Phosphorus in Agriculture

Some current issues

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Phosphorus – the issues

- **Phosphorus is an essential, irreplaceable nutrient in crop and animal nutrition**
- **Phosphorus lost from agriculturally managed soils to surface water bodies, *e.g.* lakes, causes the adverse effects of eutrophication**
- **Global reserves of phosphorus are limited**

Phosphorus in crop nutrition

Roots take up phosphorus (P) as $H_2PO_4^-$ or HPO_4^{2-} ions from the soil solution

P concentration in the soil solution in agricultural soils ranges from 0.01 to 0.3 mg P/L

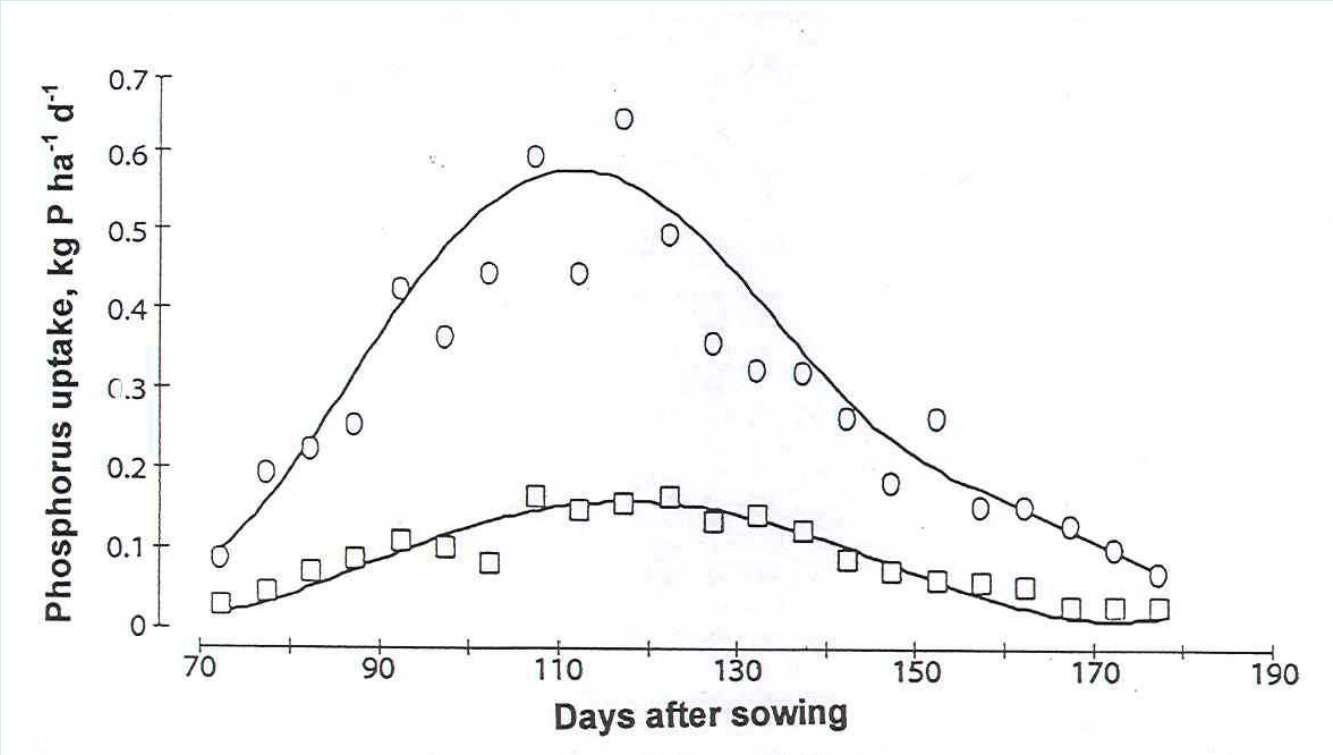
This equates to 0.3 to 3.0 kg P/ha, but roots are in contact with only about 25% of the soil solution, *i.e.* "available" P 0.08 to 0.75 kg P/ha

Daily maximum P uptake rate by spring barley with:

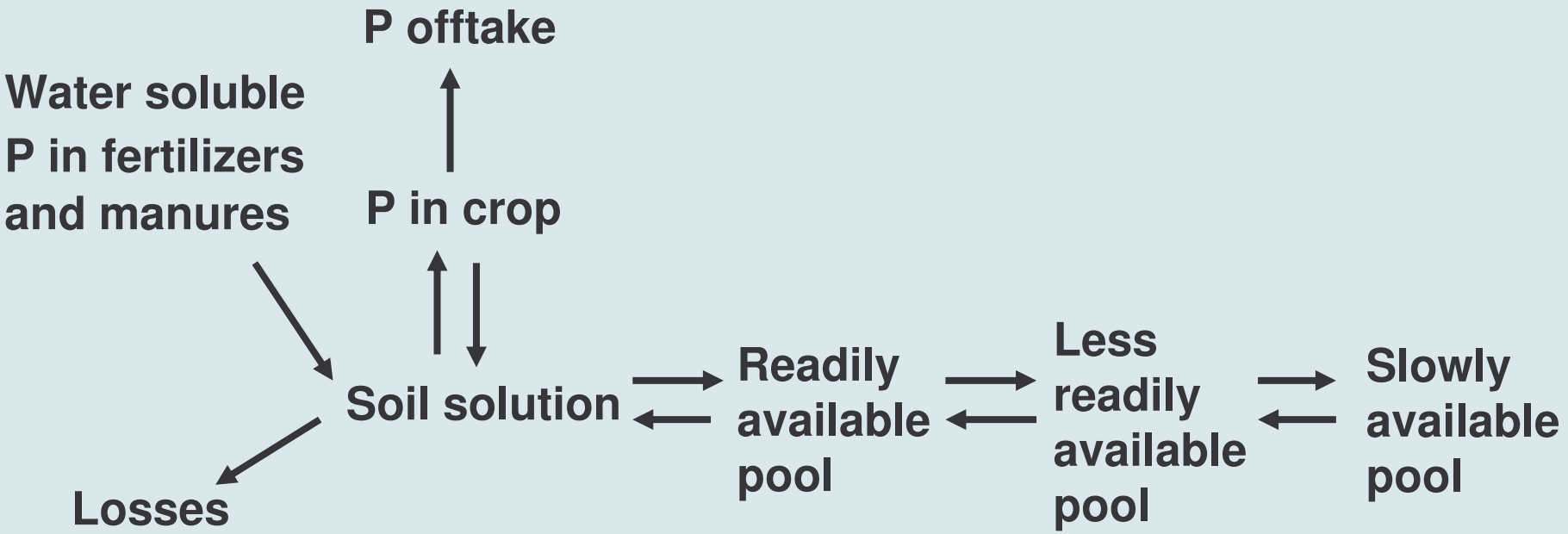
Adequate P was 0.6 kg P/ha and grain yield was 6.4 t/ha

