MANAGING SOIL ACIDITY IN THE SHORT AND LONG TERMS

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The objectives of research on farming systems

- Improved productivity and profitability
  - the short-term imperative.
  - lime, tolerance, enterprises that are currently profitable.
  - to beat the cost-price squeeze.
- A sustainable production system
  - the long-term necessity.
  - the demand for sustainability constrains the scope of profitable systems that can be used.

Acid production processes

- Understanding the processes
- Effects of the acid reactions and transport
- The implications for management

Understanding acidification processes: the biological cycling of C and N

- **C CYCLE**
- Association/dissociation of added organic acids
  - $RCOOH = RCOO^- + H^+$
- Oxidation of organic anions
  - $RCOO^- + H^+ = RCOOH = CO_2 + H_2O$
- Synthesis organic acids and dissociation
  - $C_6H_{12}O_6 = RCOOH = RCOO^- + H^+$

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- **N CYCLE**
- **Ammonification**
  - **$RNH_2 + H^+ = NH_4^+$**
- **Nitrification**
  - **$NH_4^+ = NO_3^- + 2 H^+$**
- **Denitrification**
  - **$NO_3^- + H^+ = N_2, N_2O$**
- **Excretion of H^+ or OH^-, (HCO_3^-)**
  - **H^+ excreted if cation uptake exceeds anion uptake**
  - **OH^-, (HCO_3^-) excreted if anion uptake exceeds cation uptake**

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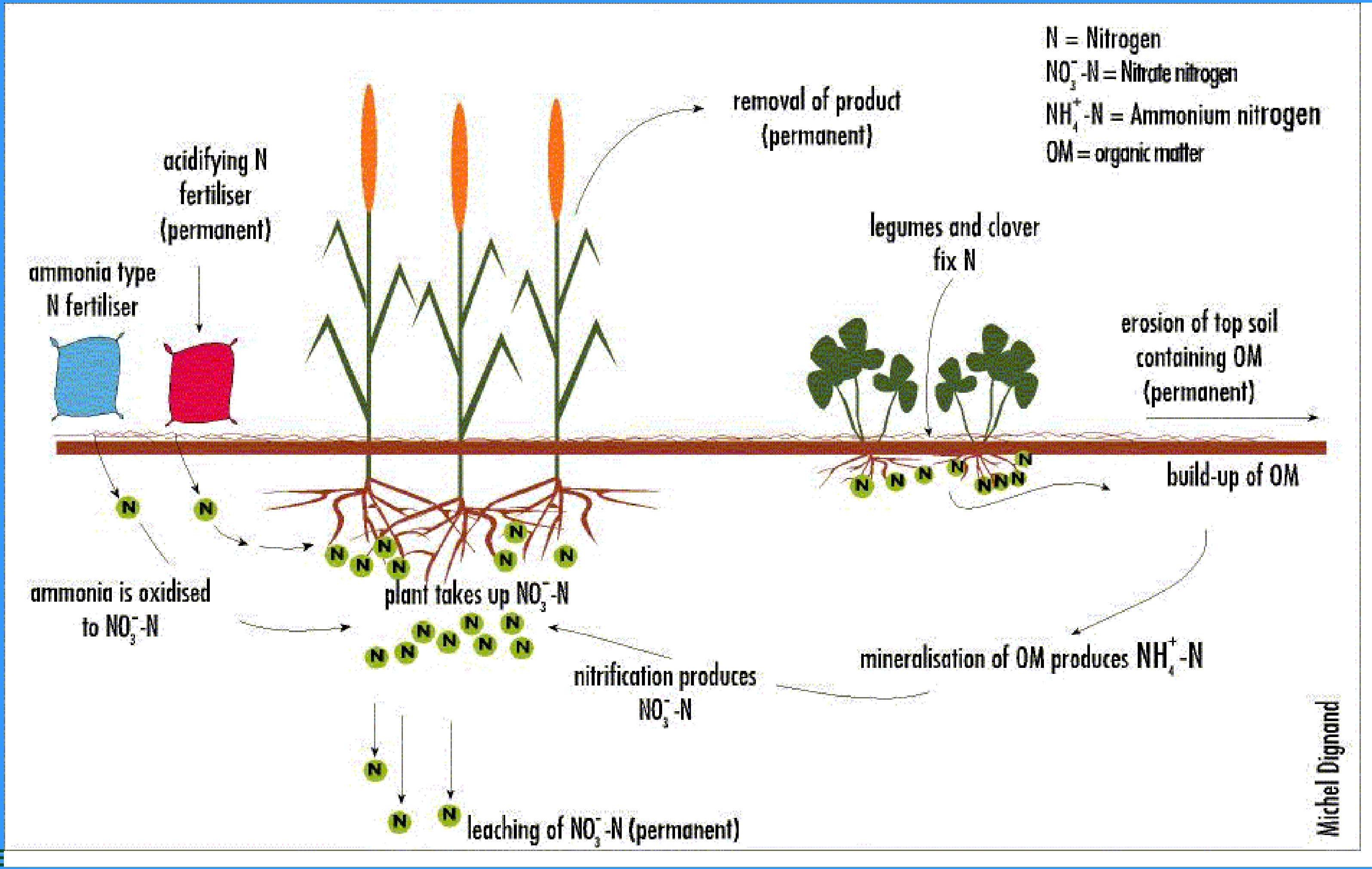
- **Plant processes that indirectly affect soil acidity**
- The reduction of nitrate (plants, micro-organisms)
  - $NO_3^- + (RCOOH) + 4H_2 = NH_3^0 + 3H_2O + RCOO^-$
- Ammonium metabolism
  - $NH_4^+ + C_6H_{12}O_6 = RNH_2 + H^+$
- Production of organic acids in plants (TCA cycle)

$$(CH_2O)_n + O_2 \rightarrow CH_3(CH_2O)_{n-3}COOH + H_2O + CO_2$$

Review of C and N cycle processes



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Leaching, H^+ addition from carbonic acid and weathering reactions

- If CO_2 soil air > CO_2 atmosphere and the pH is in the range 5.5 to 7.4 then net H^+ addition from $CO_{2(g)}$ occurs

$$CO_{2(g\,soil\,air)} + H_2O \Leftrightarrow H_2CO_3$$

$$\left.\begin{aligned} H_2CO_3 &\Leftrightarrow HCO_3^- + H^+ \\ HCO_3^- &\Leftrightarrow CO_3^{2-} + H^+ \end{aligned}\right\} \quad pH > 5.5$$

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Consumption of acid in weathering reactions

$$CaCO_3 + \boxed{2H^+} \Leftrightarrow Ca^{2+} + CO_{2(g)} + H_2O$$

Illite

$$K_{0.6}Mg_{0.25}Al_{2.3}Si_{3.5}O_{10}(OH)_2 + \boxed{8H^+} + 2H_2O \Leftrightarrow 0.6K^+ + 0.25Mg^{2+} + 2.3Al^{3+} + 3.5H_4SiO_4^0$$

Kaolinite

$$Al_2Si_2O_5(OH)_4 + \boxed{6H^+} \Leftrightarrow 2Al^{3+} + 2H_4SiO_4 + H_2O$$

$$Al(OH)_3 + \boxed{3H^+} \Leftrightarrow Al^{3+} + 3H_2O$$

Adsorption/desorption H^+ at pH dependant CEC sites

Organic matter

$$RCOO^-K^+_{(ex)} + \boxed{H^+} \Leftrightarrow RCOOH + K^+$$

Clay mineral and oxide edges

$$\begin{matrix}(>Fe) \\ >Al \\ (-Mn)\end{matrix} O^-K^+_{(ex)} + \boxed{H^+} \Leftrightarrow \begin{matrix}(>Fe) \\ >Al \\ (-Mn)\end{matrix} - OH + K^+_{(sol)}$$

