Mitigation Potential from Agricultural Croplands in California

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California Agricultural Emissions by Source (CARB, 2011)

Agricultural Source	2009 Emissions (Tg CO_2e)	Percentage of Total
Manure management	10.34	32.2
Enteric fermentation	9.28	28.9
Soil management	9.02	28.1
Energy use	2.63	8.2
Rice cultivation	0.58	1.8
Histosol cultivation	0.16	0.5
Residue burning	0.06	0.2

Cropland emissions make up <40% of total agricultural emissions, and <3% of total California state emissions

Introduction

- California's Global Warming Solutions Act (Assembly Bill 32)- reduce CA GHG emissions to 1990 levels by 2020 and a further 80% by 2050
- AB 32 does not require agricultural producers to report or reduce their greenhouse gas emissions
- In 2009, California emitted a total of 457 Tg CO_2e across all economic sectors, with agriculture contributing 32.1 Tg CO_2e, or 7.0% of the state's total (CARB, 2011)

California Agricultural Emissions by Gas(CARB, 2011)

Agricultural Source	**2009 Emissions (Tg CO_2e)**	**Percentage of Total (%)**
CH_4	18.7	58
CO_2	2.8	9
N_2O	10.6	33
Total	**32.1**	**100**

- N_2O emissions made up 33% of emissions from the agricultural sector, but only made up 4% of total emissions across all economic sectors.
- CO_2 accounts for 9% of agricultural emissions, while accounting for 86% of emissions across all economic sectors of California.

Objectives

1) Review the available scientific literature relevant to greenhouse gas emissions from cropland in California.

2) Conduct a quantitative assessment of the biophysical potential of various agricultural mitigation strategies relevant to California cropping systems.

Methods and Approach

- Addendum to Eagle et al., (2012) *Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature (Third Edition)*
- Identified the "standard" or "conventional" management practice across studies
- Determined the baseline emissions value for this practice
- Calculate emissions with alternative management(s)
- Standard – alternative = Biophysical Mitigation Potential
- Positive values reflect a net increase in mitigation potential, as GHGs are reduced relative to the control

Management Activities Addressed

- Farmland Preservation
- Expansion of Perennial Crops
- Conservation Tillage
- Cover Crops and Organic Amendments
- Nitrogen Fertilizer Rate and Source
- Nitrogen Fertilizer Placement and Timing
- Nitrogen Fertilizer Efficiency Enhancers
- Irrigation Practices
- Rice Management

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Farmland Preservation

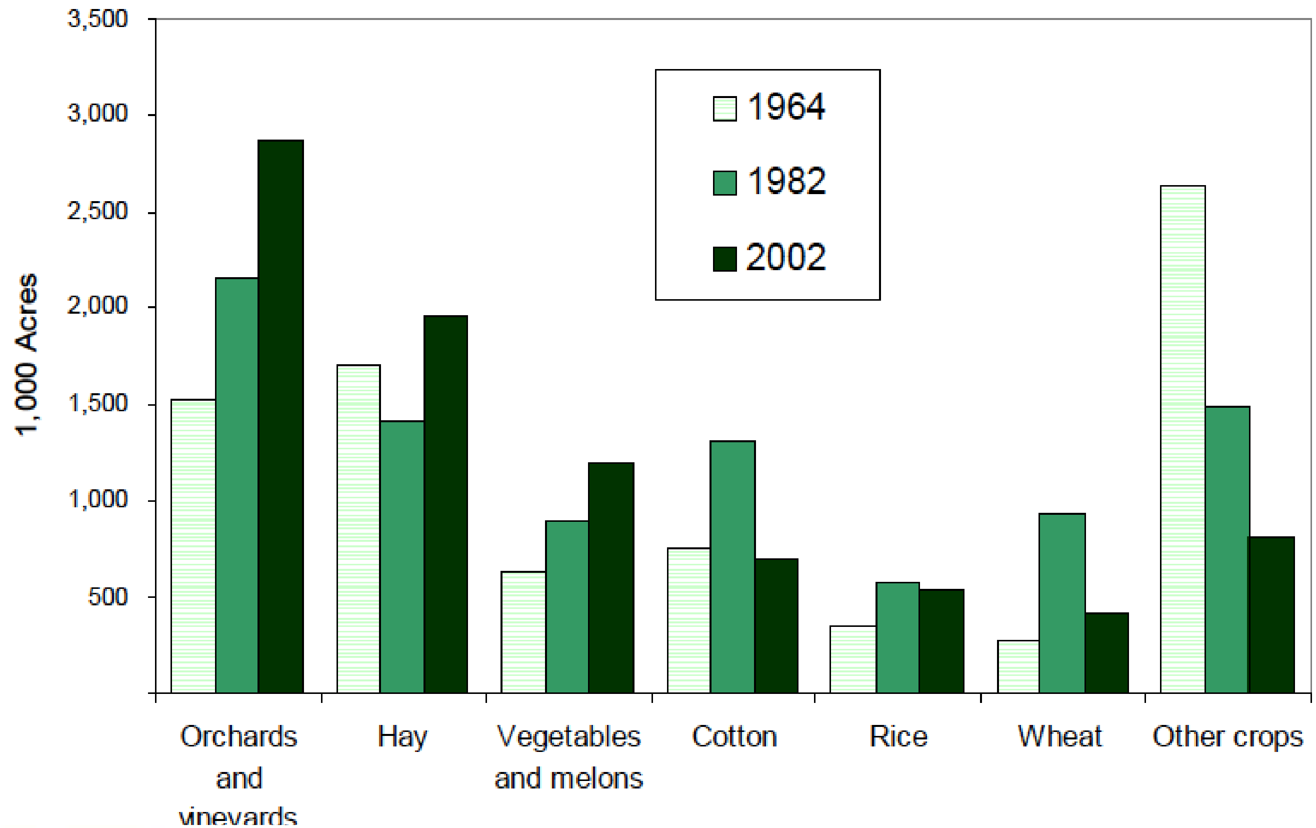
	Land Area (ha)		Average Emissions Rate (t CO2e ha^{-1} yr^{-1})	
Land-use Category	**1990**	**2008**	**1990**	**2008**
Urban Land-uses	9,078	12,072	152.0	Data not available
Irrigated Cropland	139,407	131,439	2.19	1.99

