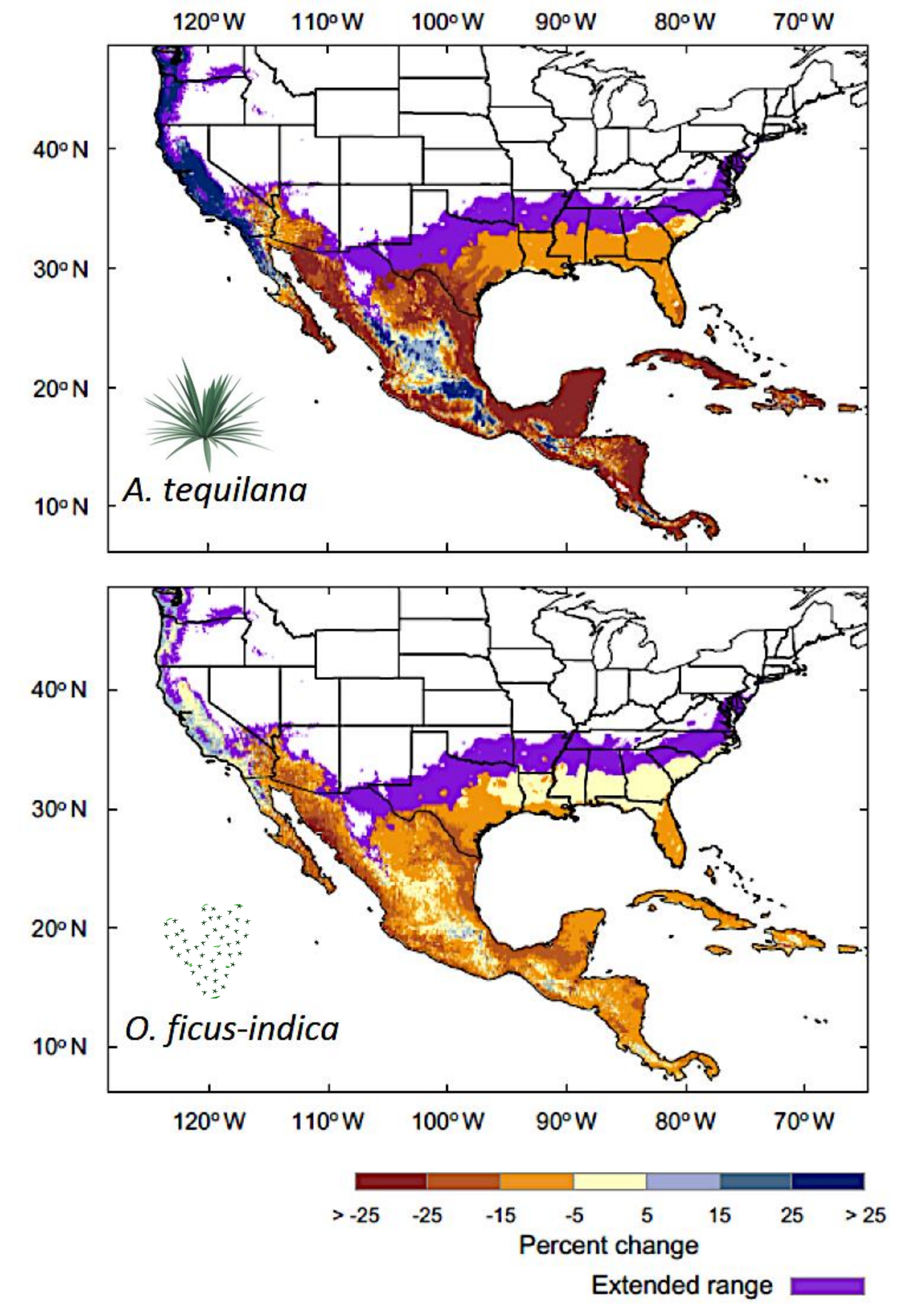
Yield Productivity under Current Climate Conditions



- Highly productive regions in Southeastern states.
- *O. ficus-indica* outperforms *A. tequila* in most parts of North America.
- Monthly isotherm set to 0 ° C. *O. ficus-indica* can survive to -9 ° C.
- Annualize productivity of *O. ficus-indica* expected to increase from rising CO_2 concentrations (Nobel 1991).

Nick Owen: Yang et al., (2015) New Phytologist

Simulated Yield under Future Climate Conditions



- Comparison of present conditions with worst-case climate change scenario in 2070.
- Productive range likely to double for both species (purple).
- *A. tequilana* will perform better in mountainous regions (dark blue).
- *O. ficus-indica* shows greater resilience to climate change.