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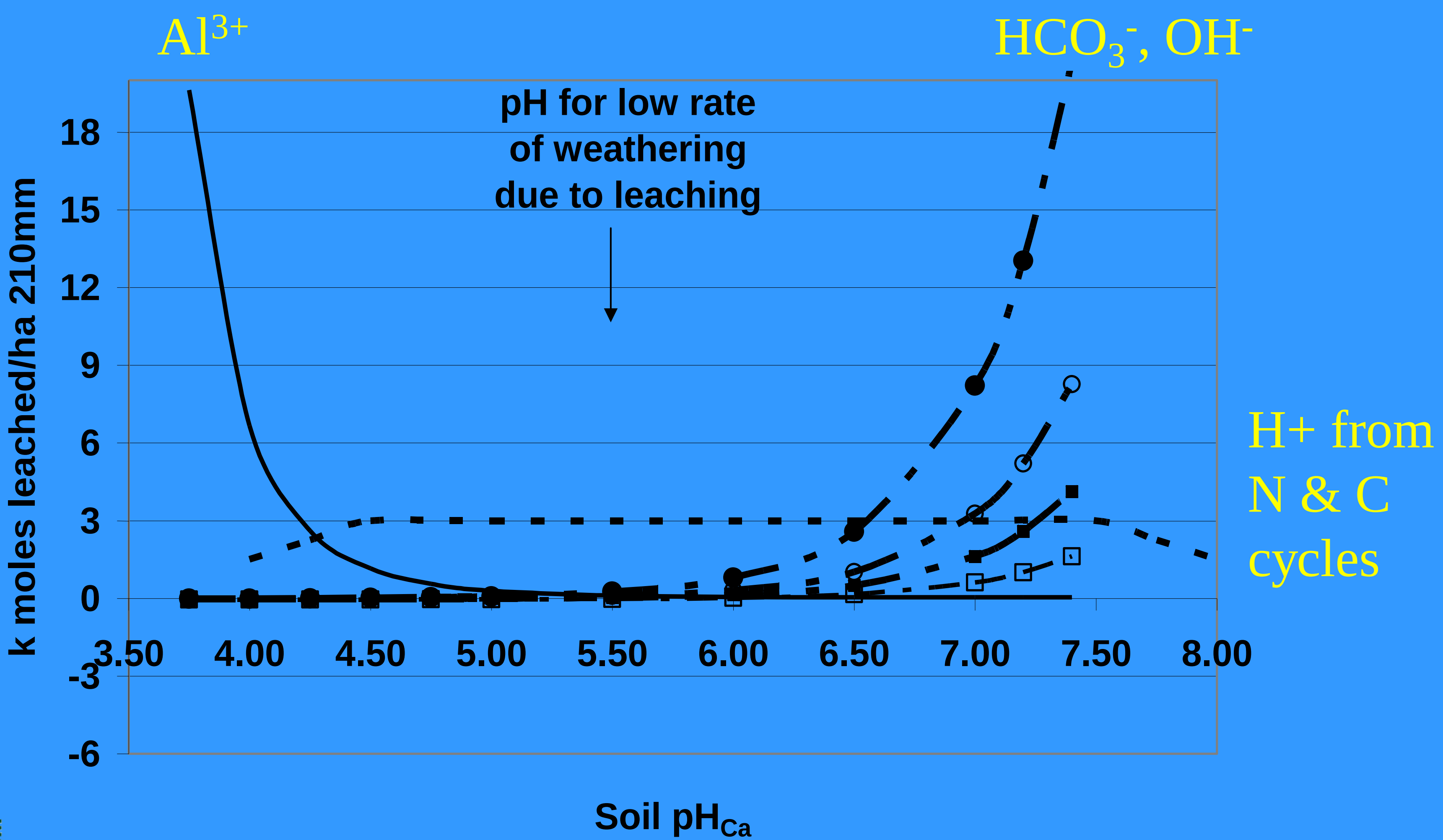
Review of leaching and weathering effects



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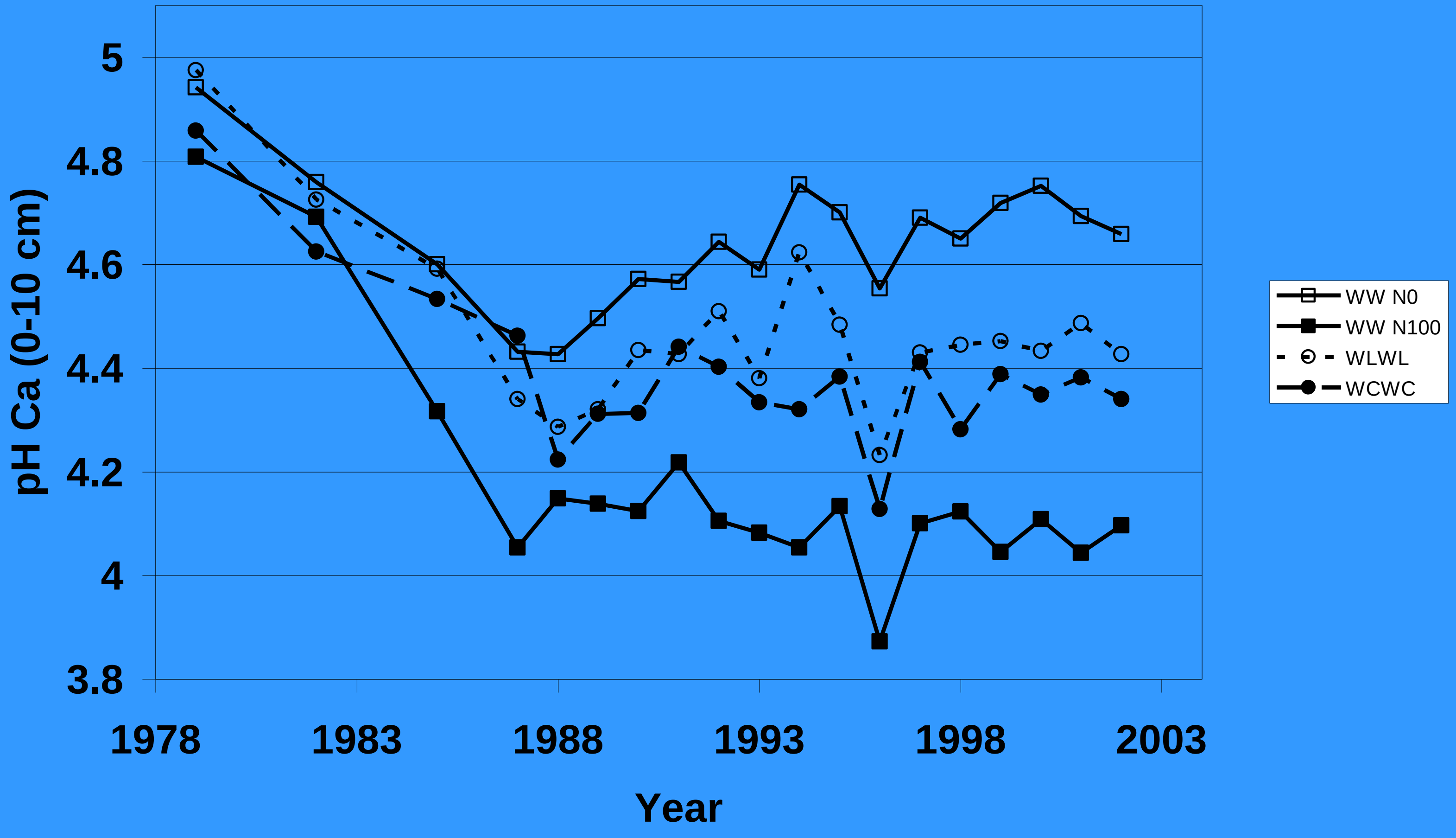
Equilibration of pH in a layer for different production systems (Heenan et al.)



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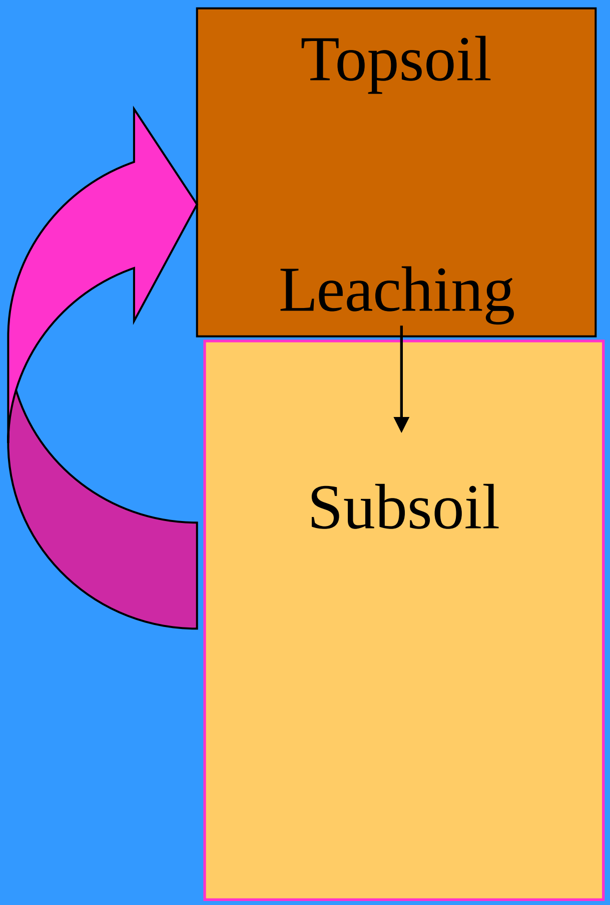
Profile processes

