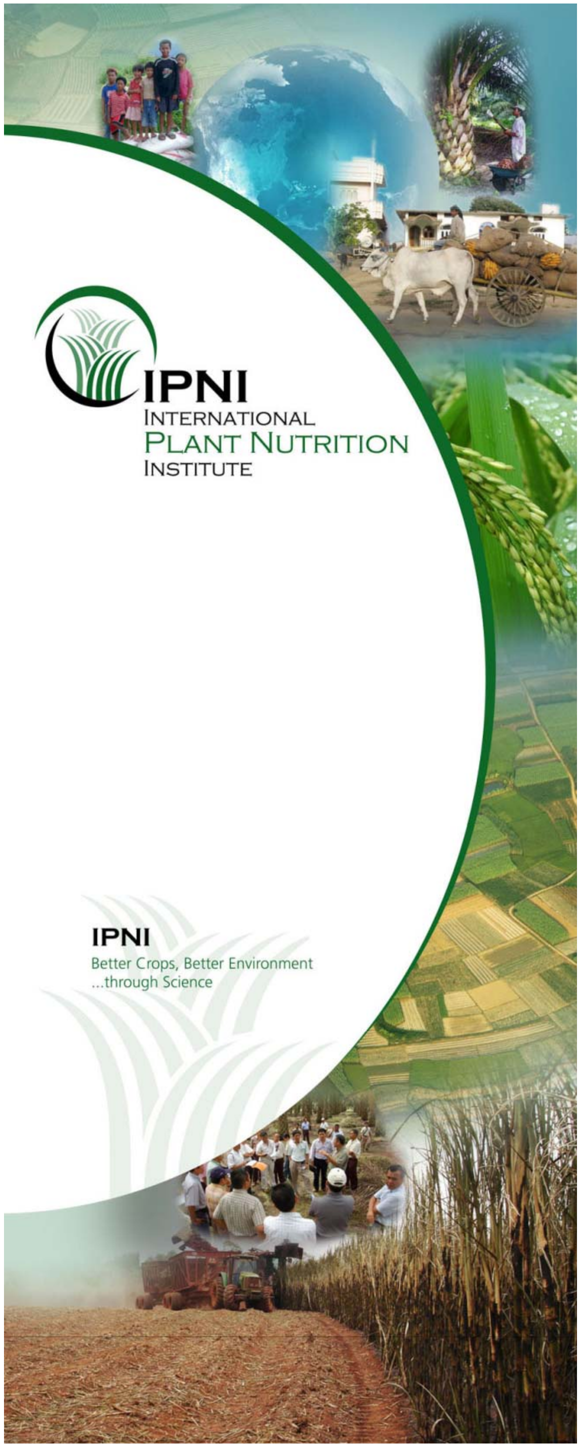
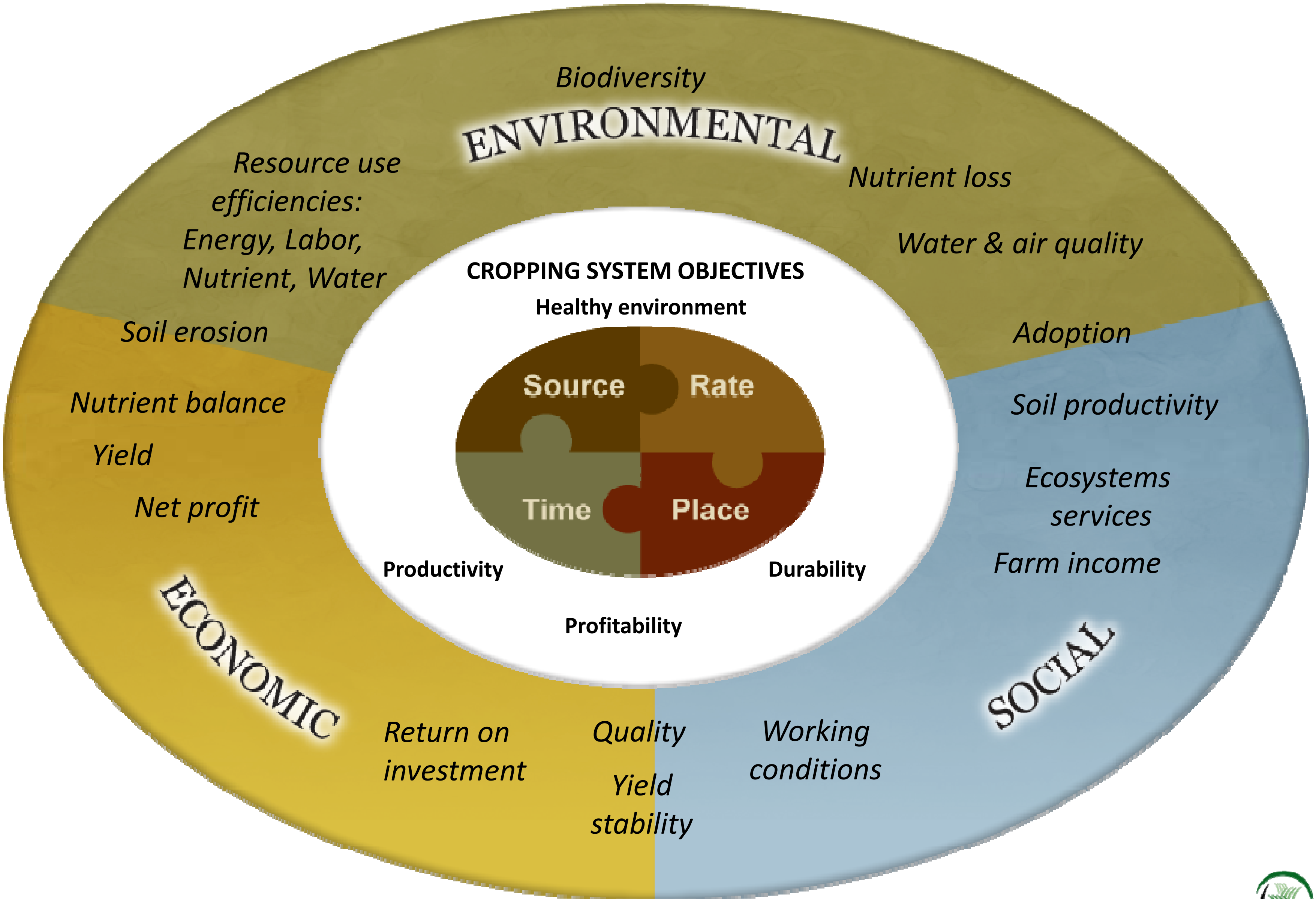
Nutrient Balances in North American Soils

Fertilizer Outlook and Technology Conference
Tampa Marriott Waterside Hotel
October 28, 2009

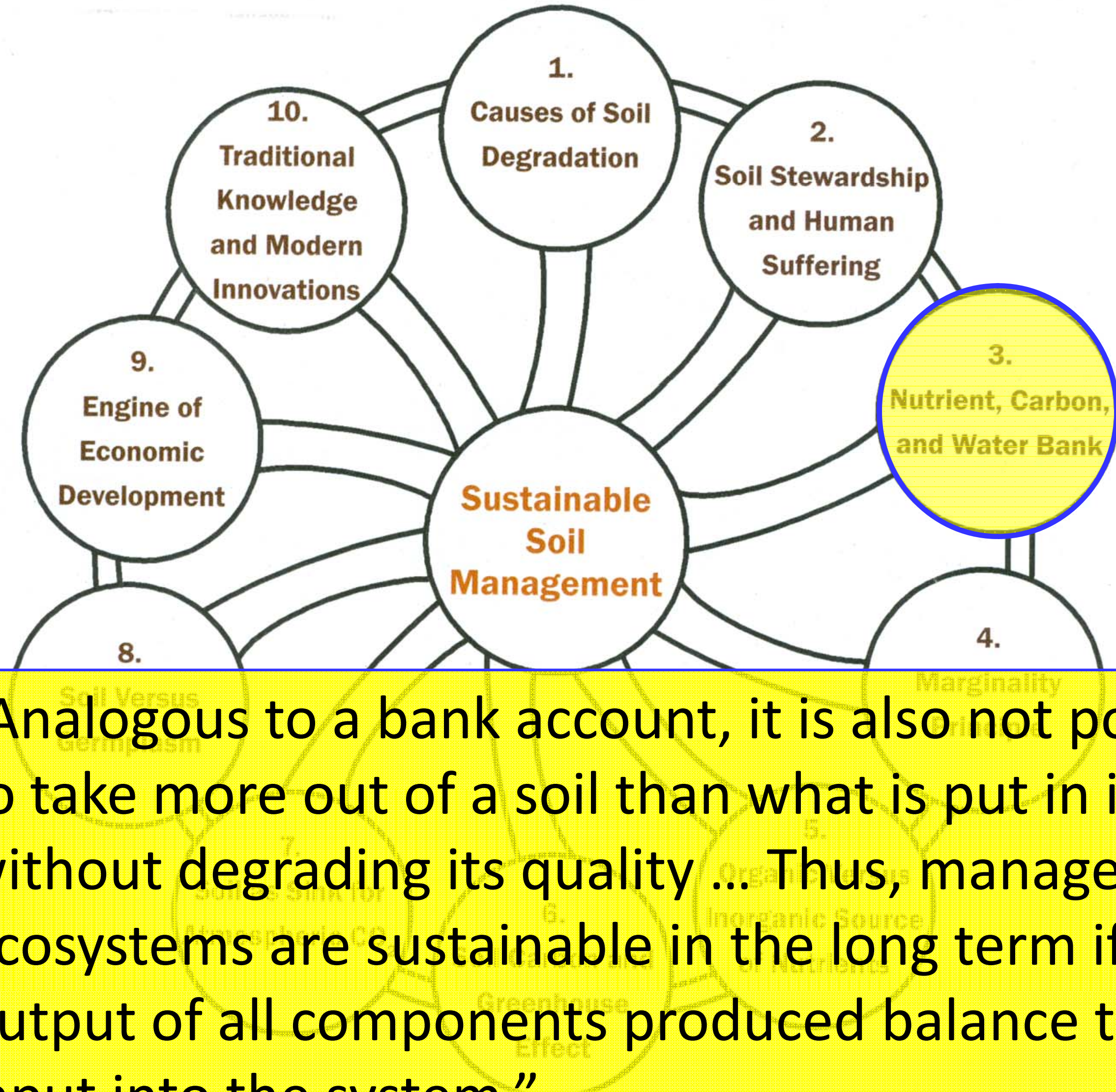
Terry L. Roberts
President, IPNI



Nutrient balance and 4R nutrient stewardship



Ten tenets of sustainable soil management



"Analogous to a bank account, it is also not possible to take more out of a soil than what is put in it without degrading its quality ... Thus, managed ecosystems are sustainable in the long term if the output of all components produced balance the input into the system."

Source: Rattan Lal. J. Soil and Water Conservation 64(1): 20-21A

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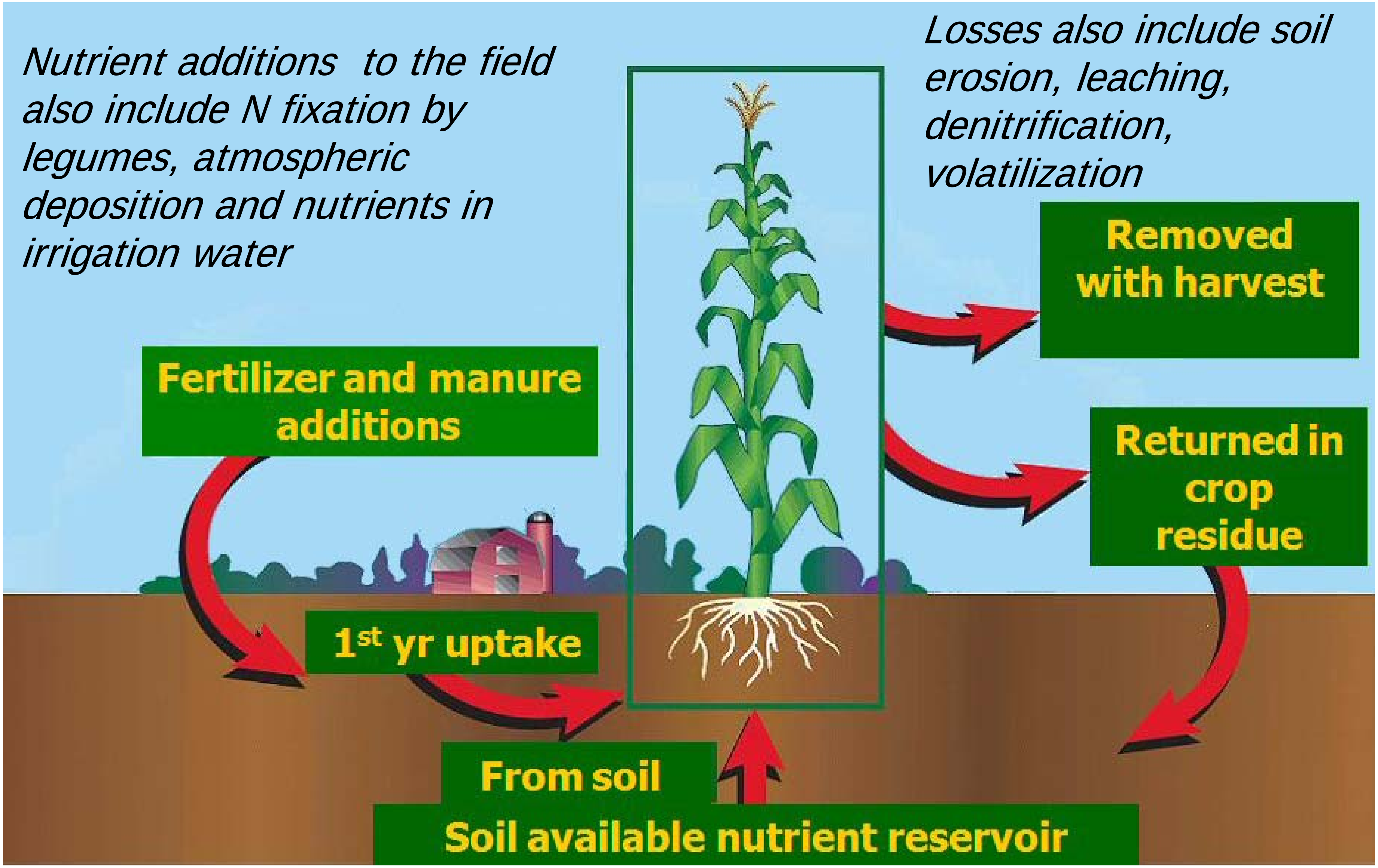
Nutrient Budgets ...

- useful insights into the balance between nutrient inputs and outputs in crop production
- unlike financial budgets … only partial budgets because of inaccuracies in determining inputs/outputs

Partial Nutrient Budget



Nutrient Budgets in North America

By P.E. Fixen and A.M. Johnston

Nutrient budgets are valuable in that they provide insight into the balance between inputs and outputs in crop production. Unlike financial budgets, however, they are only partial budgets because of inaccuracies in determining inputs/outputs. There are many sources of error, including variations in crop removal, estimation of N fixation by legumes, nutrient compositions of various manure sources, etc.

Manufactured mineral fertilizers are the primary nutrient sources (inputs), although significant amounts are provided through N fixation by legumes and the application of manure. In North America, only N fertilizer use increased during the last 20 years of the 20th century, with minor declines in P and K use. The ratio of N to P_2O_5 and K_2O nearly doubled during that time. Also, there was a large increase in the numbers of livestock grown in confined feeding operations, significantly increasing the amounts of recoverable manure nutrients.

Crop nutrient removal (outputs) occurs in the forms of grains, oilseeds, fruits, vegetables, fiber, hay, and forage that are exported from production fields. Other outputs include erosion losses, leaching, denitrification, and volatilization.

Partial N budgets (**Table 1**) show that for North America, the amount of N removed in harvested crops is equivalent to about 77 percent of inputs (fixation, fertilizer, and recoverable manure). Nitrogen recovery in the leading U.S. corn states is about 82 percent, compared to 75 percent for the U.S. as a whole. Recovery in Canada is 94 percent.