Too little P was 0.2 kg P/ha and grain yield only 2.9 t/ha

Determining daily phosphorus uptakes

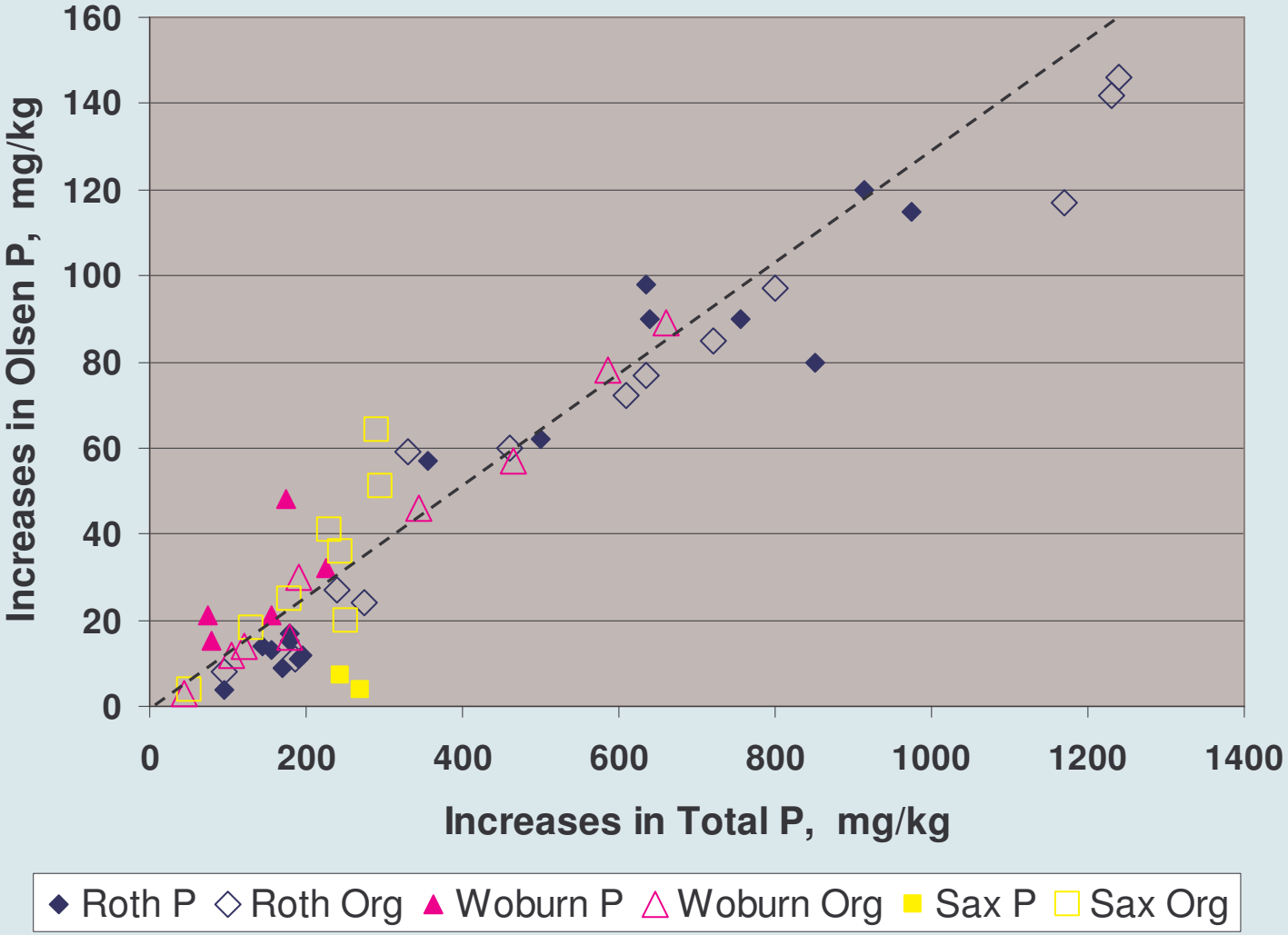


Current concepts of the behaviour of P in soil



Soil analysis measures P in the soil solution and the readily available pool

Relationship between total P and Olsen P



Dashed line represents 13% of added P remaining as Olsen P

Relationship between total P, Olsen P and $CaCl_2$ P

	Total P mg/kg	Olsen P mg/kg	$CaCl_2$ P µg/l
Broadbalk			
No P	580	8	0.2
P	1080	81	6.6
FYM	1215	97	19.5
Barnfield			
No P	670	18	0.5
P	1215	69	3.0
FYM	1265	86	12.8
FYM + P	1875	145	22.3

Changes in P balance and Olsen P from 1856 to 1958 as a result of cropping and manuring, silty clay loam

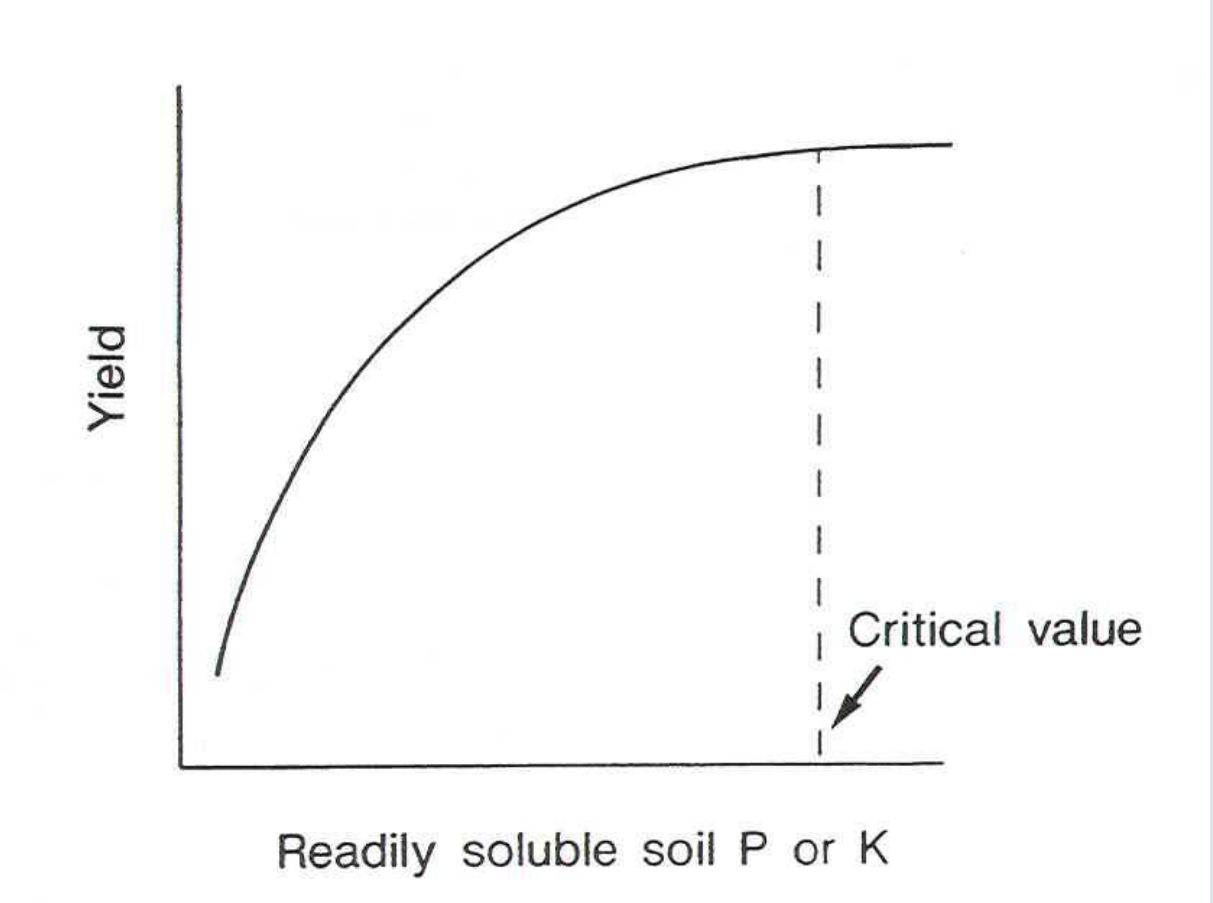
Treatment	Period	P balance kg/ha	Change in Olsen P kg/ha	Change in Olsen P as a % of P balance
None		-80	-5	6
FYM	1856-1903	1030	170	17
PK		1220	170	14
None		-190	-5	3
FYM*r*	1903-1958	-380	-130	34
PK*r*		-340	-140	41

