Impact of FGD Gypsum on Soil Fertility and Soluble P concentrations

Dexter B. Watts

USDA-ARS
National Soil Dynamics Laboratory
Auburn, AL

Benefits of Gypsum

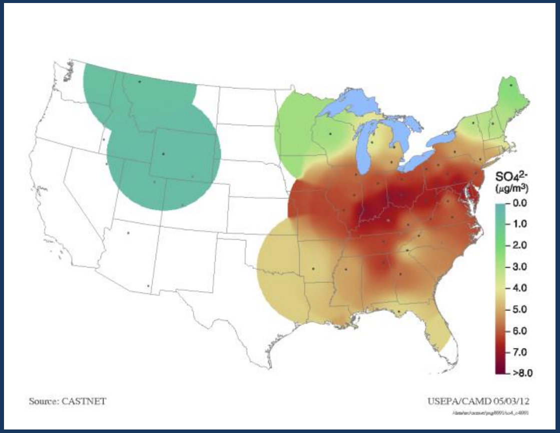
- Improve soil properties
  - Nutrient soil for crops (Ca and S)
  - Improve water infiltration
  - Control soil erosion and crusting
  - Alleviate the effects of subsoil acidity (Al Toxicity)
- Reduce contaminates in water runoff.

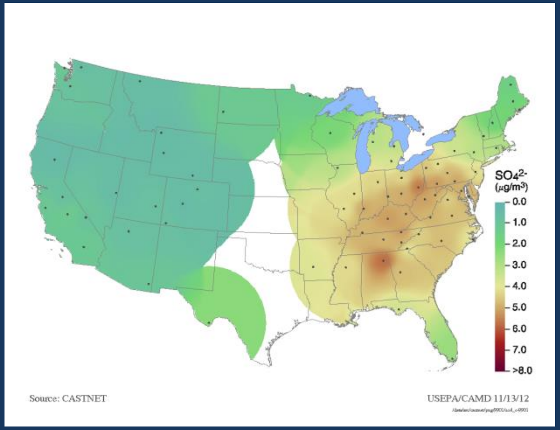
Gypsum

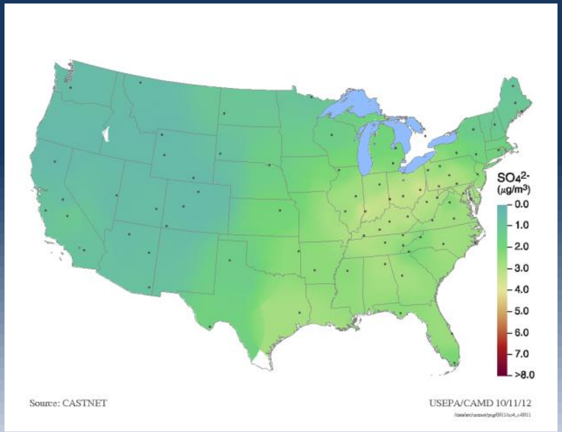
FGD Gypsum

Mined Gypsum

Sulfur Deposition Trends







US EPA-Clean Air Status and Trends Network

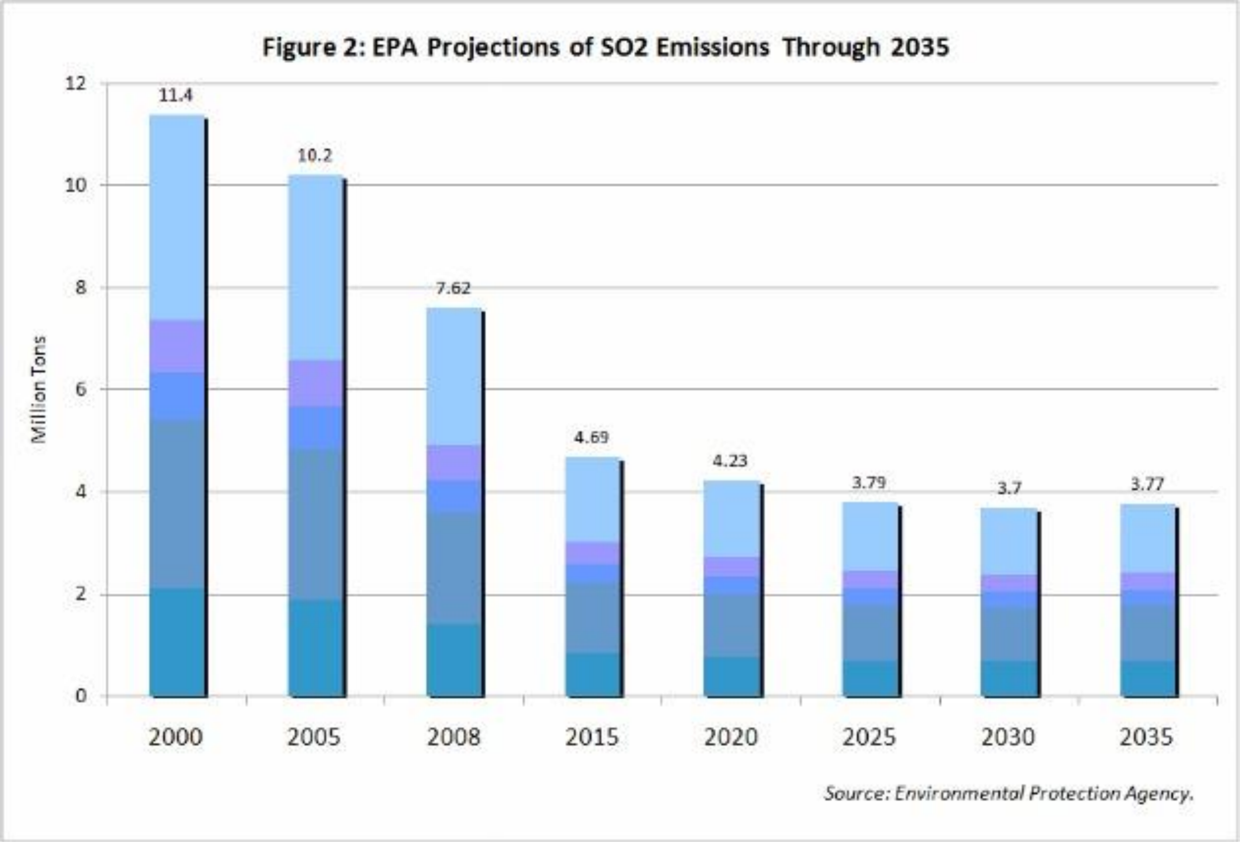


Figure 2: EPA Projections of SO2 Emissions Through 2035
Million Tons
0
2
4
6
8
10
12
11.4
10.2
7.62
4.69
4.23
3.79
3.7
3.77
2000
2005
2008
2015
2020
2025
2030
2035
Source: Environmental Protection Agency.

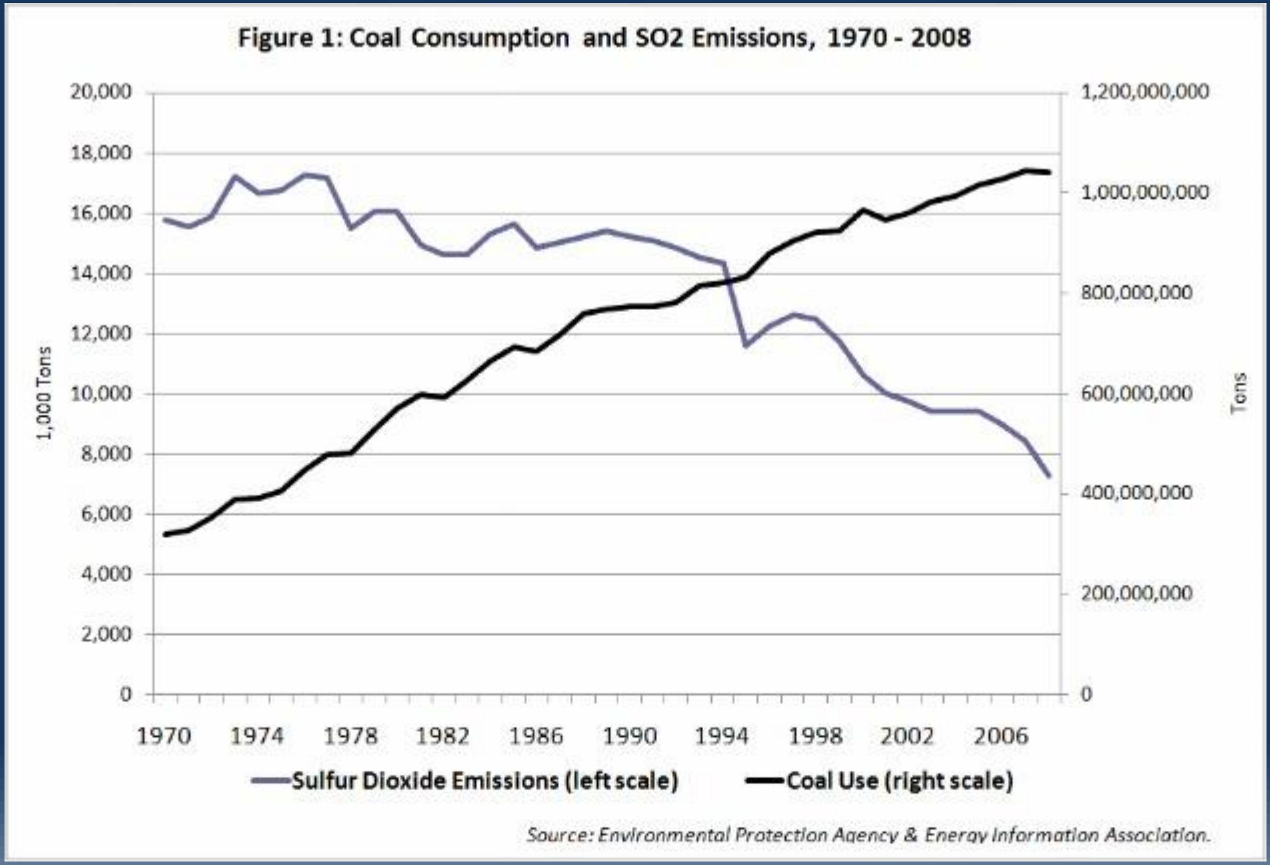
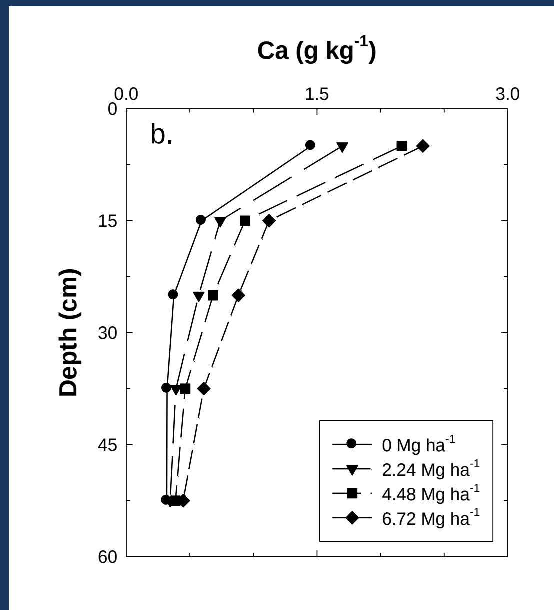
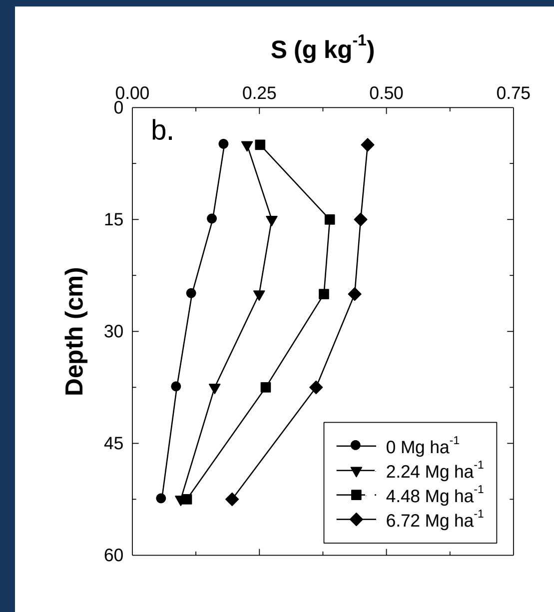


Figure 1: Coal Consumption and SO2 Emissions, 1970 - 2008
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1,000 Tons
1,200,000,000
1,000,000,000
800,000,000
600,000,000
400,000,000
200,000,000
0
Tons
1970
1974
1978
1982
1986
1990
1994
1998
2002
2006
Sulfur Dioxide Emissions (left scale)
Coal Use (right scale)
Source: Environmental Protection Agency & Energy Information Association.

Results





Comments: Calcium and sulfur distributions with soil depth indicate that three consecutive years of surface applied FGD gypsum amendments on no-till cotton have resulted in significant increases in these essential plant nutrients at depth.

Note: 0, 2.24, 4.48, and 6.72 Mg ha-1 correspond to 0, 1, 2, and 3 tons/acre.