Uptake of nutrients and return of residues

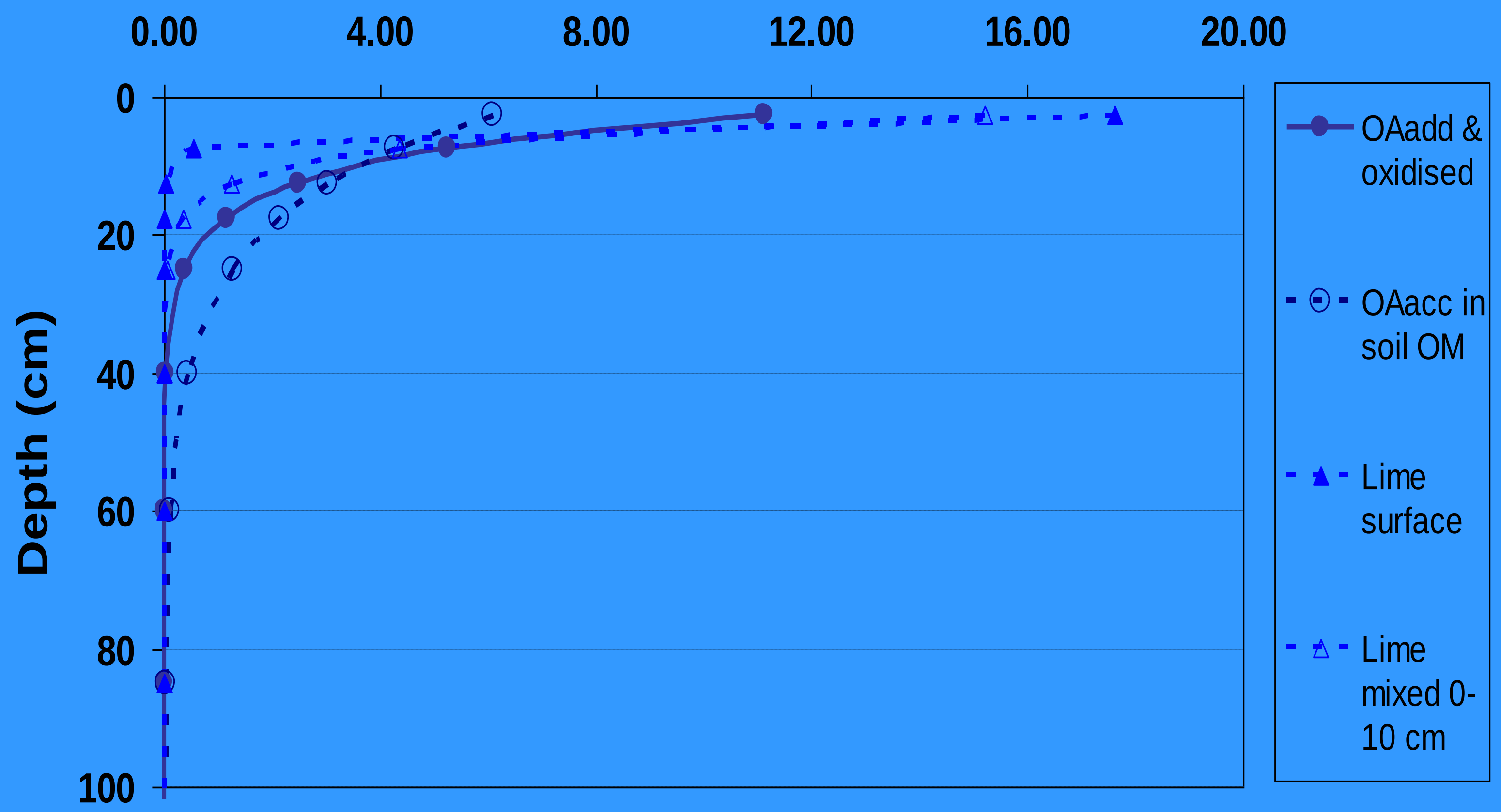


Most activity:

• ammonification, nitrification, residues, most organic matter, etc. exponential trends

•Subsoil: water and nitrate uptake, uptake leached nutrients, accumulation leached elements.

Exponential functions C cycle processes (% of organic anions oxidised etc./cm)



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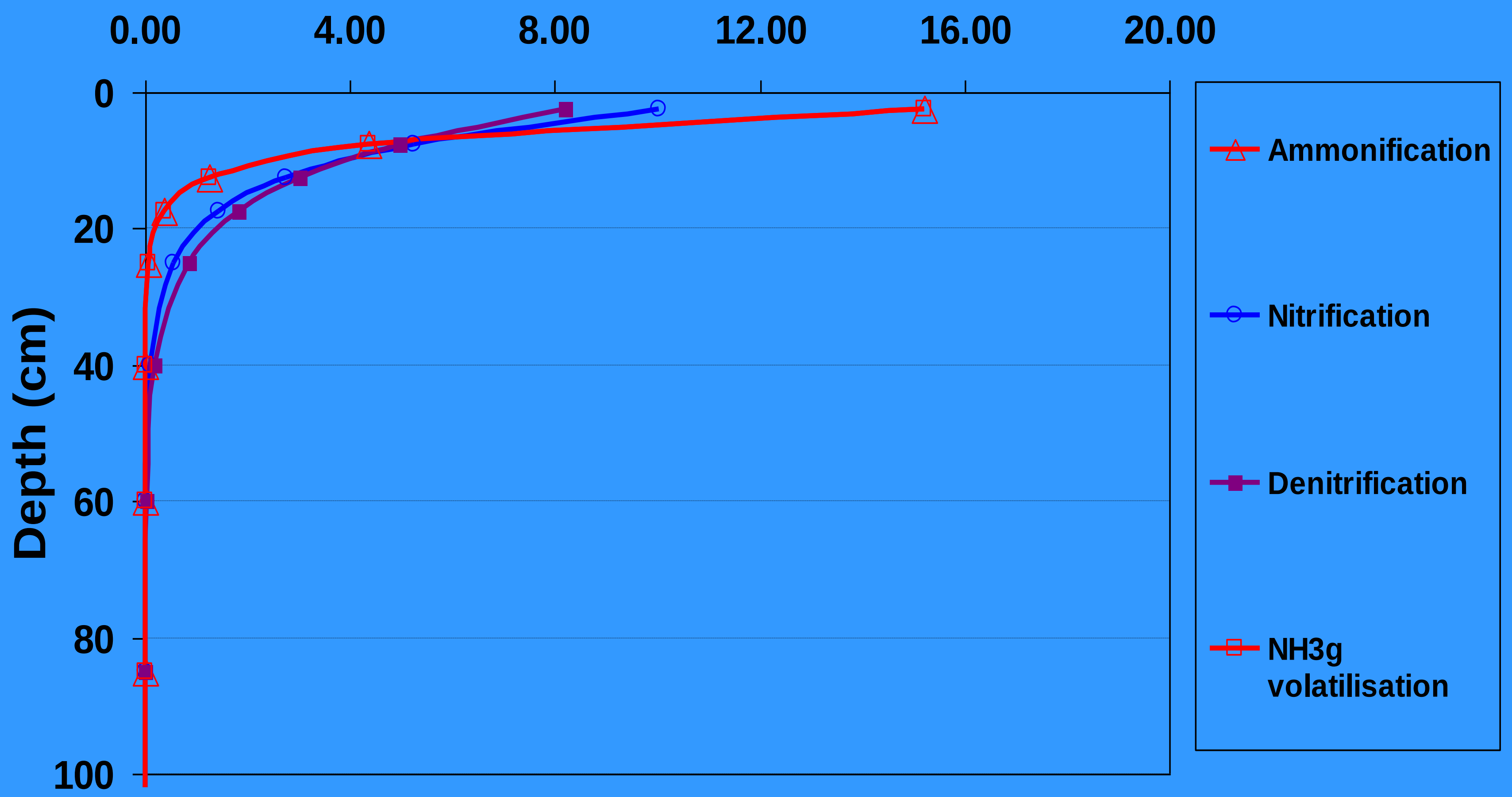
Exponential functions for N cycle processes (% of nitrification etc./cm)



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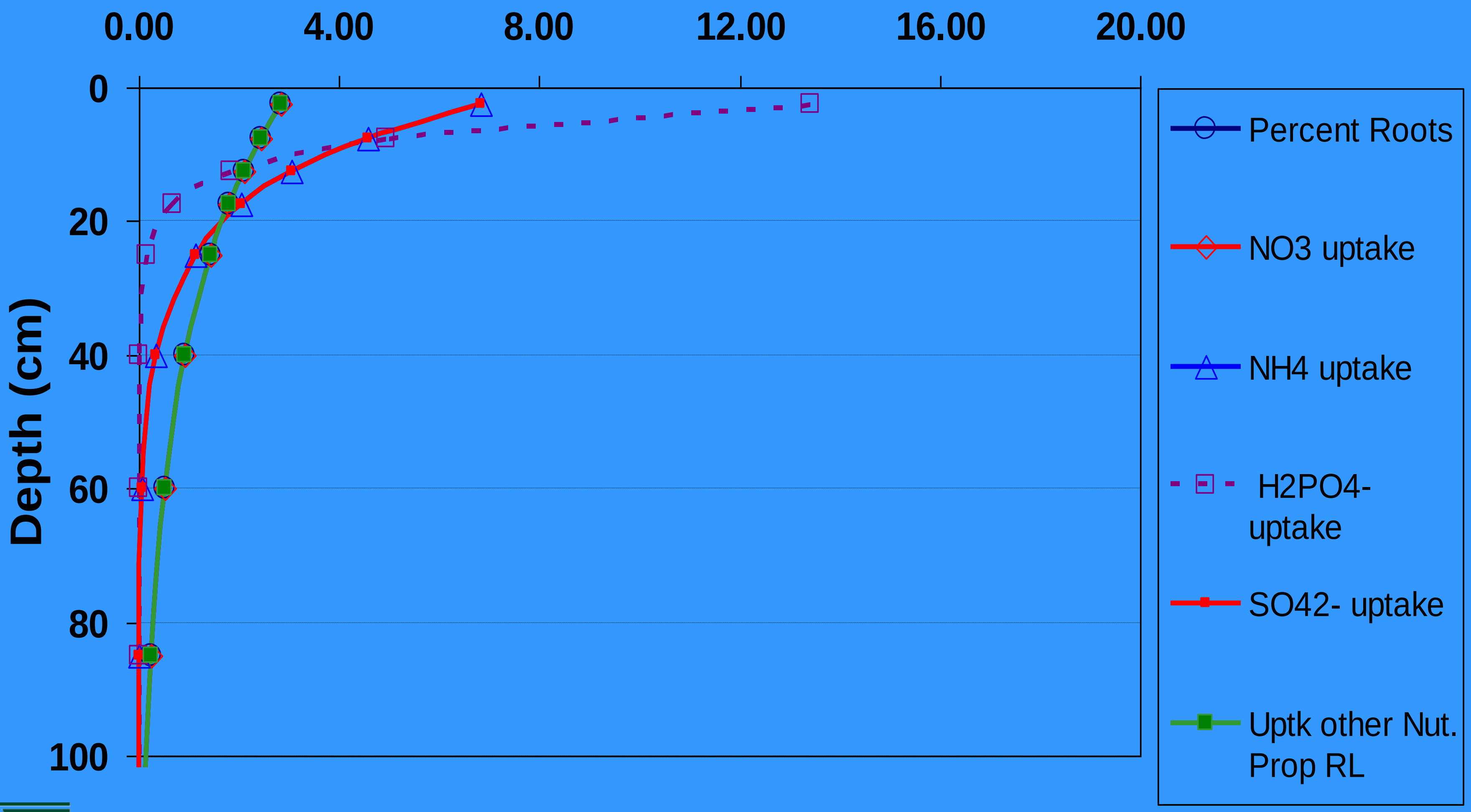
Exponential functions for ion uptake
(% of nitrate uptake etc./cm)