PK applied 1856-1901, FYM 1876-1901 no PK or FYM applied after 1901

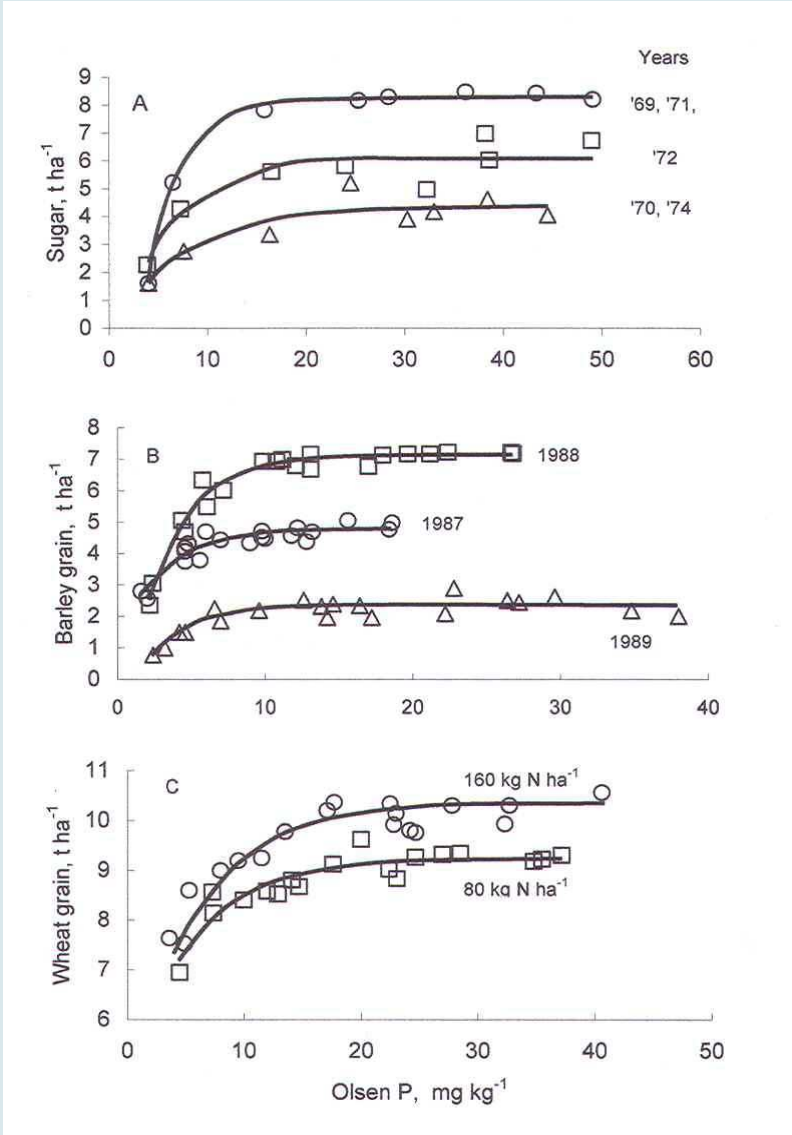
Phosphorus balance and the decline in Olsen P on a sandy clay loam soil, 1969-1982

Olsen P in 1969 mg/kg	3	7	21	28	44	54	67
P in crops kg/ha	94	153	217	237	256	263	263
Decrease in Olsen P, kg/ha	8	12	27	50	78	87	120
Change in Olsen P as % of crop P	8	8	12	21	30	33	46