Martin Locke - unpublished data

Soil Physical Characterization

Soil penetration resistance, 2012 Milan, TN

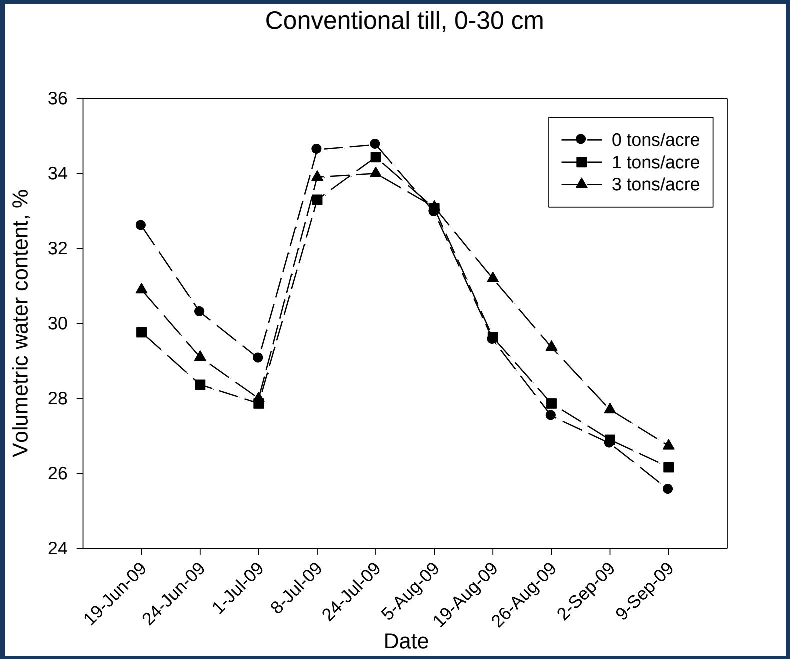
- Cone penetrometer measured integrated total force required to reach a 12-inch depth
- Crop row and middle of row (wheel track and non-wheel track)
- In all row positions, resistance tended to decrease in plots treated with FGD gypsum

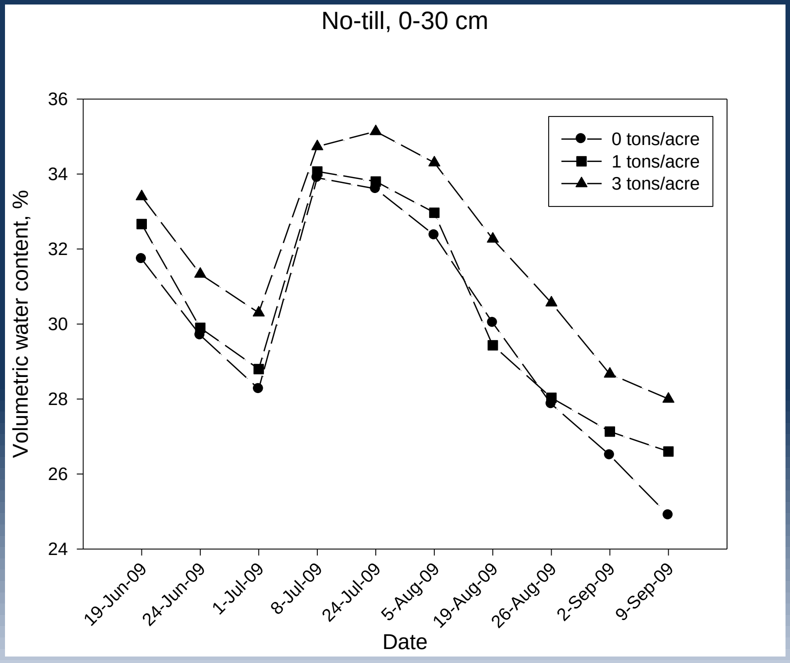
Tillage	FGD gypsum rate	Non-wheel track middle	Crop Row	Wheel track middle
	tons/acre	------------------ kPa X 10^{-3} ------------------		
Conventional	0	79.4	76.0	94.8
	1	71.2	73.3	91.3
	2	68.7	75.0	84.2
	3	72.2	71.3	89.0
	5	73.4	69.9	86.4
No-till	0	80.8	72.5	90.6
	1	68.4	68.9	83.0
	2	84.0	75.5	92.3
	3	71.4	71.4	84.3
	5	79.1	70.1	88.1

Martin Locke - unpublished data

Soil water content during the 2009 growing season Verona, MS

- Water content was measured with TDR only in 2009
- CT plots showed little difference until end of the growing season, when 3 tons/acre FGD held more water
- NT showed a more consistent advantage for the 3 tons/acre FGD treatment, with the difference starting earlier in the growing season
- Slightly higher soybean yields in NT may have resulted from the increased moisture





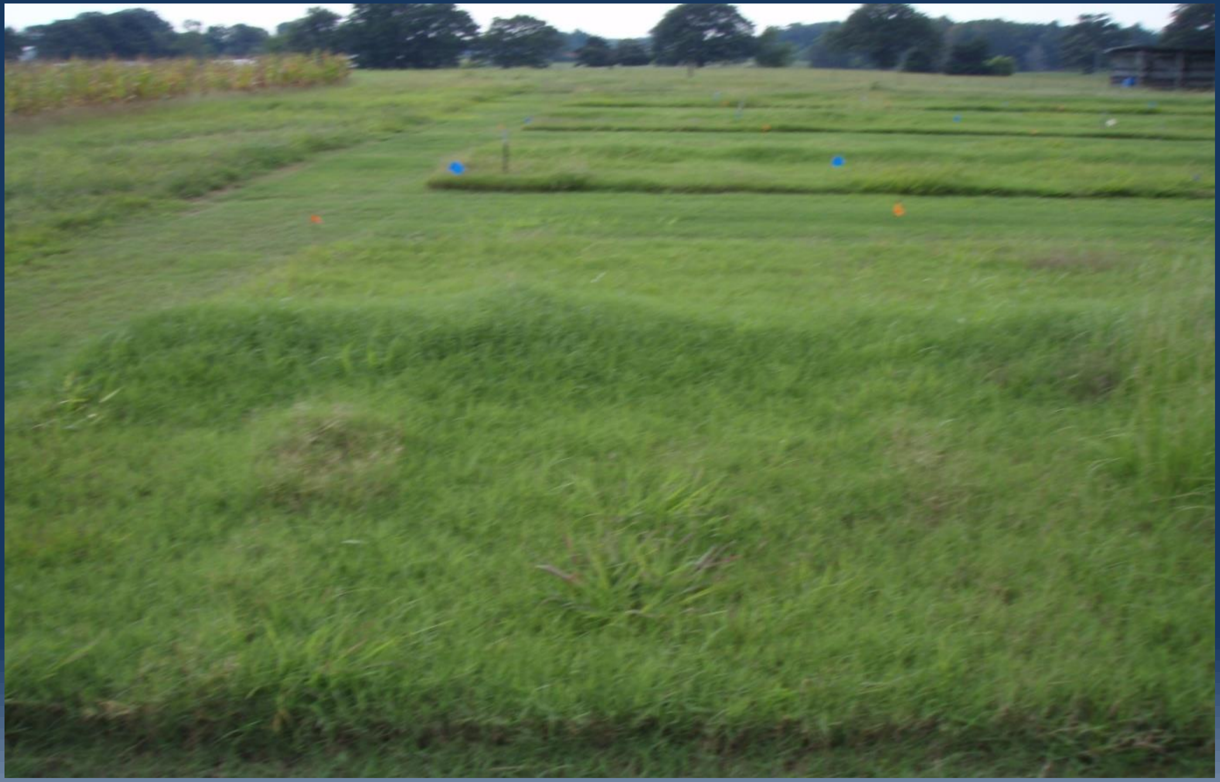
Martin Locke - unpublished data

Sand Mountain Bermudagrass Study





Sand Mountain



Soil Properties 2010

Treatment	Rate	pH	CEC meq $100g^{-1}$	EC dSm^{-1}	N %	C %
Control	0	6.46	2.82	0.13	0.08	0.88
Gypsum	2	6.73	3.08	0.12	0.09	0.92
Gypsum	10	6.95	3.80	0.11	0.10	1.07
Gypsum	20	7.19	4.01	0.14	0.09	1.03
FGD	2	6.46	2.76	0.12	0.08	0.89
FGD	10	6.73	3.01	0.12	0.08	0.90
FGD	20	6.52	4.83	0.12	0.09	1.02
FGD + Fly Ash	2	6.61	3.21	0.12	0.10	1.07
FGD + Fly Ash	10	7.27	3.51	0.12	0.08	0.90
FGD + Fly Ash	20	7.44	4.34	0.12	0.10	1.05

Mehlich 3 Extractable Nutrients 2010

Treatment	Rate	P	K	Ca	Mg	S	Al	B	Cu	Fe	Mn	Mo	Na	Zn
			------	------	------	------	---- μg^{-1}	------	------	------	------	------	------	
Control	0	248.7	929.4	711.5	638.6	125.8	12547.0	3.35	6.00	5662.9	171.2	0.49	56.2	23.7
Gypsum	2	258.7	743.4	657.3	567.7	121.2	10826.4	3.46	5.47	4961.8	159.4	0.48	34.0	20.8
Gypsum	10	294.9	809.8	997.3	713.9	160.8	12222.5	3.44	6.91	5653.8	161.8	0.49	40.4	24.4
Gypsum	20	246.7	843.7	1477.1	834.7	162.8	12258.9	3.47	5.43	5576.9	165.0	0.51	42.8	22.6
FGD	2	230.9	800.1	631.8	568.3	117.5	11776.3	3.57	5.11	5946.8	163.3	0.44	37.8	21.3
FGD	10	246.0	754.0	835.2	533.3	127.3	10984.7	3.26	5.16	5009.7	158.3	0.47	40.8	21.8
FGD	20	244.5	774.7	1361.4	567.7	148.6	11591.1	3.13	5.09	5222.8	181.6	0.44	36.6	21.7
FGD + Fly Ash	2	255.3	769.2	740.3	588.3	136.1	11547.3	3.48	5.42	5299.5	158.8	0.51	38.2	23.0
FGD + Fly Ash	10	256.2	723.7	904.3	551.2	127.4	10835.8	3.16	4.57	5000.5	149.6	0.43	37.4	20.0
FGD + Fly Ash	20	283.8	763.8	1395.0	579.2	168.5	10977.6	3.61	6.30	5146.0	142.6	0.47	37.6	23.0

2008 Bermudagrass Nutrient Concentrations

		%N	%C	P	K	Ca	Mg	S	Al	B	Cu	Fe	Mn	Mo	Na	Zn
				------------	------------	------------	------------	------------'	ug/g	'------------	------------	------------	------------	------------	------------	------------'
control	0	2.30	43.9	2446.3	17354.3	4380.6	1804.5	2806.3	67.16	4.95	5.55	139.43	123.81	0.40	267.56	16.68
Gypsum	2	2.31	43.9	2420.7	17988.8	4563.5	1813.0	3237.7	70.27	4.26	5.79	128.16	127.20	0.41	239.31	17.89
Gypsum	10	2.23	43.6	2421.2	18120.3	4640.8	1870.2	3328.4	69.90	4.32	4.72	198.80	136.48	0.39	206.89	16.58
Gypsum	20	2.32	43.5	2370.8	19547.7	4866.8	2049.2	3368.3	57.23	4.30	4.97	126.60	126.11	0.43	206.97	18.38
Fgd	2	2.13	43.8	2205.8	17782.1	3962.4	1845.8	3059.7	58.68	4.68	4.71	130.45	216.21	0.49	191.88	15.73
Fgd	10	2.19	43.7	2170.6	18016.6	4440.1	1769.4	3300.3	76.01	4.46	9.83	153.38	199.12	0.51	207.07	19.25
Fgd	20	2.28	43.7	2107.5	17502.2	4786.0	1804.6	3429.4	70.31	6.03	5.89	169.98	213.57	0.35	193.64	18.22
Fly	2	2.17	43.8	2332.1	18355.3	4392.5	1916.2	3026.5	76.73	4.42	7.36	147.55	126.04	0.49	206.12	18.96
Fly	10	2.22	43.8	2097.4	17069.1	4378.8	1751.1	3149.7	58.10	5.71	4.45	150.38	191.21	0.41	201.19	15.68
Fly	20	2.20	43.6	2205.4	18882.0	4404.2	1956.3	3282.6	55.49	5.60	4.38	138.34	173.20	0.44	193.92	16.28

2009 Bermudagrass Nutrient Concentrations

		%N	%C	P	K	Ca	Mg	S	Al	B	Cu	Fe	Mn	Mo	Na	Zn
									ug/g							
control	0	2.04	43.58	2891.5	16995.6	3801.2	1656.3	2764.8	112.2	3.24	12.15	133.32	60.83	1.32	169.38	26.90
Gypsum	2	1.98	43.21	3082.5	17541.5	3881.7	1673.4	2698.4	142.5	3.20	13.75	156.47	70.44	1.67	145.11	30.18
Gypsum	10	1.96	43.57	2916.4	16055.7	4121.7	1360.6	2879.7	139.1	3.38	15.04	162.95	75.84	1.71	154.20	28.62
Gypsum	20	1.95	43.34	3035.2	16385.3	4277.7	1360.6	2931.6	149.4	3.13	16.20	155.58	72.97	1.46	137.38	30.02
Fgd	2	2.00	42.66	2949.4	17270.1	4495.3	1541.1	2838.3	130.5	3.62	14.40	140.32	71.18	1.72	154.86	33.04
Fgd	10	1.92	43.16	3016.0	17336.1	4567.8	1465.9	2901.8	141.8	3.32	14.84	156.00	63.81	1.43	129.46	28.26
Fgd	20	1.97	43.34	3000.8	17103.5	4763.6	1720.3	3033.3	198.5	3.50	15.23	197.58	74.87	1.49	164.59	30.15
Fly	2	1.91	43.46	2837.0	16420.6	3720.8	1569.0	2759.5	152.8	3.27	13.53	165.93	90.90	1.31	154.61	27.10
Fly	10	1.93	43.28	3119.7	17169.3	4267.8	1334.3	2886.2	154.8	3.39	16.22	166.39	94.16	1.24	137.83	33.41
Fly	20	1.91	43.18	2944.3	16894.9	4191.7	1238.5	3002.6	168.9	3.10	16.44	182.64	93.36	0.97	119.61	30.57