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Net acid addition all acids and lime (H^+ +ive, OH^- -ive, kmol/ha.cm/year)

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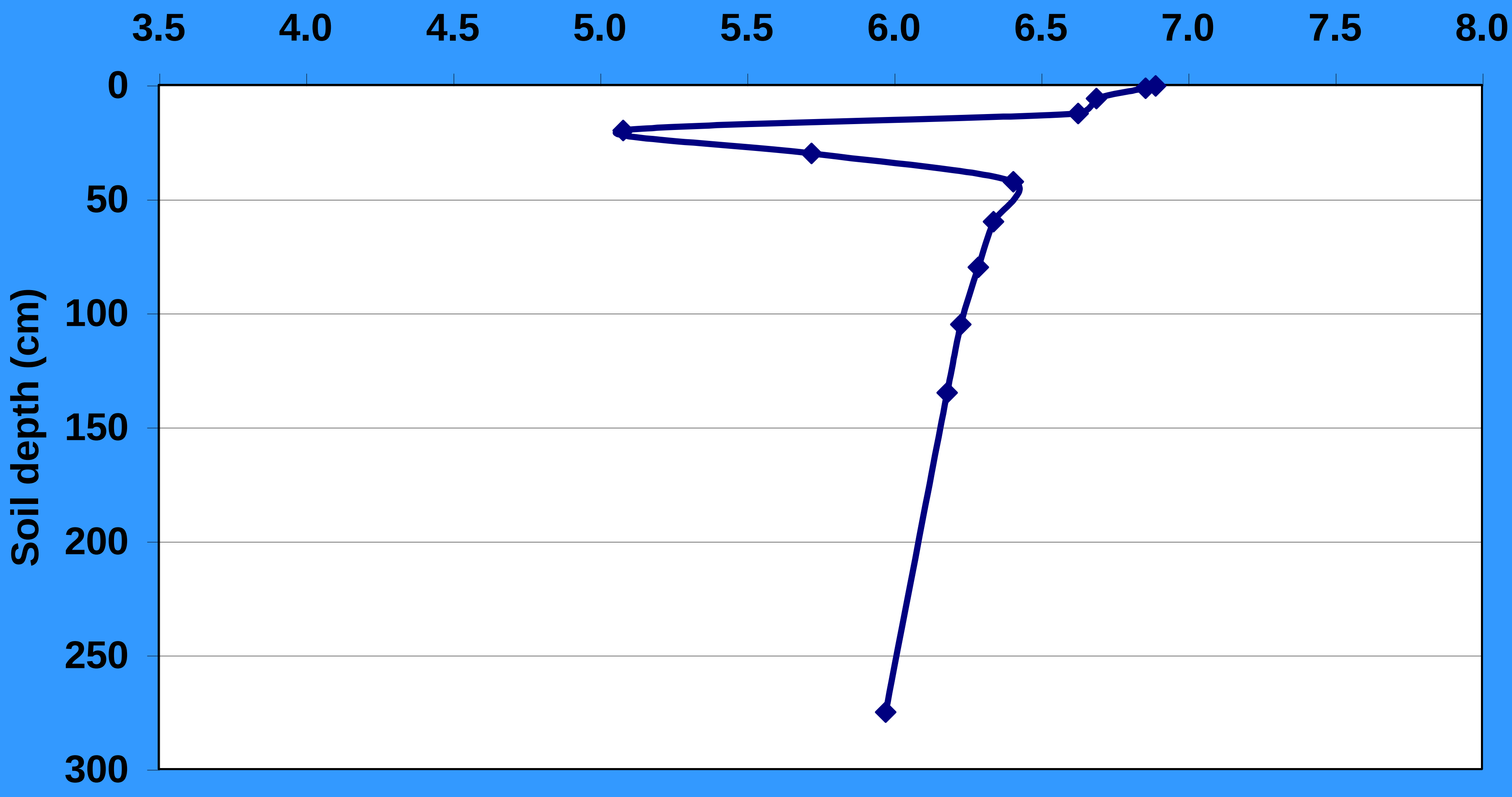
Steady-state pH profile lowest pH 5.0



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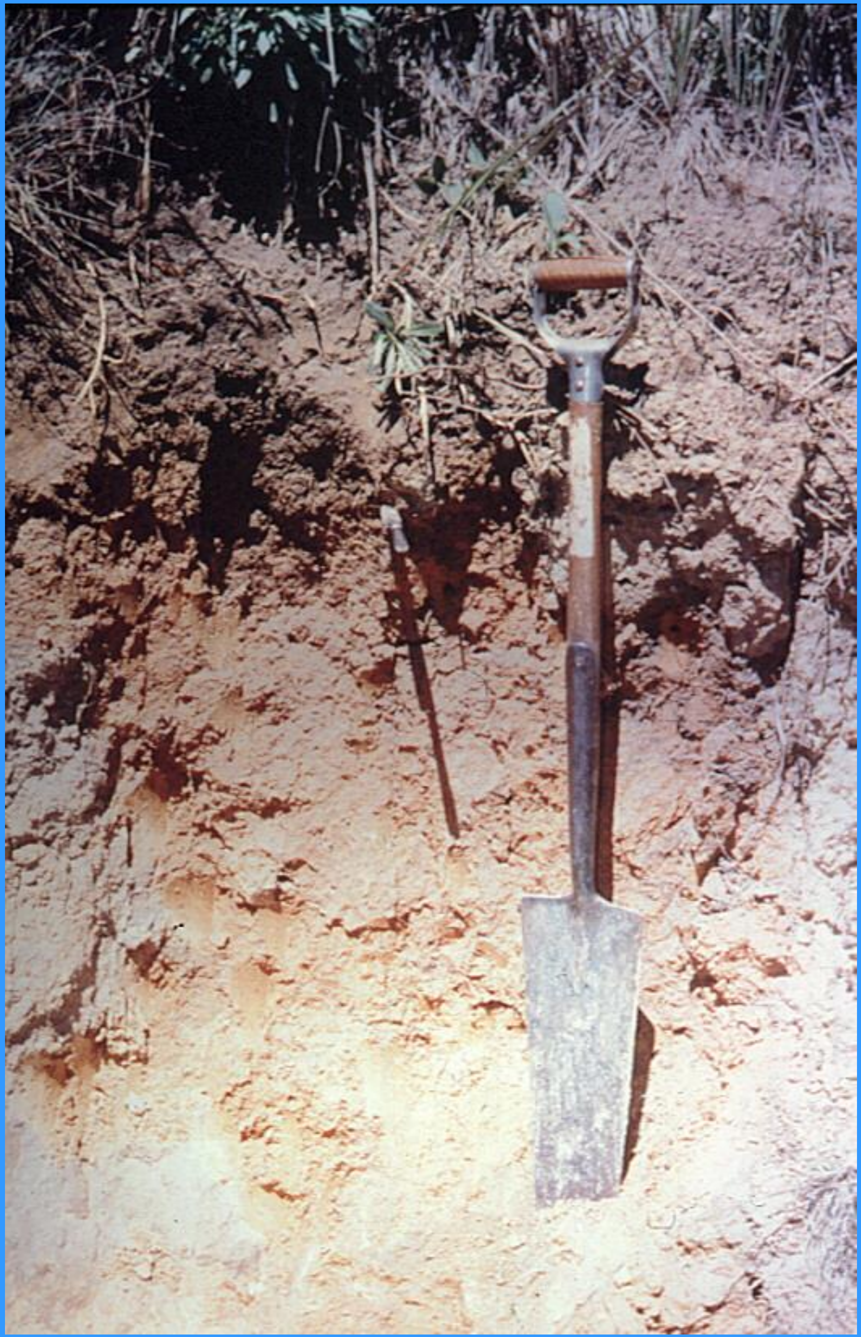
Effects of management on the pH profile

NO_3 absorption profile	i) Same as nitrification	ii) Deeper than root system	Half way between i) and ii)
NO_3 leached	0	5 (5)	0.1
kg $CaCO_3$ equiv. /ha/year	84	96 (187)	84
Lime required kg/ha/year	84	192 (194)	84
Depth min. pH	120 – 150	15 – 25 (70 – 90)	120 – 150
pH0 – 10 cm	6.8	6.8 (6.9)	6.9
15 – 25 cm	6.5	5.0 (6.5)	6.5
70 - 90 cm	6.9	6.3 (5.0)	6.3
90 – 120 cm	6.3	6.3 (5.6)	6.3
120 – 150 cm	5.0	6.2 (6.2)	5.0

