

Sulfur in Agriculture

and Fertiliser S Efficiency

Graeme Blair B.Sc.Agr., PhD (Syd), FASA
Adjunct Professor of Plant Nutrition
Past President, Australian Society of Agronomy
Agronomy and Soil Science
University of New England
Armidale, NSW, 2350, Australia
gblair@une.edu.au

Key features of S

- Soil S consists of predominately organic forms
- The nutrient is absorbed by plant roots in the sulfate form (SO_4^{2-})
- It resembles N in its many soil reactions (weakly held) and functions in the plant (proteins)
- It resembles P in the amounts taken up by plants and in adsorption to clay minerals, albeit much weaker
- High yields of good quality produce become possible only when crops have access to optimum amounts of sulfur and other nutrients
- Wool has a high S content so important in pastures

Major functions of S in plants

Chlorophyll formation

- Sulfur plays an essential role in chlorophyll formation and hence is one of the controllers of photosynthesis

Production of proteins

- Sulfur is the basic constituent of some amino acids which are important in the formation of proteins

Synthesis of oils

- Sulfur is involved in the synthesis of oil compounds which is why adequate sulfur is crucial for oilseeds

Promotes enzyme activity

Improves plant resistance to cold and disease

Other roles

- Improves baking and milling quality of cereals
- Increases the nutritive value of forages
- Is responsible for the odour and flavours of some legumes and brassicas

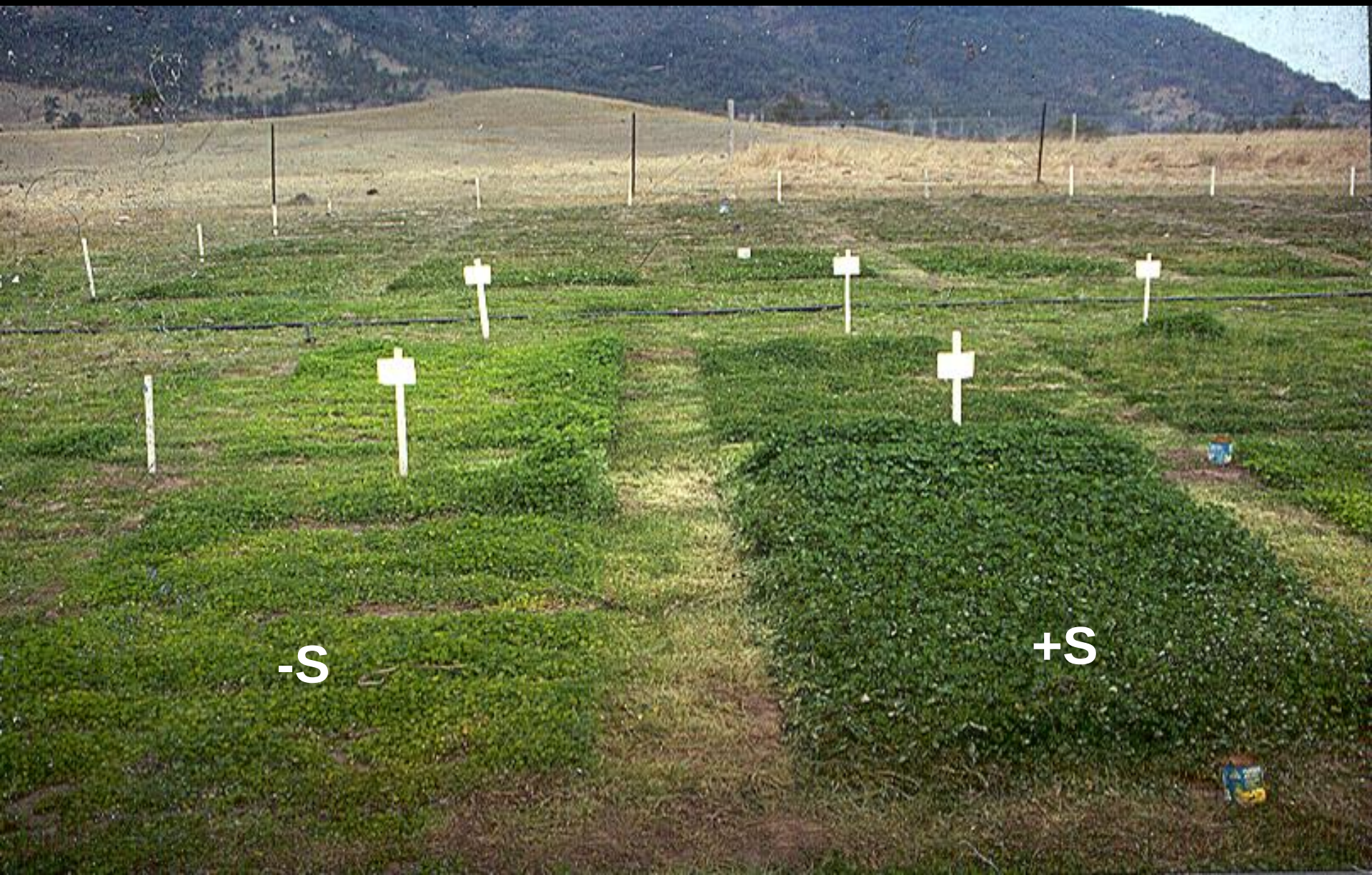
Because of the lack of mobility of the S in the plant the deficiency the yellow leaf symptom shows on the new growth



Canola fails to set seed under severe S deficiency



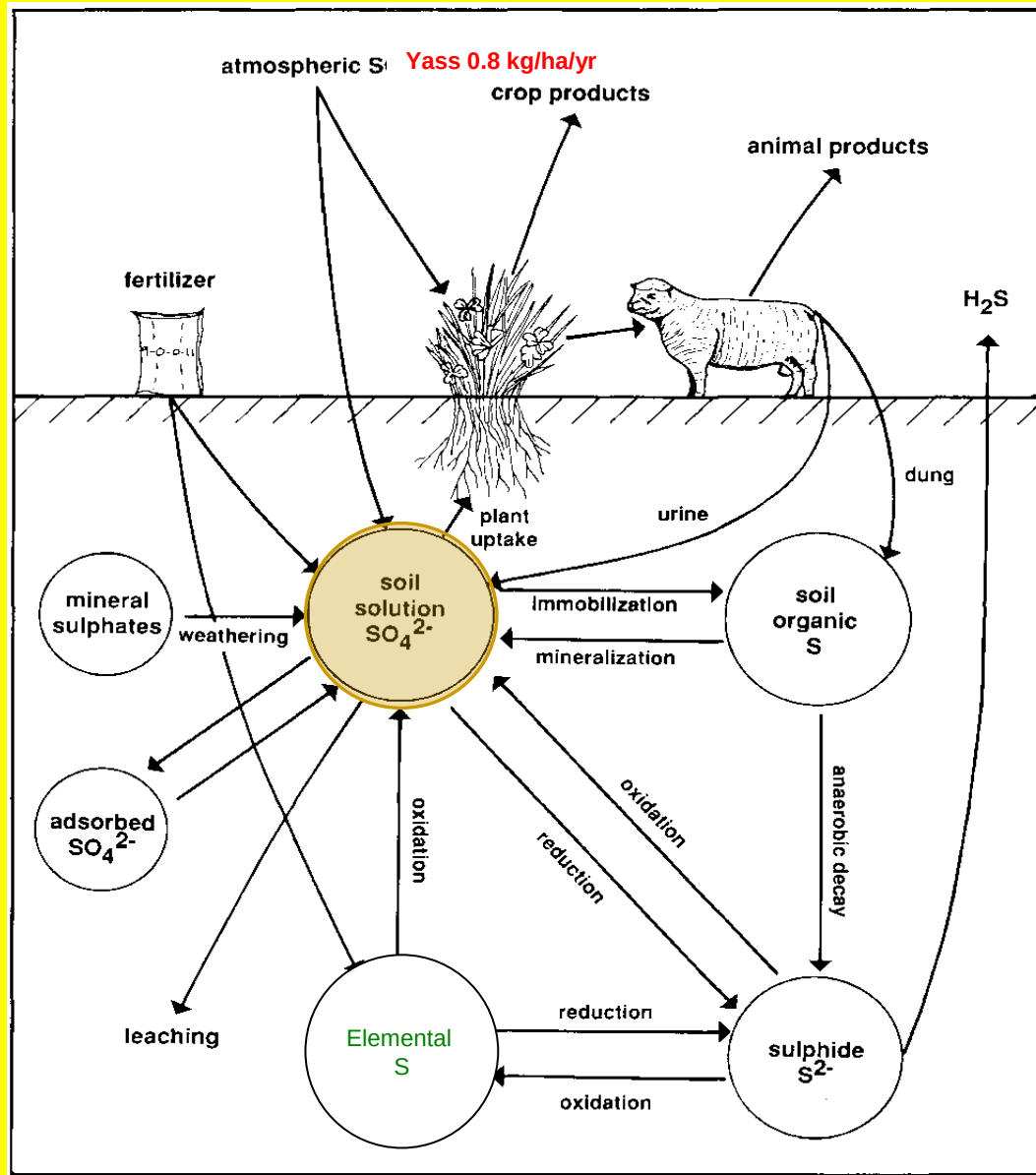
S Response in sub clover, NW slopes, NSW