- Haden et al. (2013) conducted an inventory of agricultural emissions from Yolo County
- Average emissions per unit area were about 70 times higher for urban land uses relative to irrigated cropland

Expansion of Perennial Crops

- The majority of California croplands (57%, 4.8 million acres) is occupied by perennial crops
  - Orchards and vineyards – 34%
  - Alfalfa and hay – 23 %
- Few reports of emissions on these crops in CA
  - Grapes – 1 study (Garland et al., 2011)
  - Almonds – 3 studies (Smart et al., 2006; Schellenberg et al. 2012; Alsina et al., 2013)
  - Alfalfa – 1 study (Burger and Horwath, 2012)

Trends show increasing perennial crops in California



(UCAIC, 2009)

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Conventional to Conservation Till or No-till

- Reduce the amount of physical disturbance
- GHG Mitigation
  1. Direct fuel savings
     - 0.03 - 0.10 t CO_2e ha^{-1} yr^{-1} with conservation tillage
     - 0.07 - 0.18 t CO_2e ha^{-1} yr^{-1} with no tillage
  2. Can reduce CO_2 emissions via building soil C
     - Difficult to quantify
       - Veenstra…Horwath (2007) show no effect of no till on soil C
       - Recent unpublished data from same plots do show C sequestration in no till
  3. Can increase N_2O emissions in first years (up to 20 y)
     - Reduction may only be realized in long-term no tillage systems

Soil carbon mass for tillage and cover crop treatments at two soil depths

Fivepoints, CA Long-term Conservation Till Experiment (1999)

Depth (cm)	Soil C mass§ t/ha							
	STNO		STCC		CTNO		CTCC	
0-15	10.74	(0.26)	13.68	(0.43)	14.51	(0.61)	15.95	(3.43)
15-30	11.59	(0.43)	13.69	(0.73)	11.69	(0.45)	12.89	(0.54)
Total	22.33	C	27.37	B	26.20	B	28.84	A

† ST = standard tillage; CT = conservation tillage; NO = no cover crop; CC = winter cover crop.

§Values in parentheses are standard error of the means (n = 8). North and south field means were not significantly different; treatments were combined for analysis. Letters represent significant differences among treatments using a one-way ANOVA analysis with Tukey HSD means comparison.

Conventional to Conservation Till or No-till

- Adoption very limited in California
  - <2% of acreage in 9 Central Valley Counties (Mitchell et al., 2009)
- N_2O emissions reduced 0.04 t CO_2e ha^{-1} yr^{-1} across 5 studies (range -0.69 – 0.65 t CO_2e ha^{-1} yr^{-1})

Source	Data Type	Crop
Lee et al., 2009	Field	Corn, Sunflower, Chickpea
Garland et al., 2011	Field	Grapes
Kallenbach et al., 2006	Field	Tomato
Kennedy, 2012	Field	Tomato
De Gryze et al., 2009	Modeled	Alfalfa, Corn, Rice, Tomato, Wheat, Sunflower, Safflower, Cotton, Mellon

Cover Crops

- Plants that are typically not harvested, but returned to the soil via mowing or tilling
- Can be planted anytime of year and occupy a wide range of functionality, including
  - Winter legume to fix nitrogen and build soil organic matter
  - Rye in the fall to scavenge excess soil nutrients after harvest and suppress weeds

Mitigation Potential

- Decrease greenhouse gas emissions by sequestering C in soil
- Increasing the efficiencies of N fertilization (i.e., scavenging for residual soil nutrients not taken up by cash crop)
- Leguminous cover crops may:
  - Increase direct field emissions since by increasing available soil nitrogen via BNF
  - Decrease indirect emissions by reducing the need for external N fertilizer inputs
  - Increase emissions if additional irrigation is necessary to replenish soil moisture