> Partial nitrogen (N) budgets for North America show that the amount of N removed in harvested crops is equivalent to 77 percent of major inputs. The partial phosphorus (P) budget for North America shows that P removal exceeds P applied as fertilizer by 29 percent. When recoverable manure is included in the evaluation, removal represents 95 percent of inputs. The partial potassium (K) budget shows that crops currently remove 44 percent more than the amount of K being applied as fertilizer or recoverable manure.

The partial P budget for North America shows that removal exceeds P applied as fertilizer by 29 percent (**Table 2**). When recoverable manure is included in the evaluation, removal represents 95 percent of inputs.

The partial K budget shows that crops in North America currently remove twice the amount of K being applied as fertilizer (**Table 2**). When all recoverable manure is considered, removal still exceeds input by 44 percent. In the leading U.S. corn states, removal of P and K exceeds fertilizer applied plus recoverable manure by approximately 30 percent.

Historical trends in partial P budgets for the U.S. and Canada are shown in **Figures 1** and **2** as the ratio of P removed by common crops to the sum of fertilizer P and recoverable manure P. Over the entire 40-year period in the U.S., P removal has been less than inputs. In fact, in the late 1960s and early 1970s, P removal was only 60 percent of P inputs. This resulted in build up of soil test P in many regions of the U.S., especially the Corn Belt. Since 1970, the removal to use ratio has consistently trended higher

Partial N budgets for North America, billion lb (average of 1998-2000)

	US	Canada	NA
Applied fertilizer	24.7	3.64	28.3
Recoverable manure	2.6	0.28	2.90
N fixation	15.6	1.41	17.0
Crop removal	32.1	5.02	37.1
Balance (inputs-removal)	**10.8**	**0.31**	**11.1**
Removal to use ratio with manure	**0.75**	**0.94**	**0.77**
Removal to use ratio without manure	**0.80**	**0.99**	**0.82**

Crop removal =N removed in harvested portion of alfalfa, soybeans, peanuts, 49% of lentils, and 54% of dry peas; It was assumed that any fixed N not recovered in the harvested crop was countered by soil N taken up during the growing season.

Source: Plant Nutrient Use in North American Agriculture, PPI/PPIC/FAR Technical Bulletin 2002-1

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Partial P_2O_5 budgets for North America, billion lb (average of 1998-2000)

	US	Canada	N.A.
Applied fertilizer	8.8	1.51	10.3
Recoverable manure	3.3	0.4	3.7
Crop removal	11.4	1.87	13.3
Balance (inputs-removal)	**0.7**	**0.04**	**0.7**
Removal to use ratio with manure	**0.95**	**0.98**	**0.95**
Removal to use ratio without manure	**1.3**	**1.24**	**1.29**

Source: Plant Nutrient Use in North American Agriculture, PPI/PPIC/FAR Technical Bulletin 2002-1

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Partial K_2O budgets for North America, billion lb (average of 1998-2000)

	US	Canada	N.A.
Applied fertilizer	10.1	0.78	10.9
Recoverable manure	3.8	0.5	4.3
Crop removal	19.3	2.64	21.9
Balance (inputs-removal)	**-5.4**	**-1.36**	**-6.7**
Removal to use ratio with manure	**1.39**	**2.06**	**1.44**
Removal to use ratio without manure	**1.91**	**3.40**	**2.02**

Source: Plant Nutrient Use in North American Agriculture, PPI/PPIC/FAR Technical Bulletin 2002-1

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Partial budgets for six leading corn states, billion lb (average of 1998-2000)

	N	P_2O_5	K_2O
Applied fertilizer	8.8	3.0	4.1
Recoverable manure	0.5	0.9	1.0
N Fixation	8.4	—	—
Crop removal	14.5	5.1	6.6
Balance (inputs-removal)	**3.3**	**-1.3**	**-1.5**
Removal to use ratio with manure	**0.82**	**1.33**	**1.30**
Removal to use ratio without manure	**0.84**	**1.71**	**1.62**

Source: Plant Nutrient Use in North American Agriculture, PPI/PPIC/FAR Technical Bulletin 2002-1

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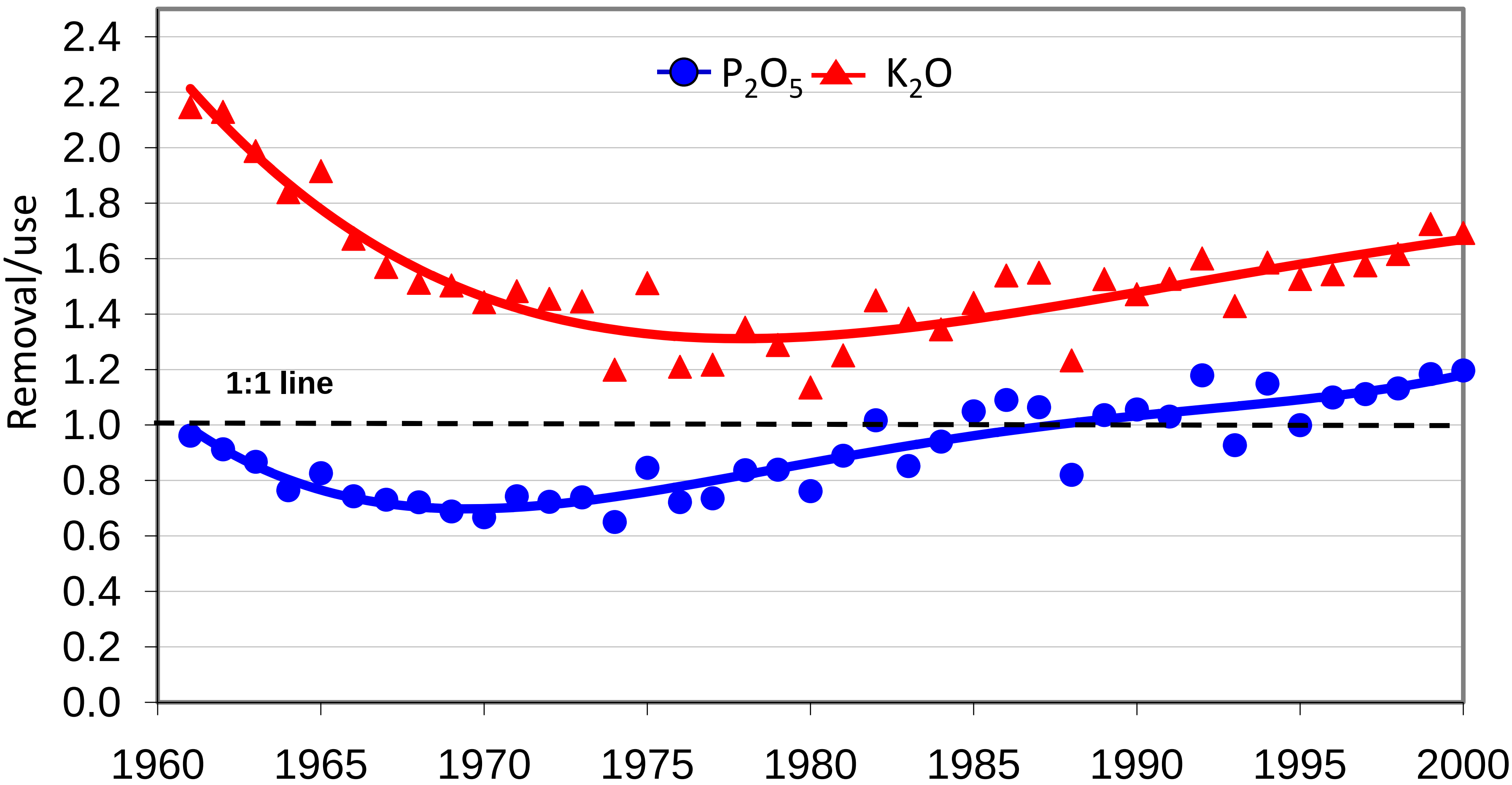
Ratio of P and K removal to fertilizer use plus manure nutrients applied to corn, soybeans, wheat, and cotton in the U.S.



Source: Plant Nutrient Use in North American Agriculture, PPI/PPIC/FAR Technical Bulletin 2002-1

NuGIS

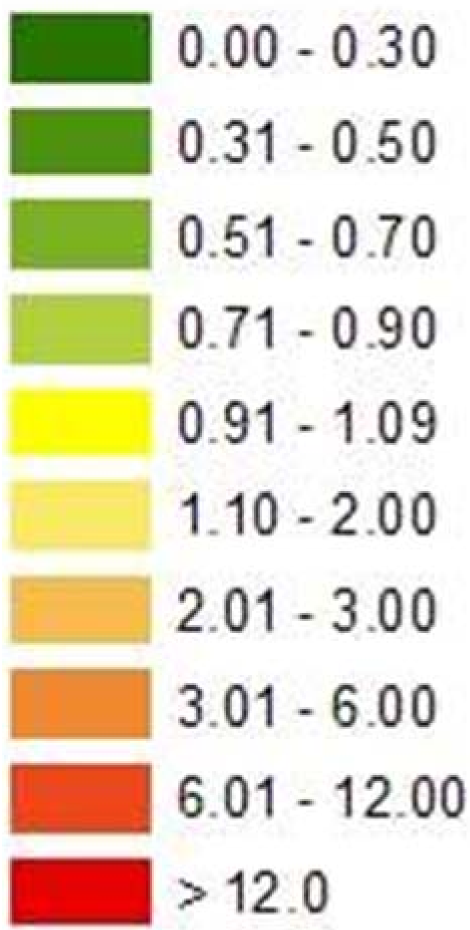
Nutrient Use Geographic Information System

- Project is about mapping and spatial analysis of nutrient use data.
  - Initially sponsored by the PPI/TFI Nutrient Use Task Force then continued by IPNI
- Phase I: discovery of data sets and sample analysis
- Phase II: focused on national net nutrient budgets at the county and watershed levels.
  - national maps of commercial fertilizer, manure and nutrient removal from major crops for the years of the Ag Census 1987, 1992, 1997, 2002, and 2007.

Legend for maps to follow

Ratio of nutrient removed by crops to fertilizer nutrient applied plus nutrients in recoverable manure.

Removal/Use Ratio



Crop removal is less than fertilizer use … building soil fertility

Balanced budget (removal = use)

Crop removal is greater than fertilizer use … depleting soil fertility

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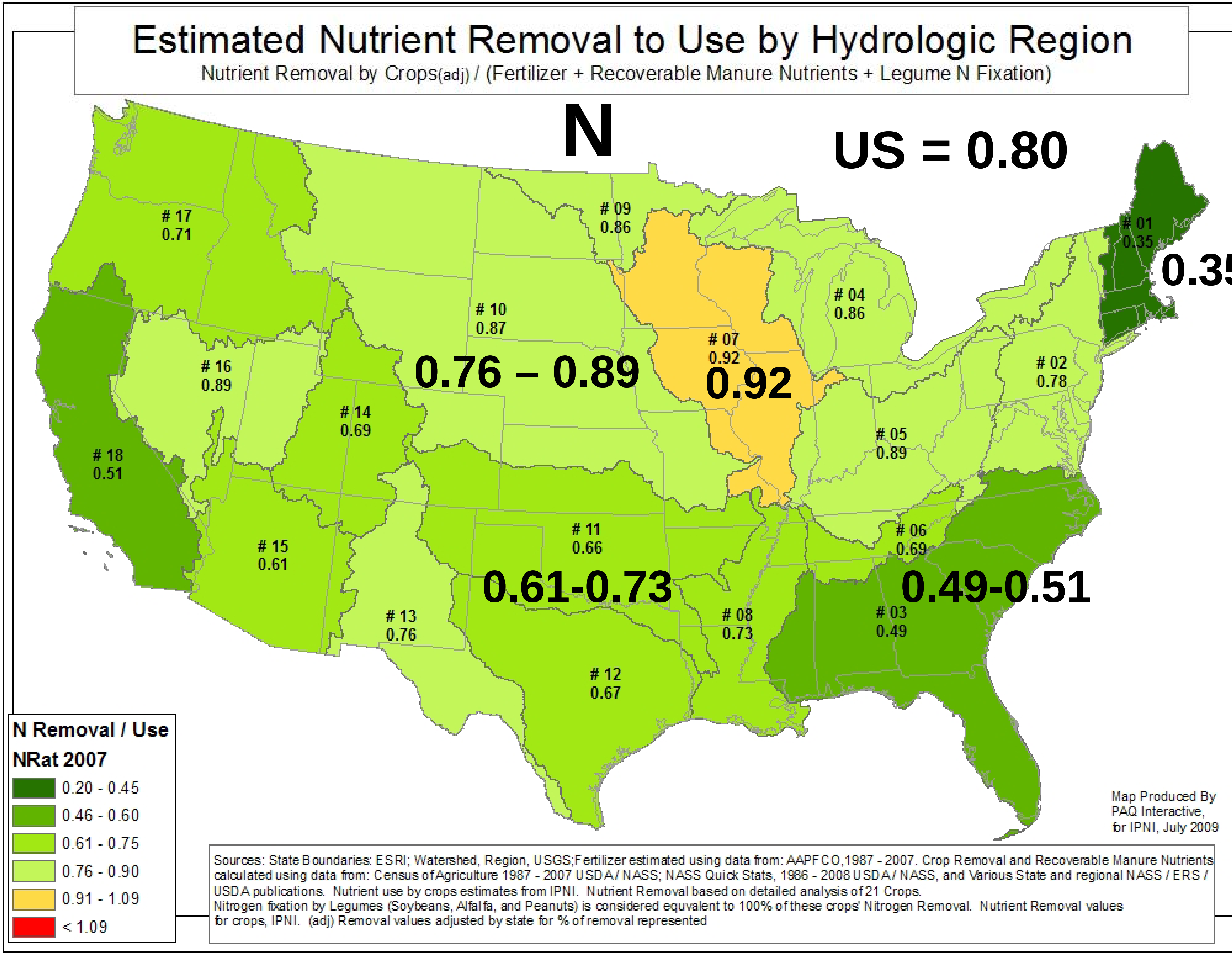
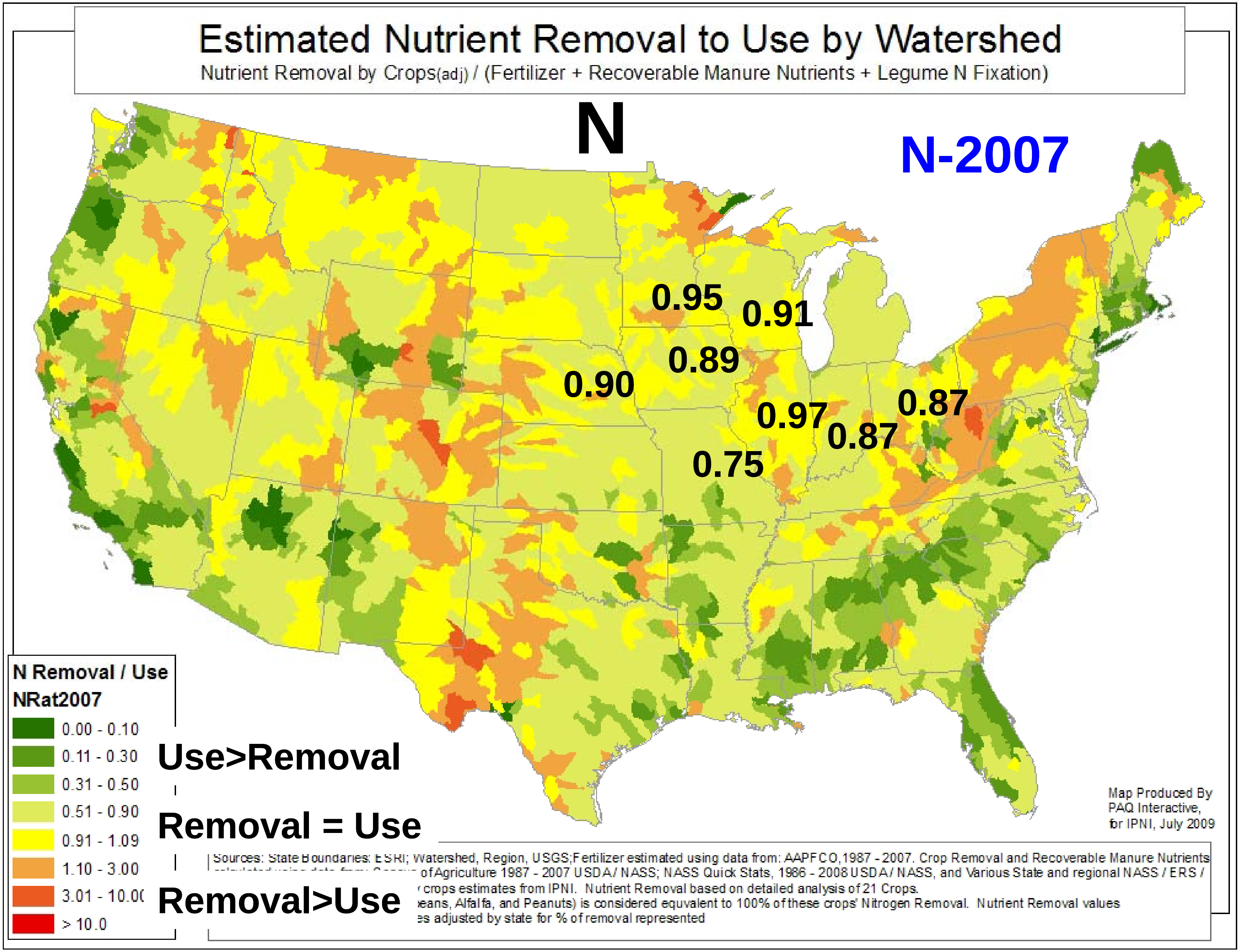