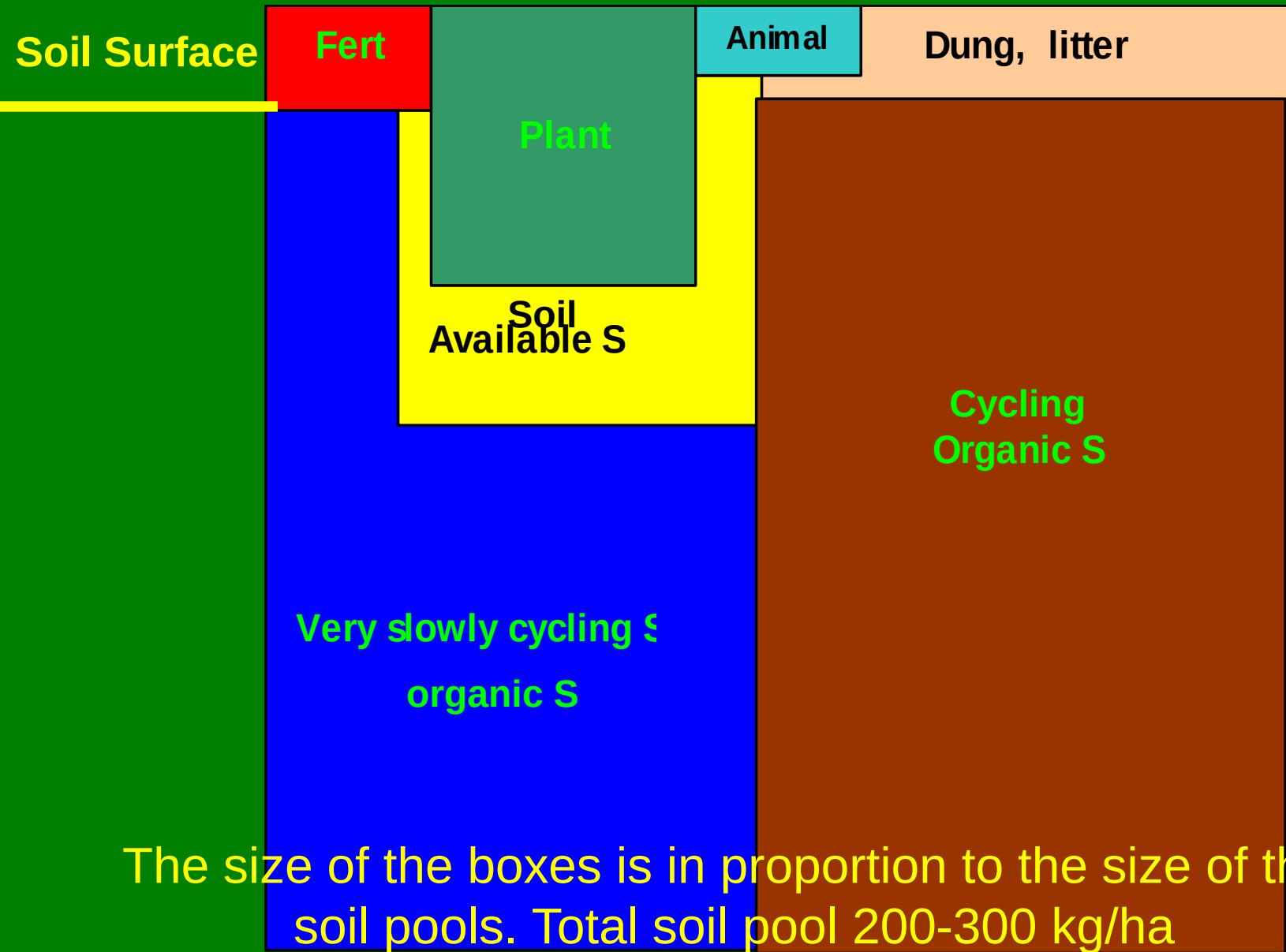
S and P deficiency, UNE McMaster Research Station, Warialda, NSW



The S cycle



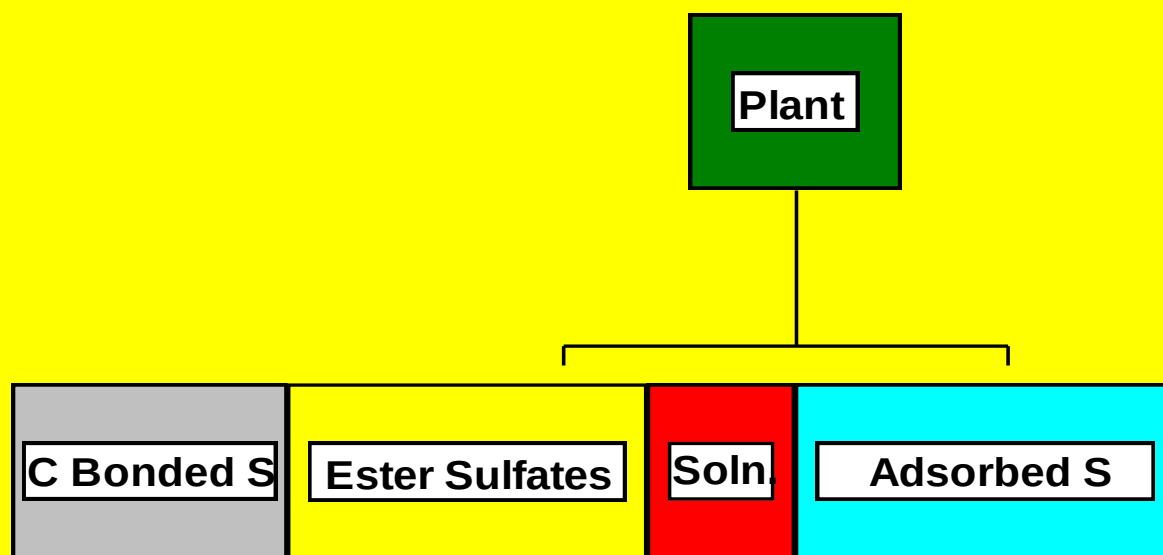
Size and forms of S pools in a grazed pasture