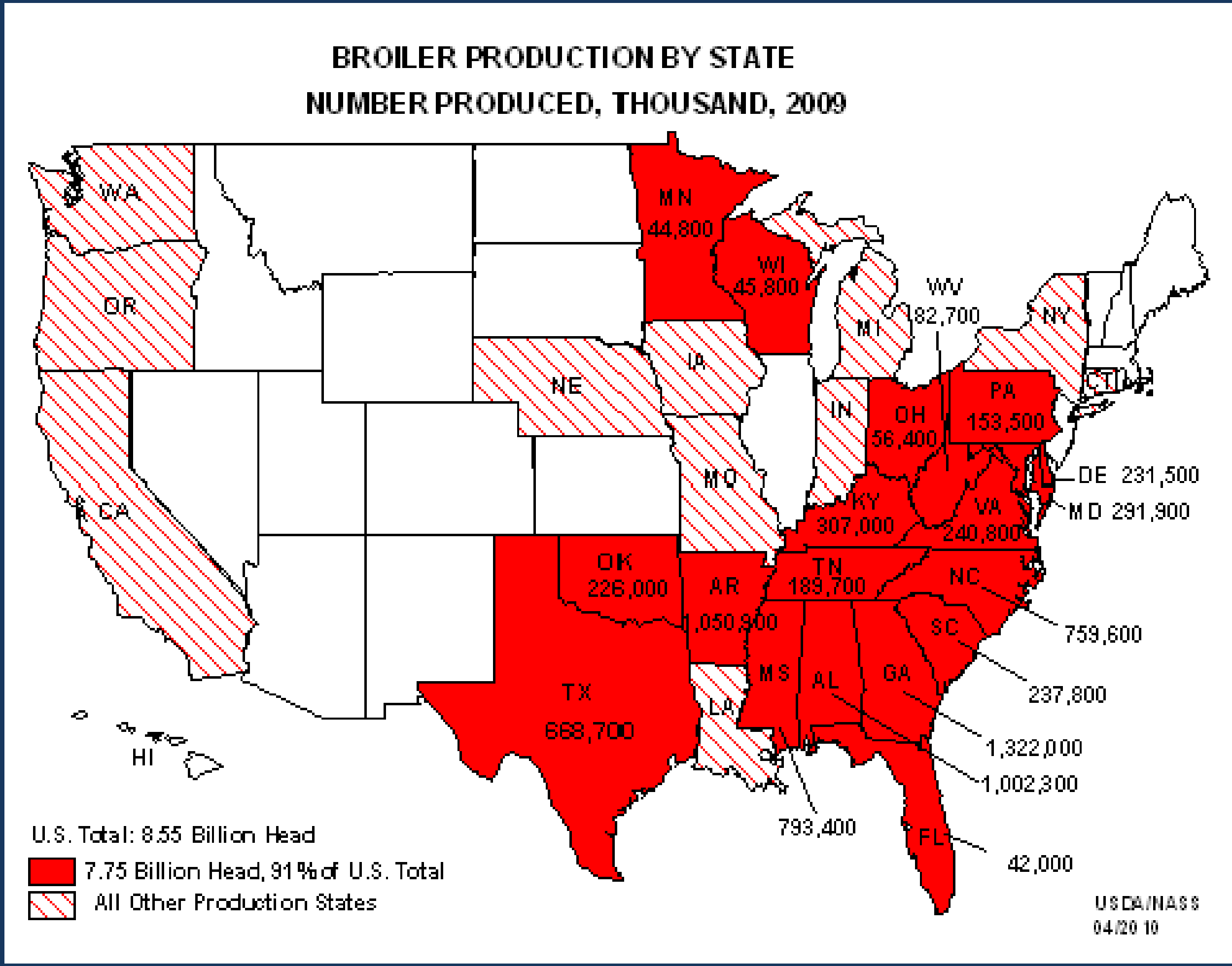
2010 Bermudagrass Nutrient Concentrations

		%N	%C	P	K	Ca	Mg	S	Al	B	Cu	Fe	Mn	Mo	Na	Zn
				--'					ug/g	--'						
control	0	1.98	43.49	3084.5	18094.0	3906.6	1780.4	2267.2	37.86	3.46	7.25	195.99	93.33	1.13	154.13	30.32
Gypsum	2	1.90	44.10	3241.0	16999.0	3984.9	1756.4	2203.3	36.94	3.70	6.43	121.70	64.99	1.26	139.70	28.88
Gypsum	10	1.96	43.87	3174.2	17136.8	4391.6	1740.4	2424.9	49.53	3.36	7.16	238.55	62.87	1.54	139.03	31.35
Gypsum	20	1.86	43.80	3250.8	18142.5	4600.2	1611.1	2457.6	32.30	2.84	6.24	109.76	66.56	1.28	128.68	27.81
Fgd	2	1.84	43.98	3110.8	17205.9	3883.4	1646.0	2294.7	40.53	3.32	6.91	107.77	96.22	1.05	132.68	30.15
Fgd	10	1.95	44.10	3082.8	15882.2	4296.3	1428.8	2373.1	38.23	3.34	6.32	101.43	75.52	1.14	144.42	27.84
Fgd	20	1.83	44.01	3196.8	16640.2	4304.3	1399.9	2453.3	39.60	3.64	6.19	146.57	96.88	1.06	115.35	28.53
Fly	2	1.95	44.03	3213.3	16561.5	4135.8	1726.4	2380.0	44.46	3.74	7.69	109.37	69.59	1.66	148.23	32.15
Fly	10	1.87	44.27	3054.5	15185.8	4291.6	1435.6	2402.4	32.15	3.36	6.79	105.97	71.53	1.43	135.43	27.01
Fly	20	1.82	44.24	3011.1	14200.6	4334.9	1426.7	2415.9	30.30	3.38	7.24	92.14	68.87	1.46	129.79	27.60

Water Quality Concerns in Southeast

Water Quality

- What is quality of water in the U.S.
  - * 45% of river miles are impaired
  - * 47% of lake acres,
  - * 32% of estuarine water is impaired.
- Agriculture is considered to be one of the major contributors to water quality
- Phosphorus loss from agriculture
- Poultry Industry
  - Improper disposal of waste from poultry industry

Broiler production during 2009. From USDA National agricultural statistics available at http://www.nass.usda.gov/Charts_and_Maps/Poultry/brlmap.asp.

Gypsum Interaction with Soluble P

- Formation of an insoluble Ca-phosphate complex

- Insoluble hydroxyapatite and fluorapatite

Orthophosphate PO_4^{3-} → $Ca_5(PO_4)_3(OH)$

Orthophosphate PO_4^{3-} → $Ca_5(PO_4)_3F$

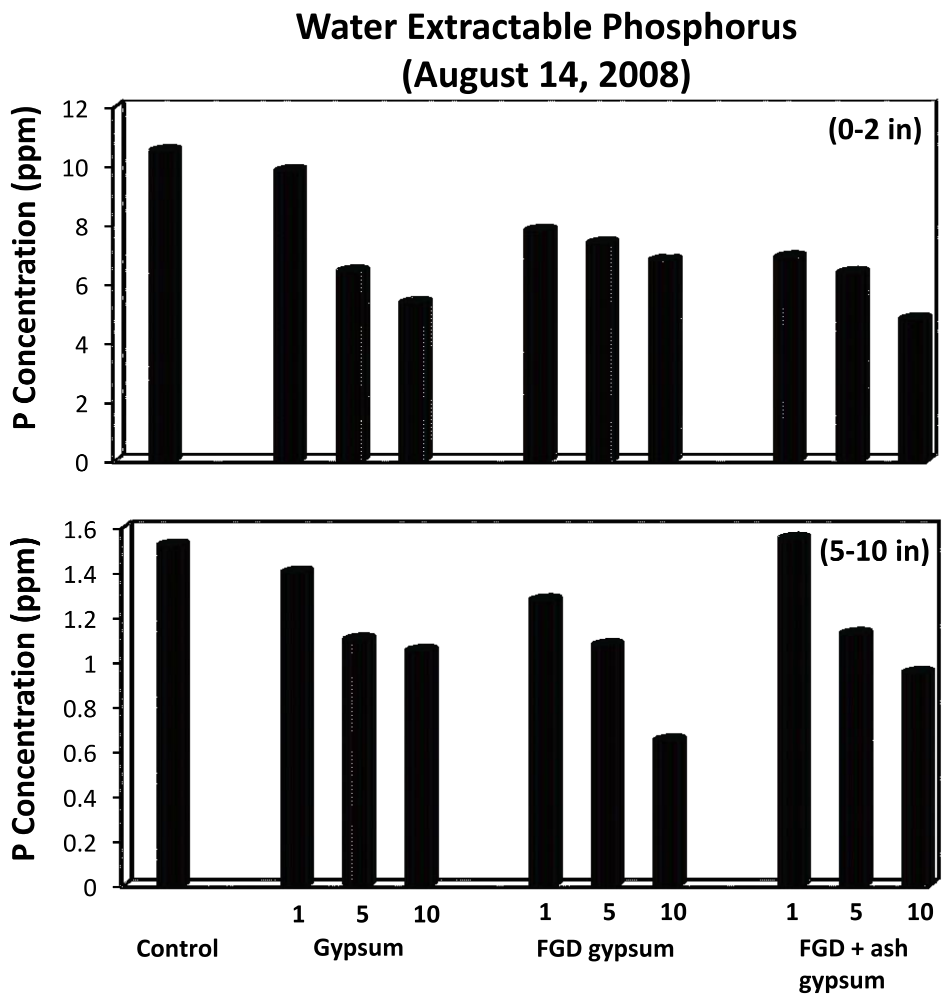


Figure 1. Water soluble P concentrations observed on August 14th 2008, in soil at two depths (0-2and 2-6 inches) amended with gypsum, FGD gypsum, and FGD gypsum + fly ash applied at 1, 5, an 10 tons acre^{-1} and compared to a poultry litter only control.

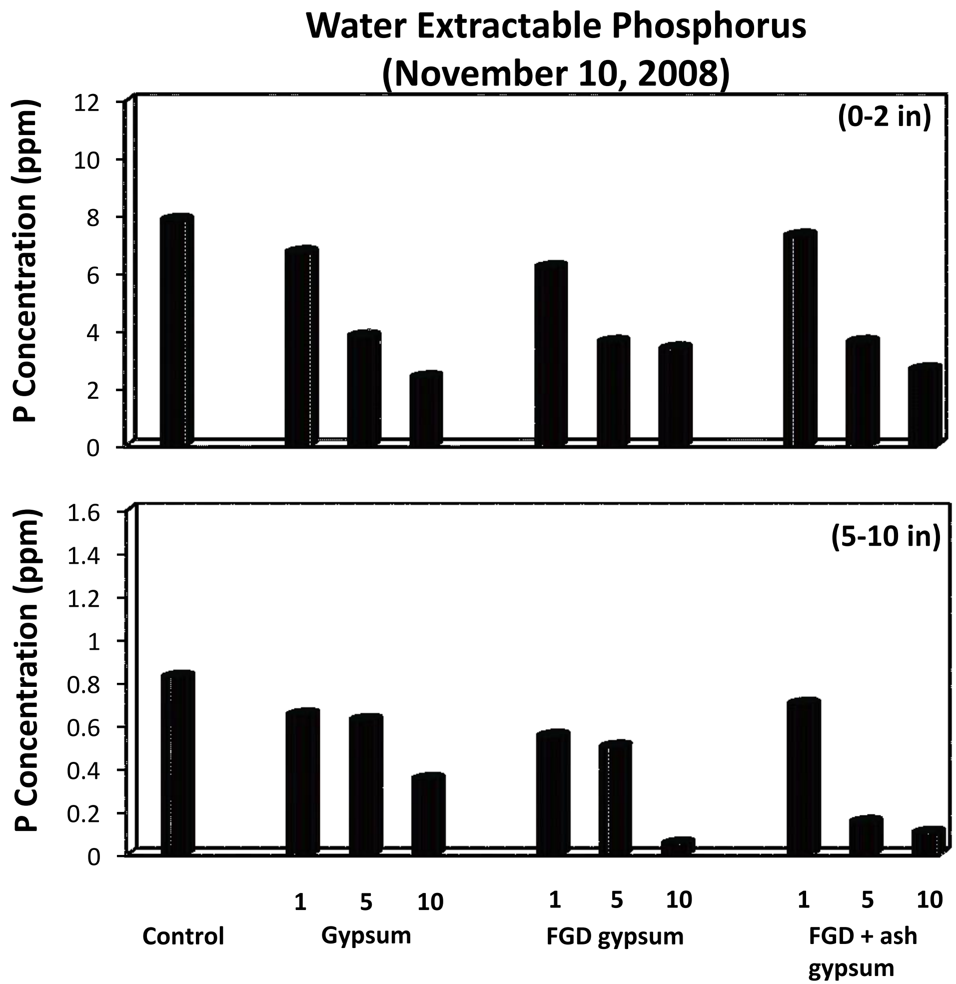


Figure 2. Water soluble P concentrations observed on November 10th 2008, in soil at two depths (0-2and 2-6 inches) amended with gypsum, FGD gypsum, and FGD gypsum + fly ash applied at 1, 5, an 10 tons acre^{-1} and compared to a poultry litter only control.

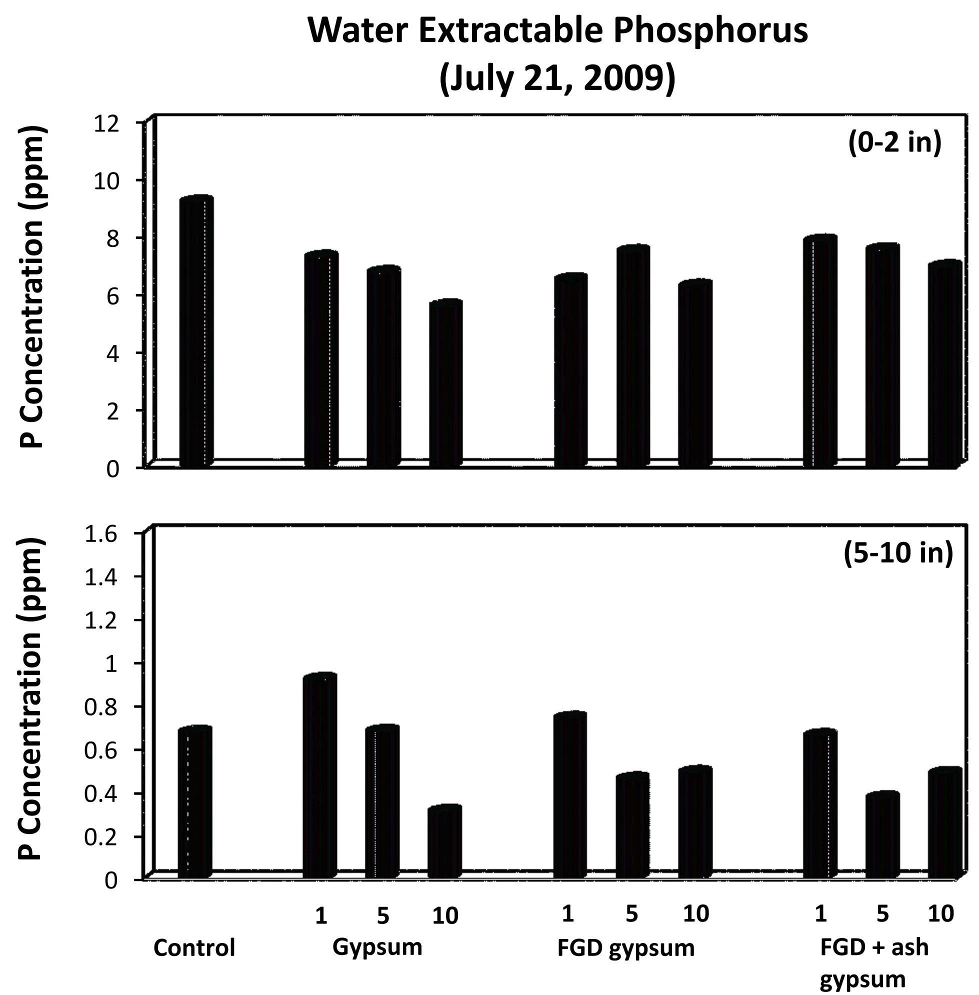


Figure 4. Water soluble P concentrations observed on July 21th 2009, in soil at two depths (0-2and 2-6 inches) amended with gypsum, FGD gypsum, and FGD gypsum + fly ash applied at 1, 5, an 10 tons acre^{-1} and compared to a poultry litter only control.