Cover Crops

- Limited number of studies in California
- N_2O emissions reduced 0.04 t CO_2e ha^{-1} yr^{-1} across 4 studies (range -1.69 – 0.89 t CO_2e ha^{-1} yr^{-1})

Source	Data Type	Crop
Kallenbach et al., 2010	Field	Tomato
Kennedy, 2012	Field	Tomato
Smuckler et al., 2012	Field	Tomato
De Gryze et al., 2009	Modeled	Tomato, Alfalfa, Corn, Rice, Wheat, Safflower, Sunflower, Cotton, Melon

Organic Amendments

Mitigation Potential

- Decrease greenhouse gas emissions by sequestering C in soil
- Increasing the efficiencies of N fertilization

- Only 2 California studies have examined organic matter
- Modeling results showed that combining farming practices (conservation tillage or cover cropping with manure application) showed the largest reductions in emissions

Source	Data Type	Crop
Burger et al., 2005	Field	Tomato
De Gryze et al., 2009	Modeled	Tomato, Alfalfa, Corn, Rice, Wheat, Safflower, Sunflower, Cotton, Melon

Crop Rotation

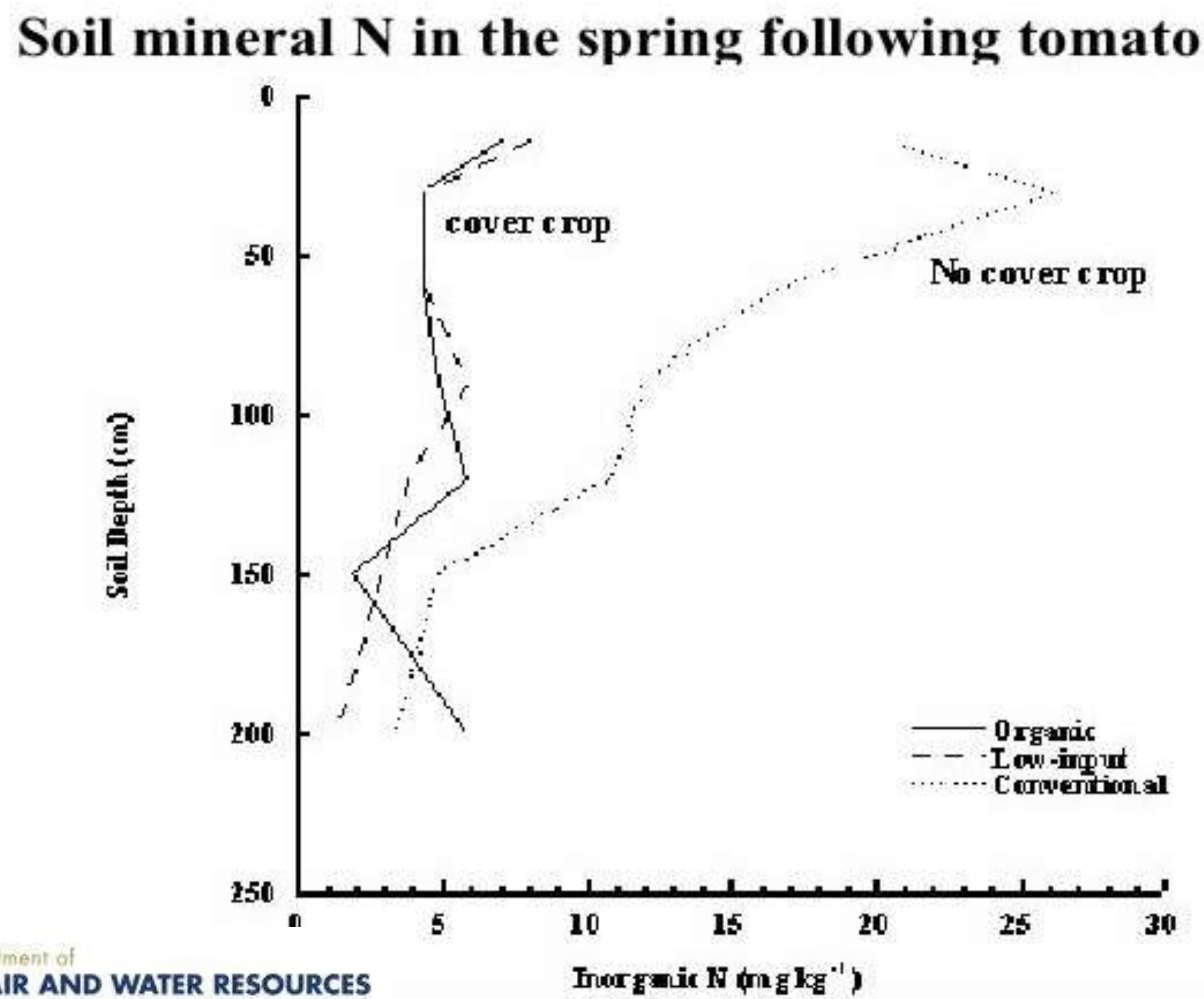
(Little research done; UCD)