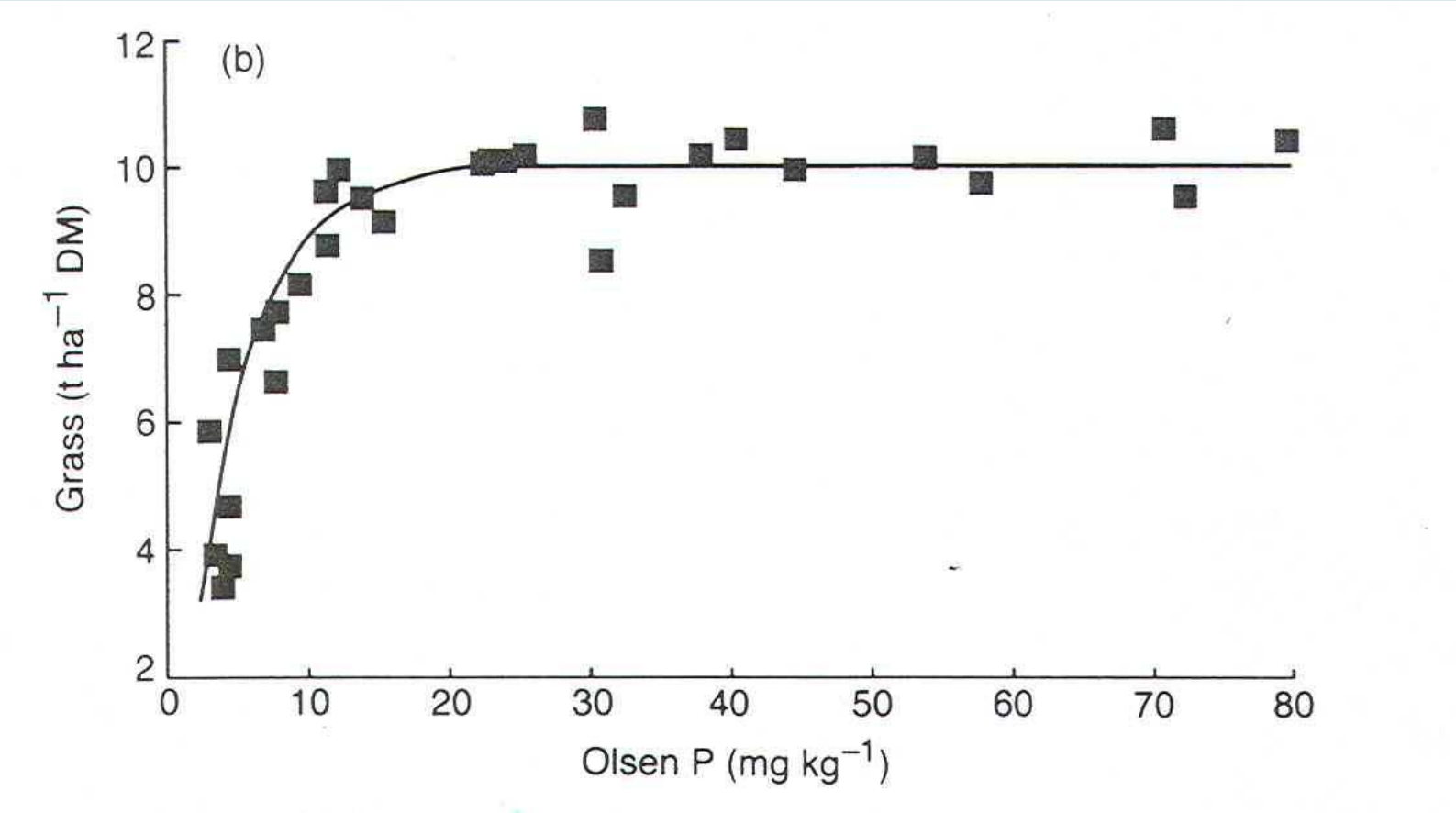
How much P should there be in the readily available pool?



Examples of critical values for arable crops



Similar phosphorus response curve for grassland



Yields of four arable crops on a sandy clay loam soil with different levels of Olsen P

Olsen P	48	30	17	7
	Yields, t/ha*			
Potatoes, tubers	43.7	40.1	38.3	30.6
Sugar beet, sugar	6.57	6.53	5.97	4.25
Spring barley, grain	5.18	5.01	4.81	4.47
Winter wheat, grain	6.42	6.65	6.06	5.00

*Yields of potatoes and sugar beet 6 years, barley 4, wheat 1

Yields of four arable crops grown on a sandy loam soil at three levels of Olsen P

	Olsen P, mg/kg			
	48	30	13	13*
Crop	Yields, t/ha			
Potatoes, tubers	44.3	25.2	23.9	10.8
Sugar beet, sugar	7.32	5.36	5.00	3.44
Spring barley, grain	4.37	4.07	3.83	3.20
Winter oats, grain	5.04	4.49	4.57	4.50

* This soil had only 38 mg/kg exchangeable K/kg

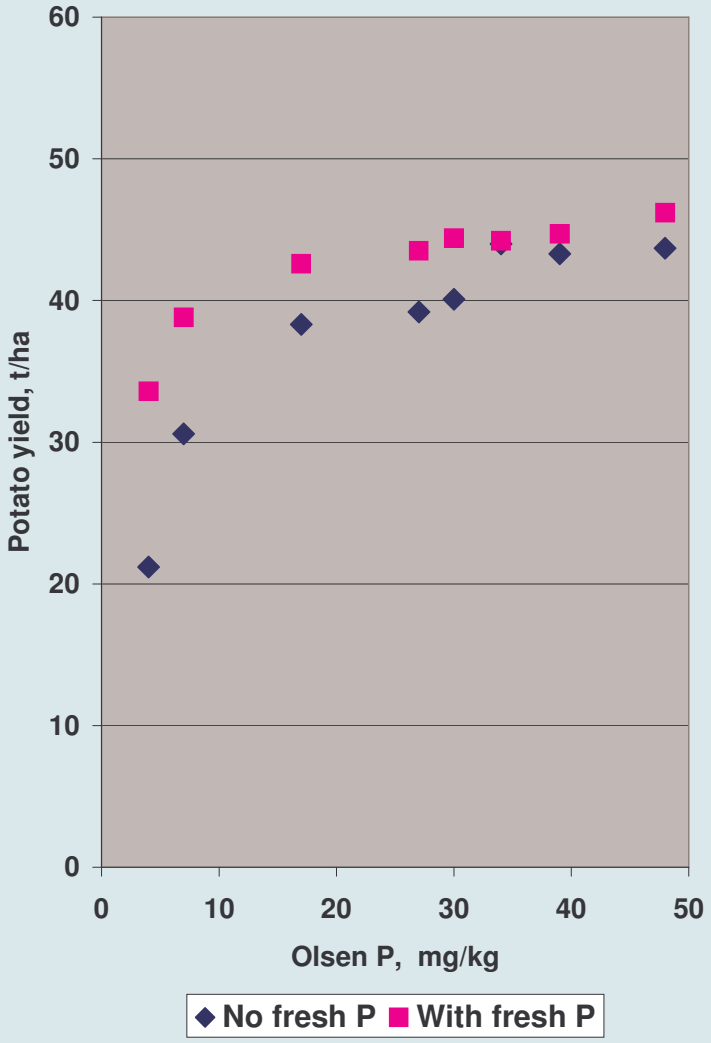
Yields of 1st and 2nd wheat given 200 kg N/ha on a sandy loam soil with 4 levels of Olsen P