Nick Owen: Yang et al., (2015) New Phytologist

Opuntia Field Production Trial in U.S.

- 0.25 ha (0.6 acre) field site in Logandale, NV
- Three (spineless) varieties:
  - *Opuntia ficus-indica*
  - *Opuntia cochenillifera*
  - *Opuntia streptacantha*

Opuntia Field Production in U.S.

- 3 Varieties:
  - *Opuntia ficus-indica*
  - *Opuntia cochillifera*
  - *Opuntia streptacantha*
- 3 watering regimes:
  - *200 mm*
  - *400 mm*
  - *800 mm*

  (local = 108 mm)
- 4 Replicates:
  - *7 plants/block*
  - *Pseudo-random design*

Opuntia Field Production in U.S.

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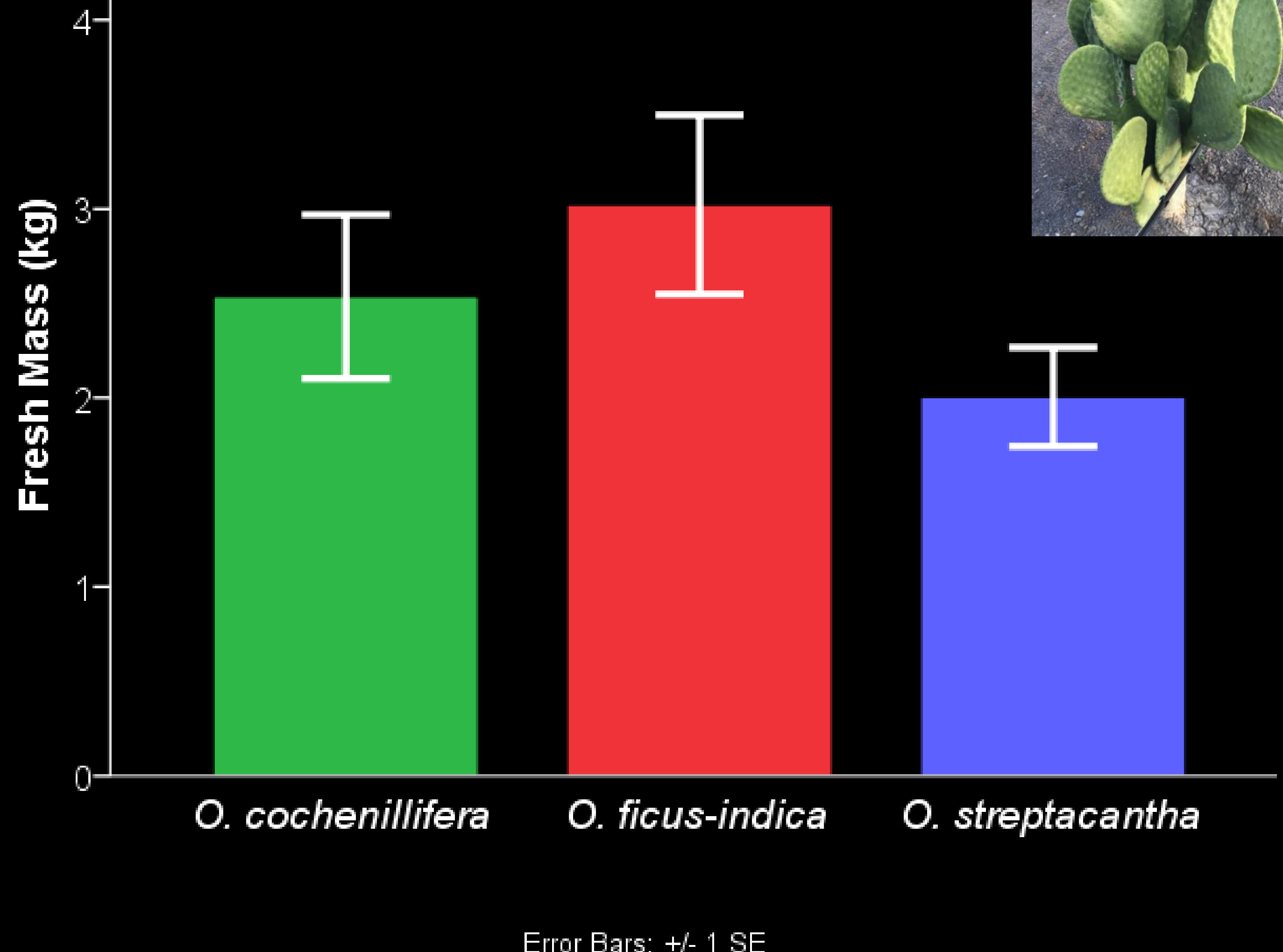
Opuntia Field Production Year 1