Estimated Nutrient Removal to Use by Hydrologic Region
Nutrient Removal by Crops(adj) / (Fertilizer + Recoverable Manure Nutrients + Legume N Fixation)
N
US = 0.80
# 17
0.71
09
0.86
01
0.35
0.35
10
0.87
04
0.86
16
0.89
07
0.92
02
0.78
0.76 – 0.89
0.92
14
0.69
05
0.89
18
0.51
11
0.66
06
0.69
15
0.61
0.61-0.73
0.49-0.51
13
0.76
08
0.73
03
0.49
12
0.67
N Removal / Use
NRat 2007
0.20 - 0.45
0.46 - 0.60
0.61 - 0.75
0.76 - 0.90
0.91 - 1.09
< 1.09
Map Produced By
PAQ Interactive,
for IPNI, July 2009
Sources: State Boundaries: ESRI; Watershed, Region, USGS;Fertilizer estimated using data from: AAPFCO,1987 - 2007. Crop Removal and Recoverable Manure Nutrients calculated using data from: Census of Agriculture 1987 - 2007 USDA / NASS; NASS Quick Stats, 1986 - 2008 USDA / NASS, and Various State and regional NASS / ERS / USDA publications. Nutrient use by crops estimates from IPNI. Nutrient Removal based on detailed analysis of 21 Crops.
Nitrogen fixation by Legumes (Soybeans, Alfalfa, and Peanuts) is considered equvalent to 100% of these crops' Nitrogen Removal. Nutrient Removal values for crops, IPNI. (adj) Removal values adjusted by state for % of removal represented

NI



Estimated Nutrient Removal to Use by Watershed
Nutrient Removal by Crops(adj) / (Fertilizer + Recoverable Manure Nutrients + Legume N Fixation)
N
N-2007
0.95
0.91
0.89
0.90
0.97
0.87
0.87
0.75
N Removal / Use
NRat2007
0.00 - 0.10
0.11 - 0.30
0.31 - 0.50
0.51 - 0.90
0.91 - 1.09
1.10 - 3.00
3.01 - 10.00
> 10.0
Use>Removal
Removal = Use
Removal>Use
Map Produced By
PAQ Interactive,
for IPNI, July 2009
Sources: State Boundaries: ESRI; Watershed, Region, USGS;Fertilizer estimated using data from: AAPFCO,1987 - 2007. Crop Removal and Recoverable Manure Nutrients
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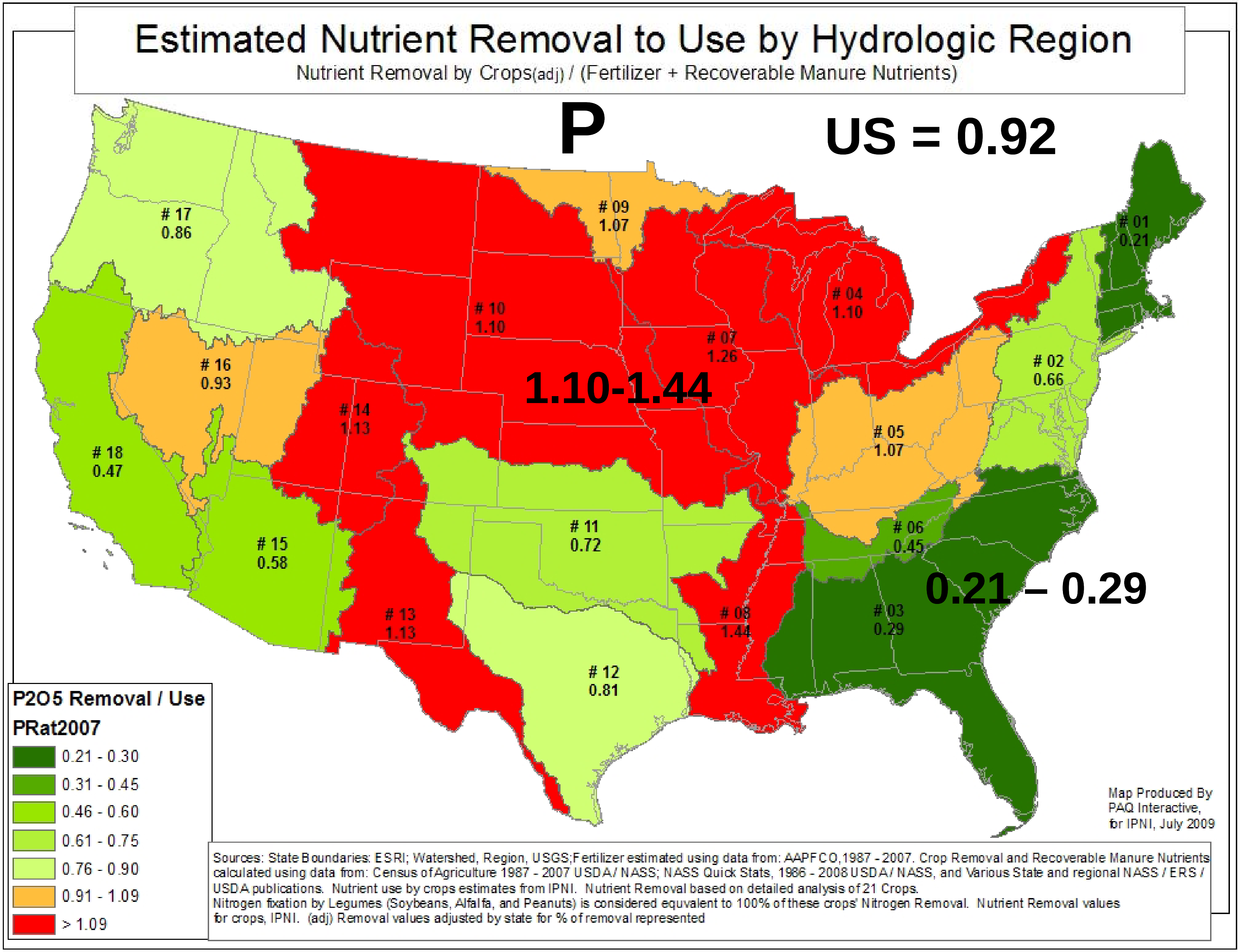
NI



Estimated Nutrient Removal to Use by Hydrologic Region
Nutrient Removal by Crops(adj) / (Fertilizer + Recoverable Manure Nutrients)
P
US = 0.92
# 17
0.86
09
1.07
01
0.21
10
1.10
04
1.10
07
1.26
16
0.93
02
0.66
1.10-1.44
14
1.13
05
1.07
18
0.47
11
0.72
06
0.45
15
0.58
0.21 – 0.29
13
1.13
08
1.44
03
0.29
12
0.81
P2O5 Removal / Use
PRat2007
0.21 - 0.30
0.31 - 0.45
0.46 - 0.60
0.61 - 0.75
0.76 - 0.90
0.91 - 1.09
> 1.09
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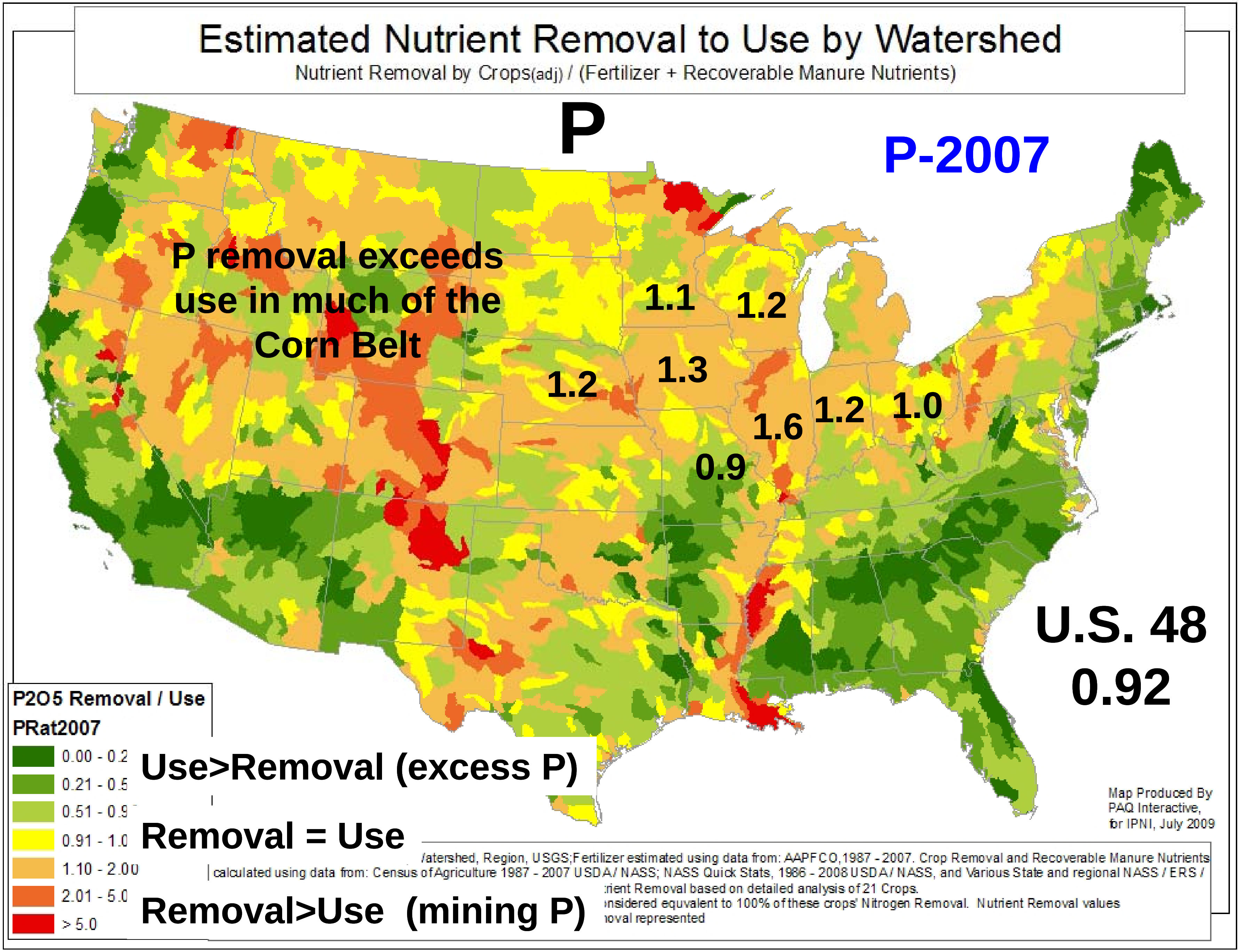

Estimated Nutrient Removal to Use by Watershed
Nutrient Removal by Crops(adj) / (Fertilizer + Recoverable Manure Nutrients)
P
P-2007
P removal exceeds use in much of the Corn Belt
1.1
1.2
1.3
1.2
1.6
1.2
1.0
0.9
U.S. 48
0.92
P2O5 Removal / Use
PRat2007
0.00 - 0.2
0.21 - 0.5
0.51 - 0.9
0.91 - 1.0
1.10 - 2.00
2.01 - 5.0
> 5.0
Use>Removal (excess P)
Removal = Use
Removal>Use (mining P)
Map Produced By
PAQ Interactive,
for IPNI, July 2009
/atershed, Region, USGS;Fertilizer estimated using data from: AAPFCO,1987 - 2007. Crop Removal and Recoverable Manure Nutrients
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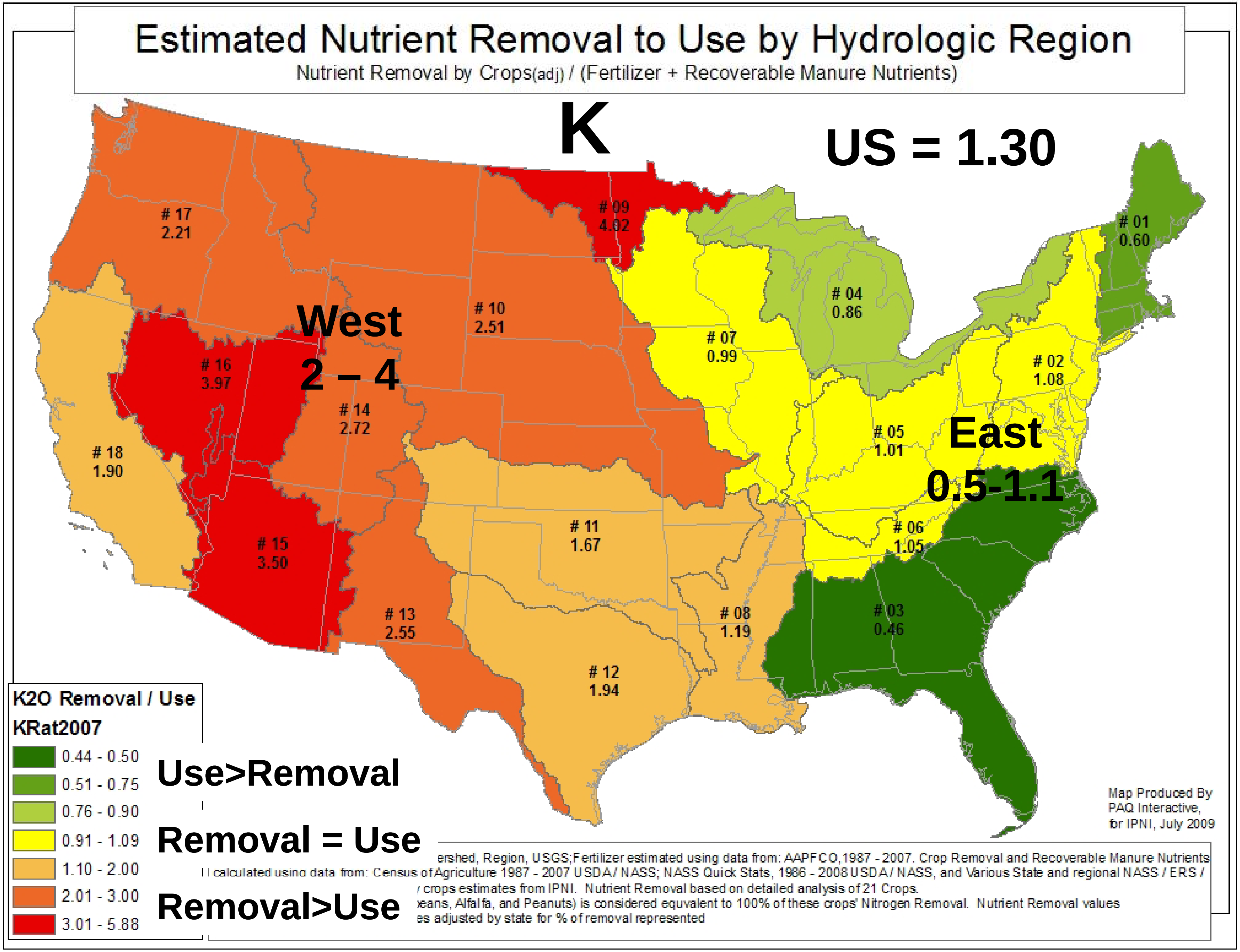
ıoval represented



