Fertility management in organic rice systems

Organic Rice: Current Research and Future Needs

Yuba City

Bruce Linquist

July 26, 2023

UCCE

UC DAVIS DEPARTMENT OF PLANT SCIENCES

Topics covered

- Fertilizer options
- Nutrient (and moisture) composition
- Decay series for manures
  - When are they available?
- Managing manure
  - Preplant and top-dress
- Cover crops
- Challenges

Sources of fertility

- Animal based products
  - Farm yard manure (FYM)
  - Bone/blood meals (high N products such as 13-0-0)
- Cover crops
- Fish emulsions
  - Hard to provide enough nutrients
- Microbial additives
- Straw
  - In continuous rice systems where straw is returned annually
  - straw provides roughly 25 lb N/ac.

Nutrient composition of manures

- Highly variable
  - Moisture
  - Composted vs non composted
  - Source/animal
- Manures tend to have a lot of P relative to N

Table 1. Typical nutrient content, moisture content, and weight of manure.

Type of Animal Manure	N	P[2]	K	Moisture, percent	Weight, lb/cu yard
	lb per ton as is[1,2]				
Chicken with litter	73	28	55	30	900
Laying hen	37	25	39	60	1,400
Sheep	18	4.0	29	72	1,400
Rabbit	15	4.2	12	75	1,400
Beef	12	2.6	14	77	1,400
Dry stack dairy	9	1.8	16	65	1,400
Separated dairy solids[3]	5	0.9	2.4	81	1,100
Horse	9	2.6	13	63	1,400

Washington State University

Table 7 Soil properties of the Vertisol fields as affected by ecosystem management

System	n	Olsen-P mg kg^{-1}	pH	Organic carbon %	Clay %	C:P ratio*
Conventional	37	11.5 b	5.9	1.3	46	126
Organic	4	28.7 a	5.8	0.9	47	84
Wetland	7	18.1 ab	6.1	1.0	43	122
P value		0.001	0.664	0.066	0.831	0.227

Different letters grouped together within a column represent significantly different values ($P < 0.05$)

* The C:P ratio is the ratio of organic C to total organic P

Linquist et al., 2011

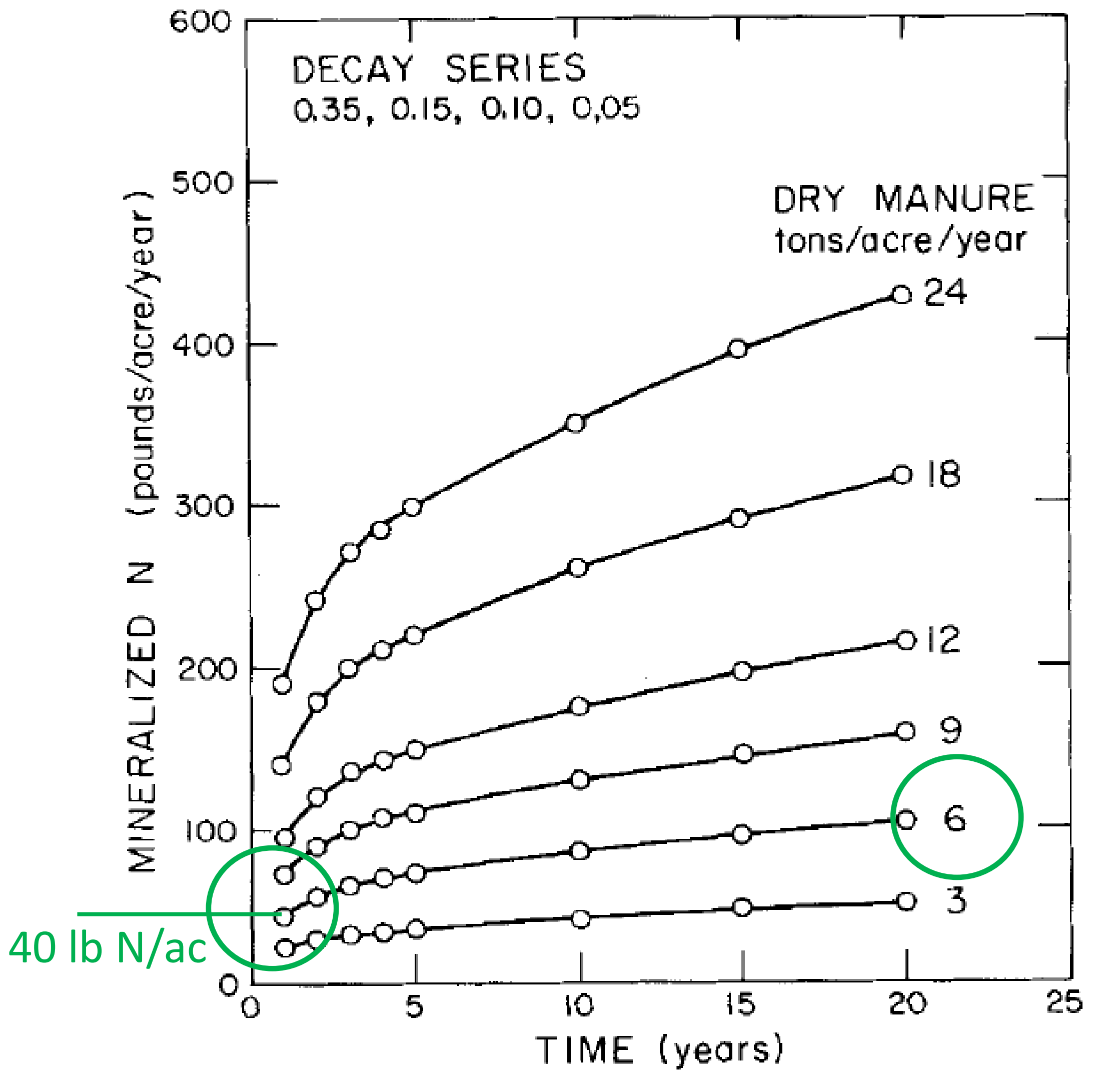
Decay series for manures:
Rate of mineralization