Yellow solodic / Sodosol



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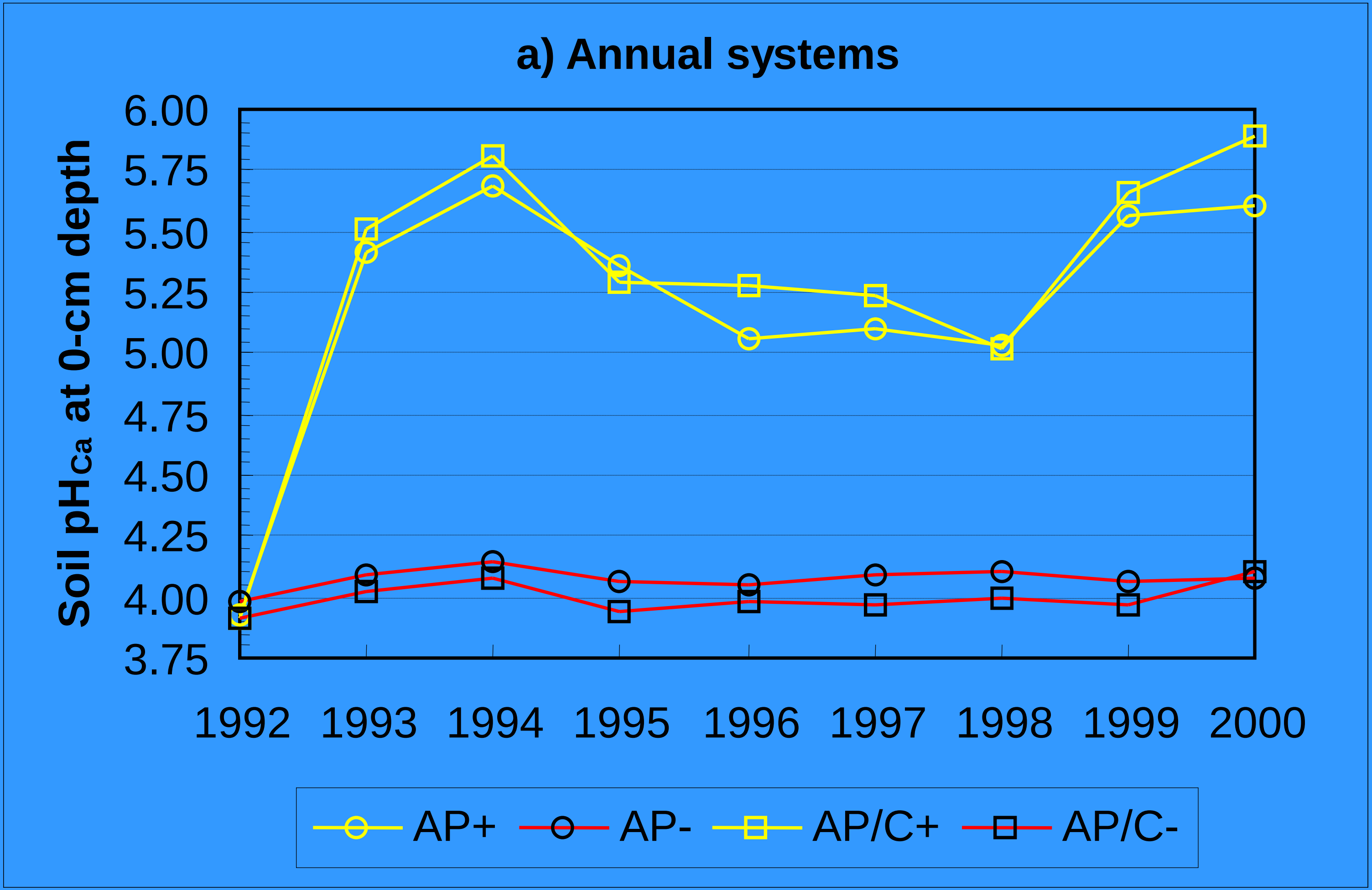
Solodic soil MASTER expt (Li *et al*., 2000)

Depth	pH	ECEC	%Al†	%Mg	%Na	%Ca
0-10	4.13	2.58	31.0	13.6	5.7	62.2
10-20	4.22	1.69	42.6	16.8	5.3	54.6
20-30	4.57	2.32	15.6	23.1	4.6	59.5
30-40	4.87	4.23	4.7	33.5	5.6	55.9
40-50	4.96	7.19	2.3	43.6	6.5	47.0
50-60	5.02	9.35	1.9	50.5	7.5	39.6
60-80	5.22	11.25	1.5	57.3	8.9	31.6
80-100	5.59	13.81	0.6	60.9	10.3	26.8
100-120	6.24	18.14	0.1	61.1	11.7	25.7

†

Soil pH_{Ca} at 0-10 cm depth



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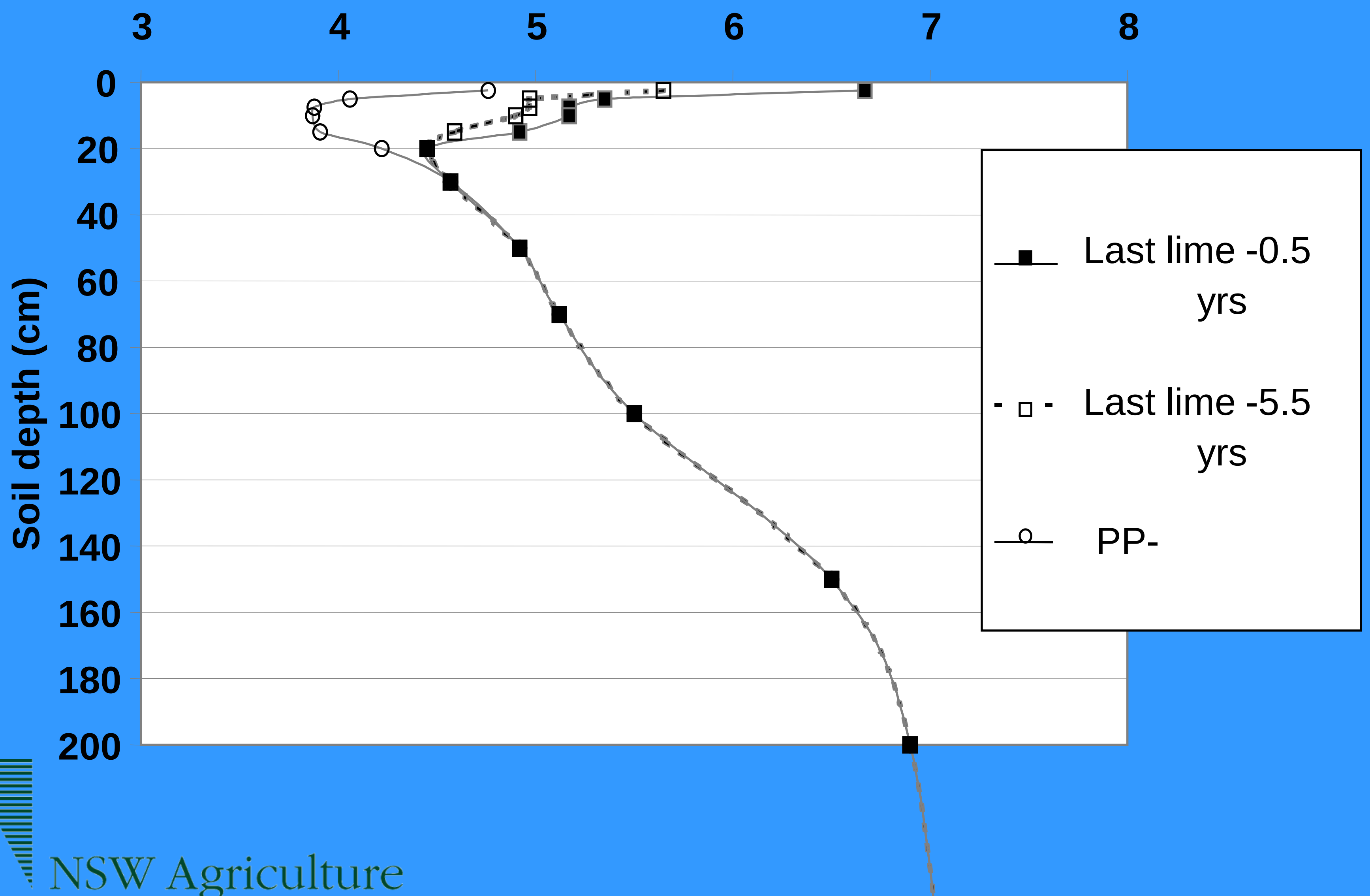
MASTER pH profiles 1999, phalaris/clover