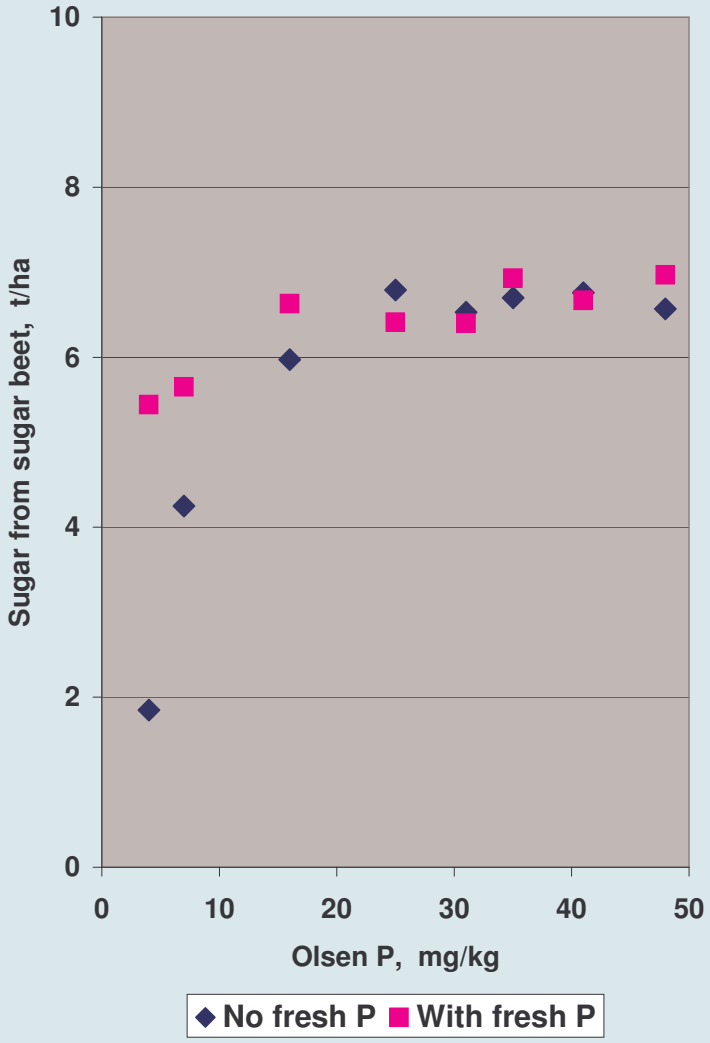
Olsen P, mg/kg	30	19	10	5
1st wheat, grain, t/ha	10.25	10.30	9.34	8.08
2nd wheat, grain, t/ha	8.28	8.18	7.68	5.54

Yields of 1st, 2nd and 3rd wheat given 320 kg N/ha on a sandy clay loam soil with different levels of Olsen P

	Yield, grain, t/ha		
	1st	2nd	3rd
P treatment			
None	10.51	5.09	2.01
None (K)	10. 76	7.06	2.42
P	11.32	10.63	8.47
P (K)	11.34	10.30	9.02

Saxmundham: response to fresh P





Grass response to phosphorus on soils with different levels of Olsen P

Olsen P, mg/kg	14	8	5	2
P_2O_5 applied, kg/ha	Annual yield grass dry matter, t/ha			
0	8.1	6.6	5.1	3.5
50	9.0	8.7	8.3	7.8
100	9.0	9.0	7.5	8.2
150	9.1	8.8	8.5	8.2

Is extra P required for early growth of grassland?

Small increases in yield are sometimes found in experiments

Can this be turned into saleable product?

If slurry is being applied is extra fertilizer P required?

Does fertilizer or slurry P increase the soil P level much above the critical value?

If required, apply slurry in spring to maintain soil at the critical level

Much of the P lost from soil to water comes from grassland

Soil analysis for P in grassland soils

Grassland usually sampled to 7.5 cm

- **Probably acceptable for advisory purposes but not for environmental issues**
- **A profile of P enrichment develops in soil under permanent grassland:**

Depth, cm	Olsen P
0-0.5	~18
0.5-1.0	~12
2	~7
7.5	~5
12.5	~4
17.5	~3

Olsen P in bulk soil to 7.5 cm was 6.6 mg/kg

Data from IGER North Wyke experiments

Factors affecting the critical level of Olsen P

- **Soil analysis carried out on soil <2mm.**

  Therefore the amount of soil <2mm is important; this is affected by soil depth and stoniness.

- **How much soil <2mm is explored by plant roots?**

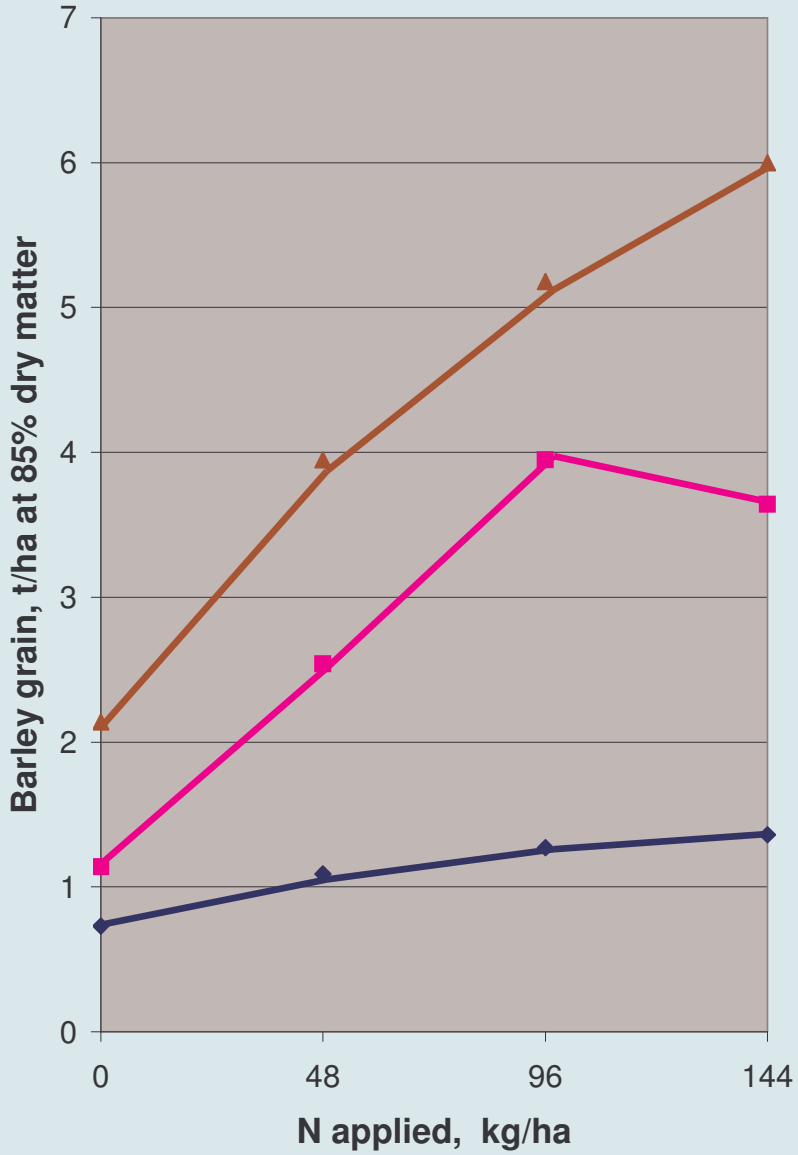
  This is related to soil structure and soil organic matter

Effect of soil organic matter on relationship between yield and Olsen P

	SOM %	Yield t/ha (asymptote)	Olsen P mg/kg (at 95%)	% variance accounted for
Spring barley	1.5	4.4	45	46
grain	2.4	5.0	16	83
Potatoes	1.5	44	61	72
tubers	2.4	45	17	89
Sugar beet	1.5	6.6	32	61
sugar	2.4	6.6	18	87
Grass in pots	1.5	6.5*	25	82
(dry matter)	2.4	6.5	23	96