- When N from manures becomes available varies
  - C:N ratio
  - Materials with a lot of carbon relative to N break down slowly (i.e. rice straw)
- Manures with higher N content tend to be available more rapidly.
- N from a manure application can be available for several years
  - High N manures – N available quickly
  - Low N manures – N available over a long time
- Where do cover crops fit in?

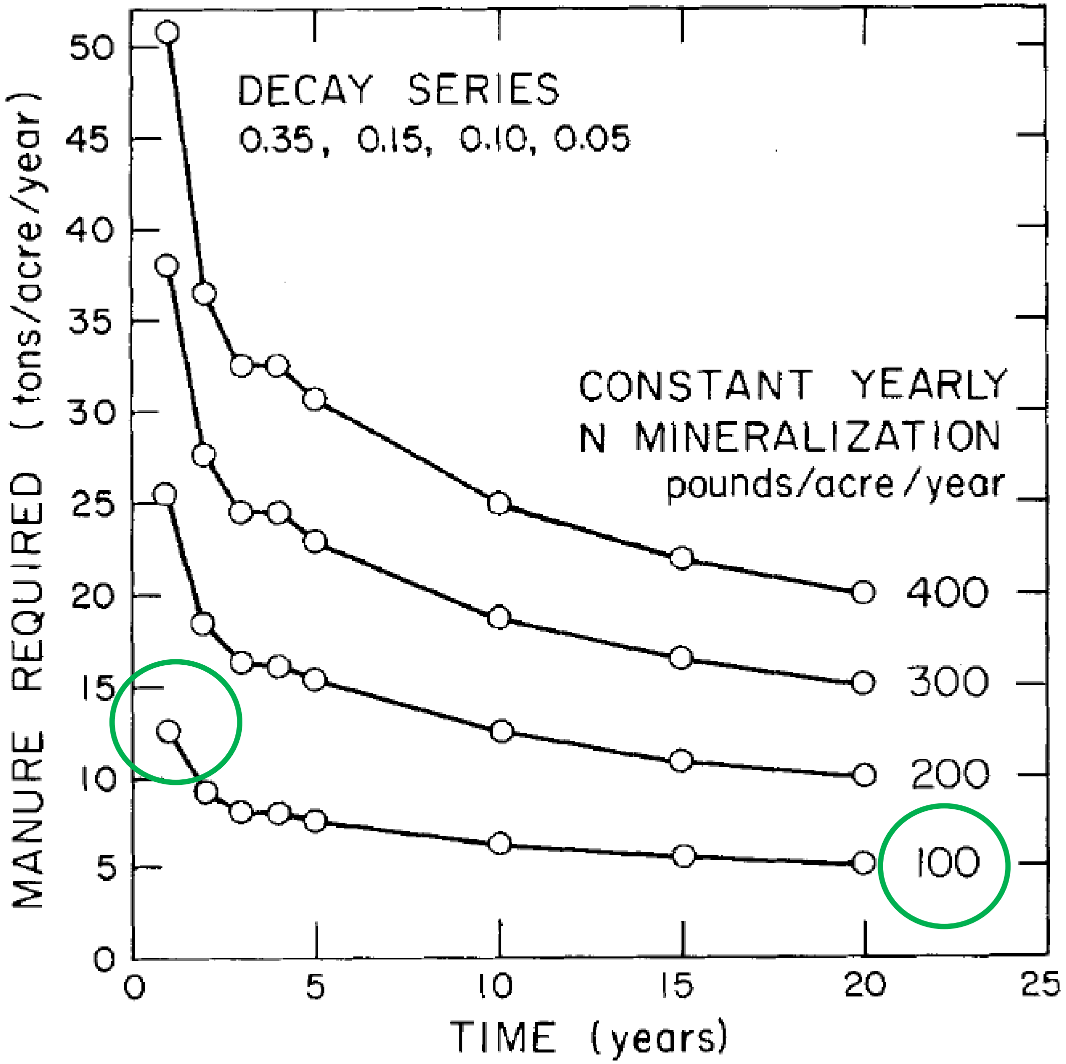
Decay series	Typical material†
0.90, 0.10, 0.05	Chicken manure
0.75, 0.15, 0.10, 0.05	Fresh bovine waste, 3.5% N
0.40, 0.25, 0.06	Dry corral manure, 2.5% N
0.35, 0.15, 0.10, 0.05	Dry corral manure, 1.5% N
0.20, 0.10, 0.05	Dry corral manure, 1.0% N
0.35, 0.10, 0.05	Liquid sludge 2.5% N

Pratt et al., 1973

GRAPH 1. YEARLY MINERALIZATION RATE IN RELATION TO TIME FOR VARIOUS CONSTANT RATES OF CORRAL MANURE HAVING 25% WATER AND 1.5% N ON A DRY WEIGHT BASIS.