P and S fertiliser requirements

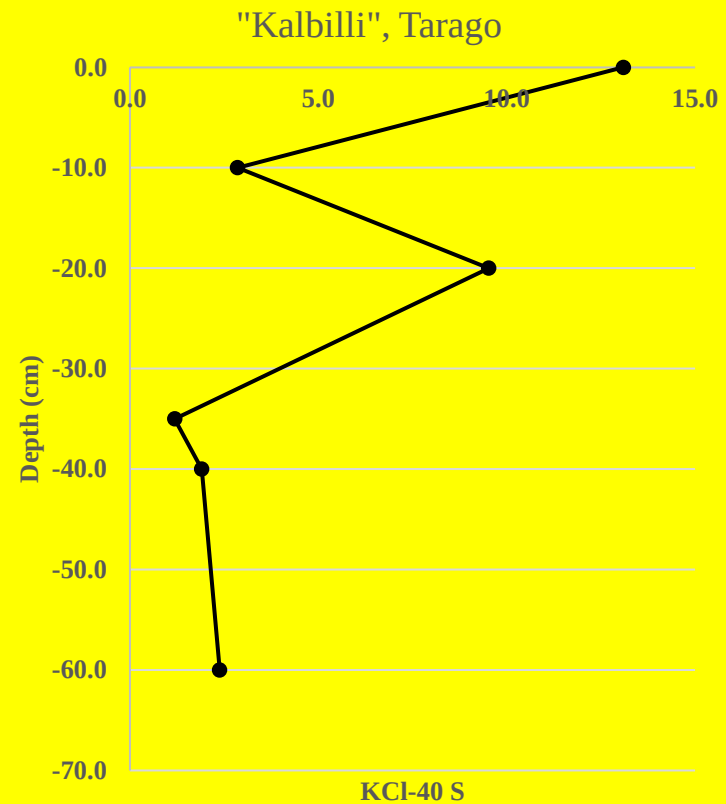
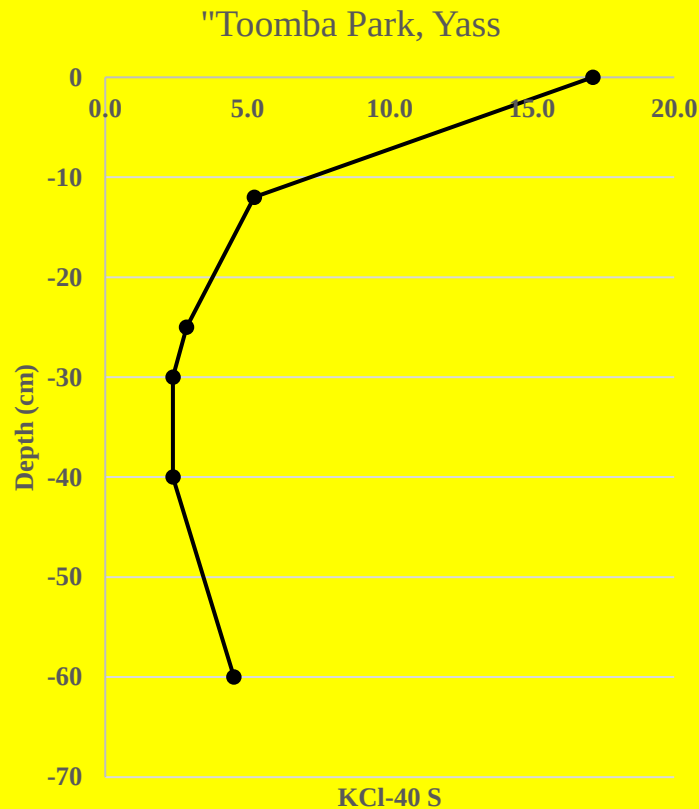
- Data from the Northern tablelands indicates a requirement of 1 kg P/ha/yr/DSE to maintain soil P supply
- Modelling of P and S cycling in grazed pasture indicates a P:S ratio of approximately 2:1 is required if S leaching is minimised
- SSP has a P:S ratio of 0.8 and all the S is as sulfate

Soil S testing has been improved through the development of the KCl-40 test

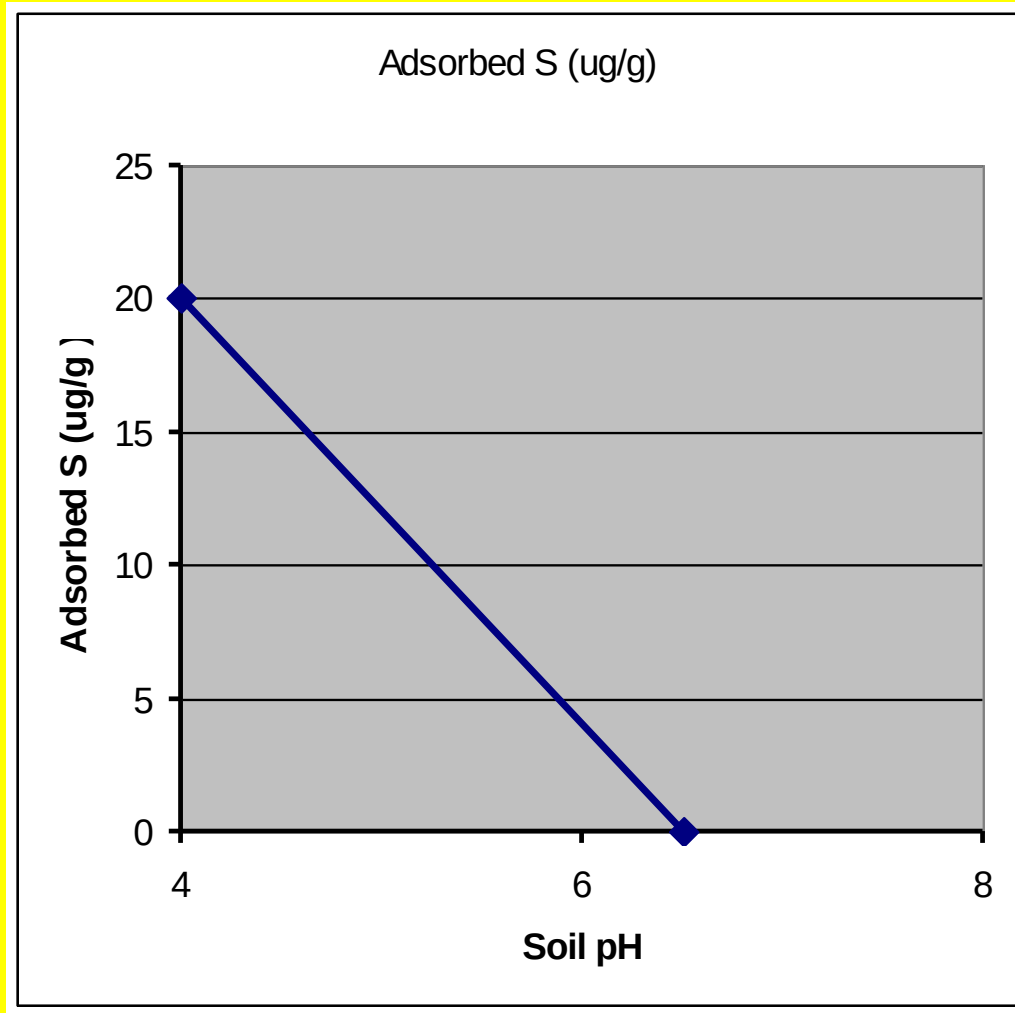


KCl-40 soil test samples the same 3 soil pools as plants

Soil profile S needs to be considered in relation to soil properties and crop



Effect of soil pH on SO_4^{2-} -adsorption



Over-liming can increase leaching losses

S requirement of crops

- **High**
 - canola
 - lucerne
 - Brassica crops and forages
- **Moderate**
 - coconut, sugarcane
 - clover, grasses
 - coffee, cotton
- **Low**
 - cereal forages
 - cereal grains, peanut

S removal in major crops

Crop	P	S
	kg/tonne	
Corn (grain)	3.1	1.2
Wheat (grain)	5.1	1.3
Soybeans (seed)	6.2	4.7
Peanuts (nuts)	2.7	2.5
Cotton(seed & lint)	4.7	1.9
Cabbage	0.4	1.0
Onions	0.6	1.1
Peas	6.1	3.6

N/S Interaction in Canola at Wellington, NSW -balanced nutrition needed

S (kg/ha)	Yield (t/ha)		%Oil	
	N 0	N 160	N 0	N 160
0	1.33	0.77	34.1	33.8
40	4.12	4.20	41.7	42.4

**Response of pasture to S and P
on the N.Tablelands of NSW
- note the synergistic effect of
combined P and S**

Soil type	-P-S	P alone	S alone	P and S together
Yield (t/ha)				
Sedimentary	8.2	18.4	10.0	25.0
Basalt	4.6	6.3	12.0	41.2
Granite	7.6	10.0	9.4	11.6

**The onset of S deficiency can be rapid
when fertiliser types are changed.**

**This data comes from 30 sites in Australia and is
the % of sites responding to S after changing
from single superphosphate (11% S) to triple
superphosphate (1% S)**

Year 1 15%

Year 2 46%

Year 3 38%

Year 4 74%

Fertiliser S sources and their management

S sources for plants

Sulfates

- Gypsum
 - Ammonium sulfate
 - Potassium sulfate
 - Ammonium phosphate sulfate
 - Potassium and ammonium thiosulfate
-
- Immediately available but easily leached, particularly in soils with low S sorption capacity (neutral to alkaline pH)
 - Gypsum can be expensive to transport (11-16%S) and ammonium sulfate is the most acidifying N fertiliser