Cumulative (kg ha^{-1}) N input, N output, soil N storage and loss (%) for organic, low-input, and conventional cropping systems at UCD long-term experiments, over 10 years

System	N input	N output	Soil N storage	Loss of Applied N %
		SAFS		
Organic	1924	933	901	4.6
Low-input	1550	1186	327	2.4
Conv-4	1827	1339	79	22.3
		LTRAS		
Organic	3368	905	685	63.0
Low-input	1500	921	-329	60.5
Conv-2	2064	1288	-383	56.2

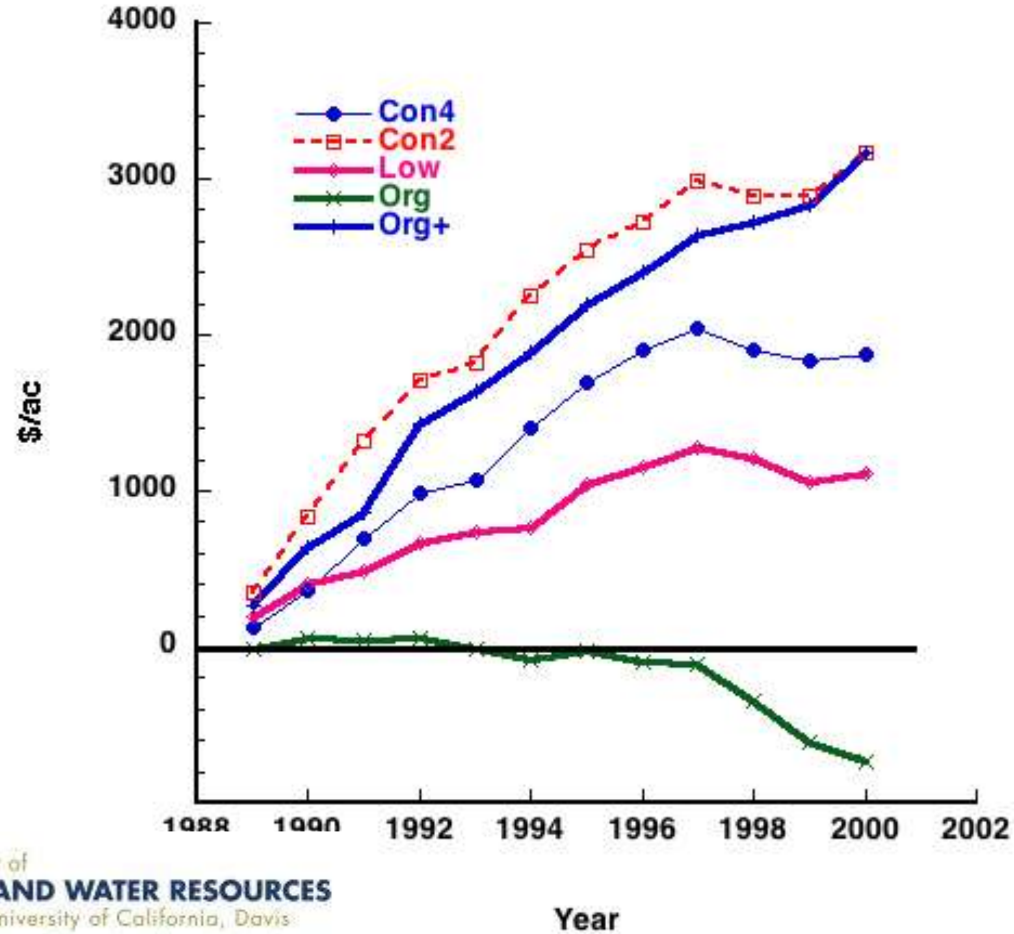
Crop rotation diversity has a significant impact on N retention