GRAPH 2. YEARLY RATES OF APPLICATION OF MANURE, CONTAINING 25% WATER AND 1.5% N ON A DRY WEIGHT BASIS, REQUIRED TO MAINTAIN VARIOUS CONSTANT YEARLY RATES OF N MINERALIZATION.



Pratt et al., 1973

Preplant N source trial

Table 2. Properties and nutrient concentrations of fertilizers used in field trials in 2008 and 2009. Nutrient concentrations are given on a dry weight basis for poultry litter, and on an air dry basis for the pelletized fertilizers.

Fertilizer	Total N	Total P	Total K	Organic carbon	C/N	P/N	K/N
	%						
2008							
Pelletized 13–0–0†	13.8	0.9	0.2	54	3.9	0.07	0.01
Pelletized 12–0–0	10.9	2.5	0.4	48	4.4	0.23	0.04
Pelletized 6–3–2	6.4	1.6	2.3	38	5.9	0.25	0.36
Poultry litter	2.6	1.6	3.3	41	15.7	0.62	1.27
2009							
Pelletized 13–0–0	12.9	1.0	0.2	54	4.1	0.08	0.02
Pelletized 12–0–0	13.0	0.4	0.4	55	4.2	0.03	0.03
Pelletized 6–3–2	6.7	1.4	1.7	40	5.9	0.21	0.25
Poultry litter	3.2	1.4	2.3	36	11.2	0.44	0.72

† Numbers refer to the N–P–K content of fertilizers as stated by manufacturers.

Wild et al., 2011

Yield Response to preplant N

- 3 site years
- N rate: 2008 (140); 2009 (120)
- All better than control: on average by 2100 lb/ac
- Pelletized > Poultry litter > Control

Table 3. Grain yield of rice in three field sites in 2008 and 2009 following the application of organic and inorganic N fertilizers.

Fertilizer	Continuously flooded 2008	Continuously flooded 2009	Drained 2009	Mean
	Grain yield, kg ha^{-1} at 14% moisture			
Pelletized 13–0–0†	11,325abc‡	10,073a	8,510a	9,969
Pelletized 12–0–0	10,621bc	10,049a	8,723a	9,797
Pelletized 6–3–2	11,522ab	9,876a	9,121a	10,173
Poultry litter	10,384c	8,968a	8,448a	9,267
Control (no N)	8,023d	7,055b	7,277b	7,452
$(NH_4)_2SO_4$	12,042a			
Average of all treatments	10,653	9,204	8,416	
Poultry litter vs. other fertilizers	*P* = 0.05	*P* = 0.04	ns	

† Numbers refer to the N–P–K content of fertilizers as stated by manufacturers.

Nitrogen recovery

- Pelletized: 35%
- Poultry litter: 20%
- In line with decay series tables

Table 5. Nitrogen recovery efficiency (%) of pelletized fertilizers, poultry litter and $(NH_4)_2SO_4$ in three field experiments.

Fertilizer	Continuously flooded 2008	Continuously flooded 2009	Drained 2009	Mean
Pelletized 13–0–0†	34b‡	50a	25a	36
Pelletized 12–0–0	25c	47a	28a	33
Pelletized 6–3–2	37b	37a	31a	35
Poultry litter	19c	19b	21a	20
$(NH_4)_2SO_4$	66a			

† Numbers refer to the N–P–K content of fertilizers as stated by manufacturers.

‡ Means with the same letter within a column are not considered significantly different at $P < 0.05$.

Wild et al., 2011

Top-dress: different pelletized sources (40 lb N/ac)

- All increased yields by 650 lb/ac
- Not a big difference among sources

TABLE 4 Yield, N uptake and N recovery efficiency (NRE) for organic fertilizer sources with varying N content (4–1–4, 6–3–2, and 12–3–0) at 45 kg N ha^{-1} and a control with no top-dress N applied