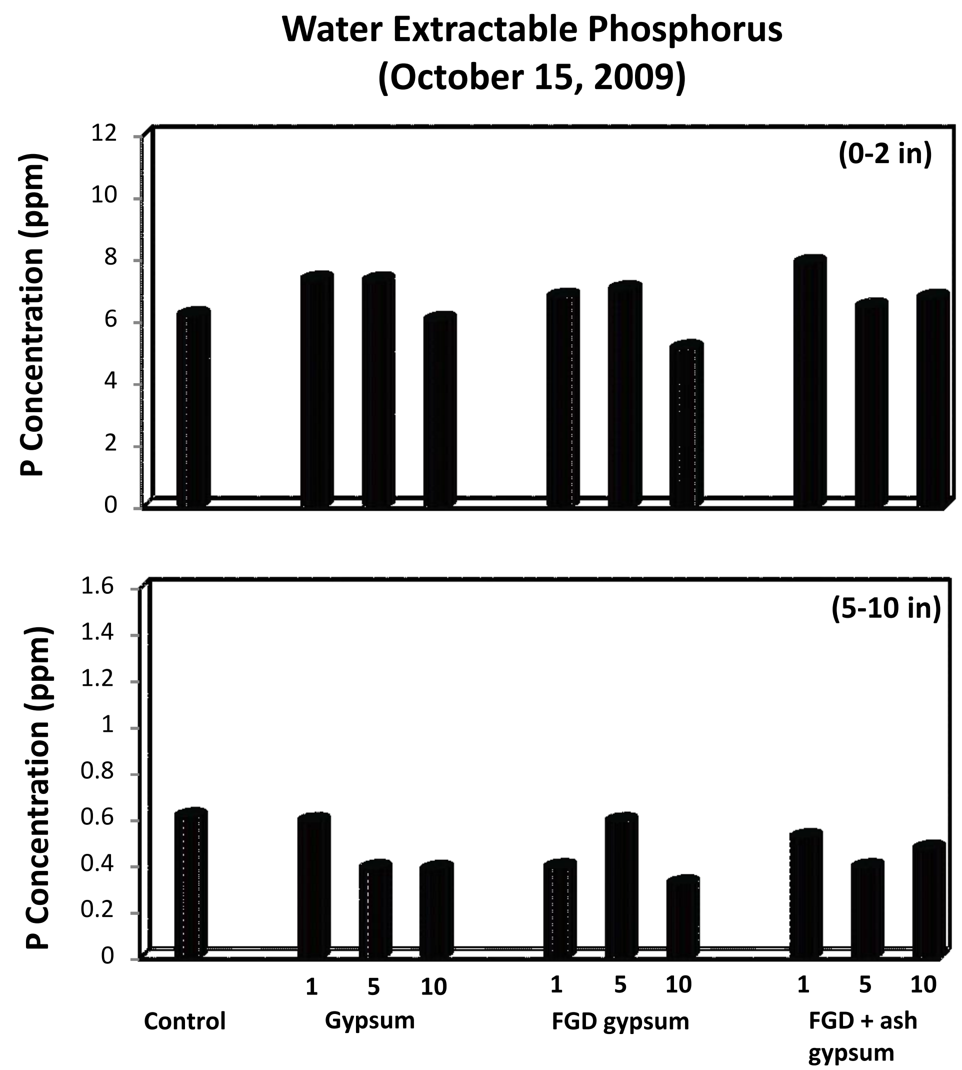


Figure 5. Water soluble P concentrations observed on October 15th 2009, in soil at two depths (0-2and 2-6 inches) amended with gypsum, FGD gypsum, and FGD gypsum + fly ash applied at 1, 5, an 10 tons acre^{-1} and compared to a poultry litter only control.

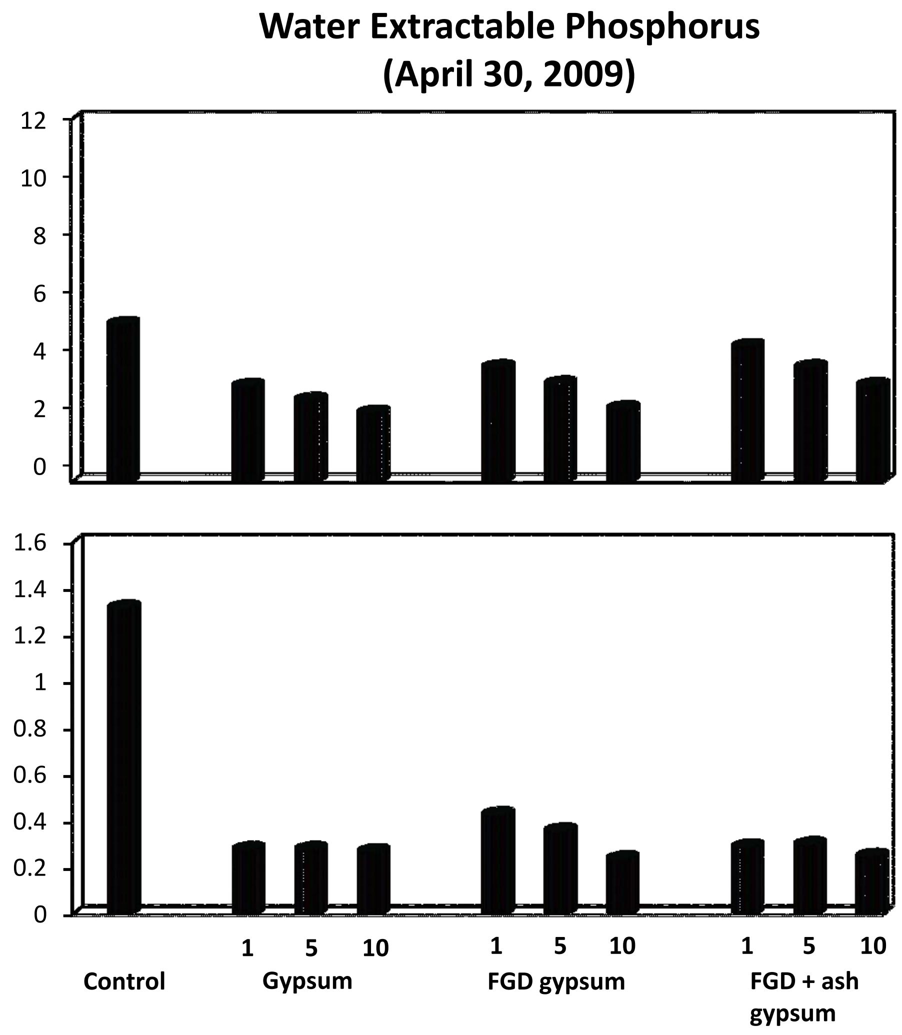


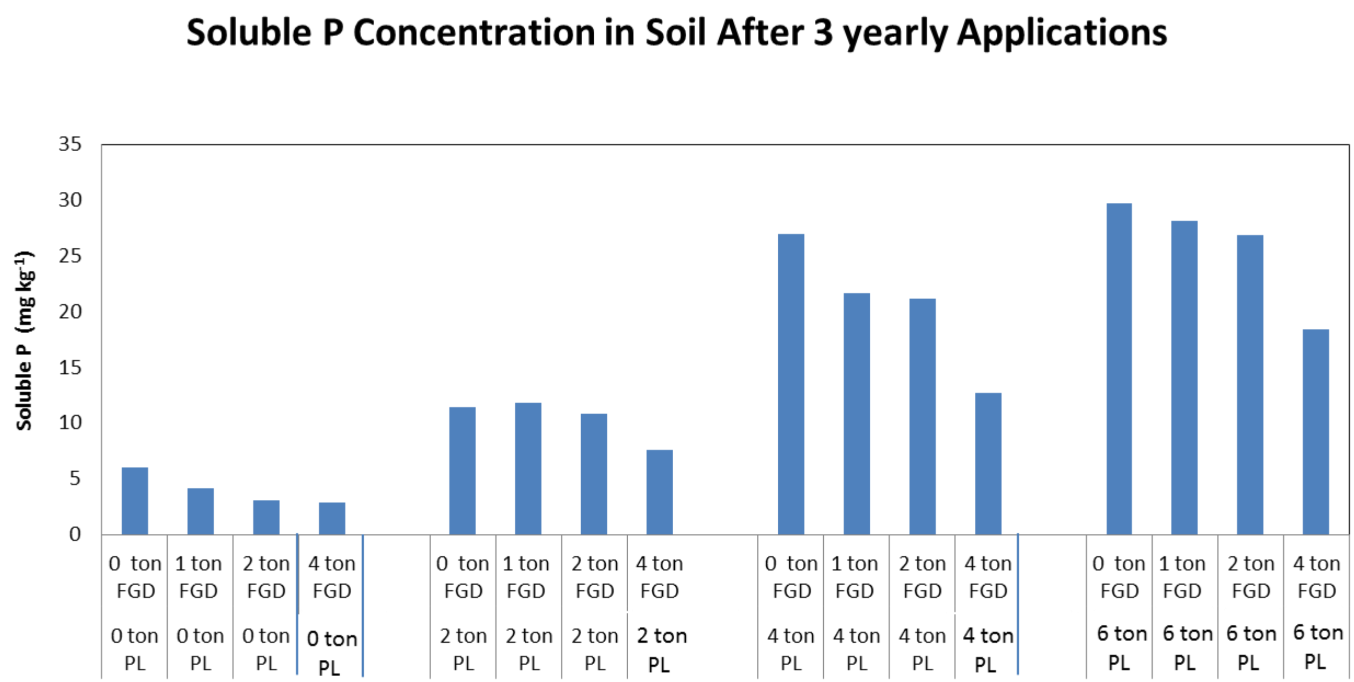
Figure 3. Water soluble P concentrations observed on April 30th 2009, in soil at two depths (0-2and 2-6 inches) amended with gypsum, FGD gypsum, and FGD gypsum + fly ash applied at 1, 5, an 10 tons acre^{-1} and compared to a poultry litter only control.

Poultry Litter (tons/acre)

Gypsum (tons/acre)

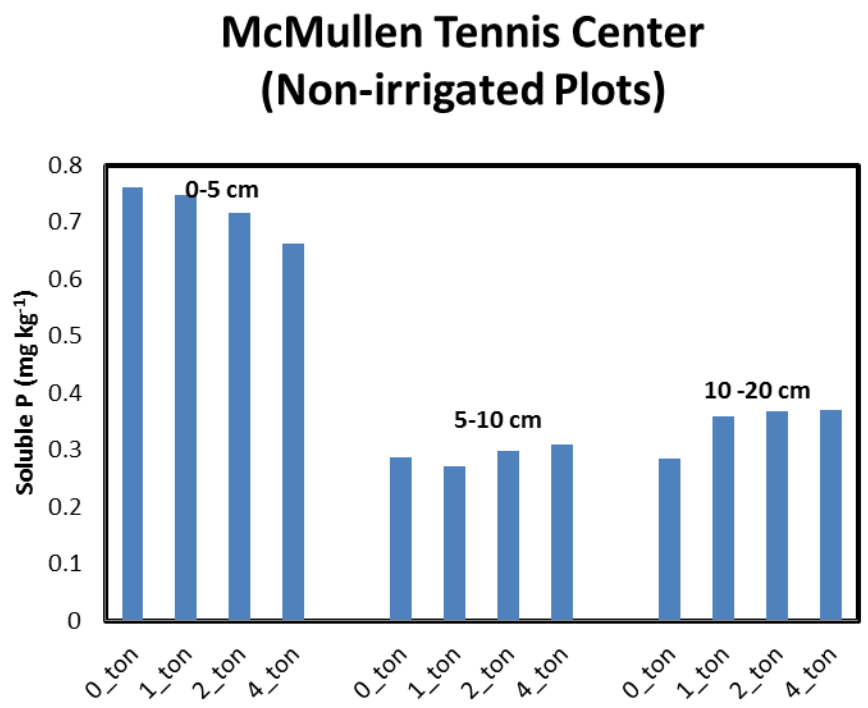
	0	2	4	6
0	0-0	0-2	0-4	0-6
1	1-0	1-2	1-4	1-6
2	2-0	2-2	2-4	2-6
4	4-0	4-2	4-4	4-6