Winter cropping effects on soil nitrate



Why growers shy away from multicrop rotations

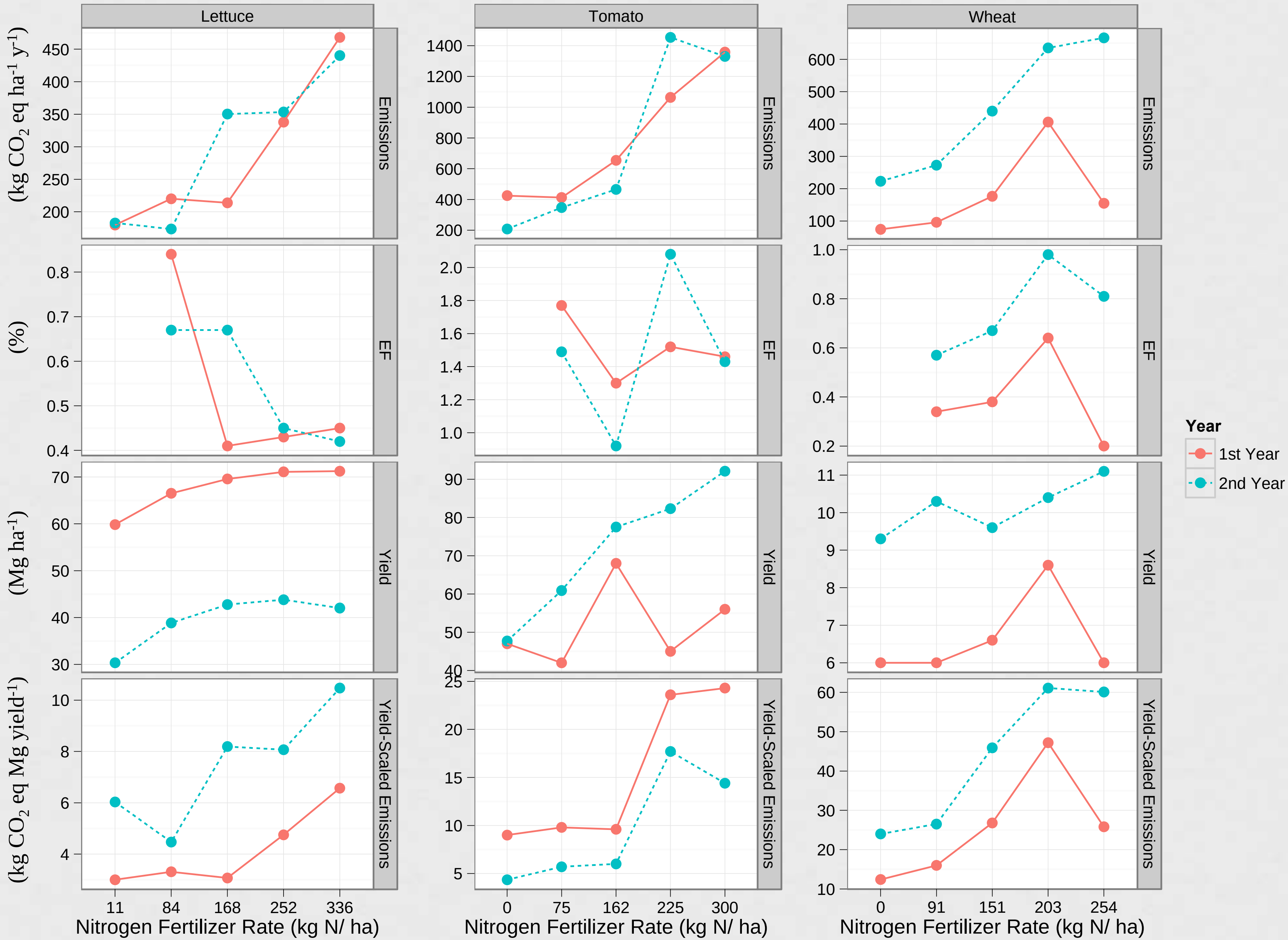
Whole Farm Cumulative Net Returns (dollars per acre)



Multicrop rotations are less profitable

Nitrogen Fertilizer Rate

- Nitrogen fertilization is an essential input in California croplands
- Numerous studies show increasing nitrogen fertilizer rates increases N_2O emissions
- Limited nitrogen rate studies in California
- Most comprehensive evaluation of the effects of N rate on emissions was recently completed and in process (Burger and Horwath, 2012, CARB report)



Lettuce
Tomato
Wheat
Emissions
EF
Yield
Yield-Scaled Emissions
(kg CO_2 eq ha^{-1} y^{-1})
(%)
(Mg ha^{-1})
(kg CO_2 eq Mg yield^{-1})
Nitrogen Fertilizer Rate (kg N/ ha)
Nitrogen Fertilizer Rate (kg N/ ha)
Nitrogen Fertilizer Rate (kg N/ ha)
Year
1st Year
2nd Year

Nitrogen Fertilizer Rates in California Vineyard

- Study in Napa County vineyard showed clear relationship between nitrogen fertilizer rate and N_2O emissions (Smart et al., 2006)

N input (kg N ha^{-1})	N_2O Emissions (kg CO_2eq ha^{-1} y^{-1})	Emission Factor (% of applied N emitted as N_2O)
0	14.88	
5.61	23.56	1.51
44.9	40.3	0.32

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Nitrogen Source

- Across 9 studies, fertilizer source reduced N_2O emissions 0.34 t CO_2e ha^{-1} yr^{-1} (-0.16 – 1.85 t CO_2e ha^{-1} yr^{-1})
- In almonds (only study in CA), replacing UAN with CAN reduced N_2O emissions 0.08 t CO_2e ha^{-1} yr^{-1}

Source	Data Type	Crop
Schellenberg et al., 2010	Field	Tomato
8 other studies	Field	Corn, Wheat outside of California

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Nitrogen Fertilizer Placement and Timing

- Placement
  - Surface applied, injected into subsurface or delivered through irrigation
  - No CA studies to date
- Timing
  - No CA studies, but the general relationship is understood
  - Lower emissions associated with fertilization when plant demand is high

Nitrogen Fertilizer Efficiency Enhancers

- Shows large promise of reducing N_2O emissions; cost and availability are major constraints
- No studies conducted in CA to date
- Polymer coated fertilizers
  - Encapsulated or modified fertilizers for slow release
  - Over 20 studies showed 35% reduction in N_2O emissions
- Nitrification Inhibitors
  - A review of 80 studies showed an average reduction of 38% N_2O
- Urease Inhibitors
  - Not as effective as polymer coated or nitrification inhibitors