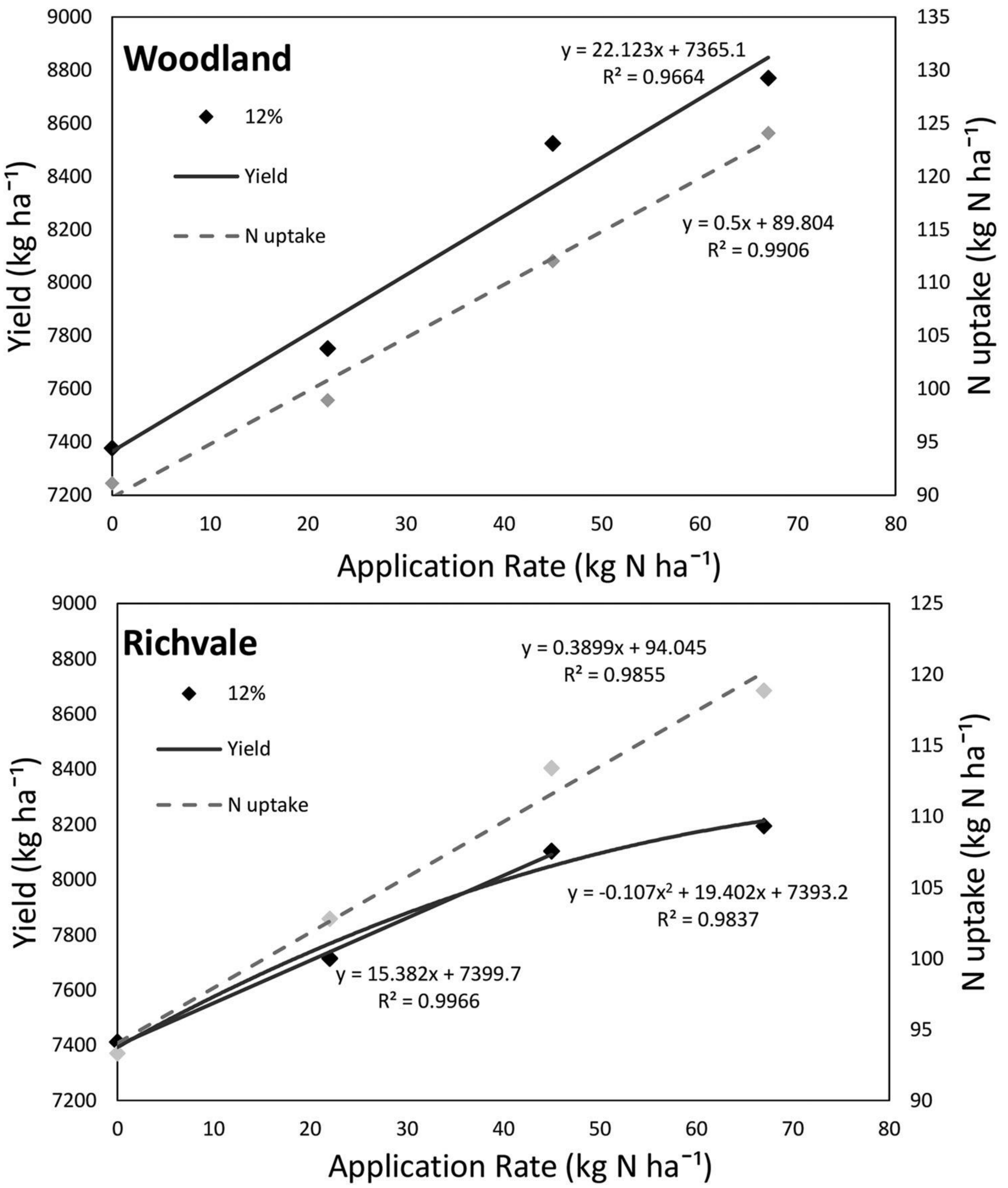
		Treatment				ANOVA
		0	**4–1–4**	**6–3–2**	**12–3–0**	***P*–values**
Woodland	Yield (kg ha^{-1})	7378 a[a]	8349 b	8169 ab	8524 b	.025
	N uptake (kg N ha^{-1})	91 a	112 b	106 b	112 b	.010
	NRE (%)	–	46 a	32 a	47 a	.651
Richvale	Yield (kg ha^{-1})	7412 a	7715 ab	7959 b	8103 b	.003
	N uptake (kg N ha^{-1})	93 a	103 b	106 b	113 c	< .001
	NRE (%)	–	21 a	28 a	45 b	.009

[a]Within each row, values not followed by a common letter are significantly different ($p < .05$).

Murray et al., 2020

Top-dress N

- 12-3-0 pellets at different rates
  - 20, 40 and 60 lb N/ac
  - 60 gave highest yields Woodland
  - 40 gave highest yields Richvale



Murray et al., 2020

Economics

- 4-1-4 was best economically
  - due to no yield difference and cheaper fertilizer cost

TABLE 5 Economic analysis of return on investment for top-dress application at 45 kg N ha^{-1} for two rice varieties. Since the yield response to each fertilizer was not significantly different from each other, the average yield increase across fertilizers within each site was used. Cost was analyzed per unit of N applied based on the listed N content of the fertilizer

Location	Variety	Rice price $ kg^{-1}	Fertilizer	Fertilizer cost $, at 45 kg N^{-1}	Application cost $, at 45 kg N^{-1} ha^{-1}	Break even yield kg ha^{-1}	Average yield increase	Profit $ ha^{-1}
Woodland	S–102	0.73	12–3–0	348	2.9	481	969	356
			6–3–2	310	5.8	433	969	392
			4–1–4	285	8.7	402	969	414
Richvale	A–202	0.88	12–3–0	348	2.9	399	514	101
			6–3–2	310	5.8	359	514	137
			4–1–4	285	8.7	334	514	159

Murray et al., 2020

Pellets vs non-pelletized

- Pellets require heat and pressure to make
  - This increases the rate of availability of N from pelletized materials
- Preplant use non-pelletized
  - Want slower release
- Top-dress use pellets
  - Need N availability fast

Table 4—Characteristics of N mineralization of manures for the Besor and Bet Dagan soils incubated at 25°C.