E.V. Smith Research



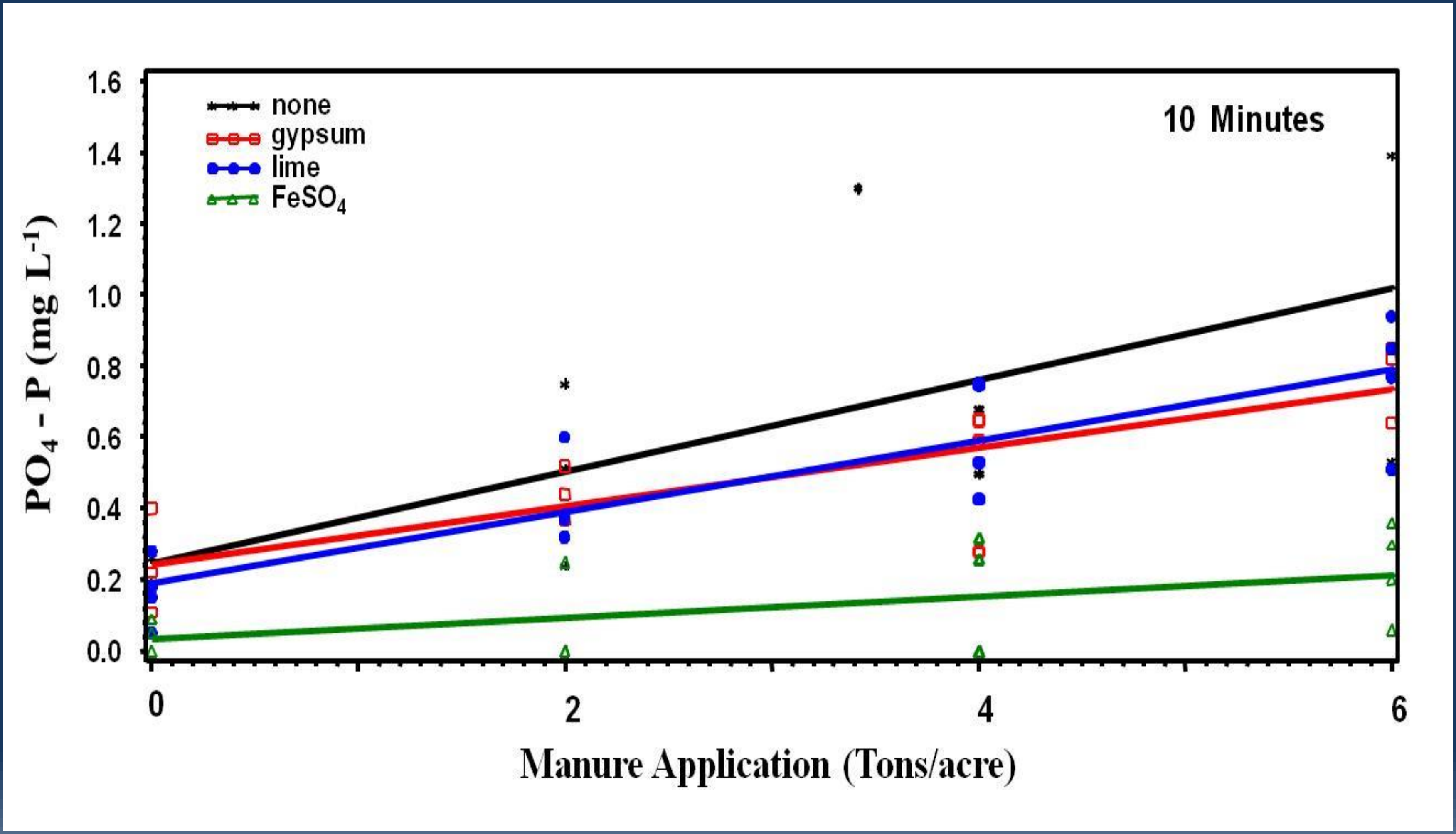
Research in Tampa Florida

Spreading FGD Gypsum



McMullen Tennis Center
(Non-irrigated Plots)
Soluble P (mg kg-1)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-5 cm
5-10 cm
10 -20 cm
0_ton
1_ton
2_ton
4_ton
0_ton
1_ton
2_ton
4_ton
0_ton
1_ton
2_ton
4_ton

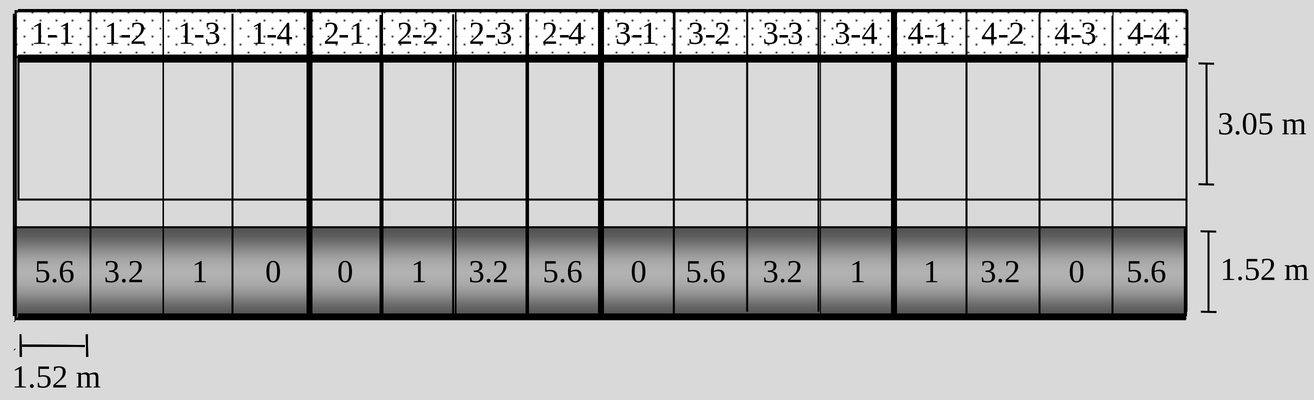
Measuring Impact of Soil Amendments on P Runoff


10 Minutes
none
gypsum
lime
$FeSO_4$
PO_4 - P (mg L^{-1})
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0
2
4
6
Manure Application (Tons/acre)

Treatments

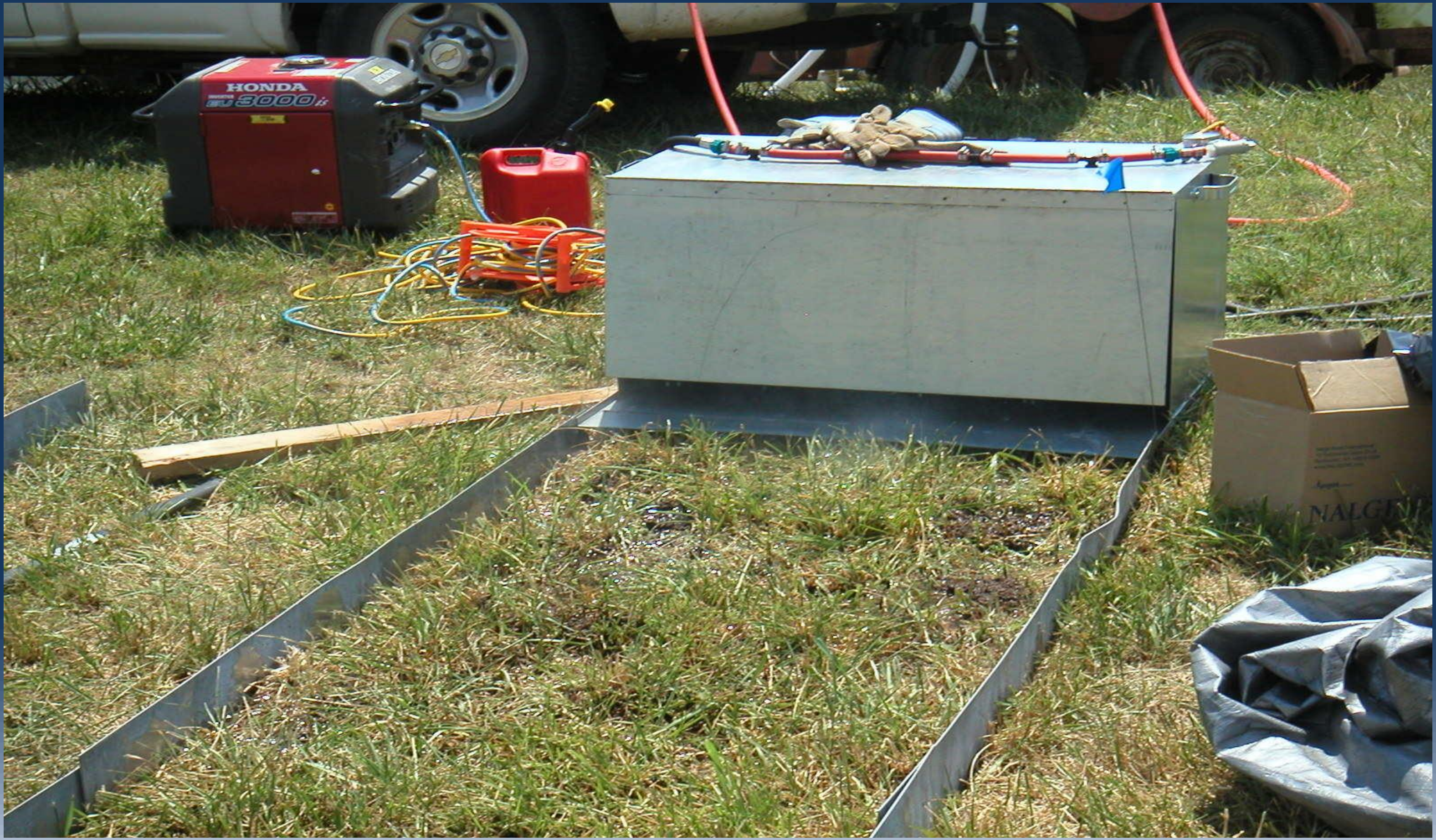
Poultry litter was at a rate of 250 kg N ha^{-1}

Buffer strips received rates of 0,1,3.2,5.6 Mg ha^{-1} commercial farm grade gypsum



Runoff

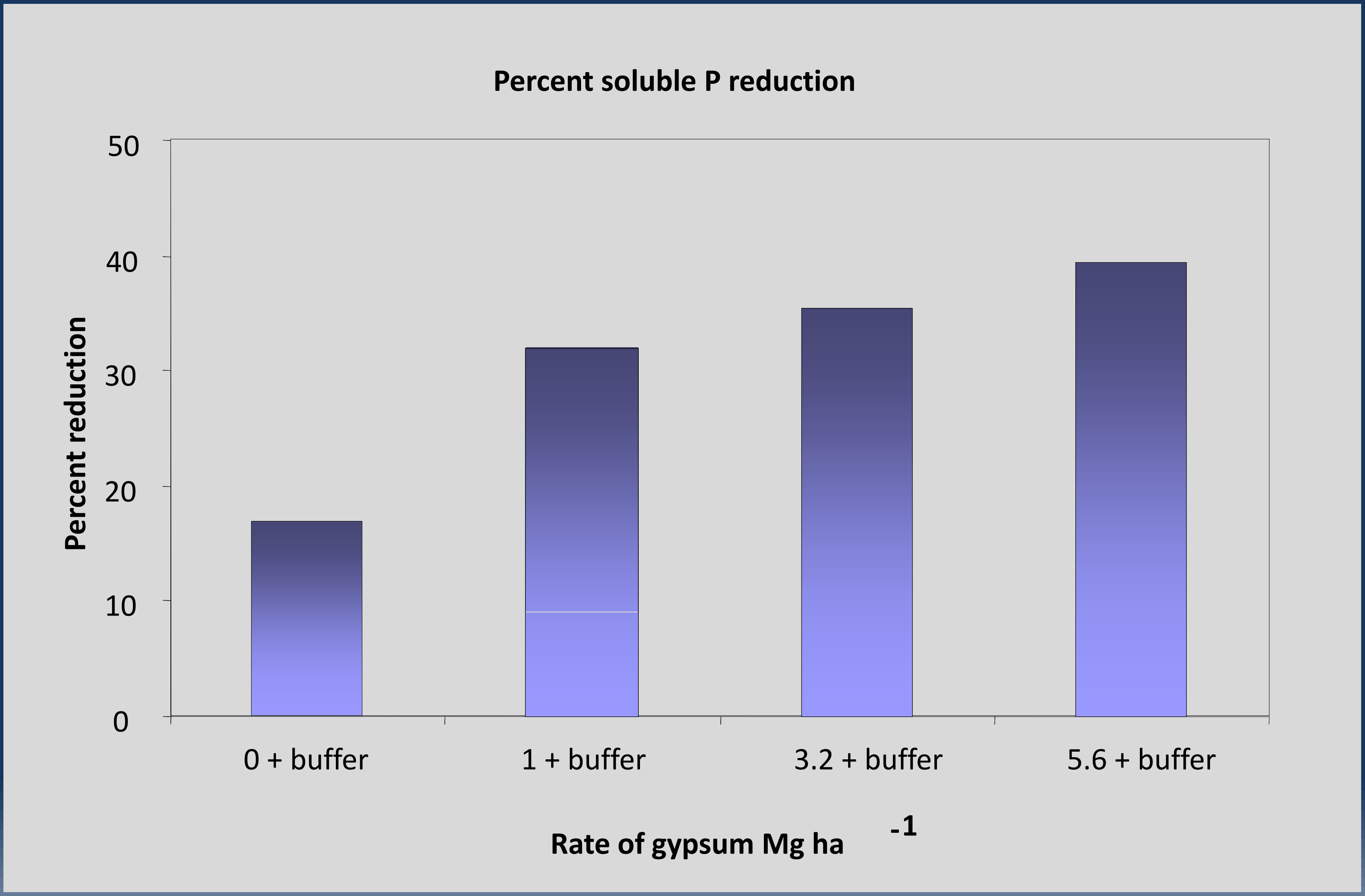
Runoff rate was equivalent to a 124 mm h^{-1}