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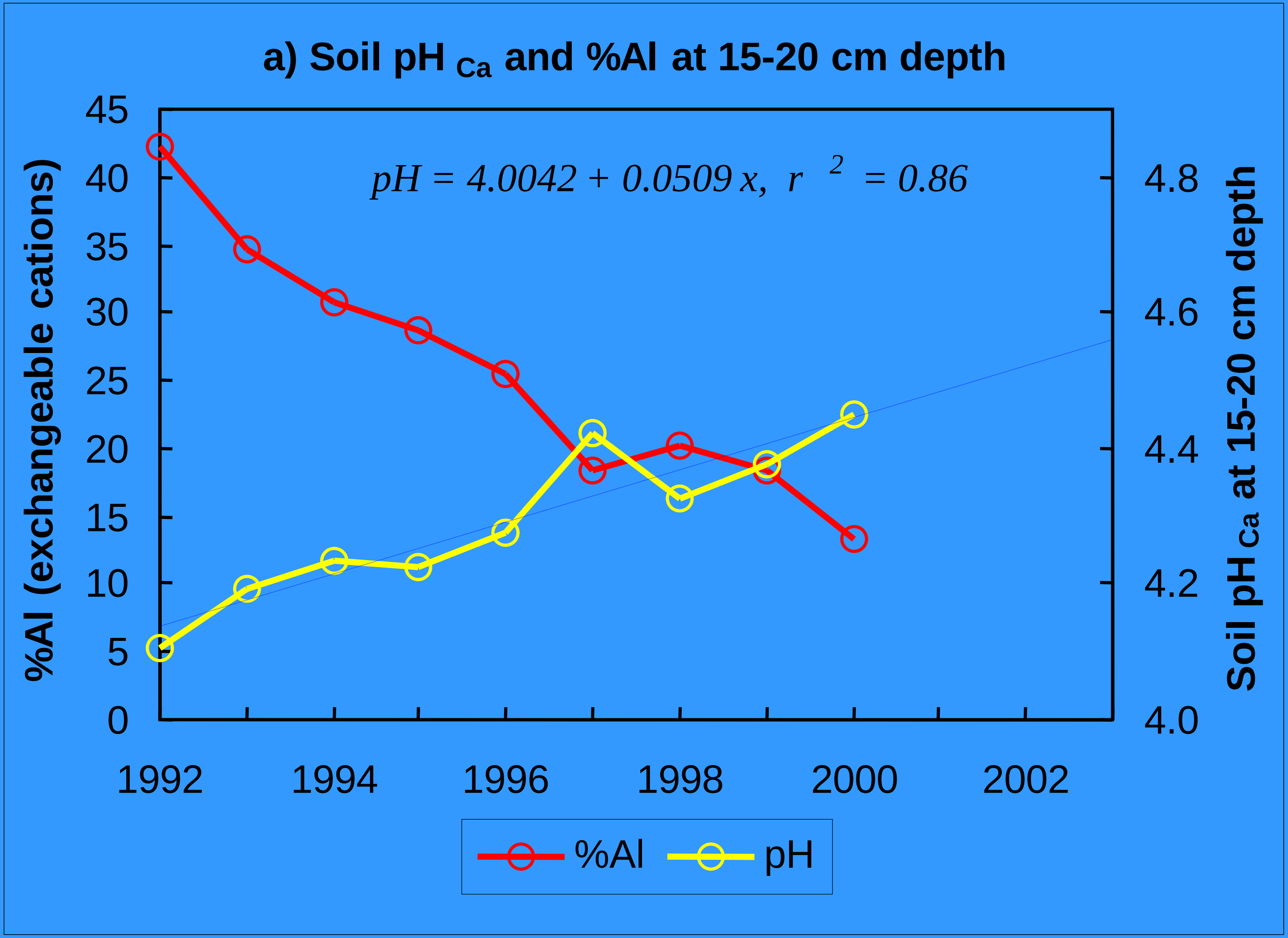
Subsoil acidity amelioration



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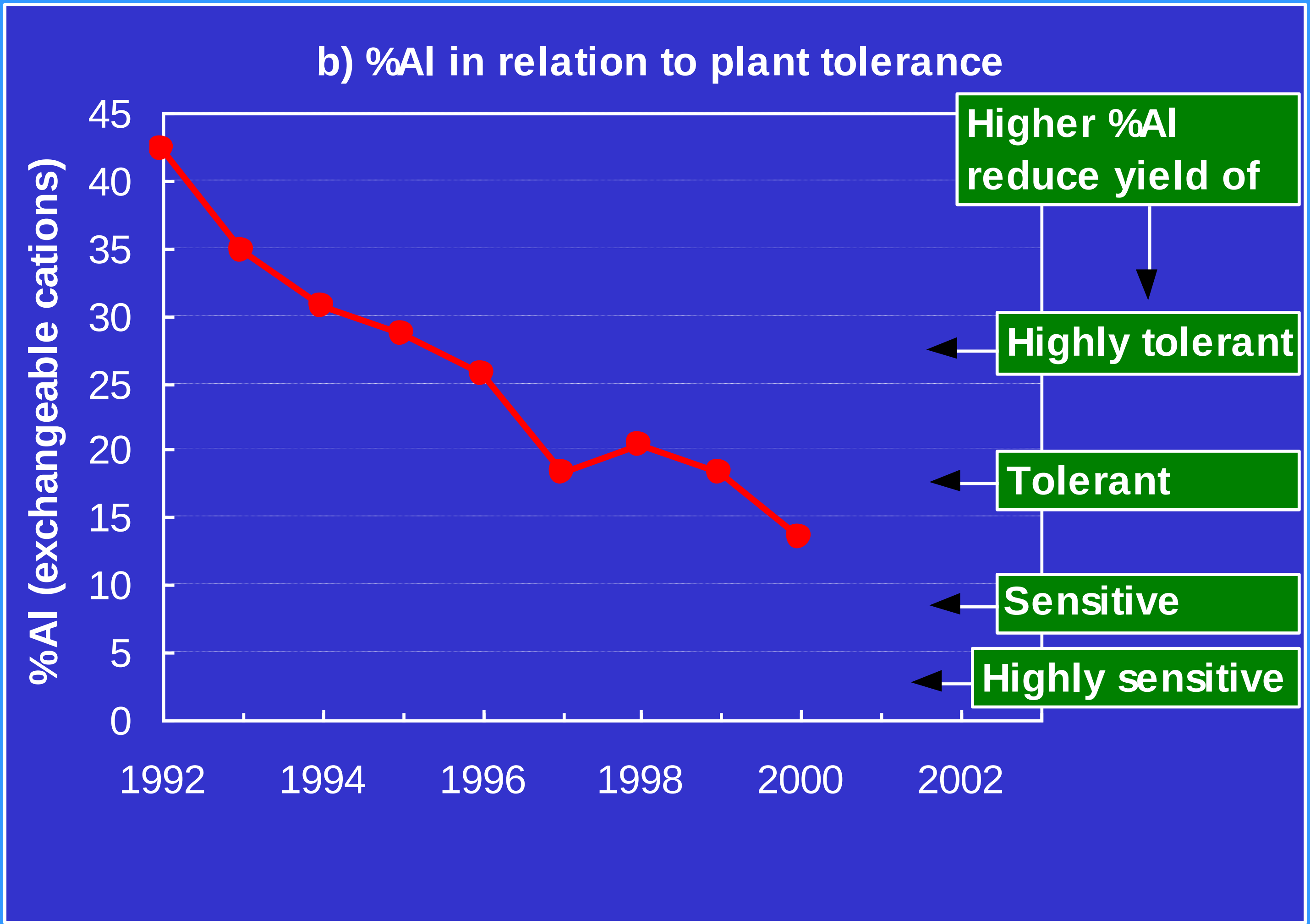
Limits of plant tolerance to Al



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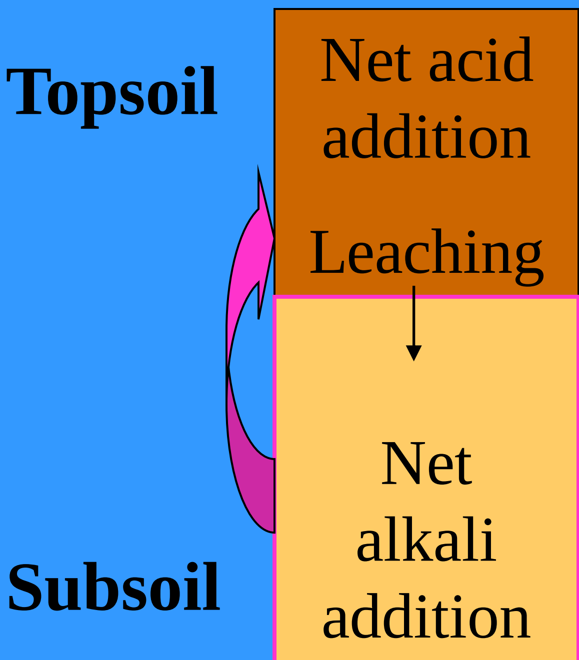
Components of 450 kg lime requirement (kg $CaCO_3$ /ha/year) preliminary estimates

N cycle	14	
C cycle	78	
Move 10-20	150	
Sub Total	242	
Missing	208	Undissolved lime, clay formation, movement below 20 cm, underestimate NO_3^- leaching