Soil	Manure	Maximal NH_4 concentration in soil	Persistence of elevated NH_4	Mineral N in soil after 1 week	Mineral N in soil after 60–90 d
		mg N/kg	d	% added N†	
Bet Dagan	Poultry, ground	277 b*	>14	38 a	47 a
	Poultry, pellet	354 a	>14	38 a	42 a
	75% Dairy, ground	118 c	> 7	15 c	27 b
	75% Dairy, pellet	126 c	> 7	21 b	28 b
	Mean	219 B		28	37 A
Besor	Poultry, ground	300 b	>90	34 b	48 a
	Poultry, pellet	456 a	>30	42 a	50 a
	75% Dairy, ground	124 c	>14	18 c	27 b
	75% Dairy, pellet	164 c	> 7	23 c	27 b
	Mean	261 A		29	36 A

Hadas et al., 1983

Cover Crops

- Why cover crops?
  - Adding nitrogen to the system
    - Nitrogen fixation (leguminous cover crop)
    - OR taking up nitrogen that would be lost from the system by leaching or denitrification
  - Improving subsequent rice yields
  - Long-term soil quality changes:
    - Increased organic matter
    - Improved soil tilth

Cover Crops

- Potential species
  - **Purple vetch**
  - **Lana/woolypod vetch**
  - **Bell bean**
  - **Balansa clover**
  - **Field pea**
  - **Biomaster pea**
  - Yellow mustard
  - Turnip
  - Rye
  - Oat

Previous research

Current research

How much N is available from cover crops?

- Range from 6 to 105 lb N/ac
  - Average 40-55
- N replacement value is higher - average about 60 lb N/ac
- Based on studies in the 1950s and 1990s

Table 2.—Effect of wheat and purple vetch as winter green manure on the production of Colusa rice.

Treatment	1954				1955			
	Green manure crop			Rice	Green manure crop			Rice
	Yield	Nitrogen		yield	Yield	Nitrogen		yield
	lbs./A.	%	lbs./A.	lbs./A.	lbs./A.	%	lbs./A.	lbs./A.
No fertilizer								
Fallow	—	—	–	2340	—	—	–	2060
Wheat	900	1.00	9	2710	530	1.65	9	2100
Vetch	910	2.82	26	3340	1250	3.50	44	3040
30 lbs. N/A.								
Fallow	—	—	–	2640	—	—	–	2370
Wheat	900	1.00	9	2890	350	1.54	5	2320
Vetch	910	2.82	26	3670	1260	3.42	43	3350
LSD 5%								
Fertilizer				310				380
Green manure				430				360

Williams et al. 1957

Table 2. Purple vetch N content and equivalent fertilizer N value in a continuous rice rotation.

	Straw burned in fall		Straw disced in fall	
Rice crop year	Vetch N content	N fertilizer replacement	Vetch N content	N fertilizer replacement
	lb N/acre			
1990	38	74	16	88
1991	105	108	86	90
1992	57	90	47	60
1993	6	0	10	0
1994	37	70	34	60
5-yr average	49	68	39	60

Data from Sills Farm, Sutter Co. (Rice Research Board annual reports, Project RM-6, 1990-94)