Runoff

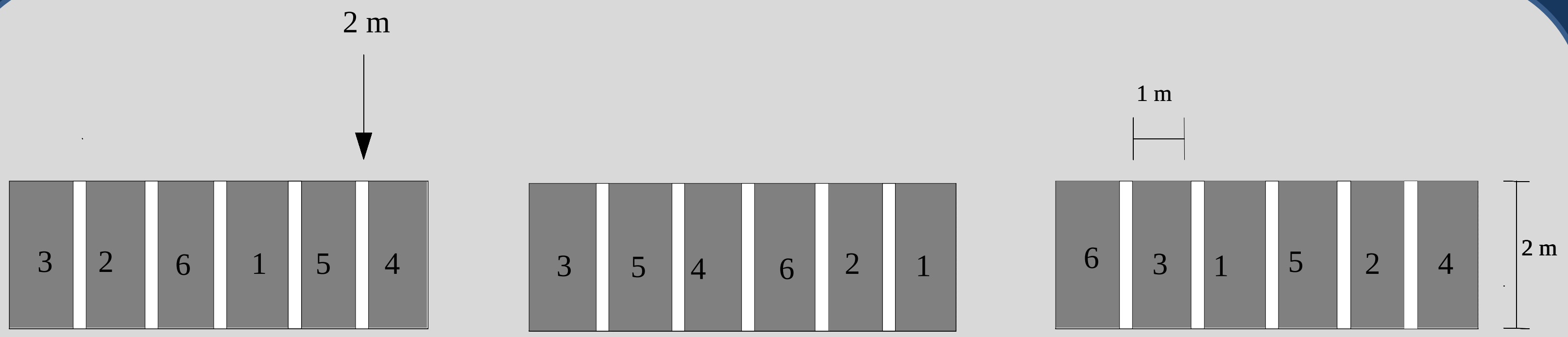
Collection of runoff at 0,10,20,30 min time intervals

Runoff Collection



Watts and Torbert 2009

Rainfall Simulation Study

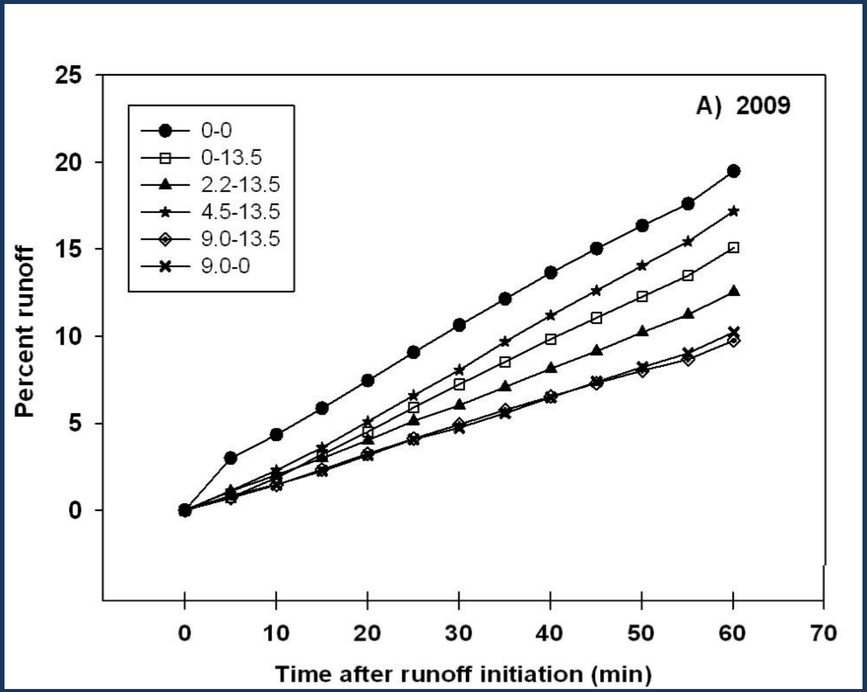


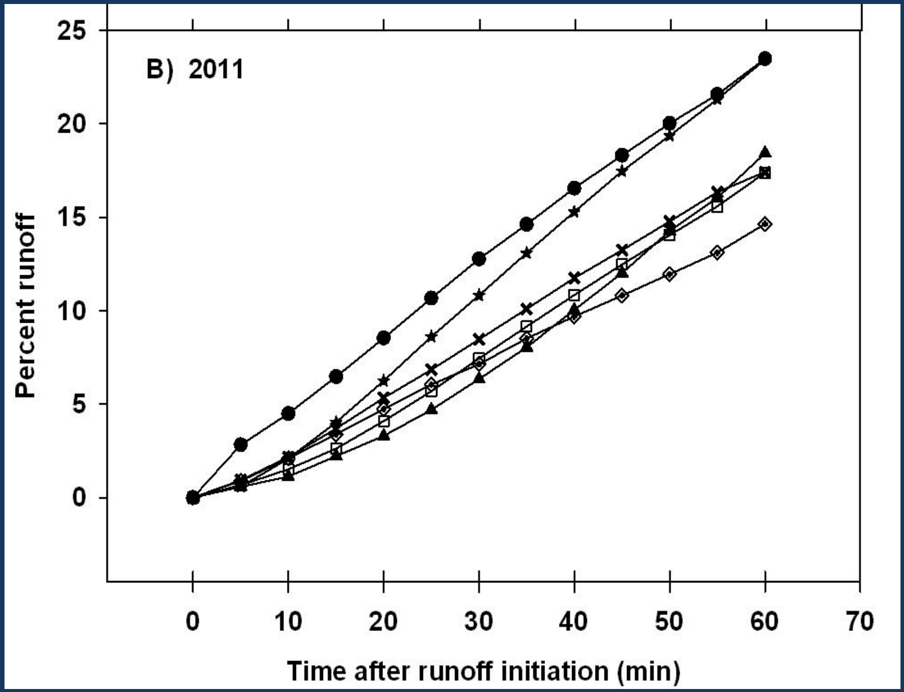
1 = 0-ton FGD, 0-ton PL
2 = 0-ton FGD, 6-ton PL
3 = 1-ton FGD, 6-ton PL
4 = 2-ton FGD, 6-ton PL
5 = 4-ton FGD, 6-ton PL
6 = 4-ton FGD, 6-ton PL

Rainfall Simulation




Runoff as % of Rainfall

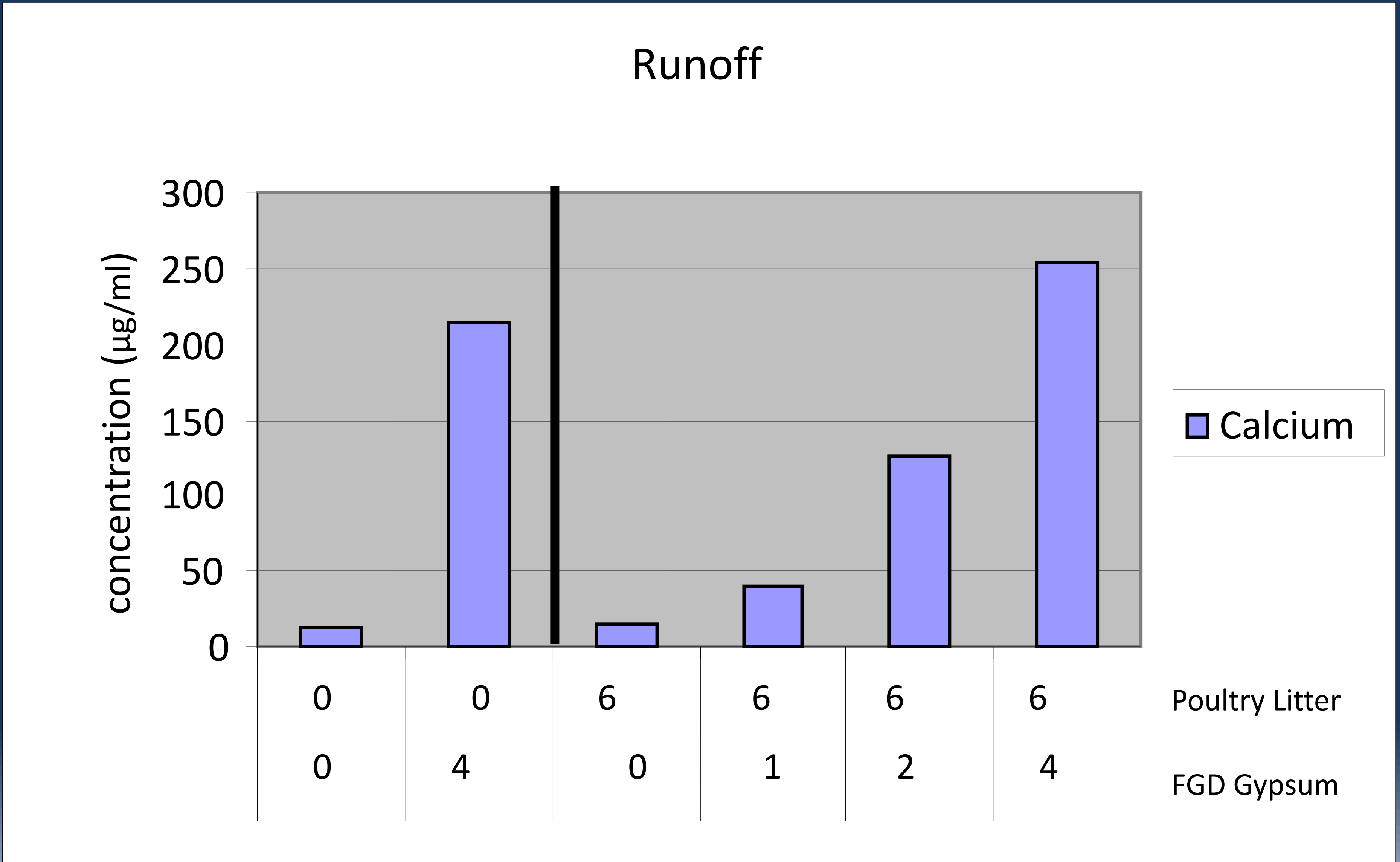




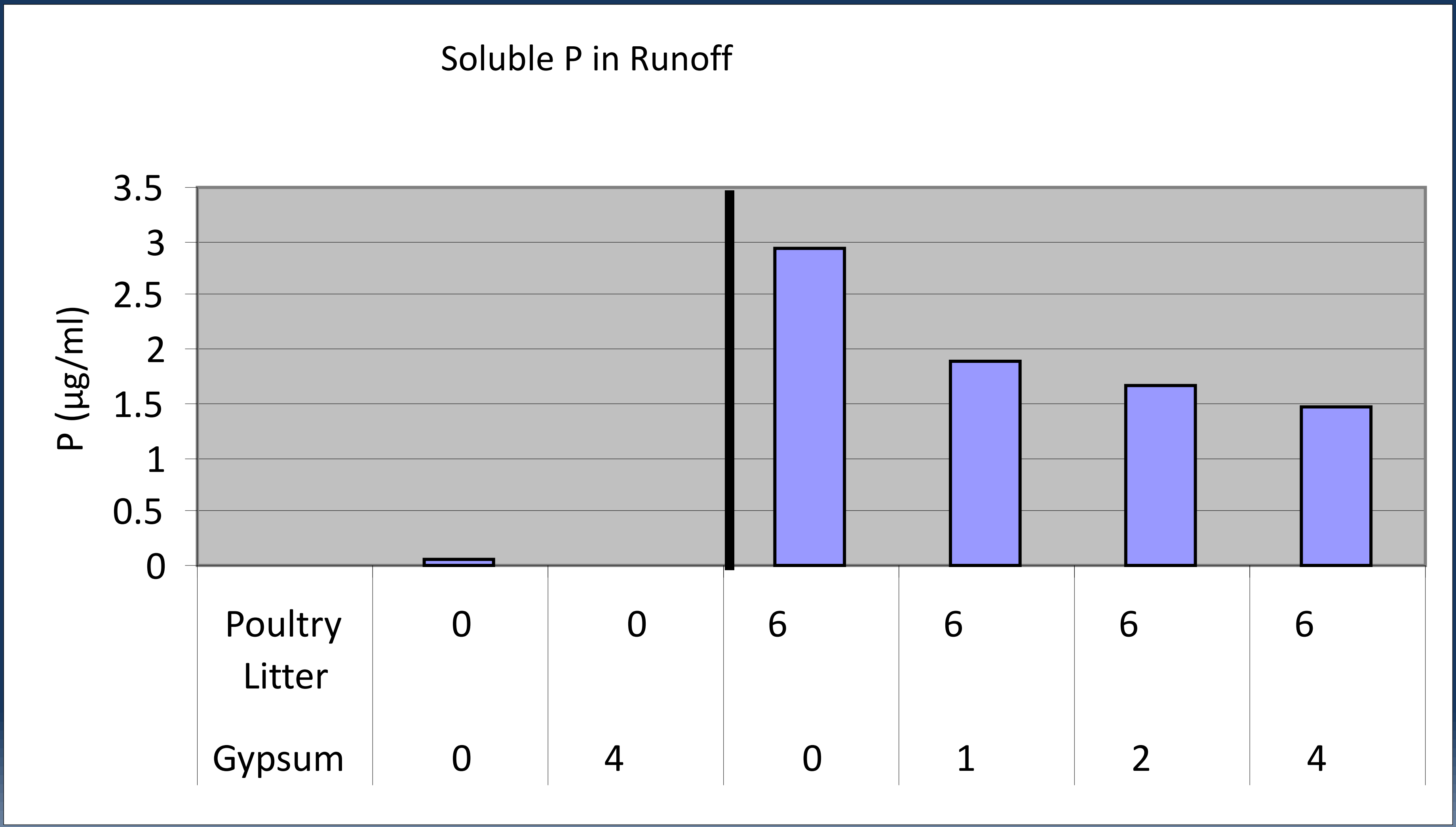
Endale et al. 2013

Runoff


FGD Gypsum Rainfall Simulation
Summer 2009 Runoff - Watkinsville, GA
Sample #: 117
40 min, Plot: 703, Rep #: 7
FGD Gypsum Rainfall Simulation
Summer 2009 Runoff - Watkinsville, GA
Sample #: 141
40 min, Plot: 706, Rep #: 7