Elemental Sulfur

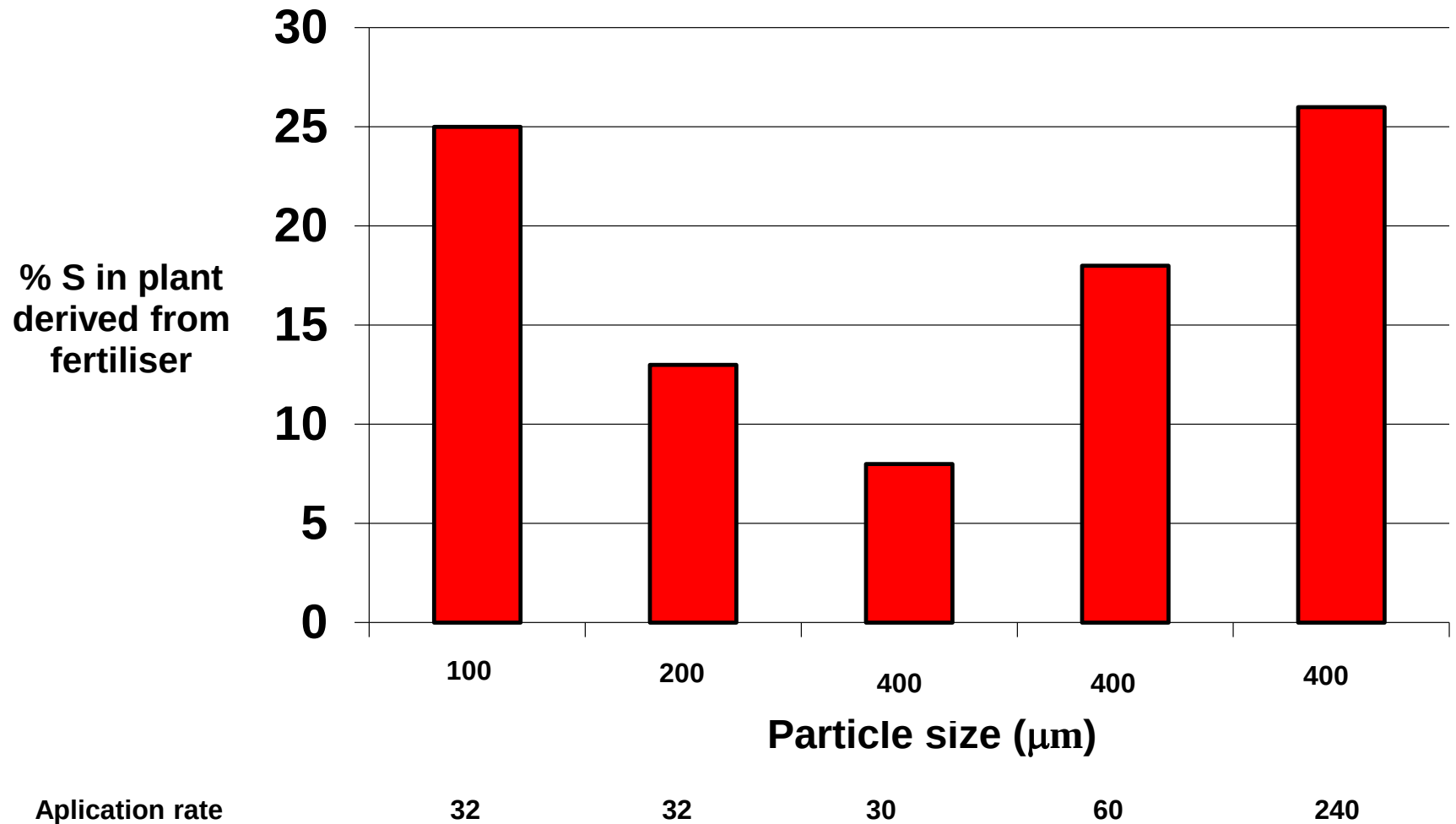
- Since S is absorbed by plant roots only in the sulfate form elemental S must be oxidized to sulfate before it is available to plants
- Oxidation is performed by micro-organisms in the soil



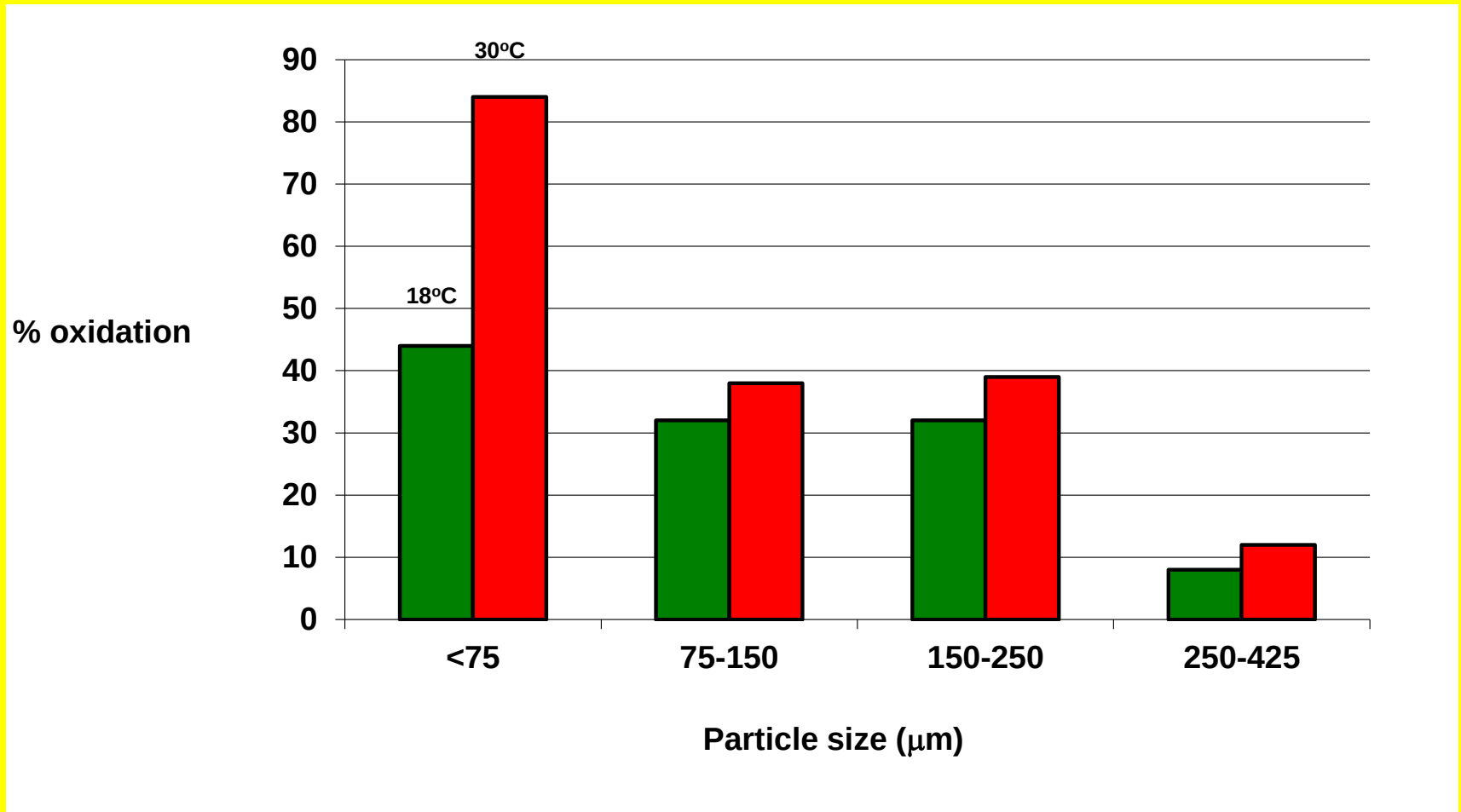
- It may take time to build up the micro-organism population in the soil, which may delay the effectiveness of elemental sulfur
- Phosphorus helps to increase the micro-organism population so inclusion of S in A/P encourages oxidation
- Elemental particle size also affects the oxidation rate (the larger the particle size the slower the oxidation rate)
- Good soil moisture conditions favour S oxidation
- Oxidation is increased by higher temperatures

Factors affecting elemental S oxidation and implications for management

Effect of particle size and rate of application on S oxidation



Effect of temperature and particle diameter on S oxidation at 6 weeks



S oxidation after 144 days (10 kg S/ha added)

Fertiliser	Plant uptake	Extractable soil sulfate	Organic S	Total recovery
		% of applied		
Gypsum	51.6	3.6	43.8	99.0
ES coated TSP	48.4	5.2	25.5	82.1
S Bentonite	23.1	8.8	26.4	58.7

S oxidation from different sources over 44 days

Fertiliser	Analysis (%)		Dry matter yield (g/pot)	% apparent S recovery
	Sulfate	Elemental S		
Control	0	0	4.11	-
S/Bentonite	0	90	5.81	2.8
PastureKing 17	3.9	13.1	9.47	31.7
MAPS =TSPS	3	5.9	11.68	42.9

The effect of banding ES (30 kg/ha) with P on % of applied S recovered in corn grown for 30 days.