Estimated Nutrient Removal to Use by Hydrologic Region
Nutrient Removal by Crops(adj) / (Fertilizer + Recoverable Manure Nutrients)
K
US = 1.30
West
2 – 4
East
0.5-1.1
17
2.21
09
4.02
01
0.60
04
0.86
10
2.51
07
0.99
16
3.97
02
1.08
14
2.72
05
1.01
18
1.90
11
1.67
06
1.05
15
3.50
13
2.55
08
1.19
03
0.46
12
1.94
K2O Removal / Use
KRat2007
0.44 - 0.50
0.51 - 0.75
0.76 - 0.90
0.91 - 1.09
1.10 - 2.00
2.01 - 3.00
3.01 - 5.88
Use>Removal
Removal = Use
Removal>Use
Map Produced By
PAQ Interactive,
for IPNI, July 2009
ershed, Region, USGS;Fertilizer estimated using data from: AAPFCO,1987 - 2007. Crop Removal and Recoverable Manure Nutrients
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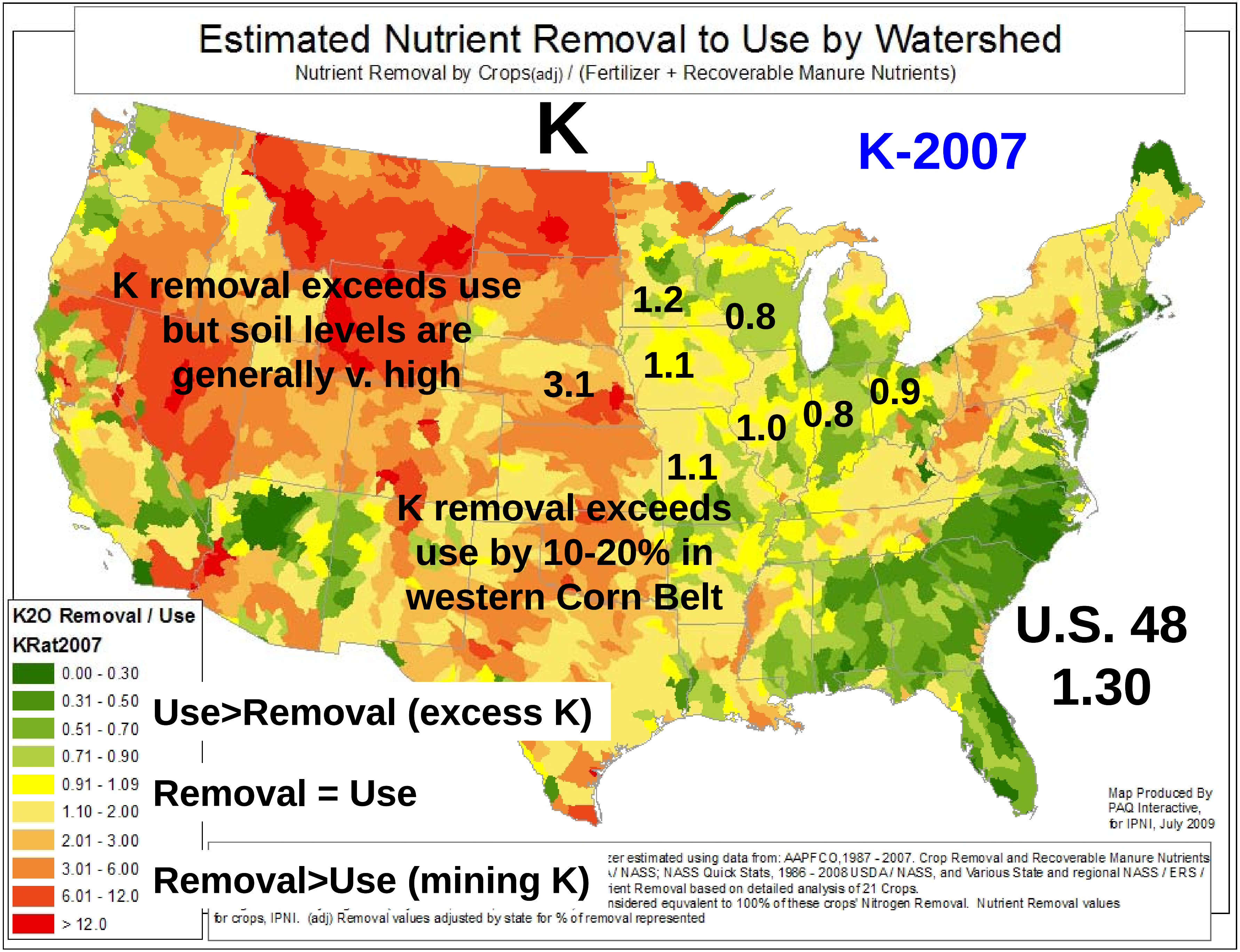

Estimated Nutrient Removal to Use by Watershed
Nutrient Removal by Crops(adj) / (Fertilizer + Recoverable Manure Nutrients)
K
K-2007
K removal exceeds use but soil levels are generally v. high
3.1
1.2
0.8
1.1
1.0
0.8
0.9
1.1
K removal exceeds use by 10-20% in western Corn Belt
U.S. 48
1.30
K2O Removal / Use
KRat2007
0.00 - 0.30
0.31 - 0.50
0.51 - 0.70
0.71 - 0.90
0.91 - 1.09
1.10 - 2.00
2.01 - 3.00
3.01 - 6.00
6.01 - 12.0
> 12.0
Use>Removal (excess K)
Removal = Use
Removal>Use (mining K)
Map Produced By
PAQ Interactive,
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\/ NASS; NASS Quick Stats, 1986 - 2008 USDA / NASS, and Various State and regional NASS / ERS /
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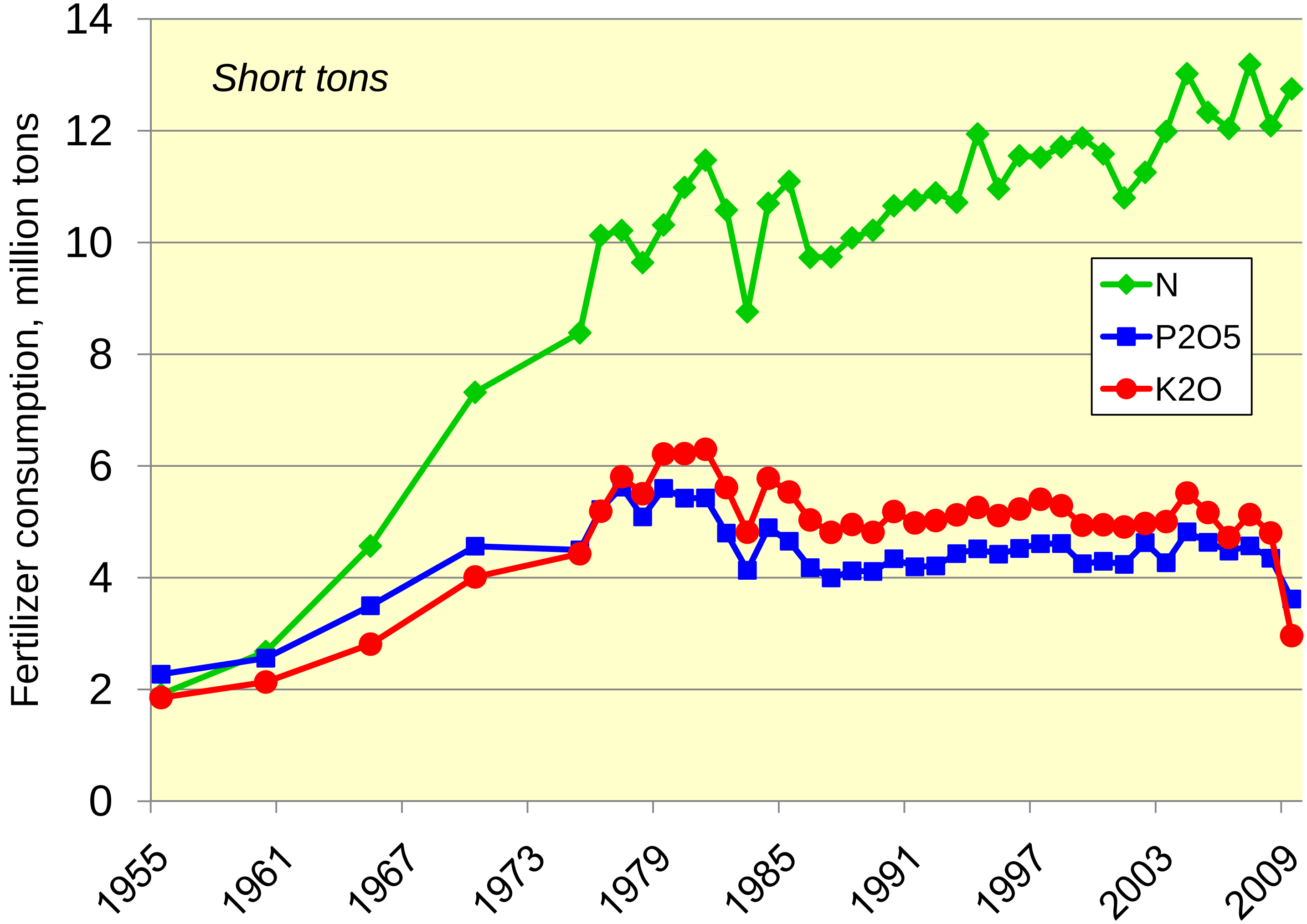
Fertilizer consumption in the U.S., 1955-2009

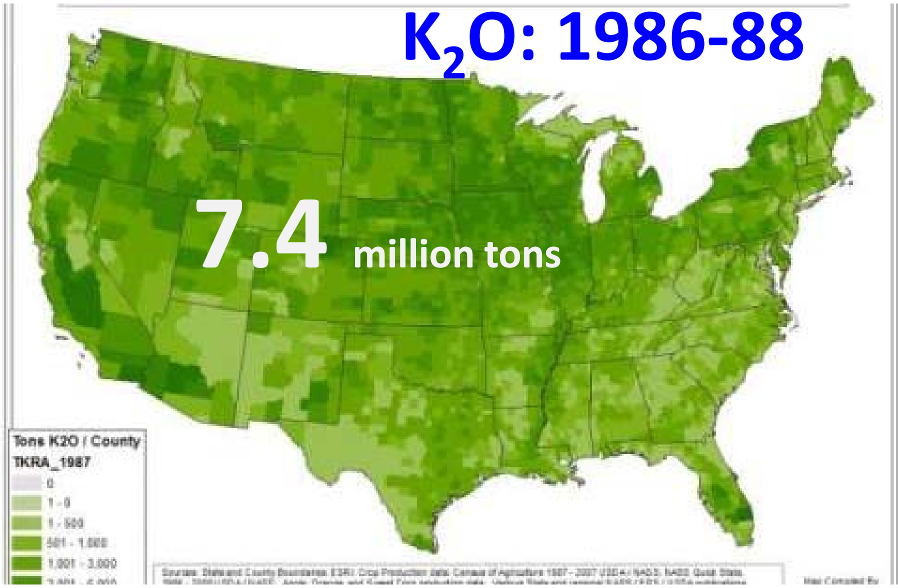


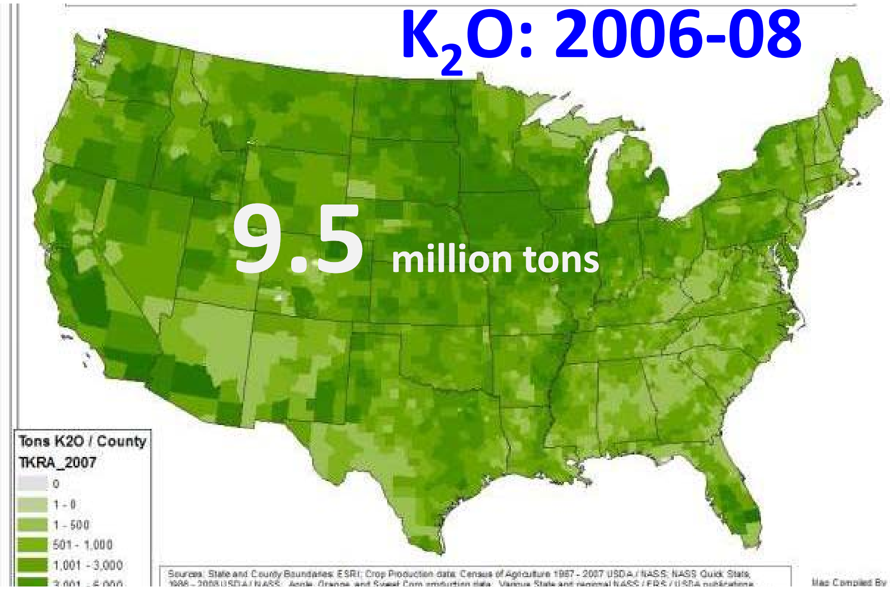
Data Source: AAPFCO (2008) and H. Vroomen, TFI (est. 2008-09)

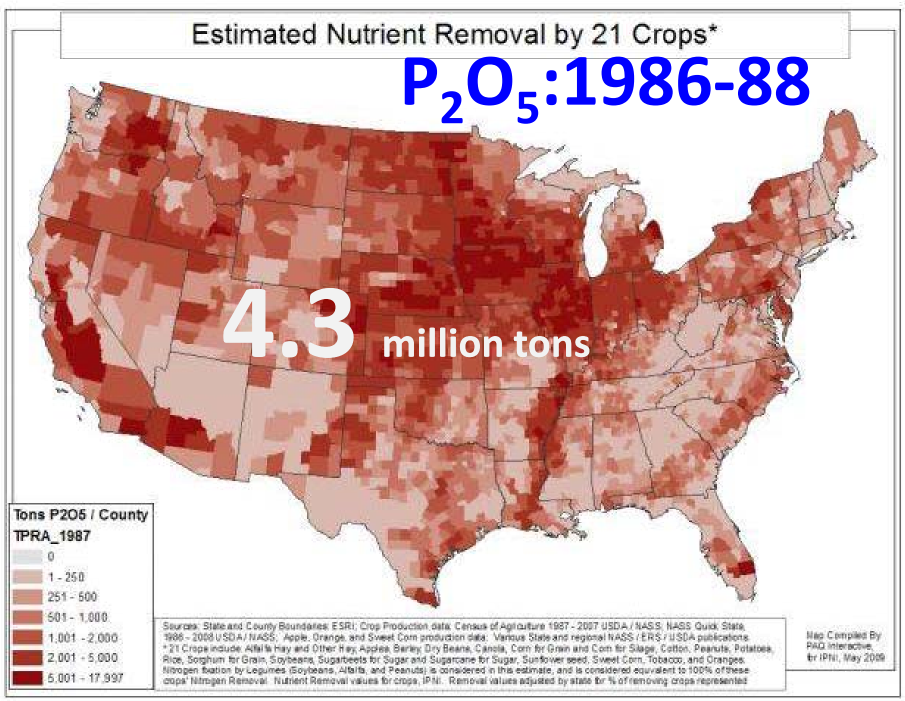
A closer look at where we were in North America before use reductions (using NASS, AAPFCO, and the Ag Census data)