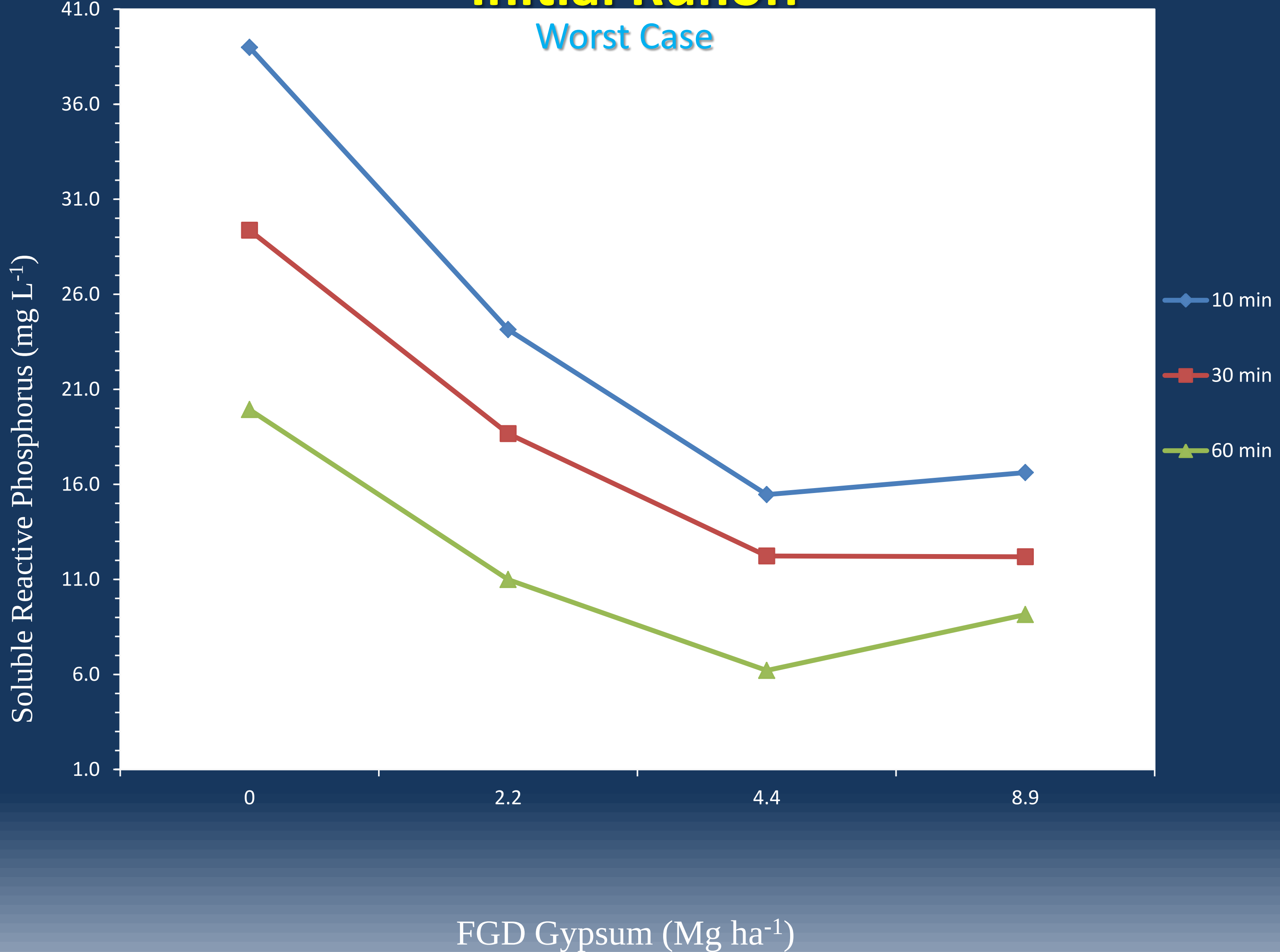


Runoff
concentration (µg/ml)
300
250
200
150
100
50
0
Calcium
0 0 6 6 6 6
Poultry Litter
0 4 0 1 2 4
FGD Gypsum


Soluble P in Runoff
3.5
3
2.5
2
1.5
1
0.5
0
P (µg/ml)
Poultry Litter
0
0
6
6
6
6
Gypsum
0
4
0
1
2
4