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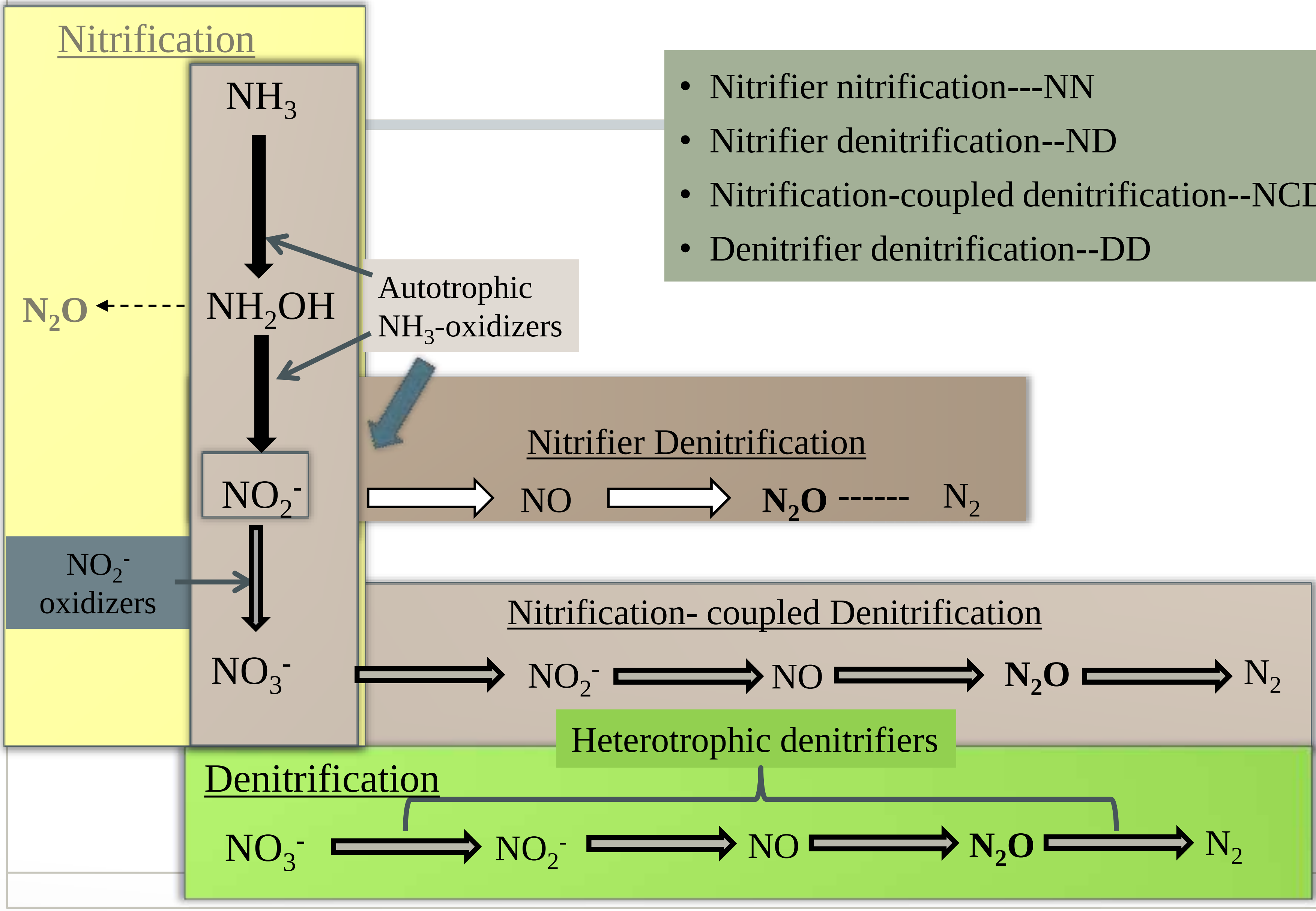
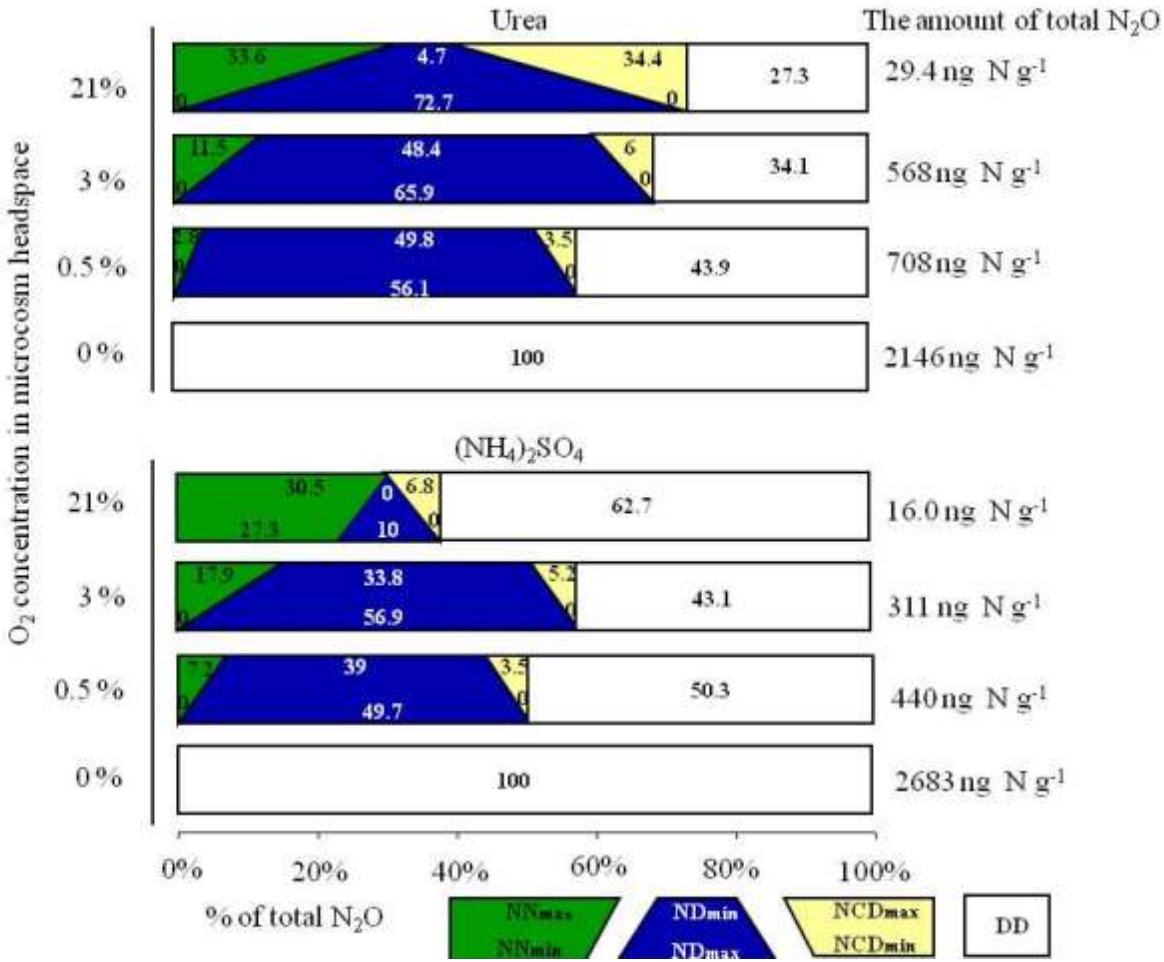
Need to understand N_2O pathways