	Elemental S	Gypsum
ES mixed with P	12.4	16.6
ES separated from P	2.7	17.0

Oxidising bacteria have a high P requirement so ES and P need to be applied in intimate contact

Effect of P on S oxidation after 6 weeks

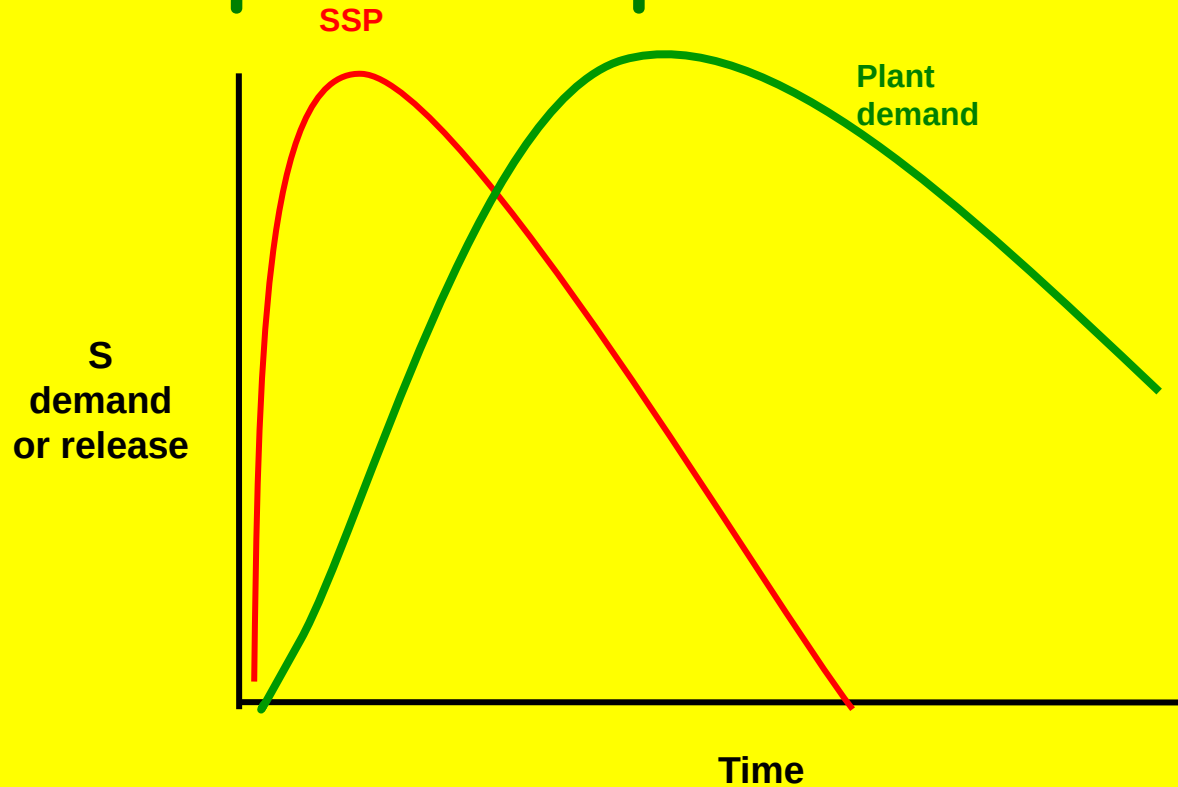
Treatment	S oxidation (%)	T. thiooxidans ($\times 10^7$ /g soil)
+ All nutrients	16.0	5.35
All - P	1.8	0.16
All - N	14.1	5.50

Oxidising bacteria have a high P requirement

Elemental S v sulfate S

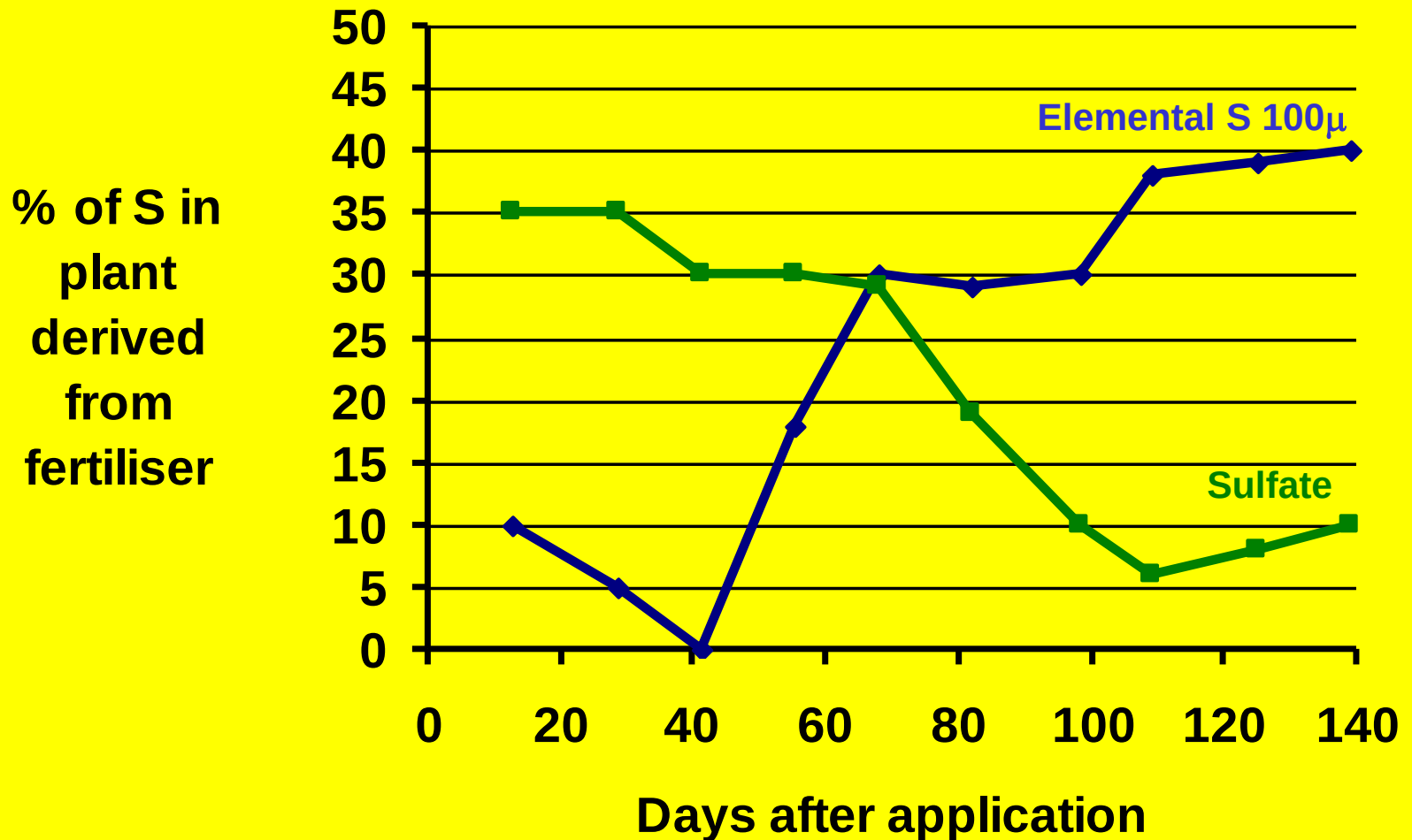
- **Sulfate sulfur in the soil is immediately available to plants, however:**
 - **Results in high plant S concentrations immediately after application and urine deposition**
 - **It is easily leached with the downward movement of soil water**
 - **Leaching of S is a major problem in sandy soils and neutral to alkaline soils which have a low ability to retain sulfate**
- **Gradual oxidation of elemental S to sulfate S**
 - **Supplies sulfate to plants throughout the growing season and minimises leaching losses**
 - **Makes negligible contribution to soil acidification**

The sulfate S in SSP is released immediately into the soil which, most often precedes plant demand