*g/pot

Effect of plant available soil P on the response to N



Olsen P

140 mg/kg

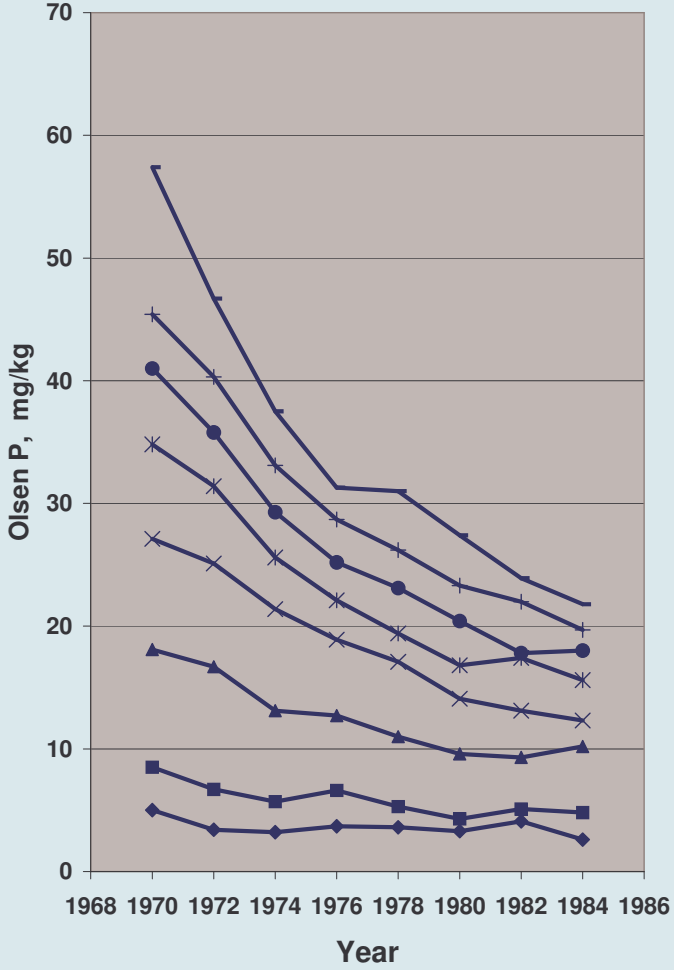
13 mg/kg

3 mg/kg

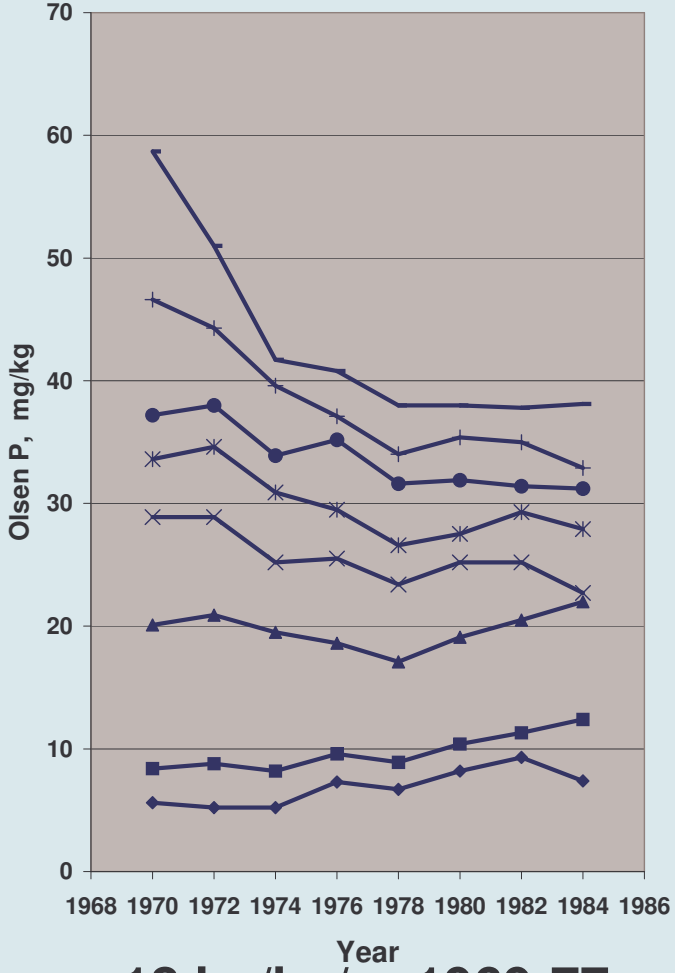
% recovery of labelled N (^{15}N)

		PK	no P, no K
W. wheat, 96kgN/ha	1980	64	46
	1981	61	39
S. barley, 140kgN/ha	1986	53	36
	1987	53	48