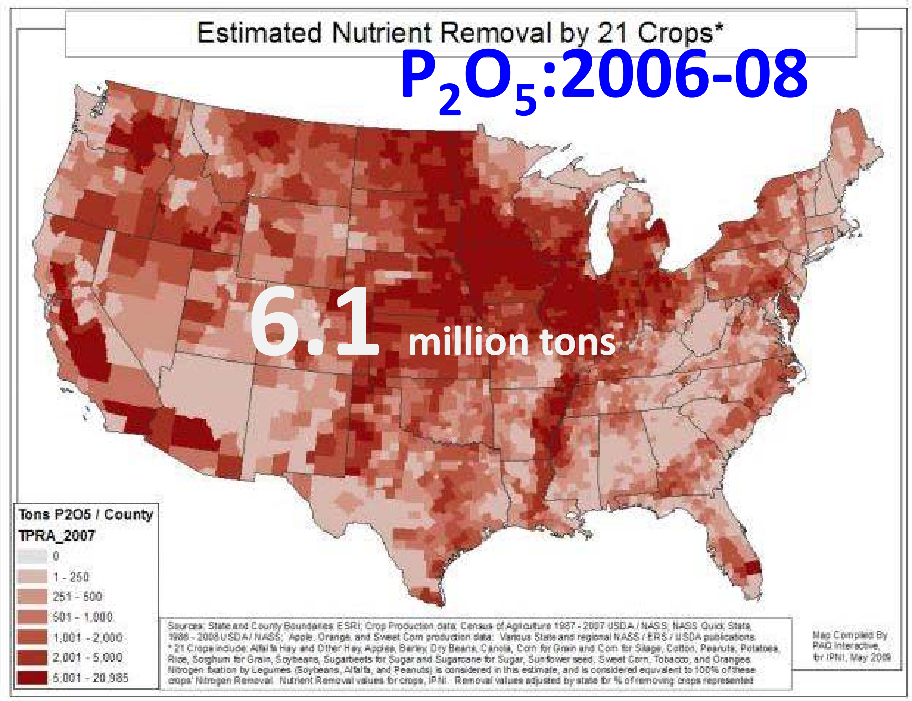
- Soils do not create P or K nutrients
- They have an indigenous amount and store what is added to them
- In a sustainable agriculture, the P and K removed by crops must eventually be replaced

Change in annual crop removal over 20 yrs, short tons



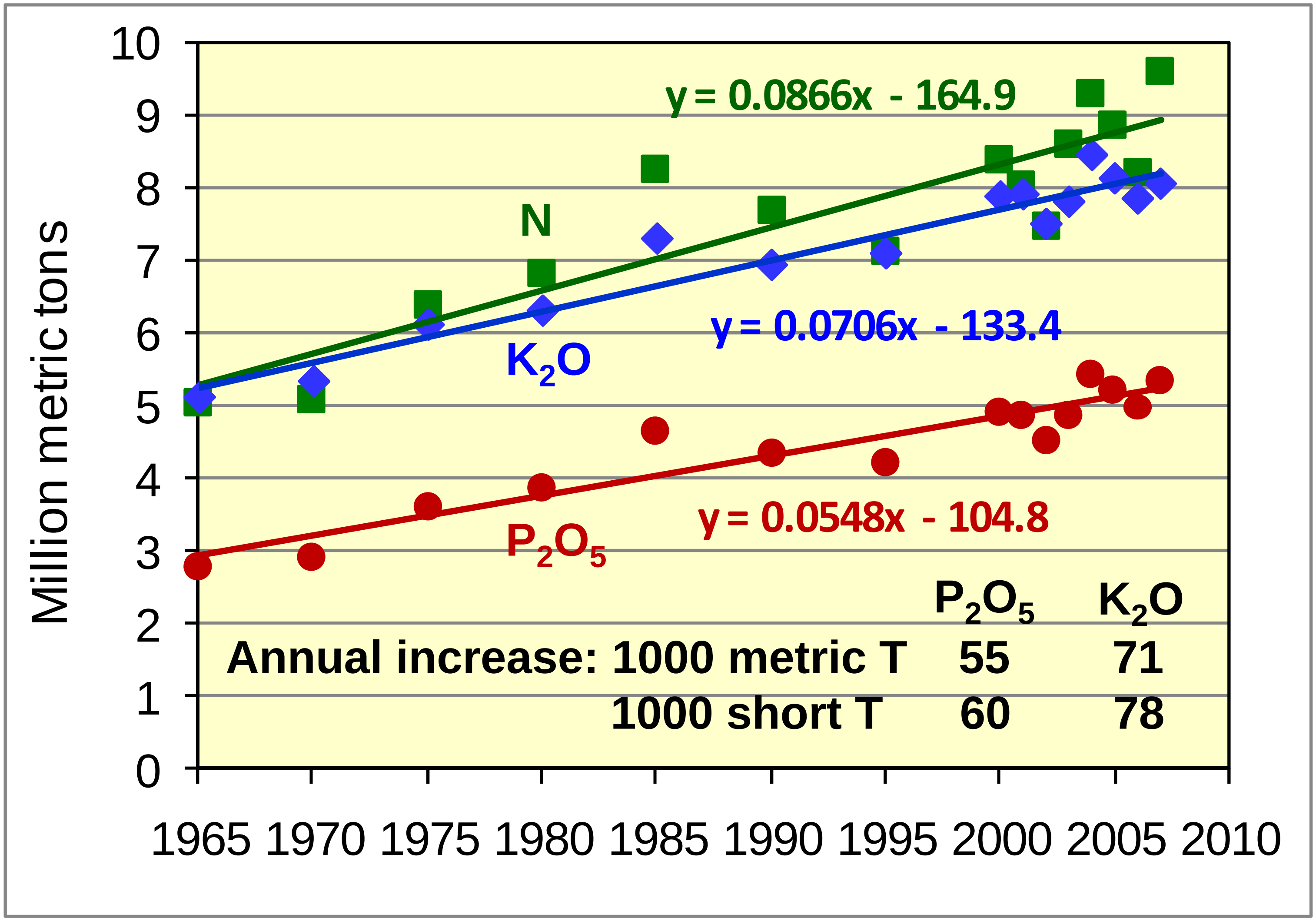






Nutrient removal by crops in the U.S.

(N removal by alfalfa, soybeans and peanuts excluded)



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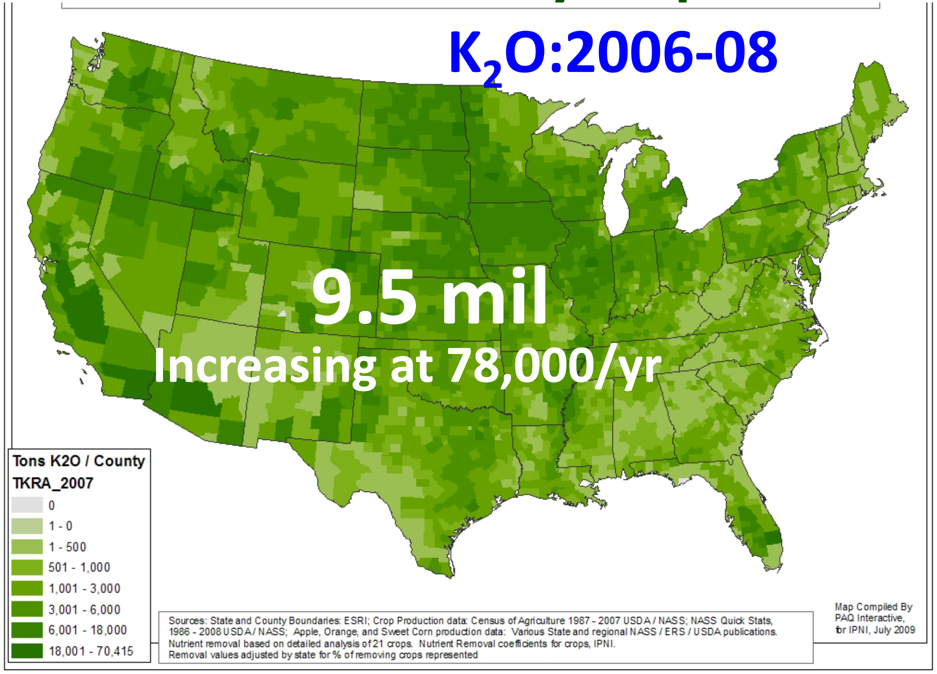
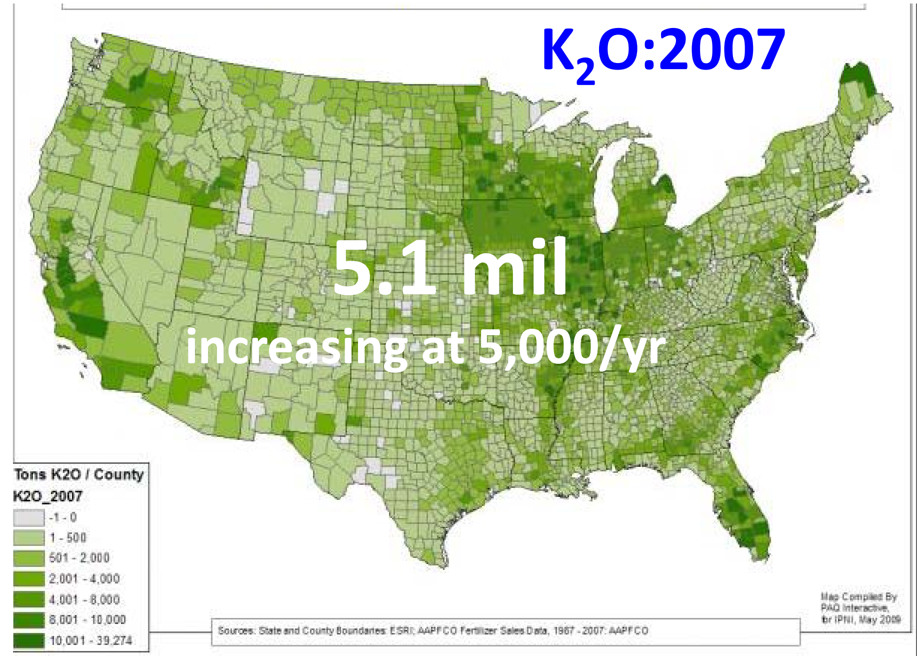
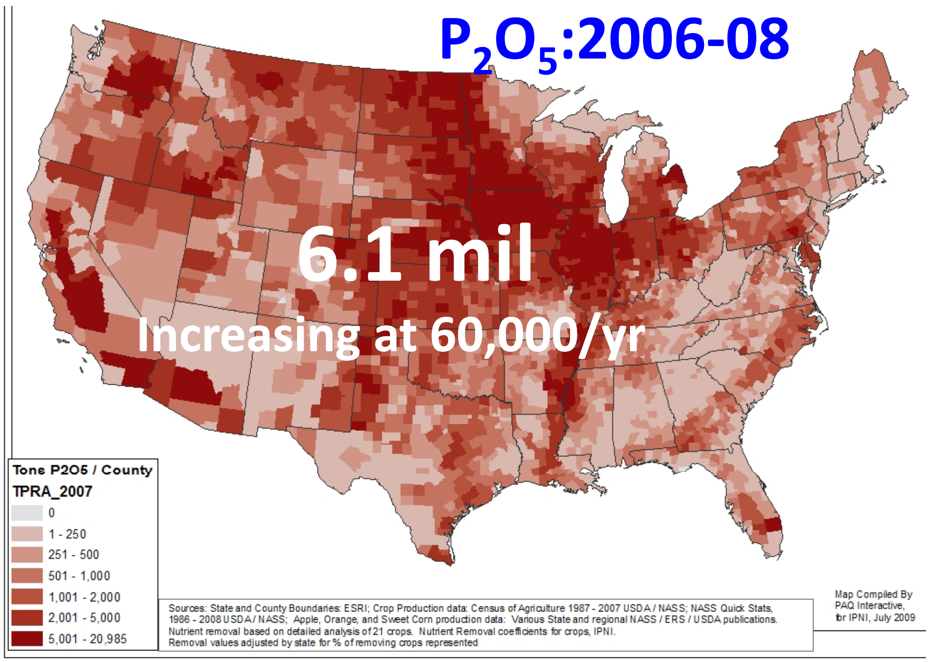
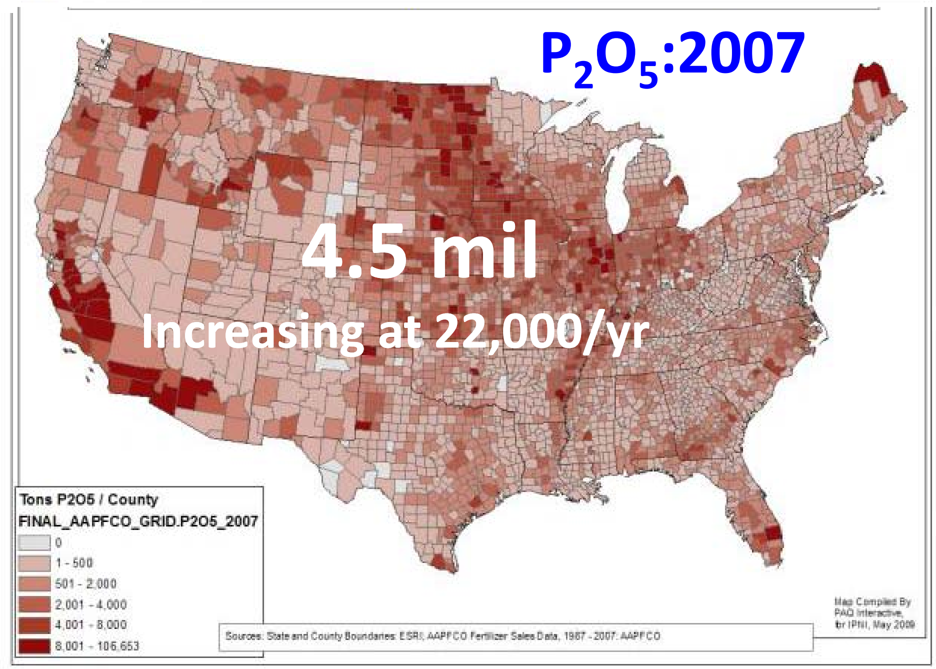
Nutrient removal by crops *(short tons)* Fertilizer nutrient sales



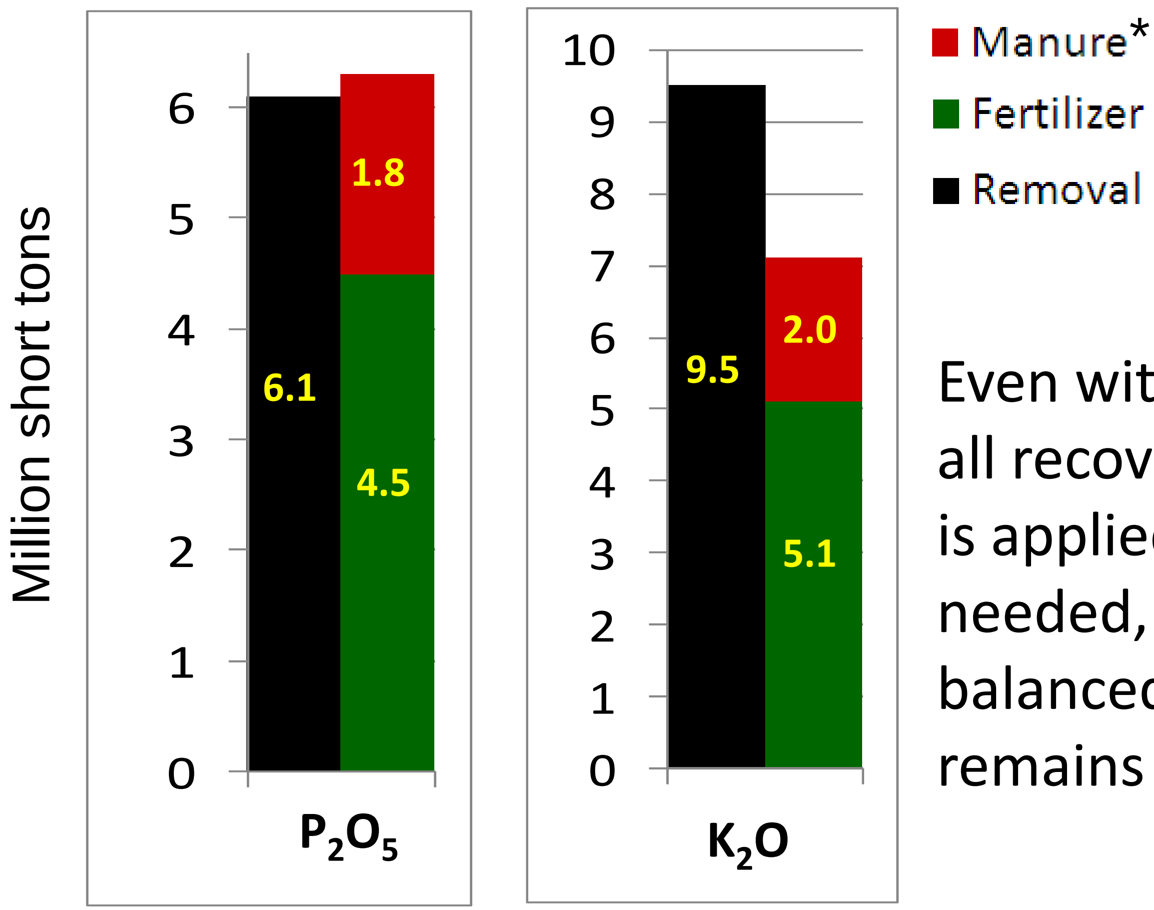






Comparison of nutrient removal by crops in the U.S. to nutrient applied as fertilizer and in recoverable manure

(removal is average of 2006-2008; fertilizer use is from 2007)



Even with the assumption that all recoverable manure P and K is applied where it is needed, the P budget is barely balanced and the K budget remains extremely negative.