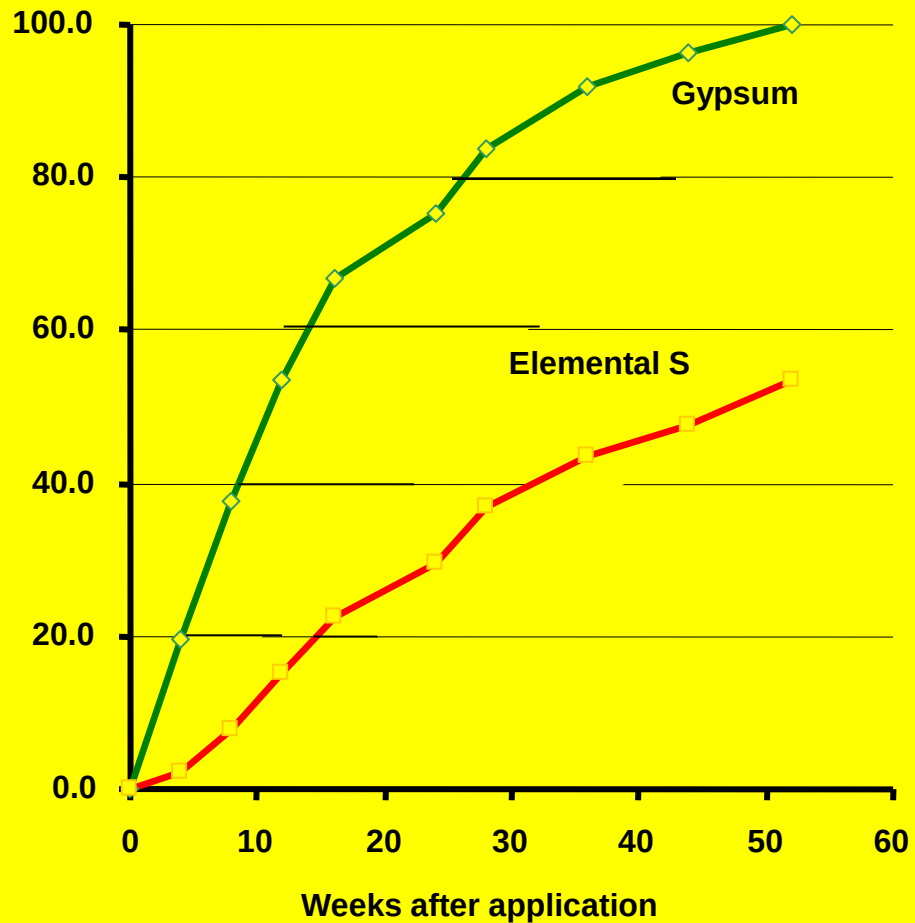
Sulfate sulfur is in danger of being leached before it is needed by plants
Additional applications of sulfur will be required to meet plant needs over the growing period

Plant S uptake from sulfate and 100 μ diameter elemental S



Leaching losses from gypsum are often much greater than from elemental S

Relative S leached
(Gypsum at 52 weeks=100)



High S concentration clover following SSP application results in high S leaching from urine patches and movement to sheep and cattle camps

	Gypsum	Elemental S
Average S concentration in clover 44d after fertiliser application (Flavel, UNE)	0.22	0.13
Estimated kg S/ha in urine patch	150	50

Different crops require S at different times so the fertiliser used needs to meet this demand

Crop	Growth stage		
	Seedling	Active growth	Post flowering
<i>% of fertiliser S taken up</i>			
Mustard	9	38	53
Rice	32	5	63
Cotton	77	26	0

Determining the appropriate fertiliser S source

S fertiliser comparisons

- As transport and spreading costs rise nutrient density (nutrient concentration in the fertiliser) becomes more important
- SSP with 8.5%P and 11%S is low density and all the S is as sulfate
- TSPS with 18%P and 10%S requires about half the application rate to supply the same amount of P as SSP and the lower S application rate is counteracted by a more efficient utilization of the S because the ES is oxidized at a rate in synchrony with plant demand, which minimizes leaching

Initial and residual response to S in pastures at Walcha, NSW

S source	S recovery in plants (% of applied)		
	0-11 months	11-23 months	Total over 23 months
E° 250-595 μ	1.8	4.2	6.0
E° 149-250 μ	5.5	8.3	13.8
E° <149 μ	13.0	7.0	20.0
Gypsum	18.0	0.4	18.4

Source: Weir et al. (1963) *Australian Journal of Experimental Agriculture and Animal Husbandry* 3(11) 314 - 318

Effect of S source on maize S content after 44 days

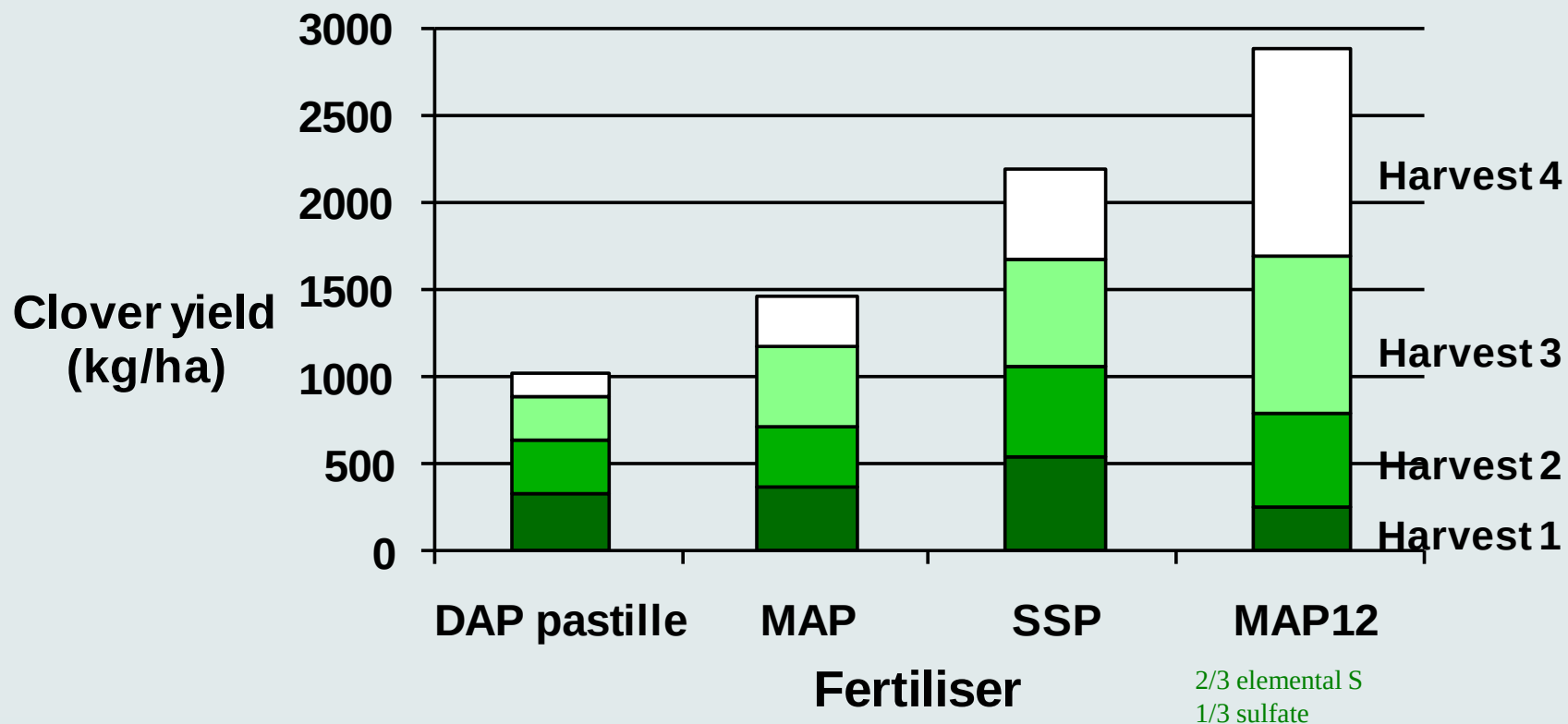
(Flavel, UNE, pot study)

Fertiliser	%S in leaf	Total S uptake (mg)	Recovered S (%)
Control	0.079	2.4	0.0
Gypsum	0.218	10.2	43.4
< 48.1 μm S ^o	0.152	7.0	25.6
75-150 μm S ^o	0.111	5.3	16.0
MAP12*	0.136	6.1	20.5

* 1/3 sulfate, 2/3 fine elemental S

S source and white clover yield

Armidale, NSW



Pastilles made from molten S have low surface area and hence slow oxidation

Armidale grazing trials

Year	TSPS	SSP	TSPS	SSP
	Wool (kg/ha)		(\$/ha)	
2010-11	62.0	53.4	773	637
2011-12	37.8	34.5	358	327
Average 2010-12	49.9	44.0	566	482