Pettygrove and Williams 1996

Nitrogen replacement value

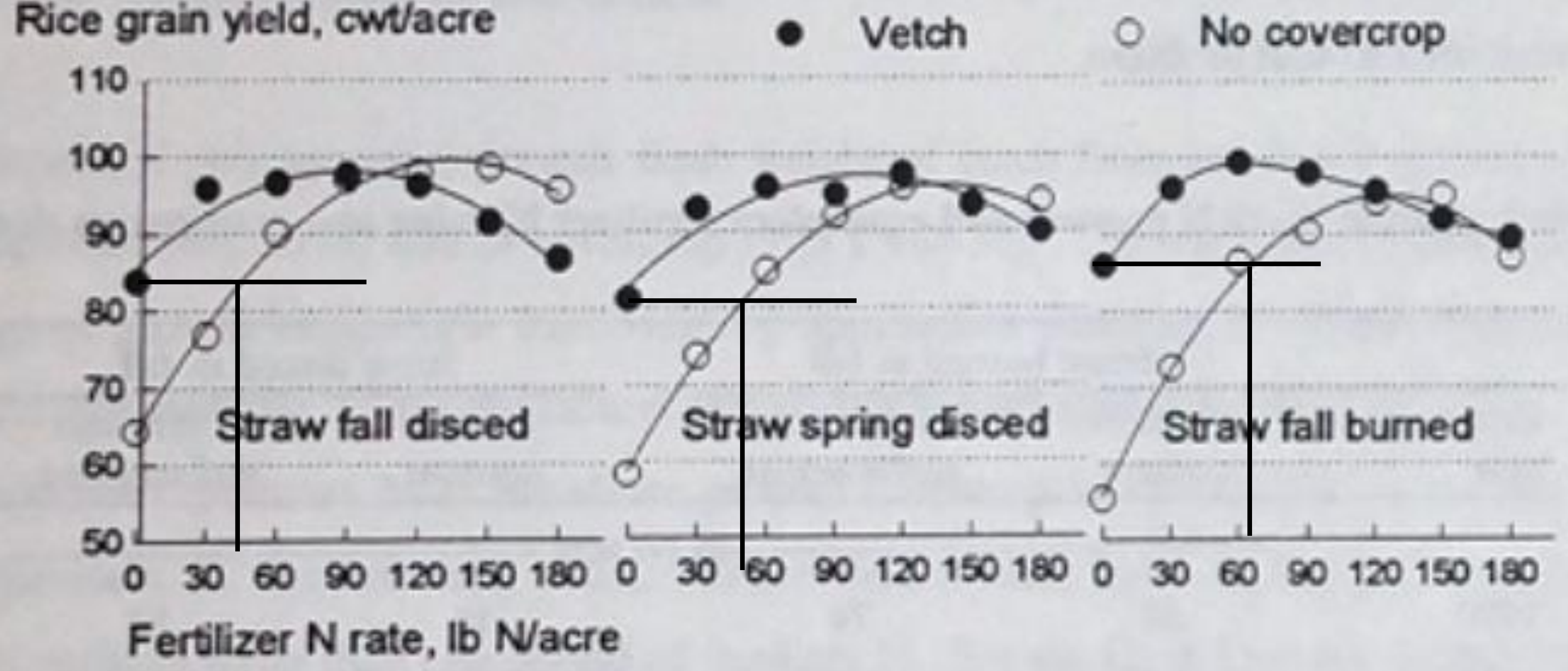


Figure 1. Five-year average yields as influenced by covercropping and rice straw management at the Sills Farms experiment in Sutter County, 1990-94. Straw management and covercropping treatments were repeated annually on the same 0.5-acre plots with six replicates.

Pettygrove and Williams 1996

Management considerations

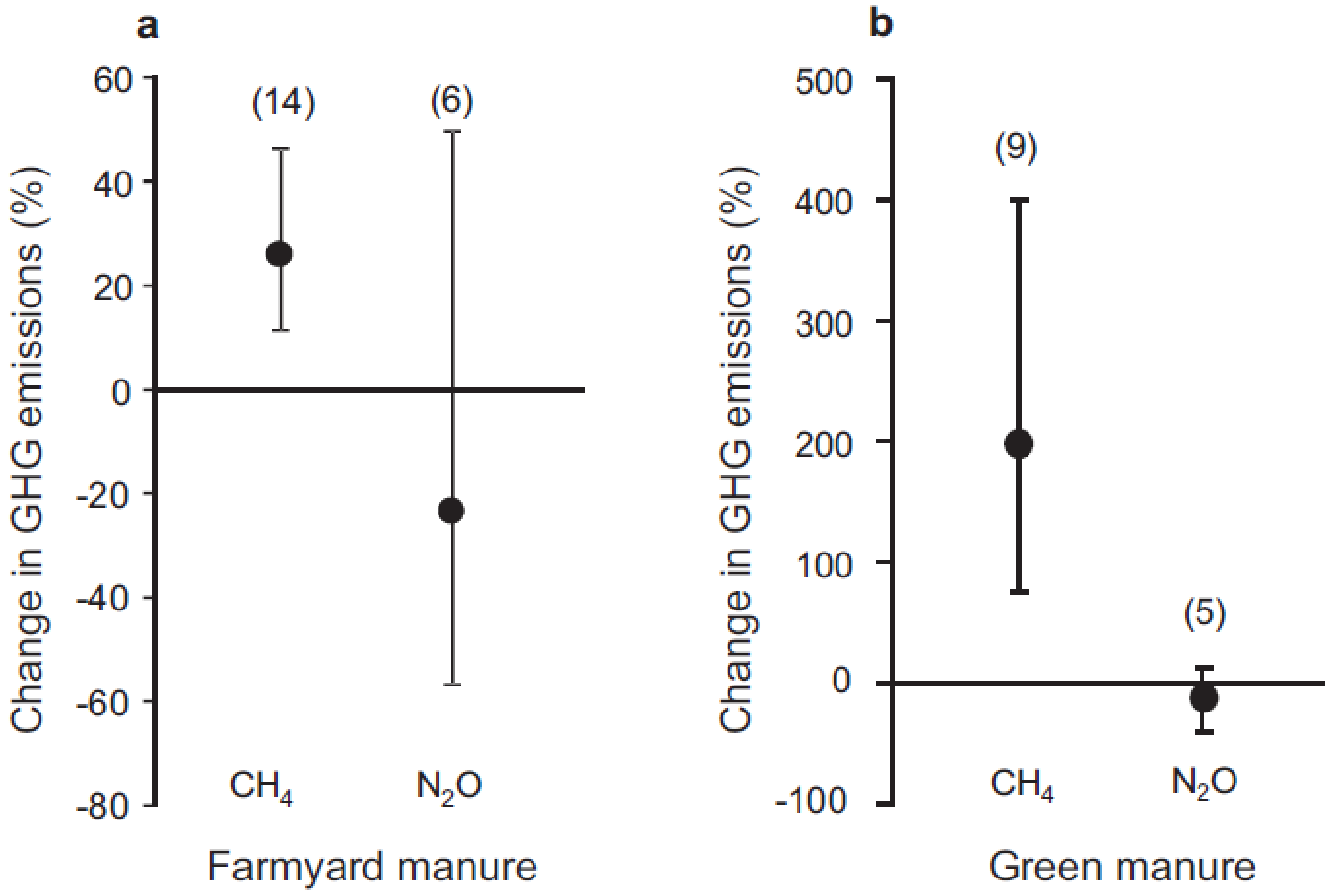
- When to plant seed
    - Before harvesting rice
    - Post harvest
- Effort in planting
    - Tillage: how many passes
    - Ridges to reduce water logging
    - May be cover crop seed in seed bank
    - Make sure fields can drain
- Mixing species
    - Increase chance that something grows
        - Wet vs dry winters
    - Mix species with different C:N ratios
        - moderate N release
- Termination
    - When?
    - How?