- Nitrifier nitrification---NN
- Nitrifier denitrification--ND
- Nitrification-coupled denitrification--NCD
- Denitrifier denitrification--DD



Different sources of N_2O



- **Nitrifier nitrification---NN; Nitrifier denitrification—ND; Nitrification-coupled denitrification—NCD; Denitrifier denitrification--DD**

Irrigation Practices

- N_2O emissions reduced 0.78 t CO_2e ha^{-1} yr^{-1} across 3 studies (range 0.31 – 1.26 t CO_2e ha^{-1} yr^{-1})
- Sub-surface drip irrigation offer opportunities to reduce N_2O emissions with co-benefits of improved yield and water use

Source	Crop	Irrigation type
Kallenbach et al., 2010	Tomato	Furrow to subsurface drip
Kennedy, 2012	Tomato	Furrow to subsurface drip
Alsina et al., 2013	Almond	Surface drip to microsprinkler

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Rice Management

- CH_4 is the major contributor in rice systems
  - <1% agricultural emissions in California
- Management opportunities
  - Reduce the amount of straw incorporated through baling and removal
  - Reduce the duration of flooding during the season or winter fallow period
- Removing straw before winter reduced CH_4 emissions 1.39 – 2.52 t $CO_2e\ ha^{-1}\ yr^{-1}$ across 2 studies (Bossio et al., 1999; Fitzgerald et al., 2000)
- Drill-seeded rice (delayed onset of permanent flood) reduced CH_4 emissions by 30-35% (Assa and Horwath 2009)

Summary of Managements

		Mitigation Potential ($t\ CO_2e\ ha^{-1}\ yr^{-1}$)			
Management Activity	**Predominant Gases Involved**	**Min**	**Mean**	**Max**	**Relative Potential**
Farmland Preservation	CO_2, N_2O, CH_4				Very High
Expansion of Perennial Crops	CO_2 N_2O				High
Conventional to Conservation Till	N_2O	-0.69	0.04	0.65	None – Low
Cover Crops and Organic Amendments	N_2O	-1.69	0.04	0.89	Low – Medium
N Fertilizer Rate	N_2O				Medium
N Fertilizer Source	N_2O	-0.16	0.34	1.85	Low – Medium
N Fertilizer Timing and Placement	N_2O				Low – Medium
N Fertilizer Efficiency Enhancers[1]	N_2O				Low - Medium
Irrigation Practices	N_2O	0.31	0.78	1.26	Medium
Rice Management	CH_4, N_2O	-0.13	1.49	2.52	Low - Medium