Fertilisers applied at the same \$/ha

Handling properties and physical spreading distribution

• **Physical spreading distribution**

• **Handling properties**

• **Physical spreading distribution**

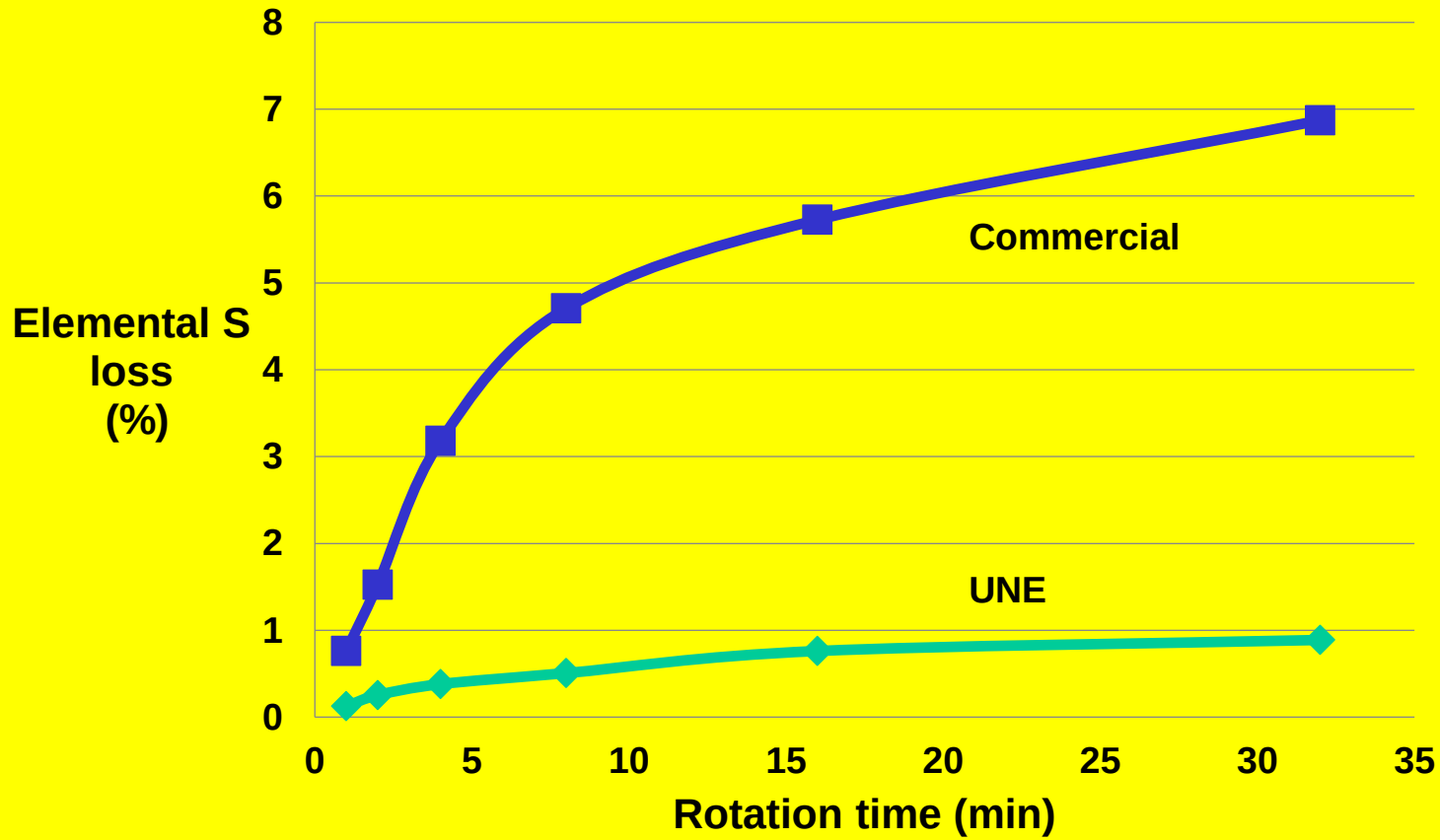
• **Handling properties**

• **Physical spreading distribution**

• **Handling properties**

Loss of elemental S from coated fertilisers

Source: Dana et al (1994) AJAR 45, 1539



Inclusion of ES in the granule reduces “dust”

Distribution of S fertiliser when applied at 10 kg/ha

	Broadcast (granules/m ²)	Drilled (granules/m)
S-bentonite	25	5
S coat or incorporation into granule	250	50

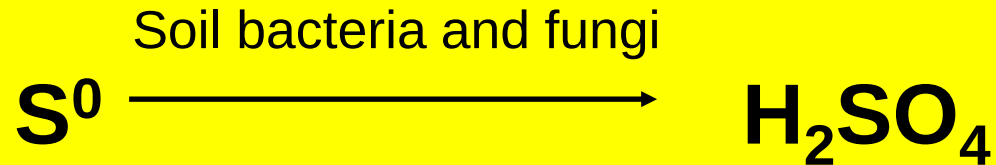
Having the ES in each granule not only increases S oxidation rate but results in better spatial distribution of the S

Distribution of S within fertiliser granules

- Average of 58300 granules/kg TriplePluS
- 50 kg/ha = 2 195 000 granules or 291 granules/m²
- 70 kg/ha = 3 731 000 granules or 373 granules/m²