Challenges

- High seed cost
- Increased management costs
- Unpredictable
- Lack of uniformity
- Difficulty with residue management can delay rice planting
- Potential for cover crops to become weed problems
- Increased greenhouse gas production in waterlogged soils

Effect of FYM and cover crops on GHG emissions

- Methane (CH_4) is the end product of organic matter decomposition under anaerobic conditions.



Linquist et al., 2012

Thank you

Thanks to LFF

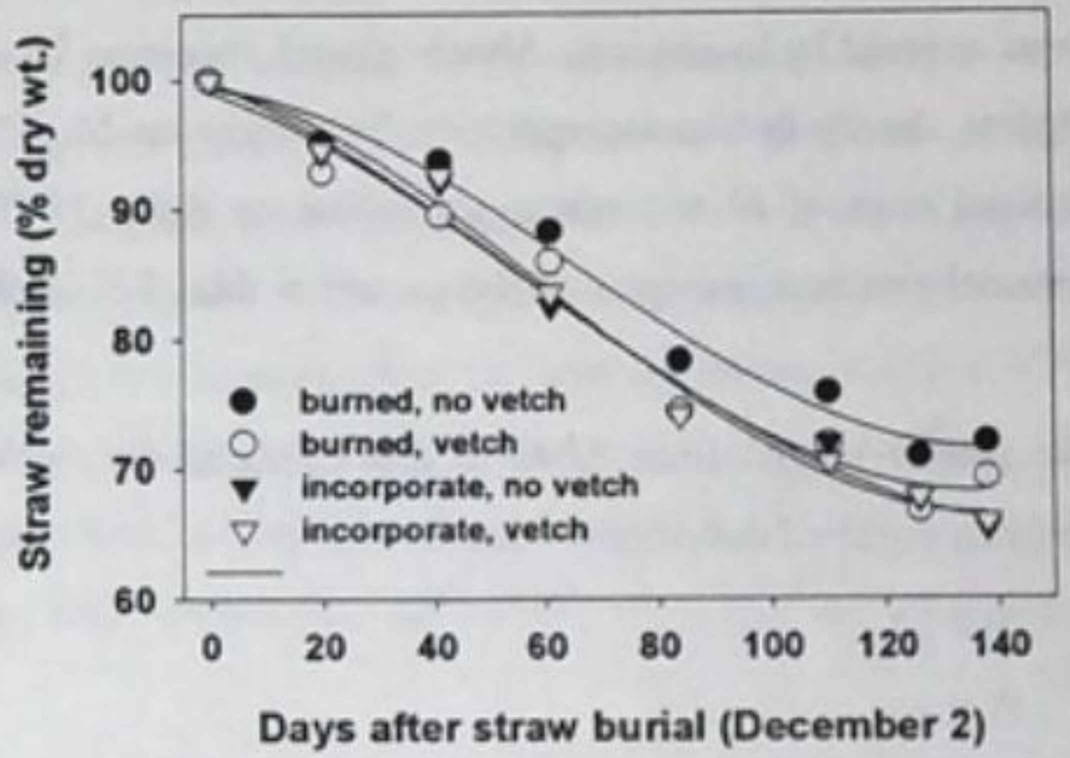


Figure 2. Effect of covercropping and rice straw disposal method on disappearance of straw buried in nylon mesh bags (Unpublished data, D. Bossio). Rice straw disposal methods and covercropping had been in effect for five years before bags were buried.

Pettygrove and Williams 1996

Mineralization rates

Table 6. Nitrogen mineralization rates of organic N fertilizers and unamended soil over three time periods, and the percentage of fertilizer N mineralized after 60 d of incubation.

Fertilizer	0–9 d	9–36 d	36–60 d	N mineralized
	—— mg N kg^{-1} soil d^{-1} ——			%
Pelletized 13–0–0†	1.64ab‡	1.08ab	0.87a	22ab
Pelletized 12–0–0	1.88ab	1.45a	0.72a	33a
Pelletized 6–3–2	2.24ab	1.51a	0.46a	26ab
Poultry litter	2.35a	0.83b	0.47a	14b
Control (no N)	1.58b	0.66b	0.68a	

† Numbers refer to the N–P–K content of fertilizers as stated by manufacturers.