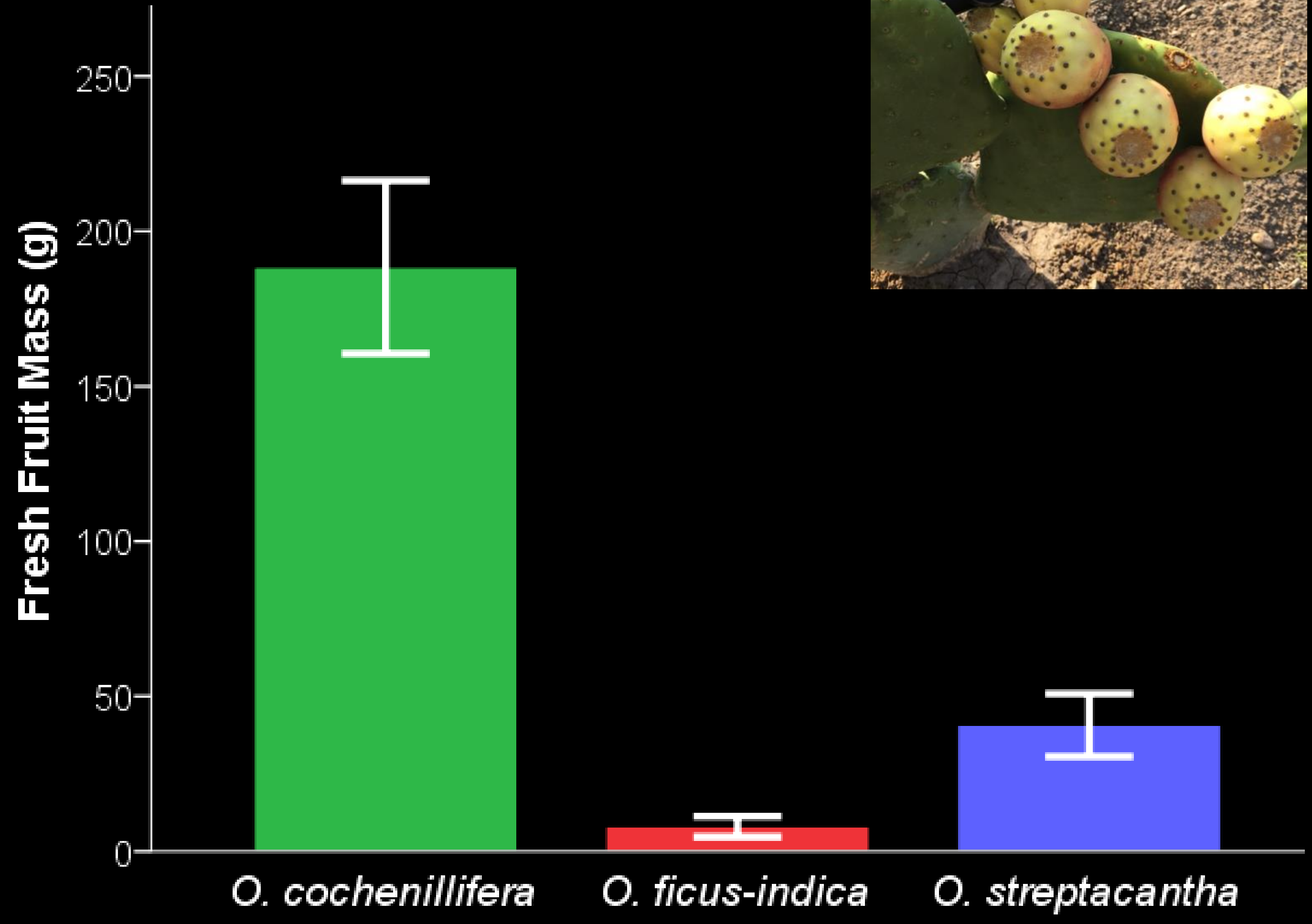
- Cladode fresh weight



Jesse Mayer

Opuntia Field Production Year 1

- Fruit fresh weight



Jesse Mayer

Drought-tolerant Germplasm Options






- *Camelina*
- *Sporobolus*
- Gumweed
- Rabbitbrush
- *Agave*
- *Opuntia*

Drought-tolerant Germplasm Options

- More water-use efficient crops will be needed in the future due to warmer, drier climate, particularly in the western US.

- Water limitations will likely force greater reliance on crops that use less water.

- Productive areas for some species (*Agave* and *Opuntia*) will double in the US over the next 50 years.

- Expanded use of these species has the potential to increase production while reclaiming abandoned or underutilized semi-arid agricultural lands.

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