* *Based on 2007 livestock census using Kellogg et al.(2000) procedure.*

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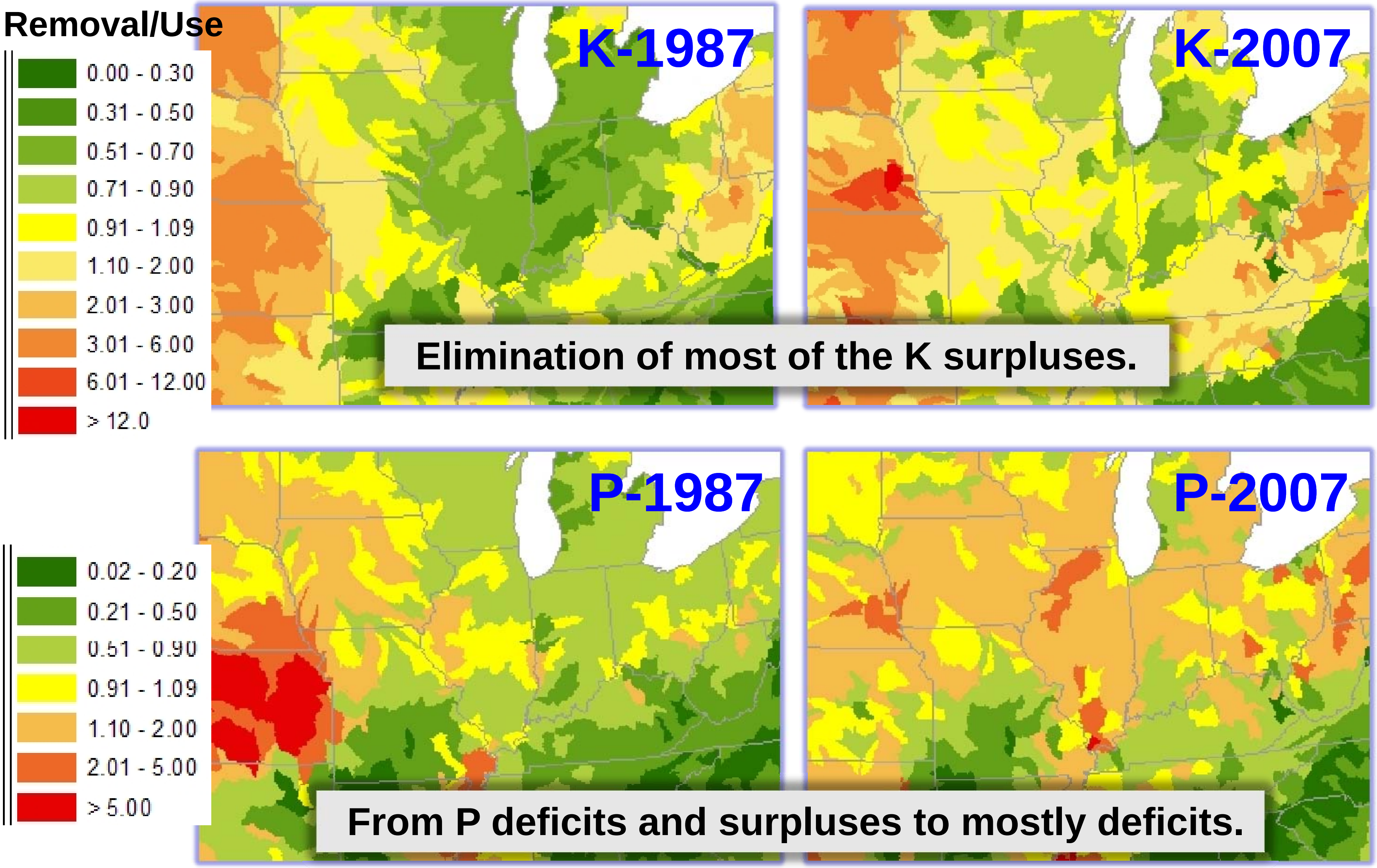
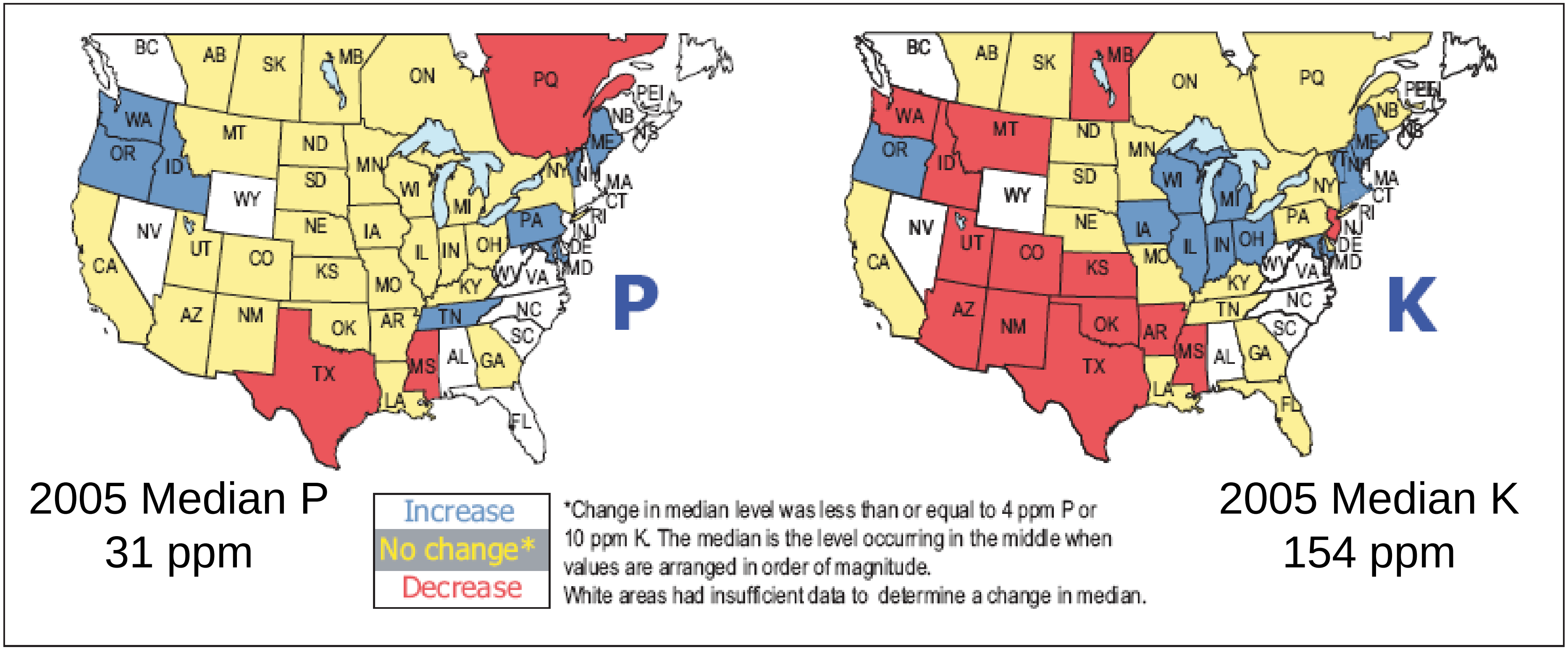
Changes in Corn Belt P and K Budgets



Green = excess nutrients Red = depleting nutrients

Changes in state or province soil fertility levels from 2001 to 2005



- Corn Belt changes from 2005 to 2010?
  - Indications are that soil levels will be lower
  - More fields will require annual P and K fertilization
  - P and K agronomic demand should increase

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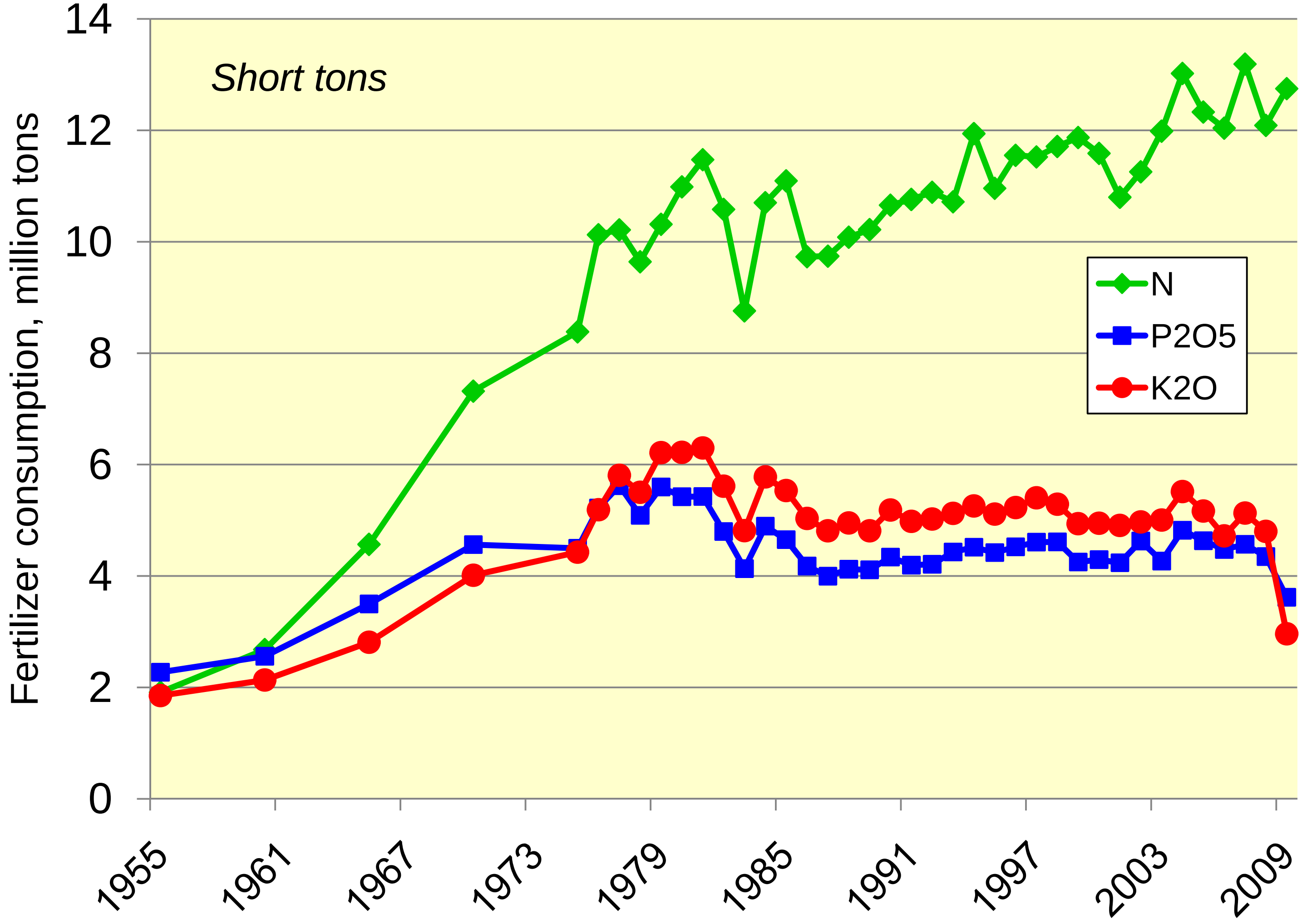
Fertilizer consumption in the U.S., 1955-2009



Data Source: AAPFCO (2008) and H. Vroomen, TFI (est. 2008-09)