Saxmundham: changes in Olsen P with treatment and time

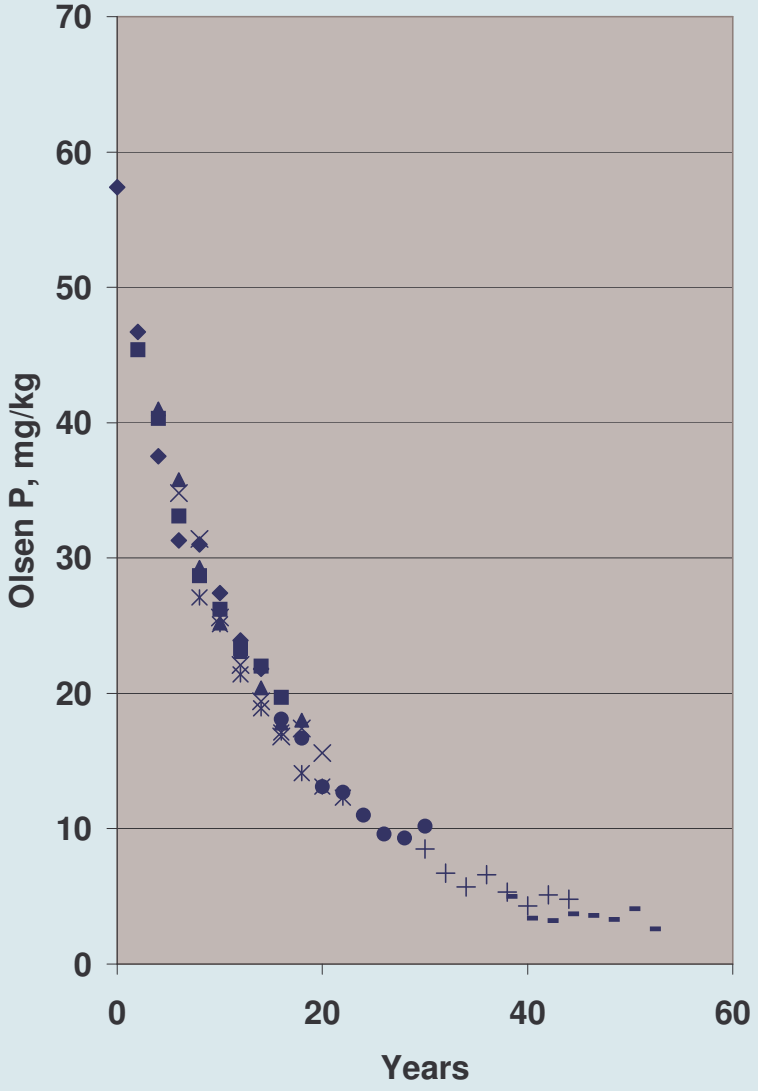


No fresh added after 1968



18 kg/ha/yr 1969-77
26 kg/ha/yr 1978-83

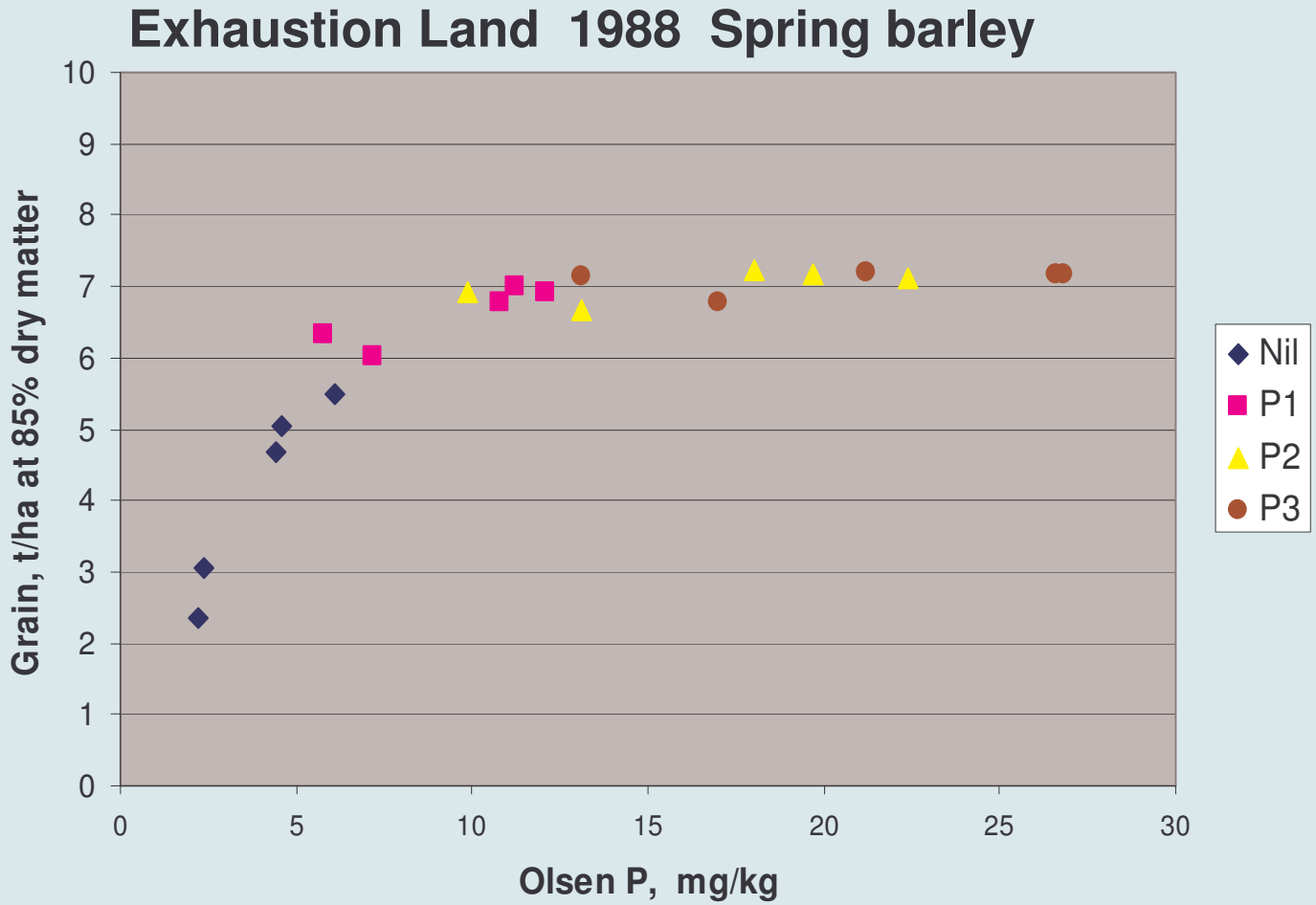
Saxmundham: decline in Olsen P, unified decay curve



No fertilizer P added after 1968

"Half-life" of about 10 years

On some soils it is possible to increase available P within a few years by applying much P so that yields are not limited; it will take much longer on "difficult" soils



P added annually since 1986; P1, P2, P3: 100, 200, 300 P_2O_5/ha

Making a judgement about applying phosphorus

Soils below the critical value – there is a yield and thus a financial loss to the farmer

- **Apply P to increase soil P to the critical value**

Soils above the critical value

- **Financial cost in applying P that will not increase yield**
- **Increased risk of P loss to water from soils excessively enriched with P**

Soils at the critical value

- **Apply P to maintain the critical value, maintenance applications.**
- **Check that this level is being maintained by sampling and analysing soil every 4/5 years**

Soil sample same time each year, same depth, minimum 16 cores

Transport of P from soil to water

In eroded soil

By movement through soil into drainage ditches and rivers

Incidental losses from surface applied slurries and fertilizers when rainfall causes surface run-off

Phosphorus transport from soil to water

The lower limiting P concentration for a lake to be considered eutrophic is 35 µg P/L and hypereutrophic is 100 µg P/L

The amount of water-soluble P in drainage need to achieve these concentrations is very small.