Elemental S and soil acidification

Oxidation of Elemental S



Neutralisation with lime

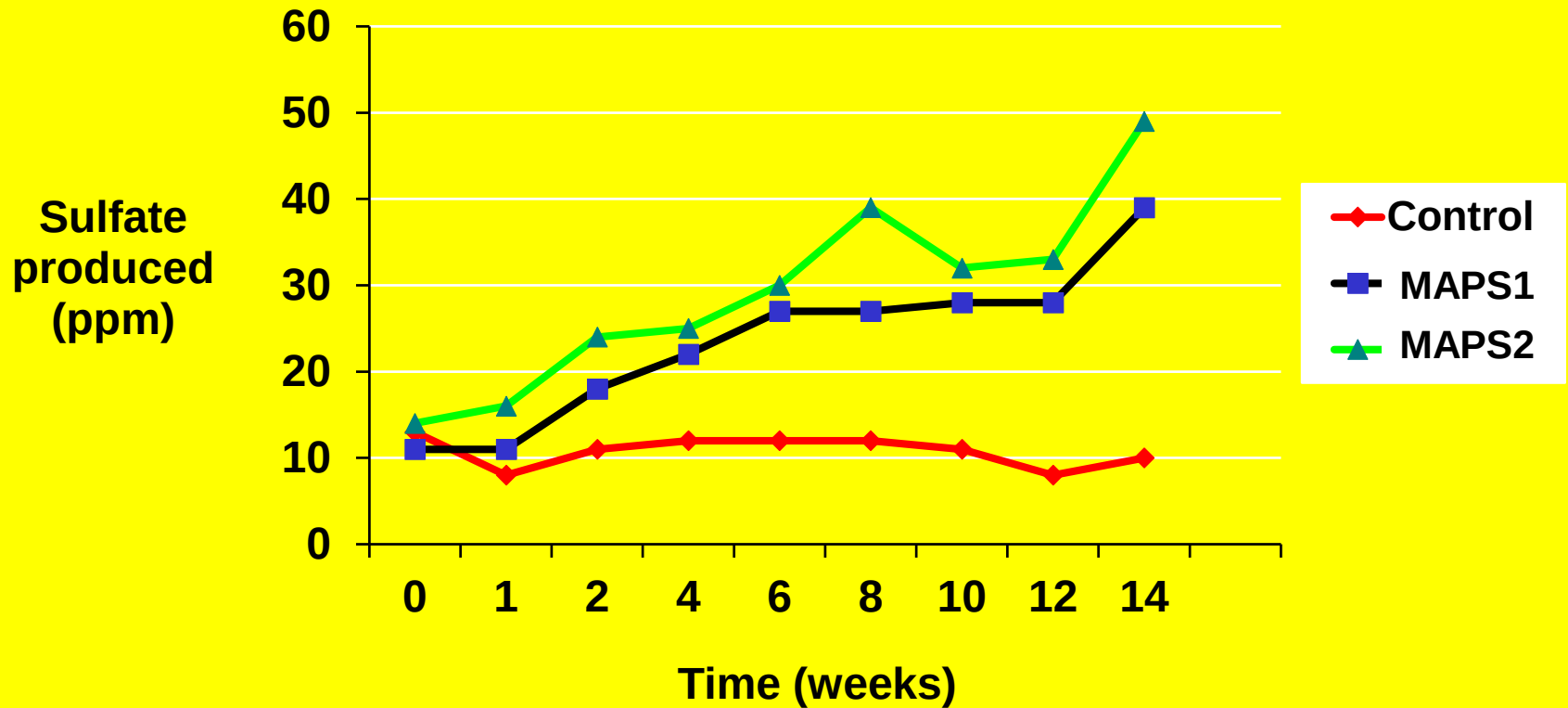


1 kg S theoretically requires 3.1 kg of lime to neutralise the H_2SO_4 produced

Theoretical acidifying effect of N and S fertilisers

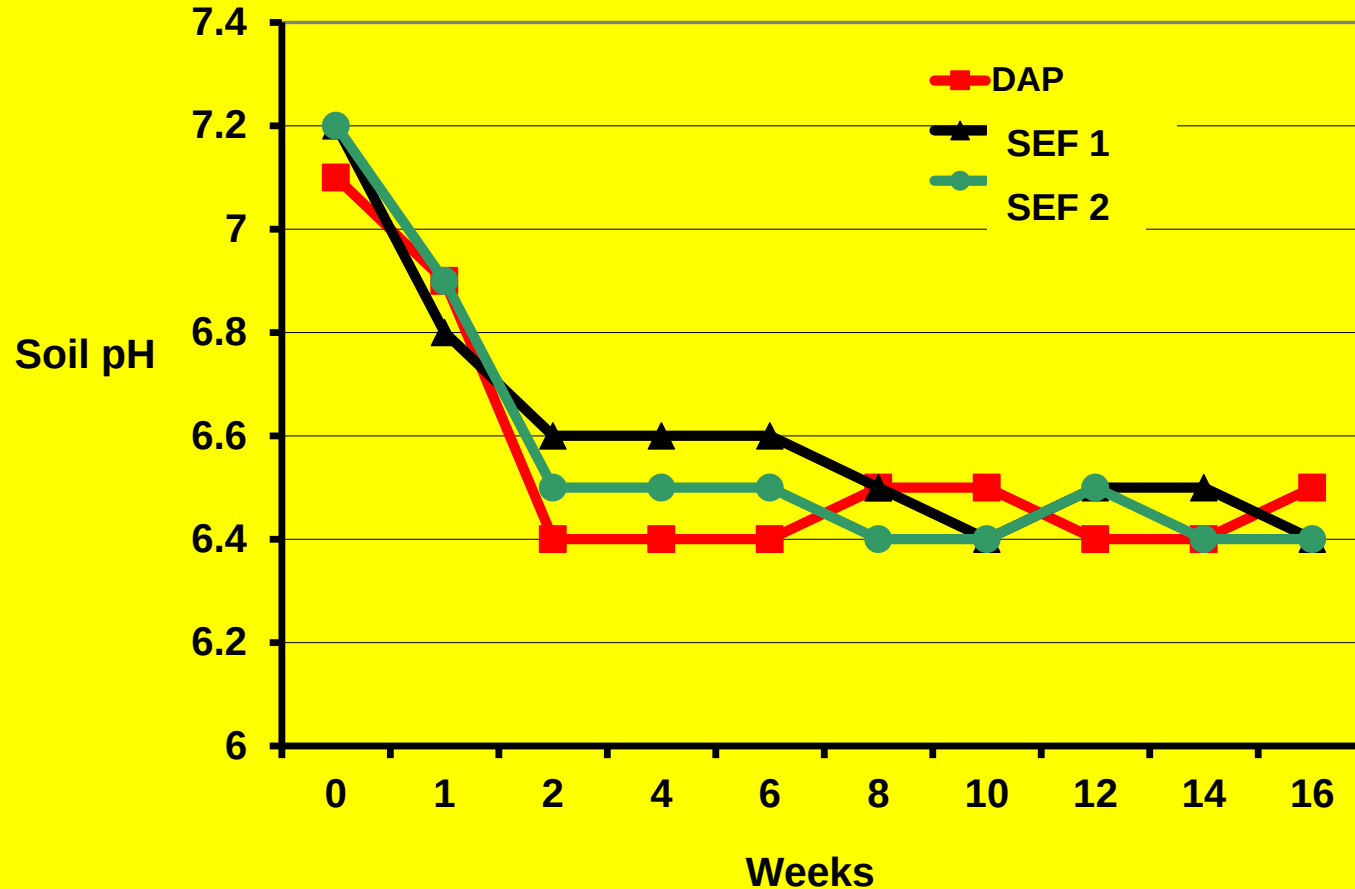
Fertiliser	% N or S	Kg of lime to neutralise 1 kg N or S	Kg of lime to neutralise 150 kg N/ha or 30 kg S/ha
Ammonium sulfate	21	5.4	810
Urea	46	1.8	270
DAP	18-21	3.5	525
Elemental S	11	3.1	93

Sulfate oxidised from elemental S in MAP during incubation



- No sulfate was produced in the control treatment where no S was added
- Sulfate was produced from both products showing that the elemental S was oxidizing

Effect of Selected Fertilisers on Soil pH



The drop in soil pH was due to the DAP, either applied alone or present in the SEF. There was no additional effect of the S in the SEF.

S application rate: 100 ppm or 200 kg/ha.

Neither SSP nor MAPS affected soil pH in Heilongjiang, China trials

Site	Crop	Before seeding	Control	MAPS	SSP
Harbin	Soybean	6.7	6.7	6.6	6.6
Shuanchen	Corn	7.9	7.9	7.9	7.9
Qingan	Rice	6.5	6.6	6.5	6.6

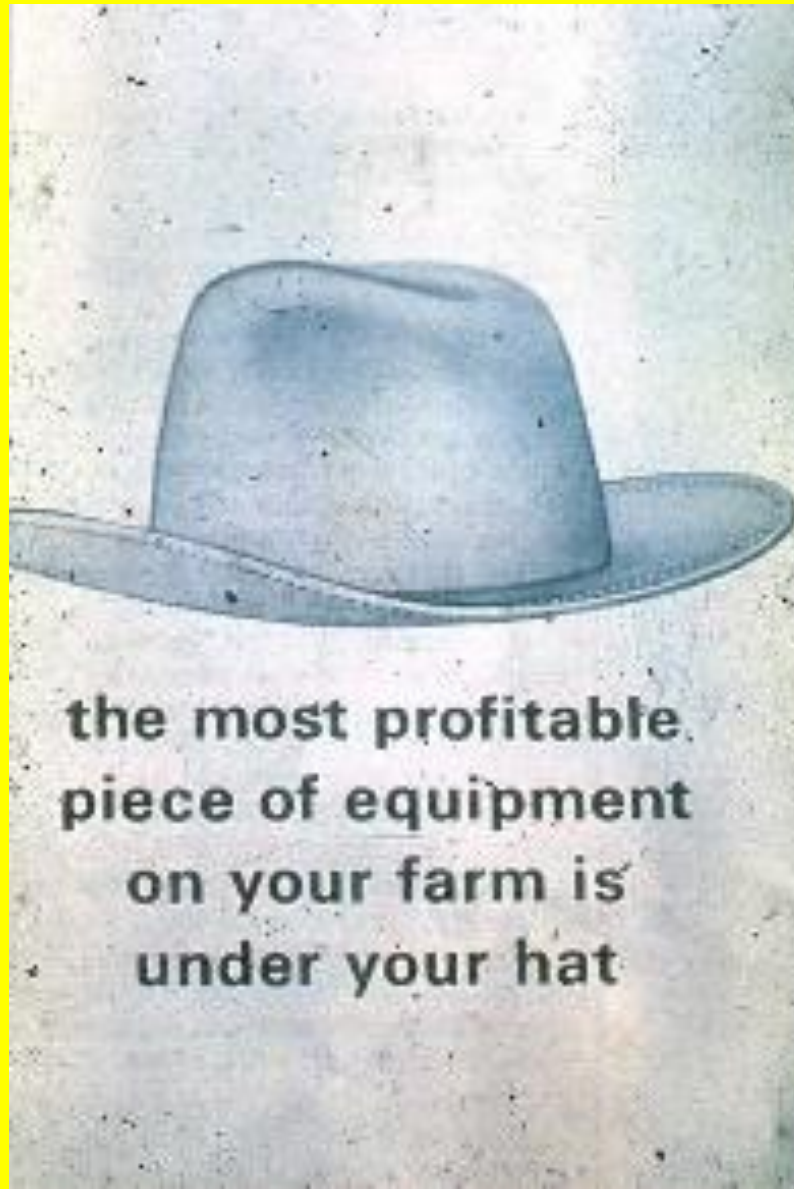
Development of TSPS

- **Because of the 2P:1S requirement to maintain the nutrient cycles TSP became a preferred base for a pasture fertiliser**
- **The high nutrient density in TSP (18%) compared with SSP (8.9%) means lower transport and spreading costs**
- **In designing TriplePluS I sought to provide an immediate supply of S via sulfate and to provide elemental S with a fine particle size to release S throughout the growth of the pasture or crop**

Conclusions

- The choice of S fertiliser source needs to be based on
 - its agronomic performance in the crop immediately after application and residual value
 - its handling properties, and
 - cost
- The agronomic performance of both gypsum and elemental S can be manipulated by altering particle size
- Addition of elemental S to fertilisers is an effective way of adding S
- Providing a combination of sulfate and elemental S provides short and longer term S availability
- Modern farming requires high analysis fertilisers of high quality which contain S
- Incorporation of elemental S within the granule provides both high analysis and good handling qualities

Final word



**the most profitable
piece of equipment
on your farm is
under your hat**