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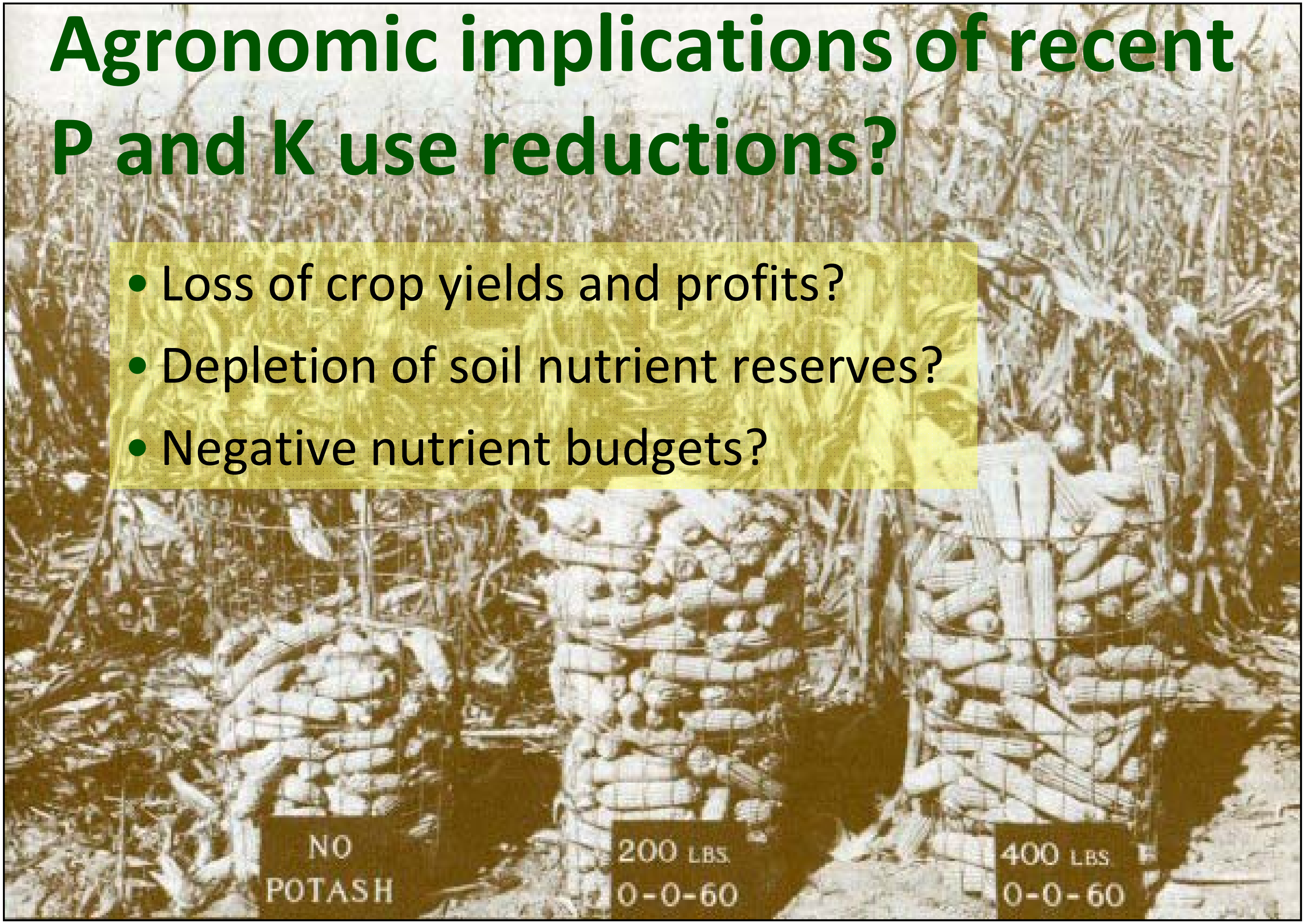
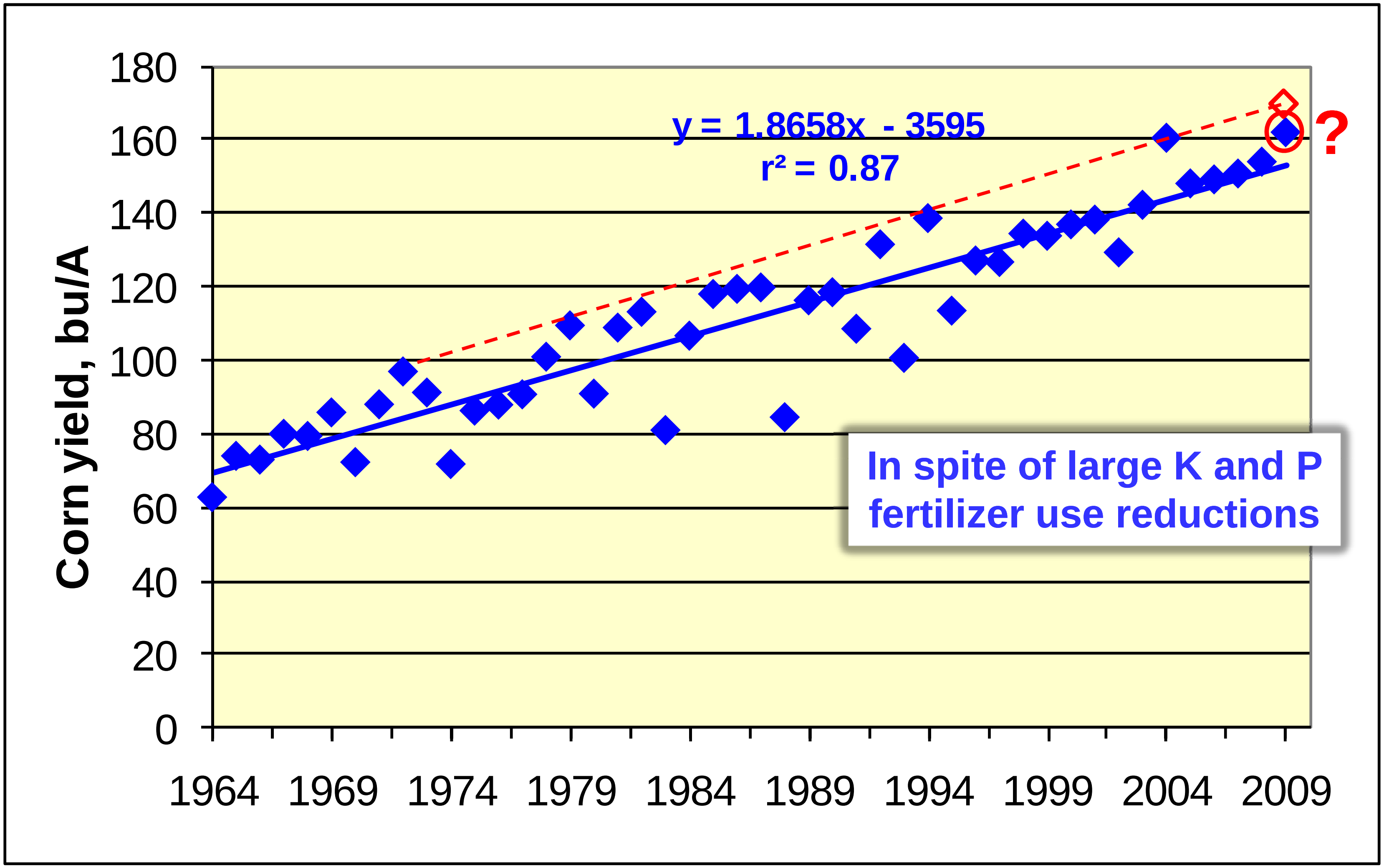
Agronomic implications of recent P and K use reductions?

- Loss of crop yields and profits?
- Depletion of soil nutrient reserves?
- Negative nutrient budgets?



2009 US Corn Yield Forecast at 161.9 bu/A
… a New Record



USDA-NASS, 8/2009.

Lots of calibration data in North America

Table 1. Soil test phosphorus calibration examples (Bray P1 except where noted).

Soil test level (ppm)	Average Relative Yield (%) maize Iowa	maize Missouri	maize Illinois	maize Ontario*	soybean Illinois	soybean Ontario*	Spring wheat S. Dakota	Spring wheat N. Great Plains*	Winter wheat Kansas (Bray)	Winter wheat Kansas (Olsen)+
2.5	66.5	31.0	42.0	82	42.0	75	75.2	61.2	35.0	41.0
5.0	77.3	40.0	54.8	86	54.8	87	79.5	78.0	56.4	68.0
7.5	86.7	48.5	69.3	89	69.3	94	83.1	85.9	73.6	82.1
10.0	91.3	58.0	81.3	92	81.3	97	86.0	90.4	82.1	89.9
12.5	94.1	66.5	90.2	93	90.2	98	88.6	93.3	87.9	93.9
15.0	95.9	75.3	94.7	95	94.7	99	91.0	95.4	92.3	97.0
17.5	97.1	84.5	97.3	96	97.3	100	93.1	97.0	95.0	98.5
20.0	98.0	90.0	98.0	97	98.0		94.8	98.2	97.1	99.9
22.5	98.7	93.5	98.6	98	98.6		96.4	99.1	98.2	100.0
25.0	99.3	96.0	99.1	98	99.1		97.8	99.9	99.3	
27.5	99.6	98.0	99.5	99	99.5		98.8	100.0	100.0	
30.0	99.8	99.3	99.8	99	99.8		99.6			
32.5	99.9	99.9	100.0	99	100.0		99.9			
35.0	100.0	100.0		99			100.0			

*Olsen P, +Calculated from Bray P1 assuming Olsen P = 0.75 Bray P1.

Data: Potash & Phosphate Institute, PKMAN: A tool for personalizing P and K management. Version 1.0. Potash & Phosphate Institute, Norcross, GA.

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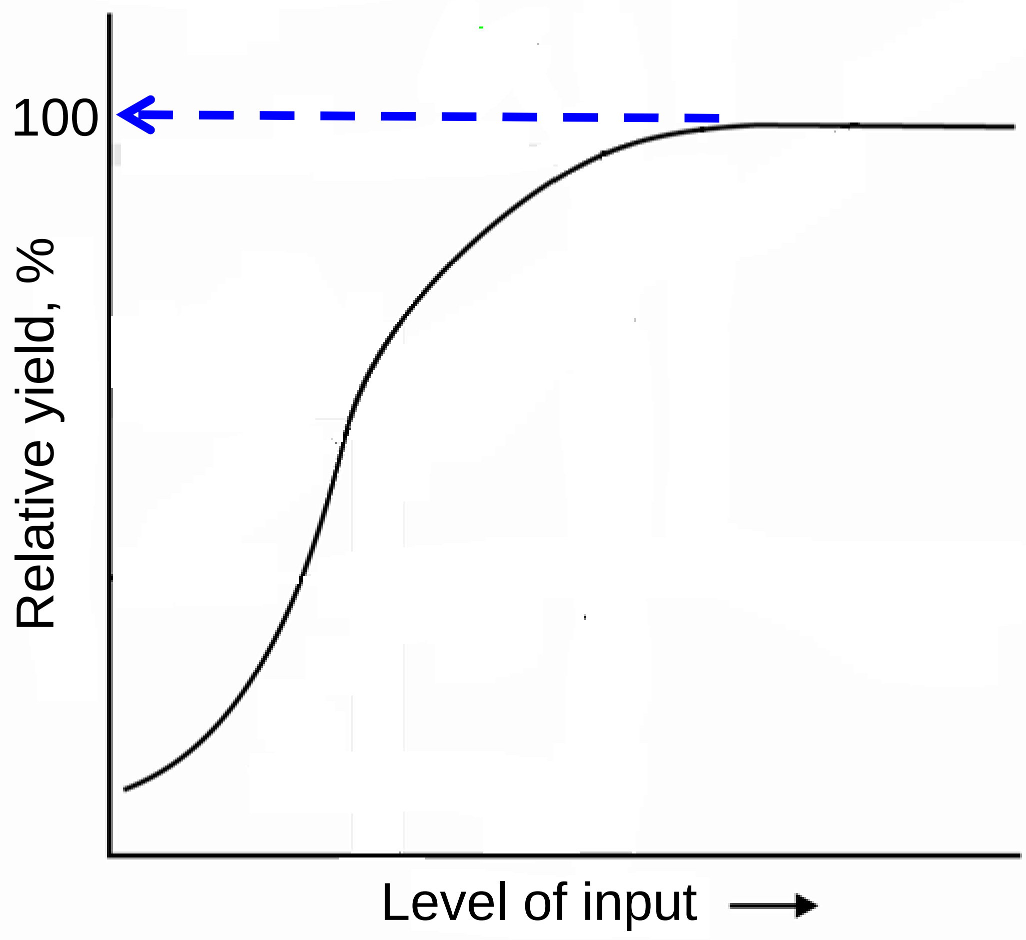
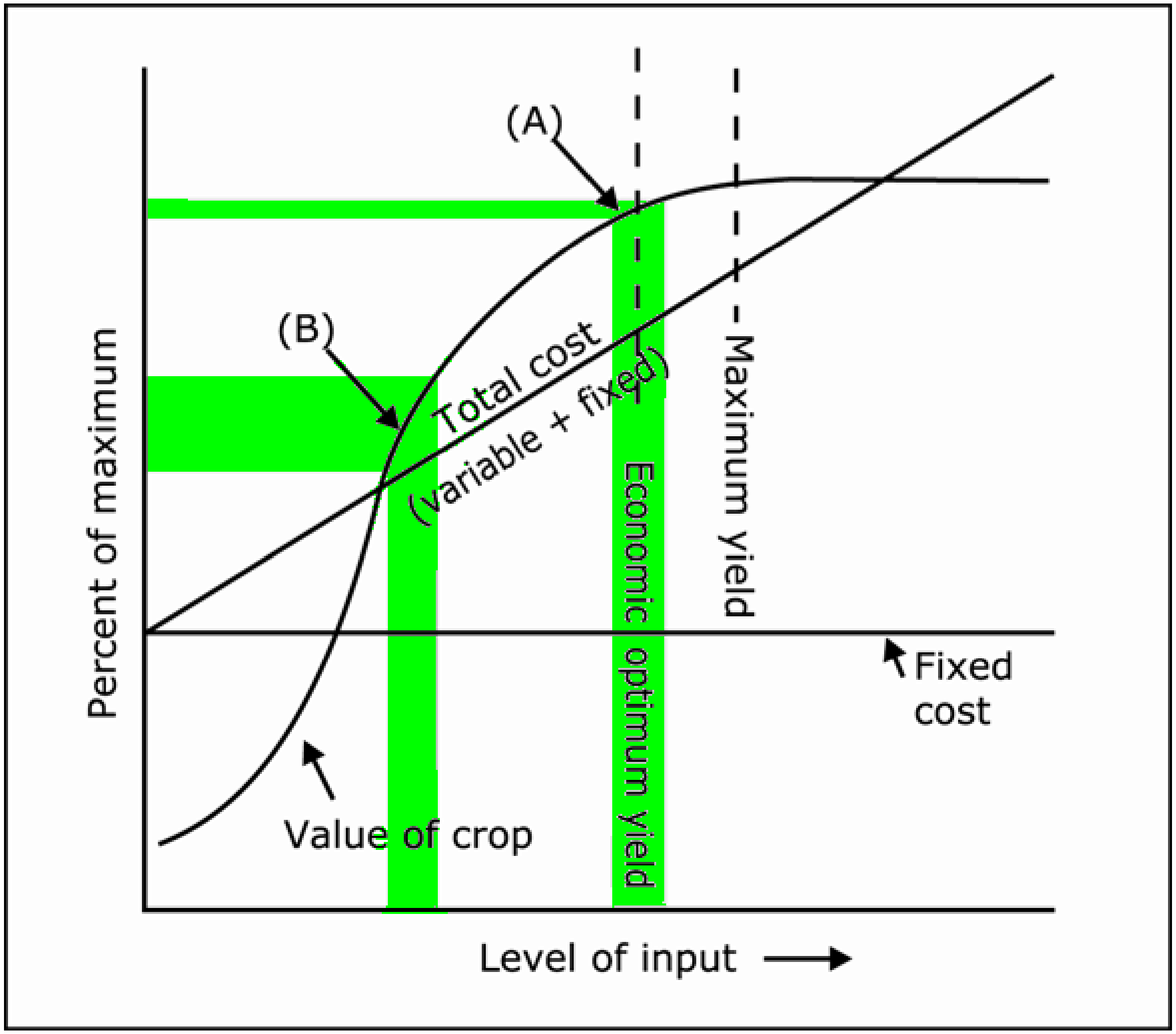
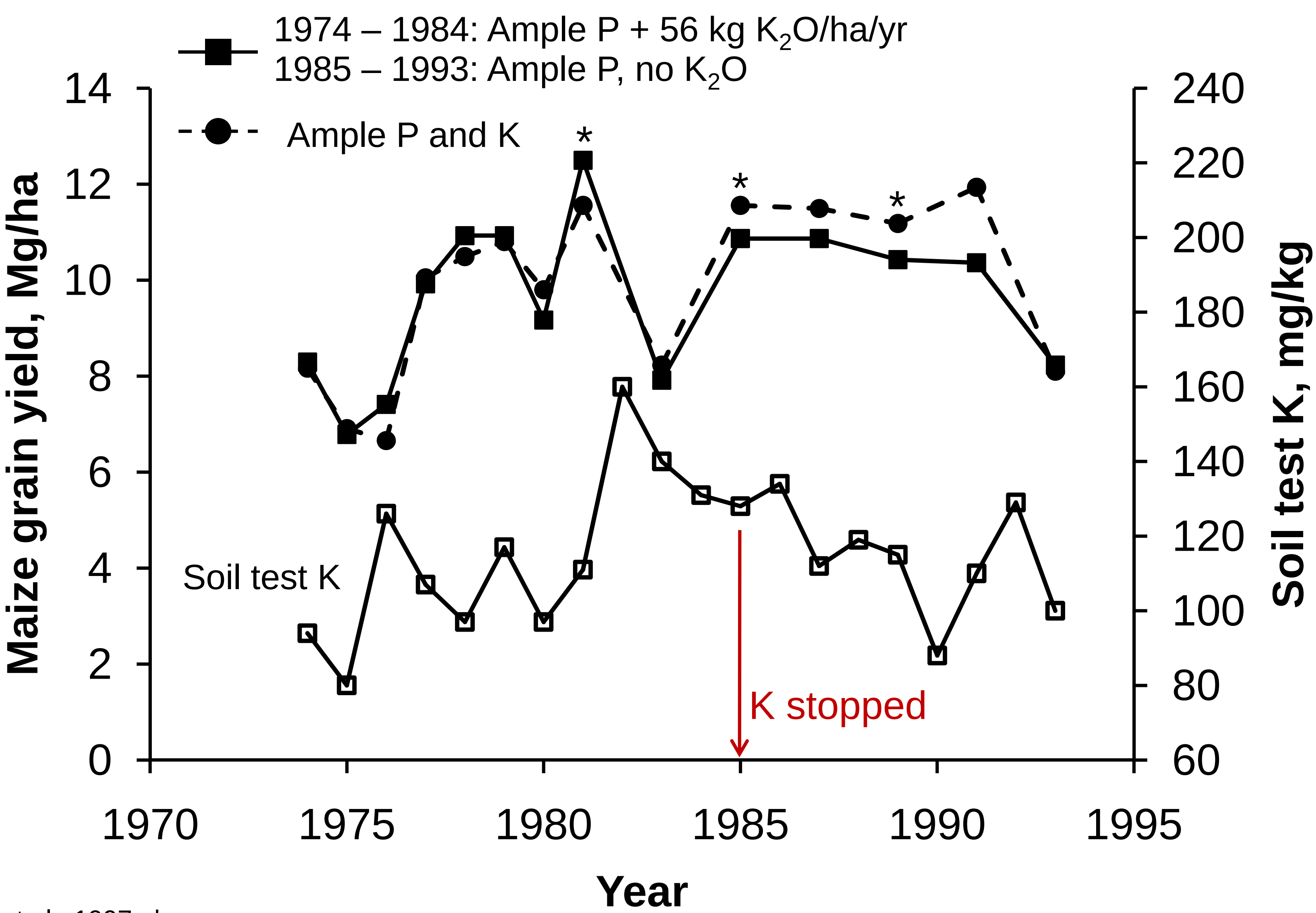
MEY concept illustrates the impact of reduced application …