Summary of Managements

Management Activity	Number of CA Studies	Uncertainty with applying relative potential from outside studies to CA
Farmland Preservation	2	Medium
Expansion of Perennial Crops	5	Medium – High
Conventional to Conservation Till	5	High
Cover Crops and Organic Amendments	5	Medium
N Fertilizer Rate	2	Low
N Fertilizer Source	1	Low – Medium
N Fertilizer Timing and Placement	0	Low
N Fertilizer Efficiency Enhancers	0	Low
Irrigation Practices	3	Medium
Rice Management	5	Medium

Future Research Priorities

- Determine impacts of farmland loss and policies that reduce urbanization of landscapes
- Inventories of C stocks and GHG emissions in herbaceous and woody perennial crops in California
- More efficient use of nitrogen fertilizers in California
  - Site- and crop-specific N-rate yield and emission trials to optimize yield-scaled emission factors
  - Participatory outreach to educate and encourage growers to optimize N fertilizer efficiency
- Development and implementation of drip and microsprinkler irrigation technologies
- More research on crop rotations
- More research on ammonia oxidation related pathways and appropriate management practices to reduce emissions

Key Findings

- Agriculture contributes approximately 7% of California's total greenhouse gas emissions with less than 3% coming from croplands.

- Since average greenhouse gas emissions from urban land uses are orders of magnitude higher than California croplands (approximately 70 times higher per unit area), farmland preservation, more than any of the above management activities, will likely have the single greatest impact toward stabilizing and reducing future emissions across multiple land-use categories.

- Over half of California croplands are devoted to perennial agriculture, with a relatively large proportion (34%) in orchards and vineyards. These perennial systems likely mitigate a relatively large amount of greenhouse gas emissions (ranging from 2.92 to 5.24 t CO_2e ha^{-1} yr^{-1} (Eagle et al., 2012)), but there is large uncertainty to what magnitude.

- Conservation tillage practices have had very poor adoption rates in California, relative to other regions in the United States. Although conservation tillage practices generally provide a number of agronomic and environmental benefits, there is large uncertainty in its potential to mitigate greenhouse gas emissions in California, as studies show ranges from -0.69 to 0.65 t CO_2e ha^{-1} yr^{-1}.

- Cover crops and organic amendments effect on emissions are not well understood in California. Cover crops and organic amendments offer opportunities to reduce synthetic N inputs and increase internal nutrient cycling efficiencies, but may also increase direct N_2O emissions (in particular leguminous cover crops). Limited studies demonstrate N_2O mitigation potential ranges from -1.69 to 0.89 t CO_2e ha^{-1} yr^{-1}.

Key Findings

- Increasing nitrogen fertilizer rates generally lead to increases in N_2O emissions. However, N fertilization is imperative in maintaining the productivity of California cropping systems. An arbitrary reduction of N fertilization rates is often not economically feasible for growers and has large implications for state, national and global food security. Efforts to increase N use efficiency by avoiding N rates that greatly exceed what is required for economically optimum yields offers moderate potential to reduce N_2O emissions. Likewise, calculations of yield-scaled emissions should be a more frequently employed to evaluate N_2O emissions relative to the productivity of the cropping system.

- Substituting a lower emitting N fertilizer source offers low to moderate potential to reduce N_2O emissions (-0.16 to 1.85 t CO_2e ha^{-1} yr^{-1}). However, very little information on California-specific cropping systems exists. The best solutions would provide comparably-priced fertilizers that do not require major modifications to current management practices.

- Field experiments examining the effects of N placement and timing have not been conducted for California cropping systems.

- Low to moderate reductions in N_2O emissions are possible with polymer coated fertilizers (35%), nitrification inhibitors (38%) and urease inhibitors (10%) which can enhance the efficiency of N fertilizers by helping match N availability with crop demand. However, these products are not widely used in California cropping systems due to concerns regarding their cost.

- Irrigation technologies such as sub-surface drip irrigation offer opportunities to moderately reduce N_2O emissions (0.31 to 1.26 t CO_2e ha^{-1} yr^{-1}) with co-benefits of improved yield and water use for some cropping systems.

- Emissions from California rice cultivation are approximately 0.01 % of total statewide emissions, thus the overall scope for emissions reductions is relatively low. However, strategies to reduce emissions from rice cultivation such as (e.g. straw removal, drill seeding, reduced duration of flooding in the season or winter fallow) and offer low to moderate potential to reduce CH_4 emissions per unit area (-0.13 to 2.52 t CO_2e ha^{-1} yr^{-1}). Constraints to straw removal include baling costs and a limited market for rice straw. Lower yields in drill seeded systems are also an important drawback.

- Relatively few California field studies exist that rigorously examine greenhouse emissions from changes in agricultural management activities and practices thus more research is needed to inform future management and policy alternatives.

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