Effect of type of vegetation on soil development

Eucalyptus **vegetation - low nutrient recycling capacity**



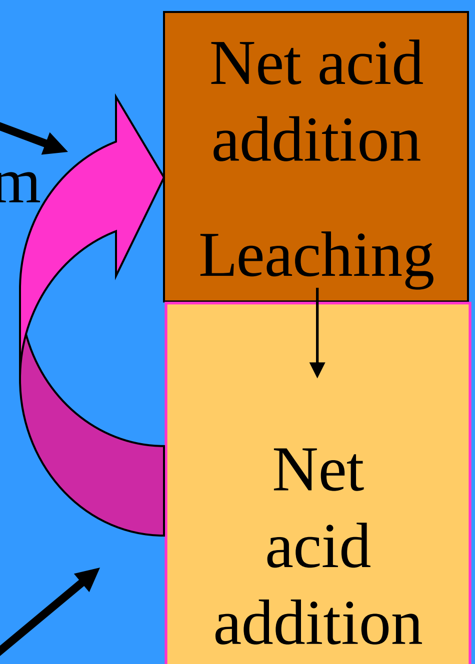
Leaching

- restores balance
- exaggerates problem

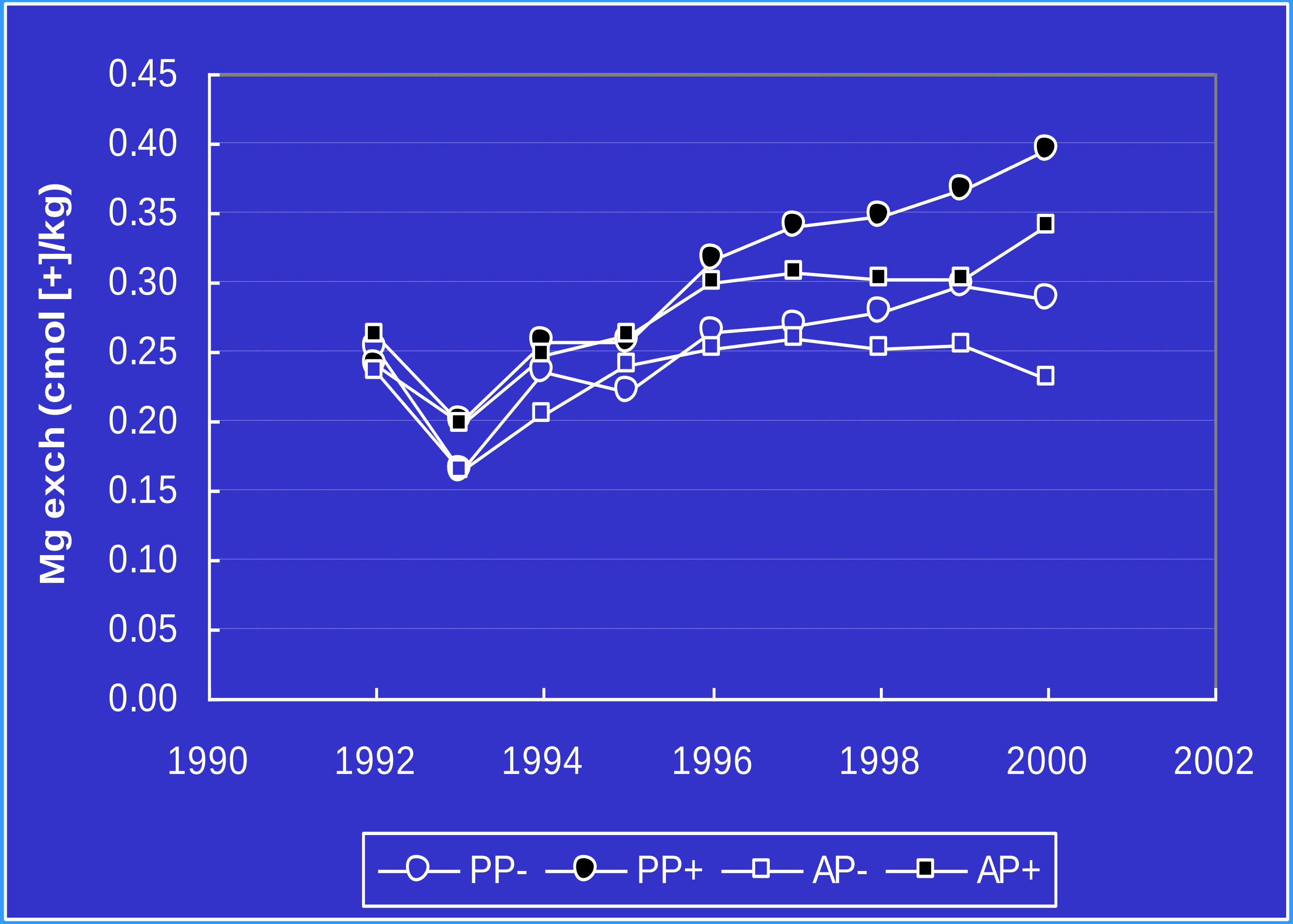
Result

- Solodic soil, acid surface, heavy clay subsoil
- Gradational well structured soil

Pastures or trees with high nutrient recycling capacity



Exchangeable Mg at 0-10 cm



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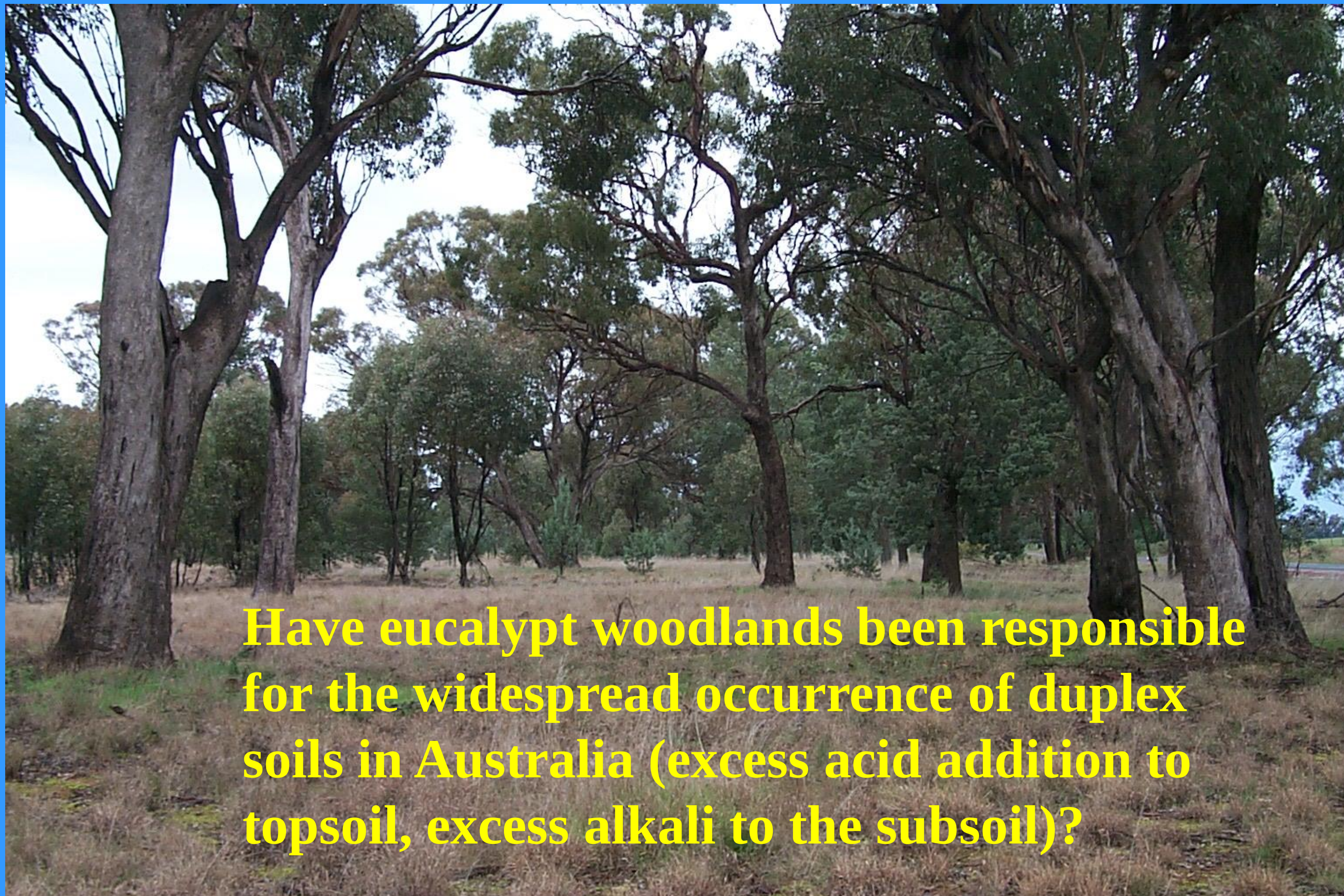
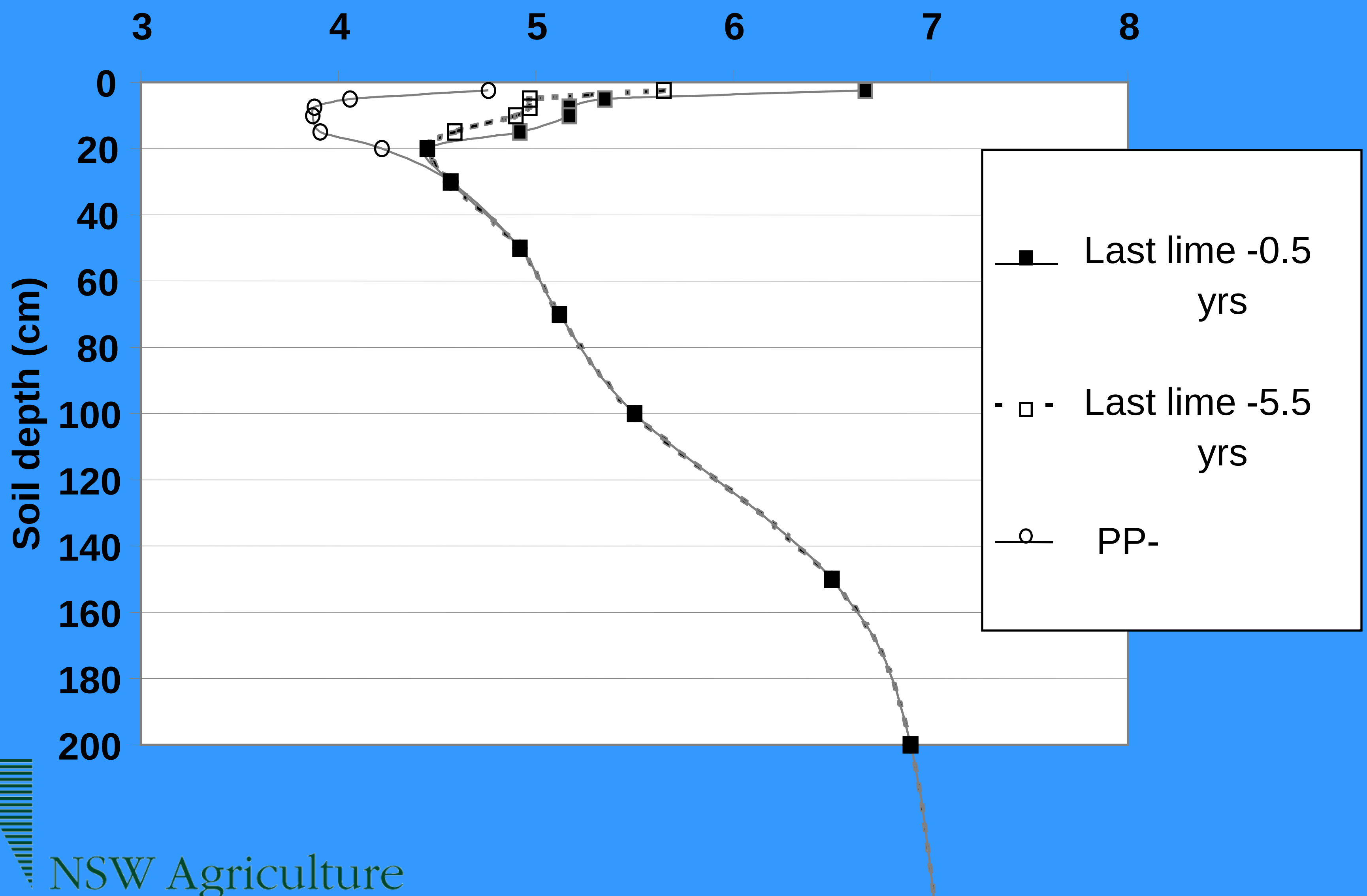