MEY concept illustrates the impact of reduced application … impact depends where you are on the yield curve

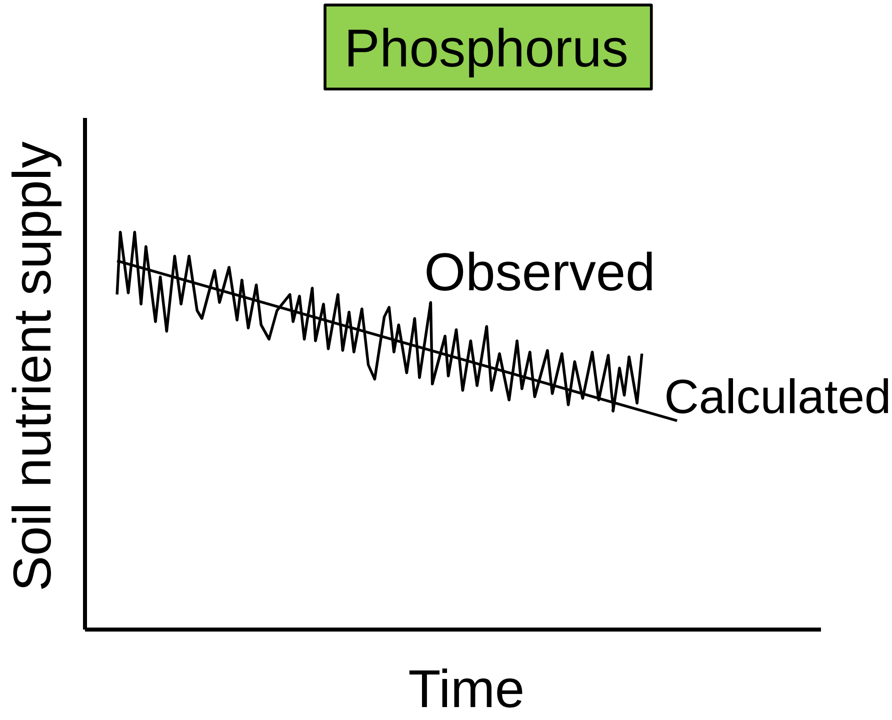


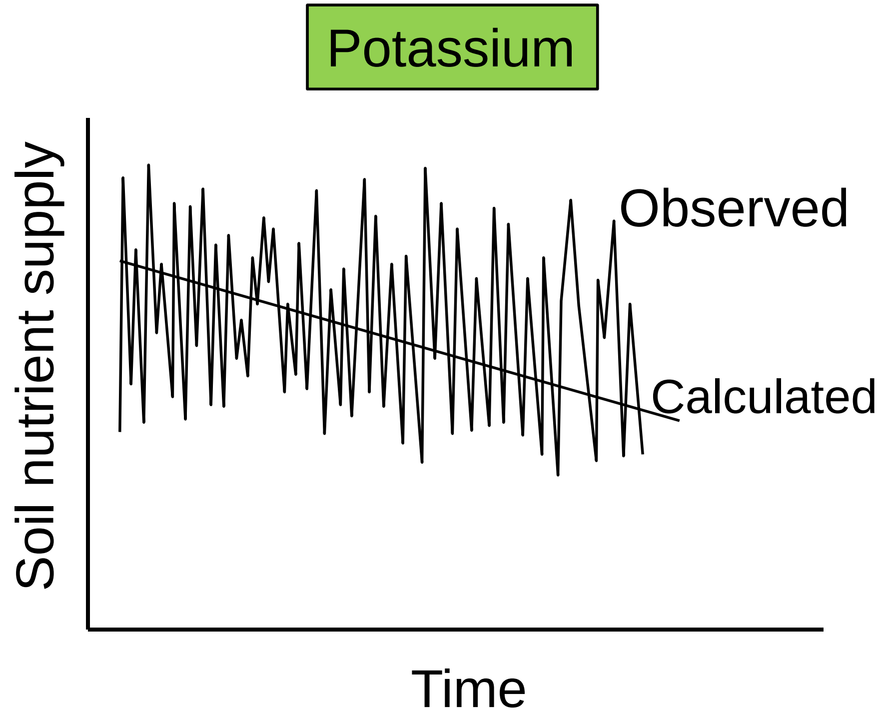
Impacts of historical K management



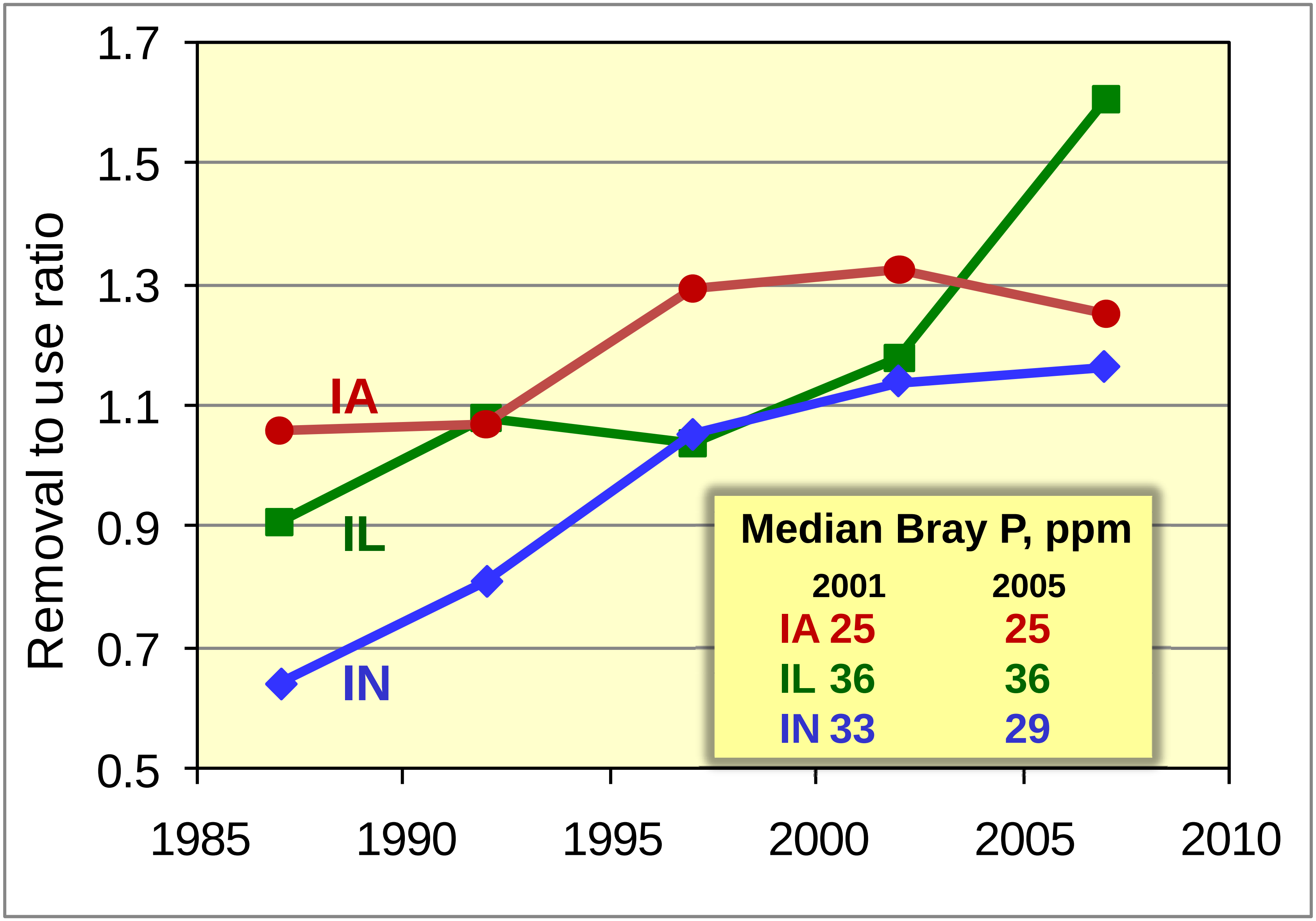
Randall et al., 1997a,b

Soil tests vary in their background noise





P removal to use ratios for the "I" states



P budgets for Iowa, Illinois, and Indiana per acre planted to principle crops

		IA	IL	IN
			lb P_2O_5/A*	
Fertilizer applied (2007)	+	30	29	33
Recoverable manure (2007)	+	12	3	8
Crop removal (avg of 06/07/08)	-	53	52	48
Balance	=	**-11**	**-20**	**-7**

*Based on avg of 2006-2008 acreage.

	IA	IL	IN
Typical Bray1 or Mehlich 3 decline†, ppm:	**0.6**	**1.1**	**0.4**
If continued for 5 years:	**3**	**6**	**2**
Median soil test levels in 2005, ppm	**25**	**36**	**29**

†Assuming 18 lb P_2O_5/ppm.

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P budgets for Iowa, Illinois, and Indiana per acre planted to principle crops **with no P fertilizer**

		IA	IL	IN
		lb P_2O_5/A*		
Fertilizer applied **(none)**	+	0	0	0
Recoverable manure (2007)	+	12	3	8
Crop removal (avg of 06/07/08)	-	53	52	48
Balance	=	**-41**	**-49**	**-40**

*Based on avg of 2006-2008 acreage.

	IA	IL	IN
Typical Bray1 or Mehlich 3 decline†, ppm:	**2.3**	**2.7**	**2.2**
If continued for 5 years:	**12**	**14**	**11**
Median soil test levels in 2005, ppm	**25**	**36**	**29**

†Assuming 18 lb P_2O_5/ppm.

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K budgets for Iowa, Illinois, and Indiana per acre planted to principle crops

		IA	IL	IN
			lb K_2O/A*	
Fertilizer applied (2007)	+	42	49	60
Recoverable manure (2007)	+	15	4	8
Crop removal (avg of 06/07/08)	-	61	54	53
Balance	=	**-5**	**-1**	**+15**

*Based on avg of 2006-2008 acreage.

	IA	IL	IN
Typical soil test K change†, ppm:	**-1**	**0**	**+2**
If continued for 5 years:	**-3**	**-1**	**+9**
Median soil test levels in 2005, ppm	**172**	**178**	**144**

†Assuming 8 lb K_2O/ppm.

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K budgets for Iowa, Illinois, and Indiana per acre planted to principle crops **with no K fertilizer**

		IA	IL	IN
			lb K_2O/A*	
Fertilizer applied **(none)**	+	0	0	0
Recoverable manure (2007)	+	15	4	8
Crop removal (avg of 06/07/08)	-	61	54	53
Balance	=	**-47**	**-50**	**-45**

*Based on avg of 2006-2008 acreage.

	IA	IL	IN
Typical soil test K change†, ppm:	**-6**	**-6**	**-6**
If continued for 5 years:	**-30**	**-32**	**-28**
Median soil test levels in 2005, ppm	**172**	**178**	**144**

†Assuming 8 lb K_2O/ppm.

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Nutrient reduction impact on soil test levels and yield … based on a budget approach

- May see little impact on soil test levels after one year of reduced rates
- May see little negative impact on yield if soil test levels are above the critical level

Summary

- Nutrient budgets are important to **farmers** and to **society** … they are indicators of **sustainability**.
- Weaknesses exist in our current capacity to accurately evaluate nutrient budgets at appropriate resolution:
  - Crop nutrient removal coefficients
  - Census data for specific nutrient use expenditures
  - AAPFCO county level fertilizer sales data

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Summary

- Crop nutrient **removal** is increasing faster than **nutrient use** nationally and in most key production areas.
- Most of the Corn Belt appears to be **mining soil P** and many areas appear also to be **mining soil K** … **intensive monitoring of soil fertility is a critical BMP**.

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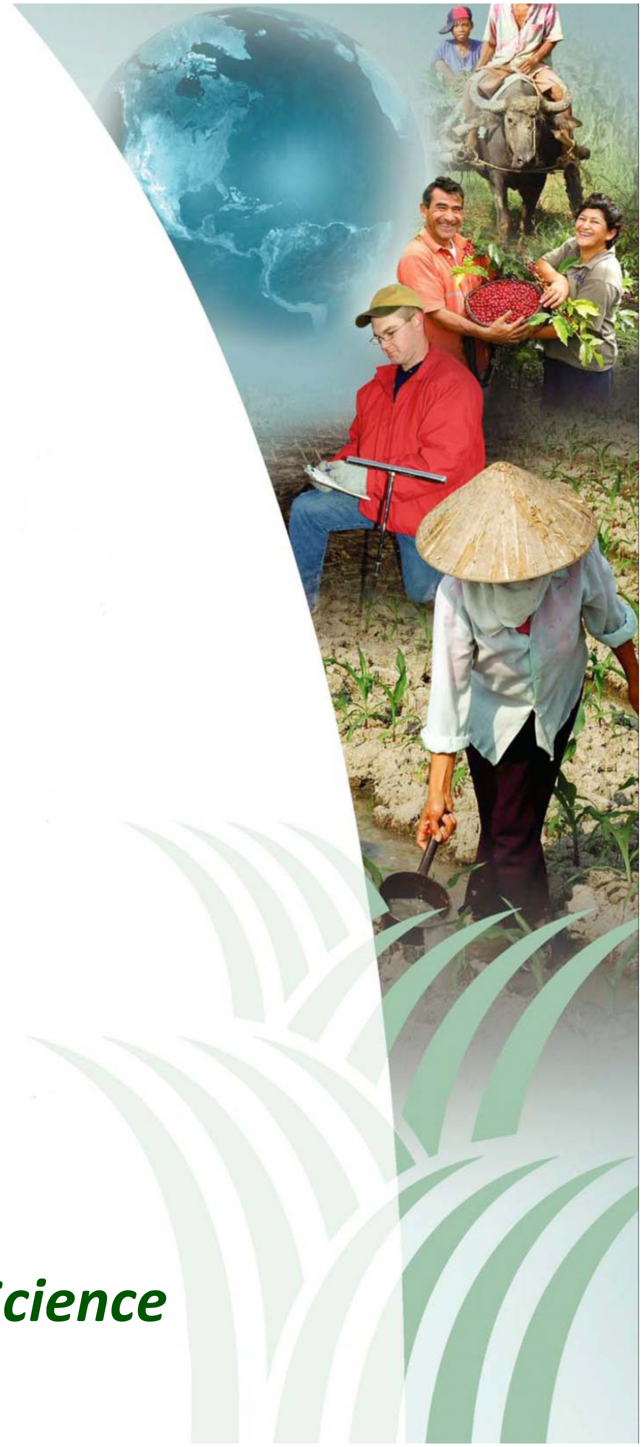

Better Crops, Better Environment … through Science