	Drainage, mm/ha/year			
Concentration of P in water	100	250	500	1000
	kg P/ha			
35 µg P/L	0.03	0.09	0.18	0.35
100µg P/L	0.10	0.24	0.49	1.00

The bioavailability of phosphorus transported to water

Bioavailable P is estimated by the method of analysis

The solution may or may not be filtered and may or may not be digested, P is determined by the molybdenum blue method

The filter is 0.45 µm to separate "dissolved" from "particulate" P

1. **Analysis of untreated solution**
   - **(i) $RP_{<0.45}$ reactive P in filtered solution**
   - **(ii) RP_{unf} reactive P in unfiltered solution**

2. **Analysis of digested solution**
   - **(i) $TP_{<0.45}$ total P in the filtered digest**
   - **(ii) TP_{unf} total P in the filtered digest**

Loss of phosphorus from agriculturally managed soils

P has to be transported in water moving by two pathways

1. **Water flowing over the soil surface (overland flow) when rainfall exceeds the capacity of the soil to accept the amount of water**

2. **Water draining down through the soil, subsurface runoff, ground water runoff. Water can move by:**

   preferential, bypass, macropore flow, through continuous pores or fissures, root channels and animal burrows resulting in rapid water movement, usually on heavy textured soils
   piston flow, uniform downward movement, usually in light textured, sandy soils

   P transported down through the soil profile can be retained at depth if there are suitable sites for its adsorption

In certain situations soil and the P it contains can be lost by wind erosion

Issues related to phosphorus loss from soil to water

The amounts of P lost are very variable both in space and time within a river catchment area

Largest losses occur in hilly terrain with large amounts of rainfall, and from inappropriate applications of slurry

If slurry is applied to arable land, *e.g.* to maize fields, then the soil should be loosened first or the slurry incorporated as soon as possible

Great care should be taken near water courses when applying slurry or fertilizers

Rainfall and its relation to phosphorus loss from soil

1. **Intense rainfall detaches soil particles, together with the P they contain, from the main body of soil and as the excess water moves over the soil surface the entrained particles are carried to ditches, streams, rivers and lakes.**

   ***i.e.* soil erosion usually from land without vegetative cover,**

   ***e.g.* poached areas**

2. **Incidental P transfers in overland flow when large amounts of manure or fertilizer are applied and heavy rain follows soon after application**

Minimising P loss

By soil erosion

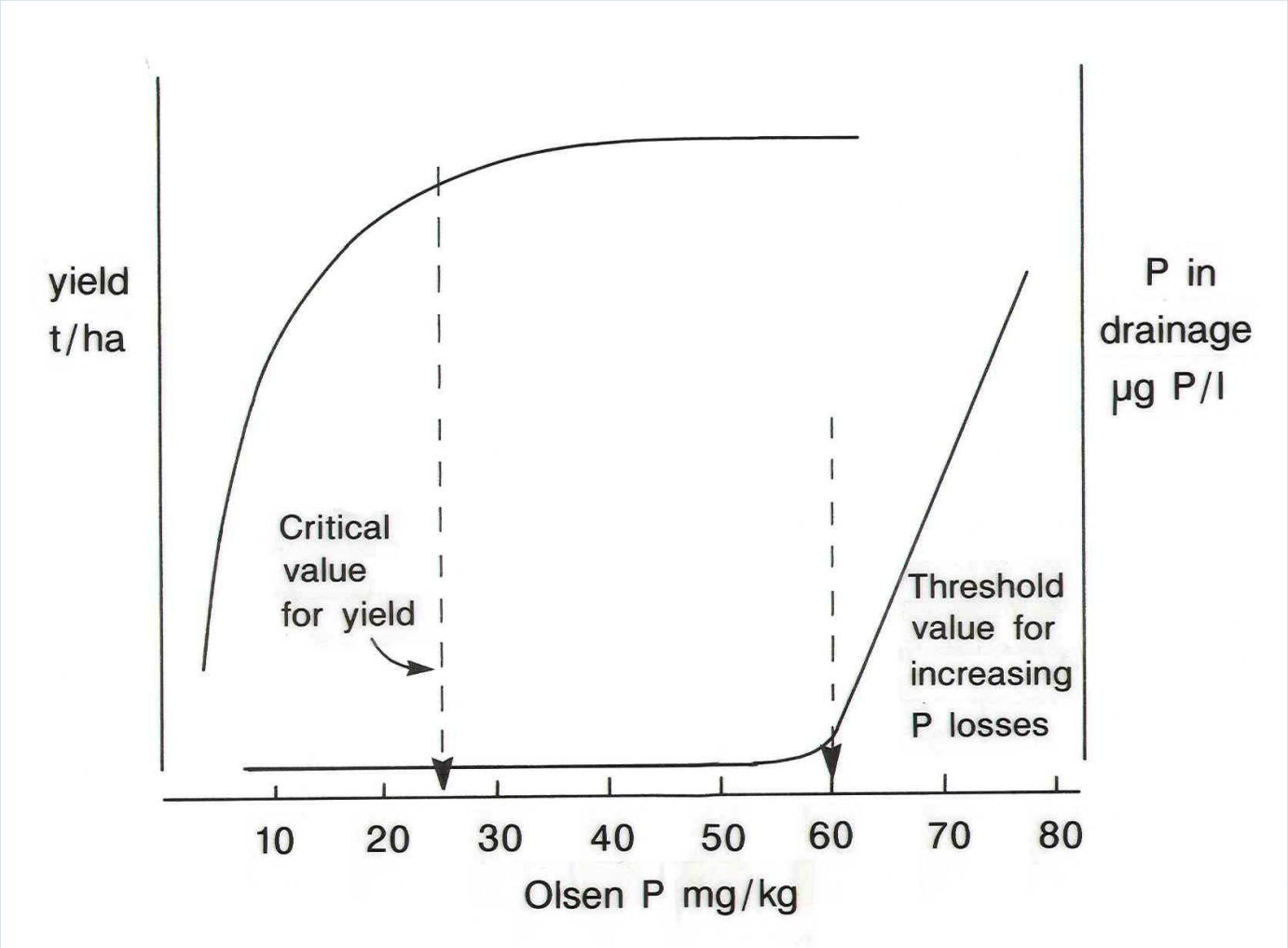
- Maintain the vegetative cover, don't let the topsoil become over enriched with P, especially the top 2 cm of grassland

By incidental P transfers

- Can be from both fertilizers and manures
- Do not apply either to water logged soils during periods of heavy rain or when heavy rain is expected
- On mainly grassland farms where maize is taken as an arable crop either cultivate the soil prior to or immediately after slurry application

There is greater opportunity to apply fertilizers at the most appropriate time

Relationship between yield, Olsen P and total P losses in drainage



Sources of phosphorus inputs for agricultural soils

Fertilizers like TSP– stated solubility in water as a % of NAC soluble P, currently 93% for TSP. But what about fertilizers with less water soluble P?

Organic manures – immediate availability of the P they contain is given in RB 209

For soils at the critical level immediate availability is less important than whether a maintenance application will maintain the critical value for Olsen P

- For FYM and slurry the answer is probably yes
- But for fertilizers other than TSP etc? I don't know

Alternative phosphorus fertilizers

For soils with a range of pH

- Nitrophosphates with 80% ws P as good as TSP in experiments
- Dicalcium phosphate (not water soluble) as good as SSP

On neutral/calcareous soils – reactive rock phosphate ineffective even after 30 years in one Rothamsted experiment where there was no increase in Olsen P and the soil was neutral in pH

On acid soils rock phosphate can give good yields

- Surface few cm of grassland, even on calcareous soils, becomes acid so that rock phosphates can be used but they must be “reactive” and finely ground