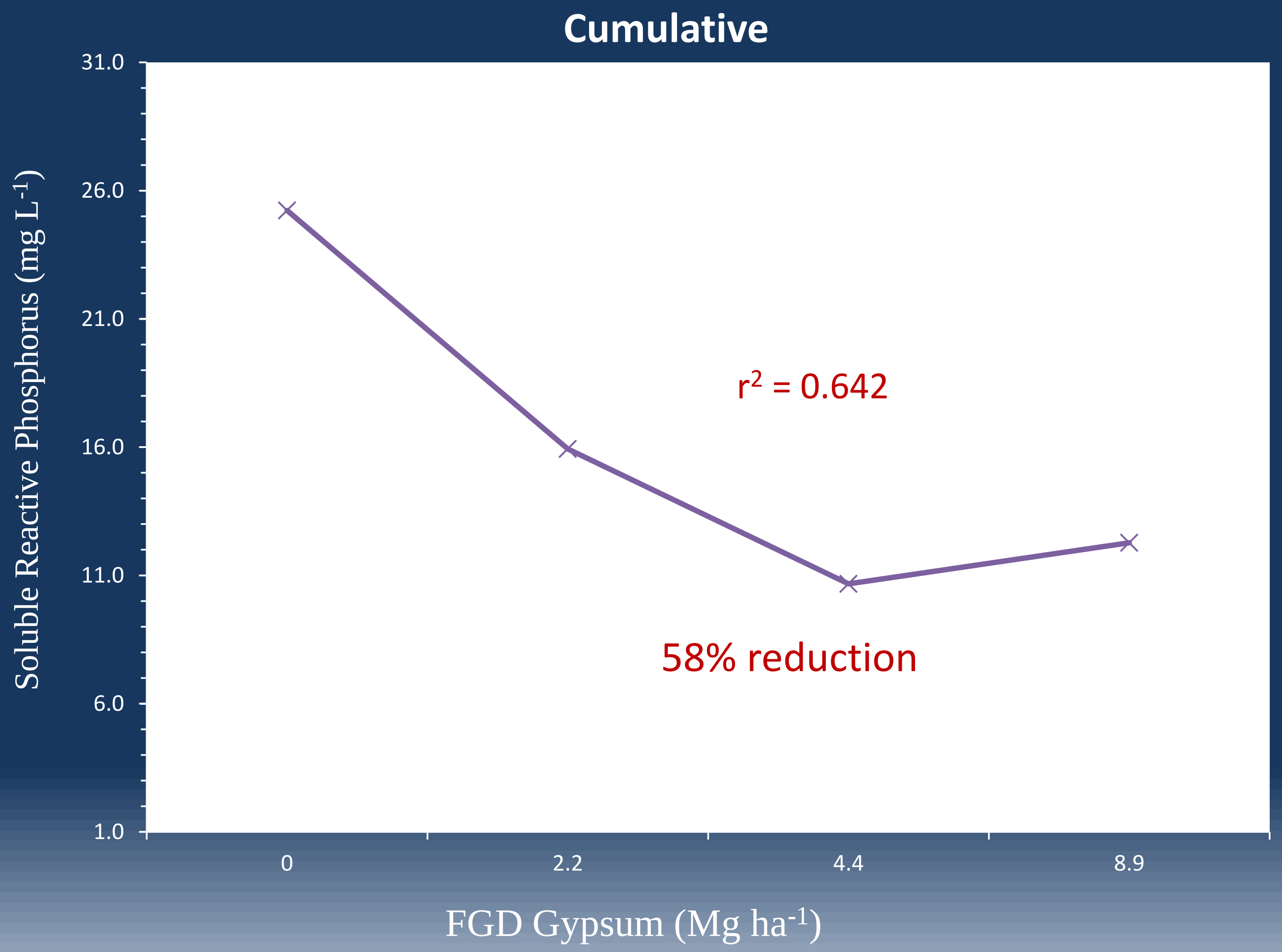
Initial Runoff

Worst Case



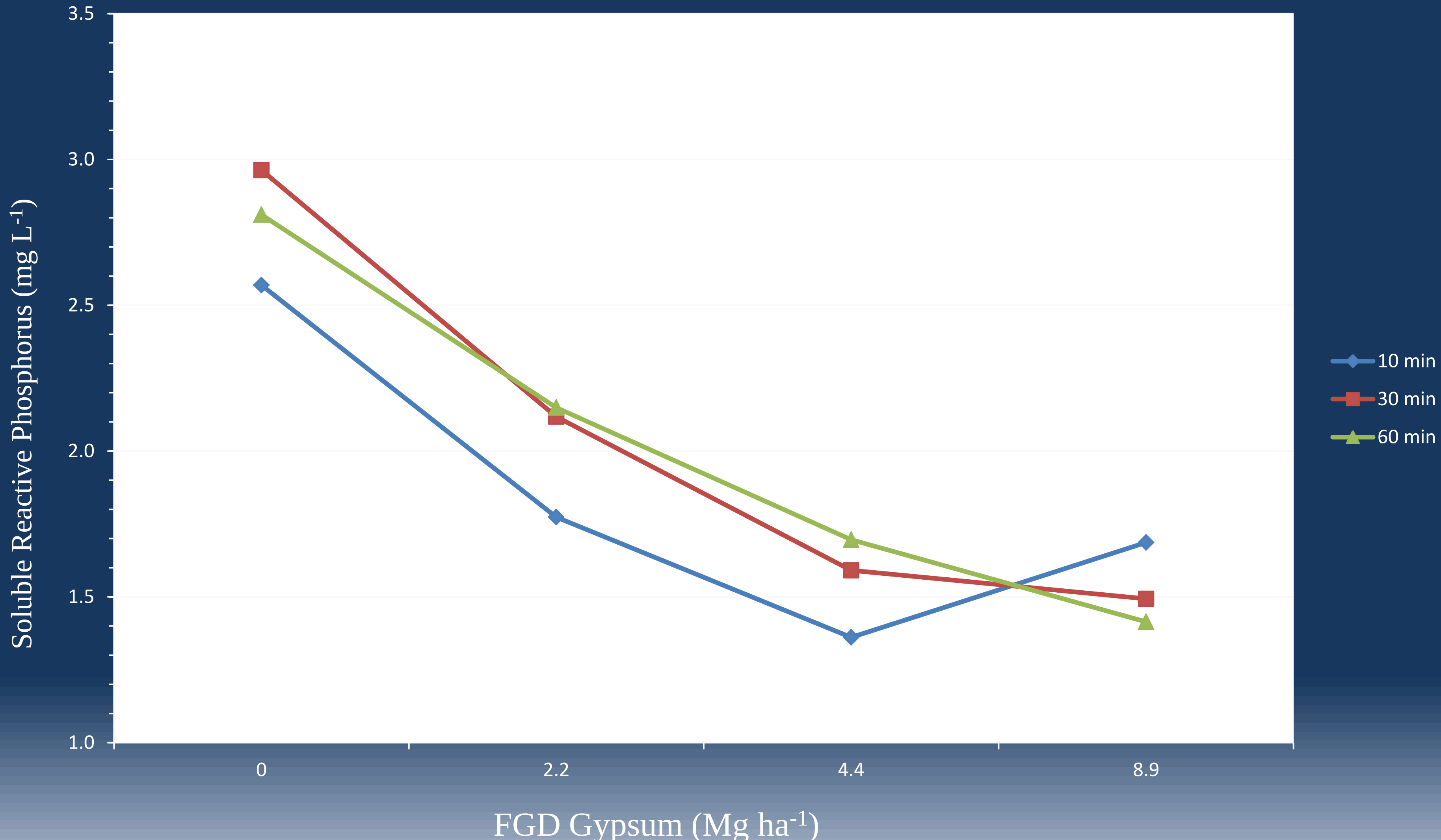
Initial Runoff

Worst Case



Six Weeks Runoff

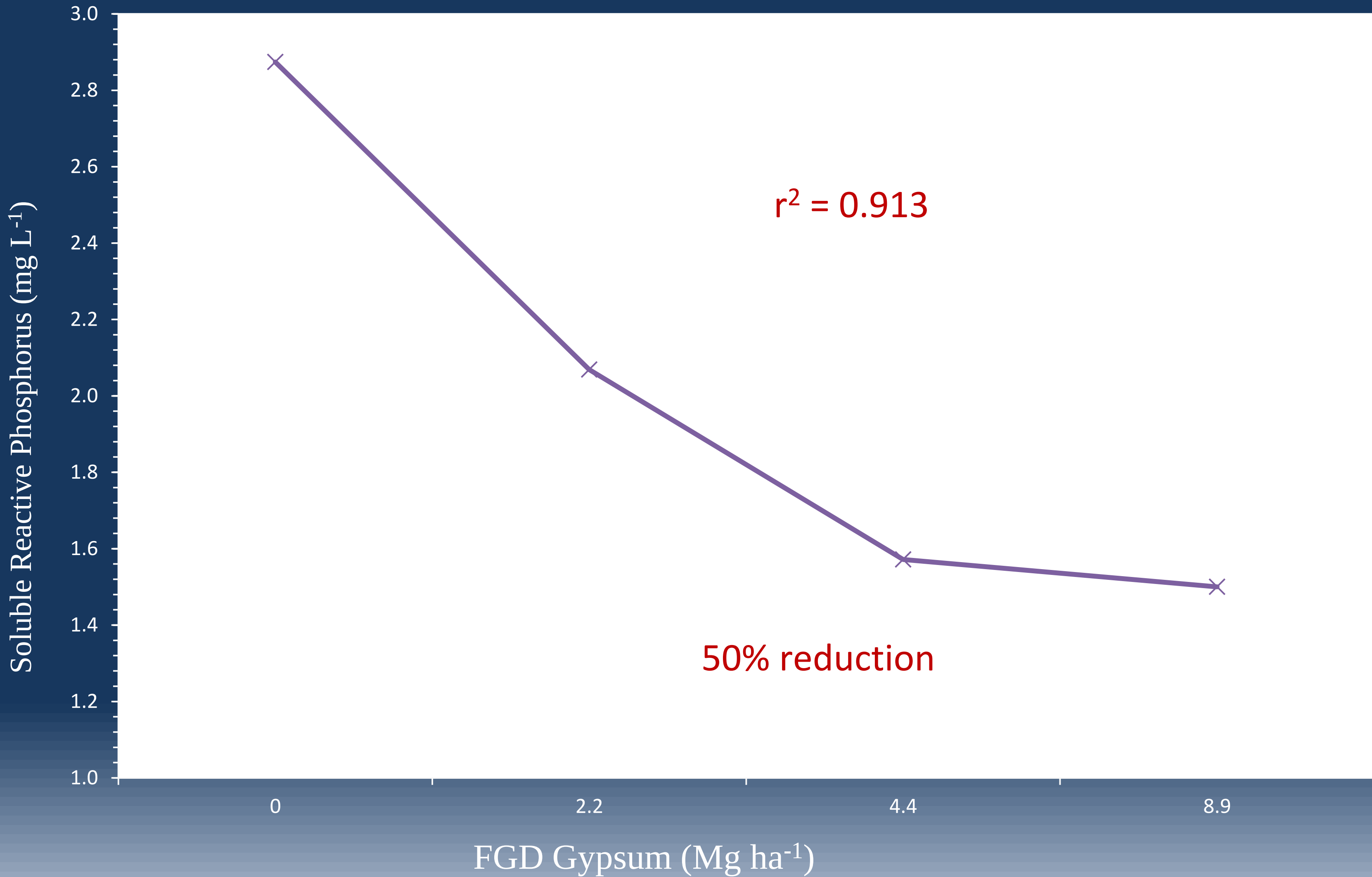
After 5 inches



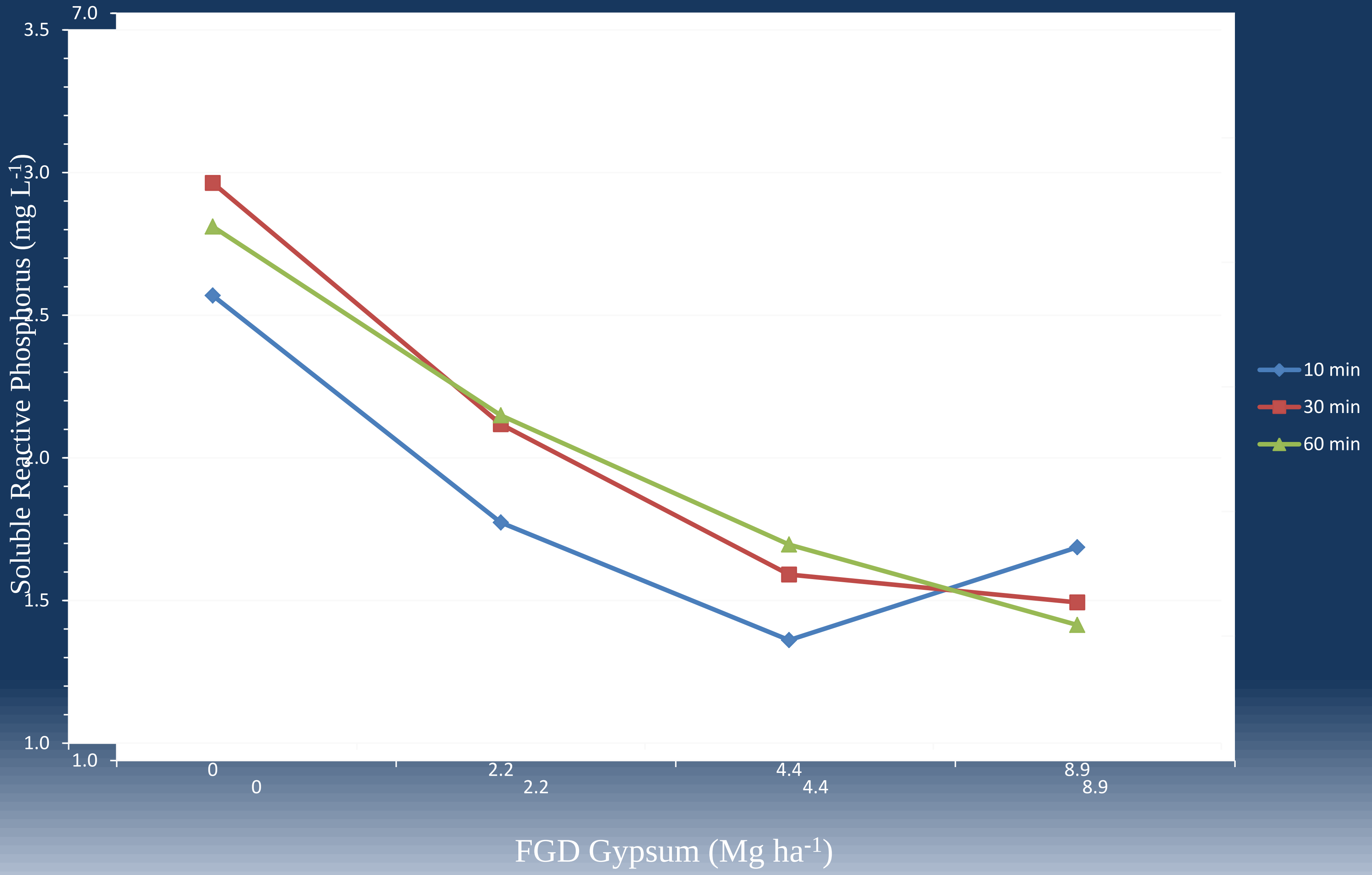
Torbert and Watts, 2013

Six Weeks Runoff

After 5 inches



End of Season Runoff



End of Season Runoff

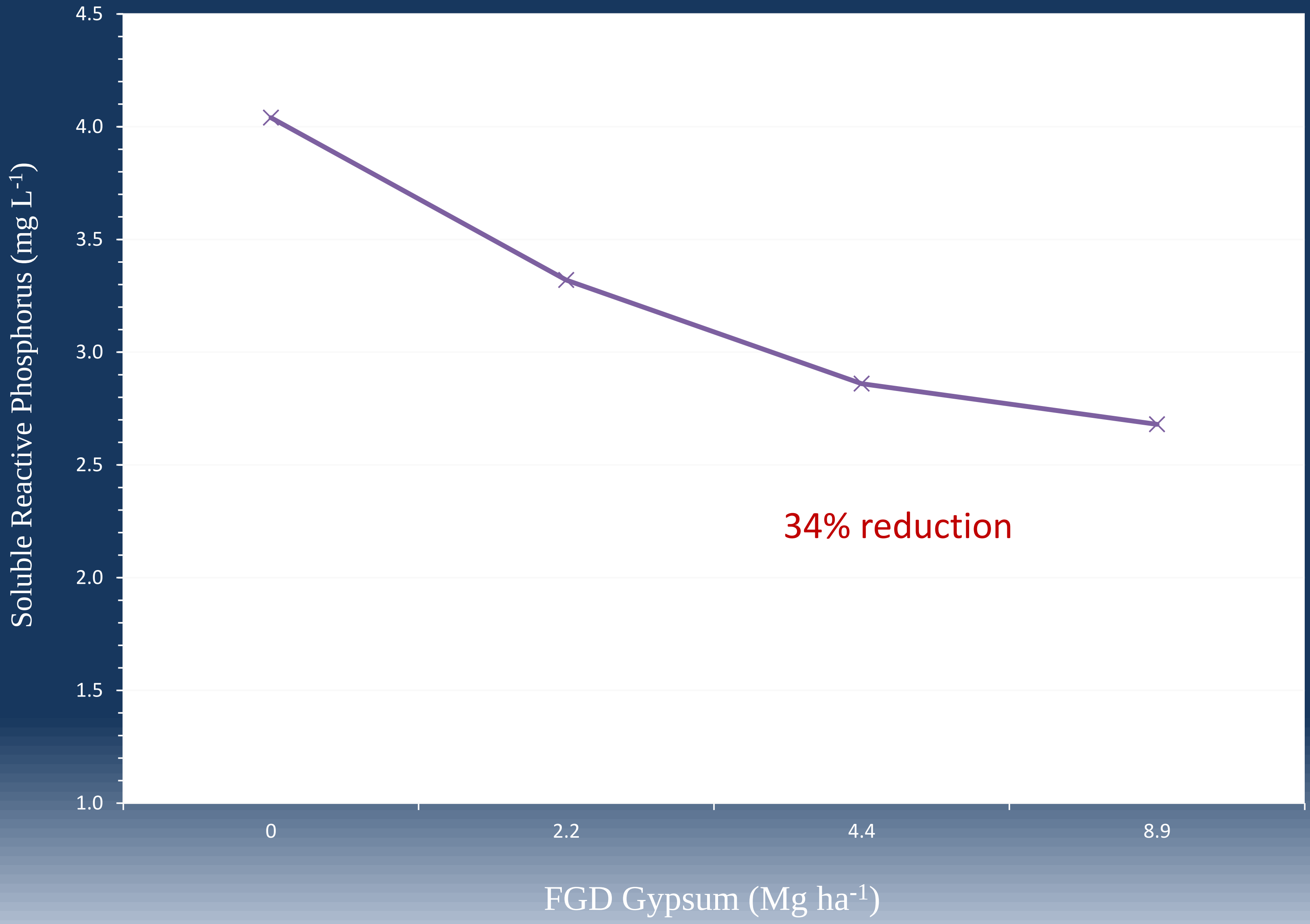
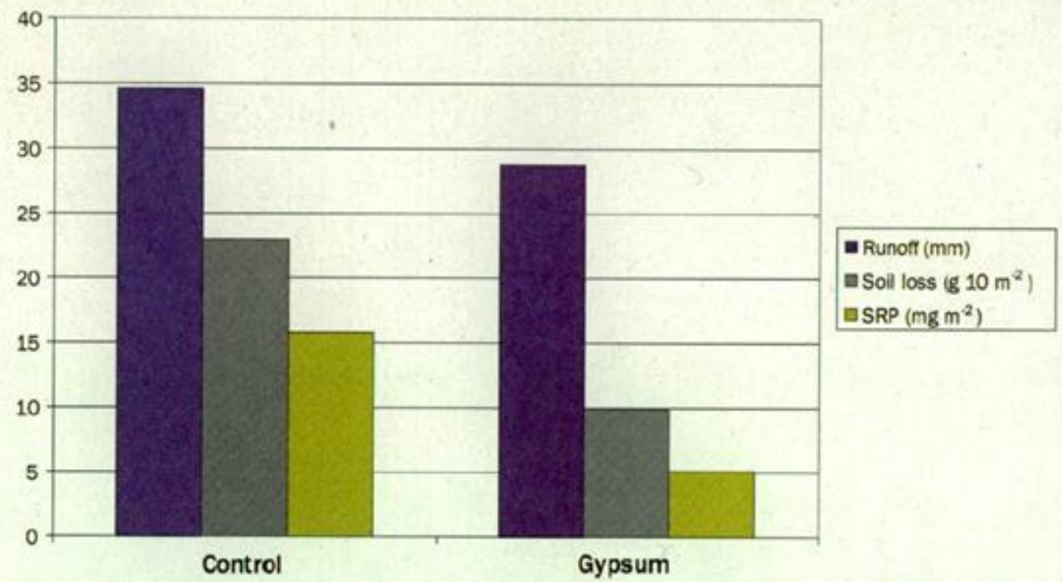


Figure 1

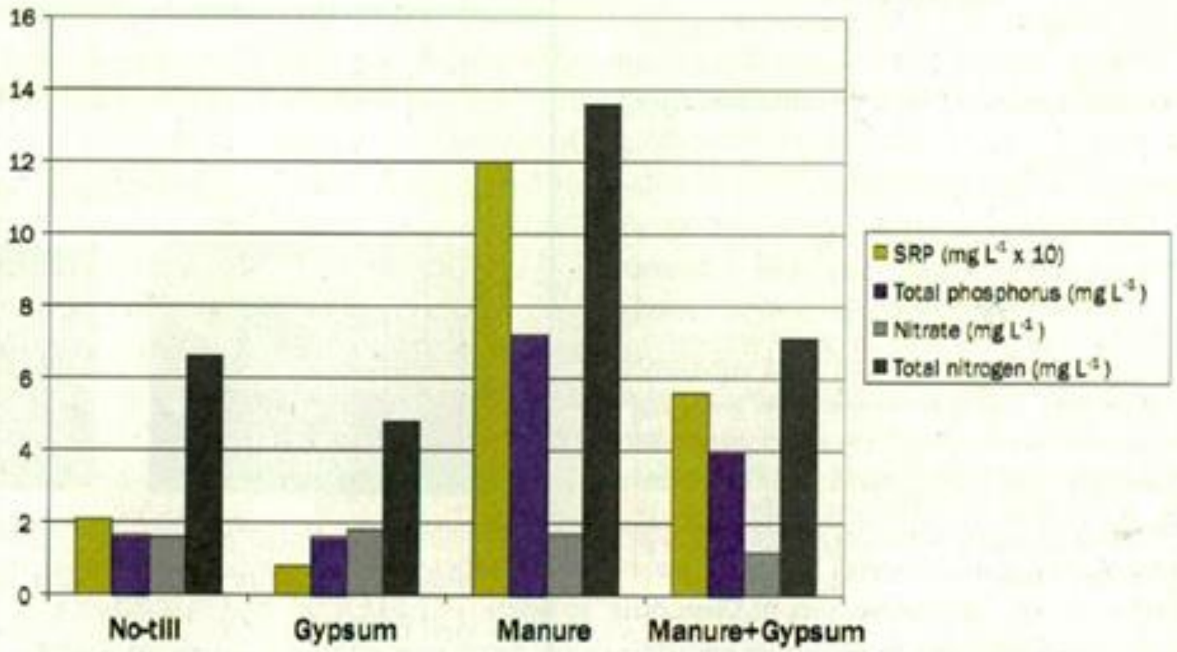
The effect of a surface application of gypsum on runoff amount, soil loss, and soluble reactive phosphorous (SRP) for a four-year rainfall simulation study under both tilled and no-tilled conditions for a Zulch soil near Kurten, Texas (Norton and Mamedov 2006). Gypsum treatment was significantly lower at the $p = 0.05$ level with the t-test.



Norton, 2009

Figure 2

Comparison of gypsum and manure application to no-till agriculture for a rainfall simulator study on a Blount loam soil near Waterloo, Indiana, for amounts of soluble reactive phosphorus (SRP), total phosphorus, nitrate, and total nitrogen in runoff. All are significantly different and the $p = 0.05$ level with Tukey's standardized range test, except nitrate, which was not significantly different in any of the treatments.



Norton, 2009

Conclusions

- Gypsum additions significantly reduced soluble P concentrations in the soil.
- Gypsum addition increased CEC and extractable Ca, S and decreased Fe , AL, and Na in soil
- Gypsum addition increased uptake of Ca and S in plant tissue.
- Gypsum can potentially decrease soil compaction and increase water infiltration

Questions

?