Have eucalypt woodlands been responsible
for the widespread occurrence of duplex
soils in Australia (excess acid addition to
topsoil, excess alkali to the subsoil)?

MASTER pH profiles 1999, phalaris/clover



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Conclusions

Base management on an understanding of the processes involved

- Key points:
  - is a measure of acid addition from N nitrate leaching cycle processes
    - cultural practices, crops and pastures to minimise leaching of nitrate
  - acid sub-surface layers develop if:
    - nitrate is leached well below the nitrification zone before it is absorbed by the plant - continuous plant absorption, nitrification inhibition.
    - most plants grown have low cation contents - change the species mix or use extra lime.

Further:

- The weathering rate of soil minerals is lowest if the soil solution pH is in the 5.0 to 6.0 range.
  - Lime to at least this pH in the surface 10 cm
  - A higher pH in the surface may be needed to neutralise sub-surface acidity
- The acidity index tables for fertiliser types need to be revised to account for modern understanding of acidification processes.

For your environment:

- You are the experts who understand your production systems.
- Study the nutrient recycling and acidification processes that are occurring.
- Solve the short term economic problem of stopping acidification.
- Design production systems so slow degradation processes, that get discounted out of contention in economic analyses, are not occurring.
- Encourage processes that slowly improve the soil - ‘make good soils out of bad soils’.

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Acidity index values (kg $CaCO_3$/kg N applied)

Fertiliser	No NO3 leached	100% NO3 leached
Ammonium sulphate	3.4	7.6
Biol. Fixed N, NH3 gas, Aqua ammonia, Ammonium nitrate, Urea	0	3.4
Na, Ca and K nitrate	-3.4	0
Diammonium phosphate	1.7	5.9
Monoammonium phosphate	3.4	7.6

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Example of solodic soil at the MASTER experiment, Book Book

(Li *et al.*, 2000)

Depth		Exchangeable cations (cmol [+]/kg)								ECECB‡		
(cm)	pH	Al	Mn	Mg	Na	Ca	K	ECEC	%Al†	%Mg	%Na	%Ca
0-10	4.13	0.78	0.10	0.24	0.10	1.12	0.24	2.58	31.0	13.6	5.7	62.2
10-20	4.22	0.68	0.12	0.19	0.05	0.56	0.10	1.69	42.6	16.8	5.3	54.6
20-30	4.57	0.28	0.11	0.57	0.09	1.18	0.09	2.32	15.6	23.1	4.6	59.5
30-40	4.87	0.16	0.04	1.55	0.23	2.14	0.12	4.23	4.7	33.5	5.6	55.9
40-50	4.96	0.14	0.01	3.22	0.49	3.15	0.17	7.19	2.3	43.6	6.5	47.0
50-60	5.02	0.15	0.01	4.78	0.76	3.46	0.19	9.35	1.9	50.5	7.5	39.6
60-80	5.22	0.13	0.01	6.42	1.08	3.40	0.22	11.25	1.5	57.3	8.9	31.6
80-100	5.59	0.06	0.00	8.34	1.52	3.65	0.24	13.81	0.6	60.9	10.3	26.8
100-120	6.24	0.02	0.00	10.78	2.14	4.95	0.25	18.14	0.1	61.1	11.7	25.7

† The %Al is the percentage exchangeable Al of ECEC. ‡ ECECB is the percentage exchangeable cations of mono- and divalent ECEC, excluding exchangeable Al.

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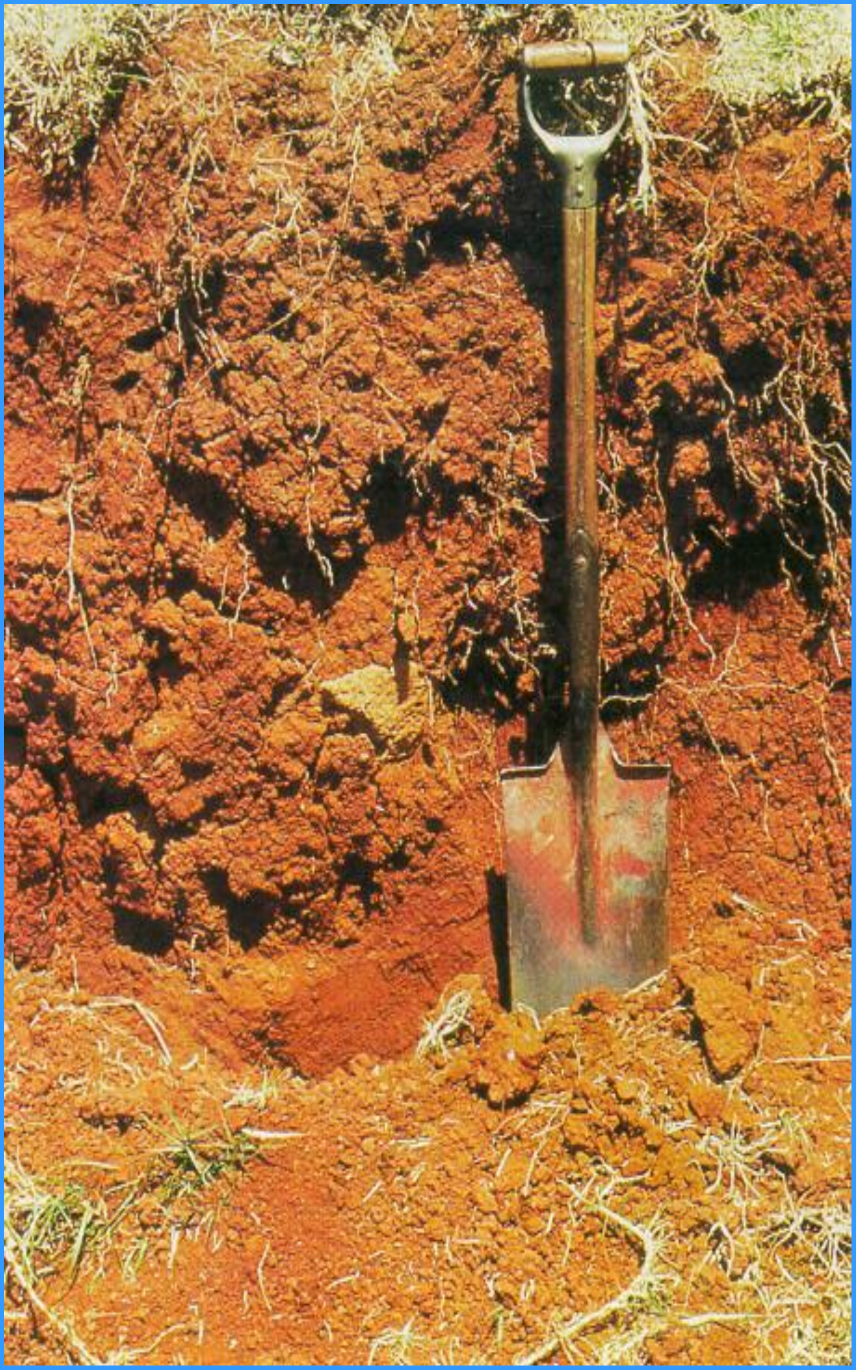
Kraznozem/Oxisol



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