‡ Means with the same letter within a column are not considered significantly different at $P < 0.05$.

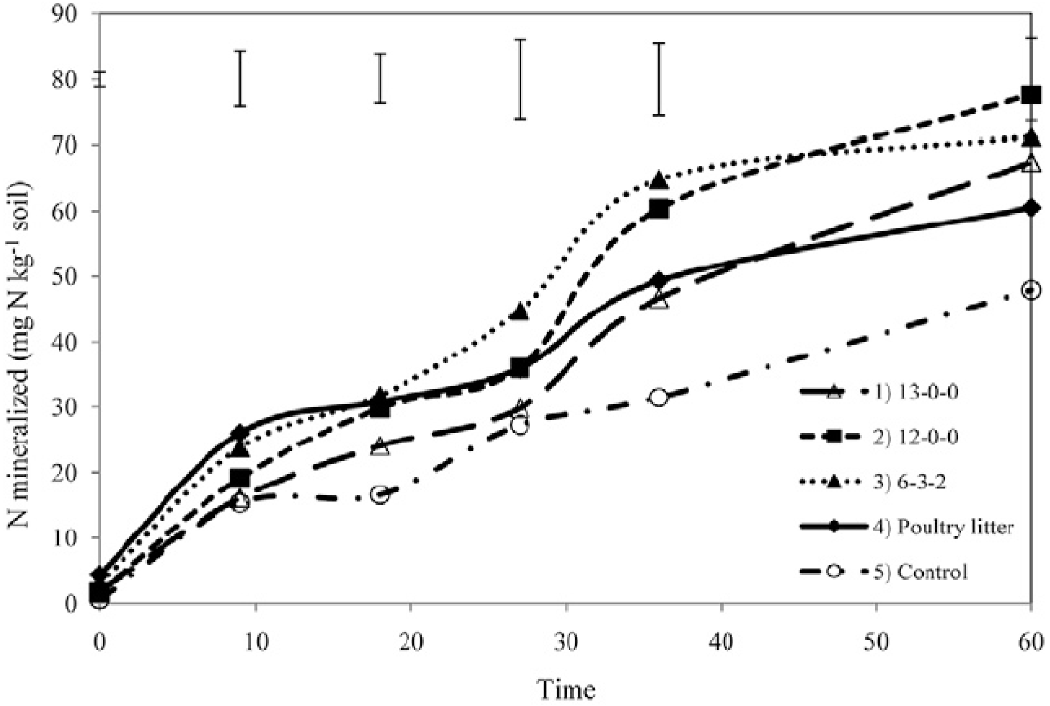


Fig. 1. NH_4–N (in mg N kg^{-1} soil) accumulation during a 60 d anaerobic laboratory incubation. Treatments were: Pelletized 13–0–0, Pelletized 12–0–0, Pelletized 6–3–2, Poultry litter, and Control (no N). Measurements were taken at six sampling times (Day 0, 9, 18, 27, 36, and 60). Least Significant Difference (P = 0.05) bars above each sample time.

Wild et al., 2011

Table 3.—Effect of vetch green manure and the placement of inorganic nitrogen on Caloro rice production.

Nitrogen source and placement lbs./A.	Rice yield lbs./A.
Check	3050
30 N as ammonium sulfate broadcast on surface	3440
30 N as ammonium sulfate drilled 4 inches deep	4050
30 N in vetch tops (4.24% N) disked once	4320
30 N in vetch tops (4.24% N) disked twice	4030
LSD 5%	850

Williams et al. 1957

Table 3. Effect of covercropping on rice grain N response in Butte Co., Skinner Ranch, 1989.

N fertilizer rate	No covercrop	Purple vetch	Lana vetch	Bell bean
lb N/acre	----------grain yield, cwt/acre, 13% moisture----------			
0	67.6	<u>82.8</u>	<u>80.2</u>	<u>83.3</u>
30	73.2	78.1	76.7	79.7
60	<u>78.2</u>	67.2	73.5	77.6
90	70.4	63.1	52.7	59.2

Covercrop treatment means LSD.05 = 2.9 cwt/acre; within N=0 treatment LSD.05 = 7.9 cwt.
Maximum yields for each covercrop treatment are highlighted.

Pettygrove and Williams 1996

Table 4. Effect of covercropping with purple vetch on rice grain yield averaged over five years and across straw-burned and straw-incorporated treatments.

N applied to rice	Purple vetch	No covercrop
lb/acre	-------- cwt/acre, 14% moisture --------	
0	43	27
40	51	41
80	<u>56</u>	52
120	54	<u>57</u>

Maximum yields for each treatment are highlighted.

Pettygrove and Williams 1996

Background Information

- Advisors have been approached by growers (and industry) asking for cover crop variety recommendations (increased in 2020-2021)
- Data from California rice systems is almost 20 years old, and only utilized vetch and bell beans (Pettygrove and Williams, 1996)
- Many legume species do not survive the wet, waterlogged soils
  - Growers have difficulty with varietal selection
- Growers need data on rice yields in rice when compared to cover crops
- Effects on soil carbon and nitrogen cycles?

“Current” Data for Varieties (1996)

- Woollypod vetch
- Purple vetch
- Fava bean (bell bean)