Role of Phosphorus, Potassium, Calcium and Magnesium on Disease Resistance

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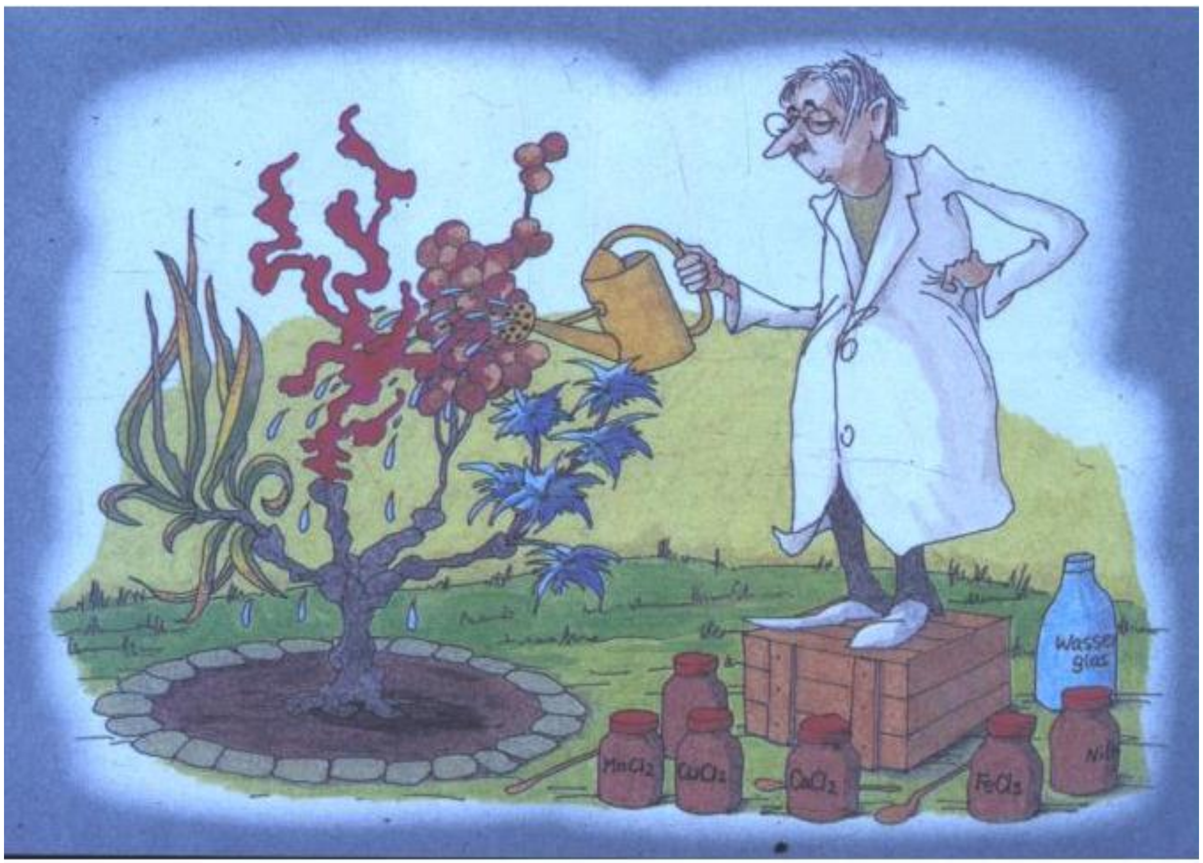
Overview

- Introduction
- Functions of mineral nutrients in disease/pest resistance
  - Balanced mineral nutrition/nutritional status?
  - Specific mineral nutrient effects (K, Mg, Ca, P)
- Conclusions / prospects

SIMPÓSIO SOBRE
RELAÇÕES ENTRE NUTRIÇÃO MINERAL E INCIDÊNCIA DE DOENÇAS DE PLANTAS
PIRACICABA-SP, 28/02 - 01/03/2005

Introduction

A main objective in modern plant production is a reduced input of toxic agrochemicals such as insecticides and fungicides to ensure good food quality and less health risk.



Thus, the question arises:

Can we improve disease / pest resistance by foliar or soil application of mineral nutrients?

From the following nutrients it is well know, that they can effect disease resistance:

N, K, Ca, (Mg, P)
Mn, Zn, Cu, B, Cl, Fe, Si

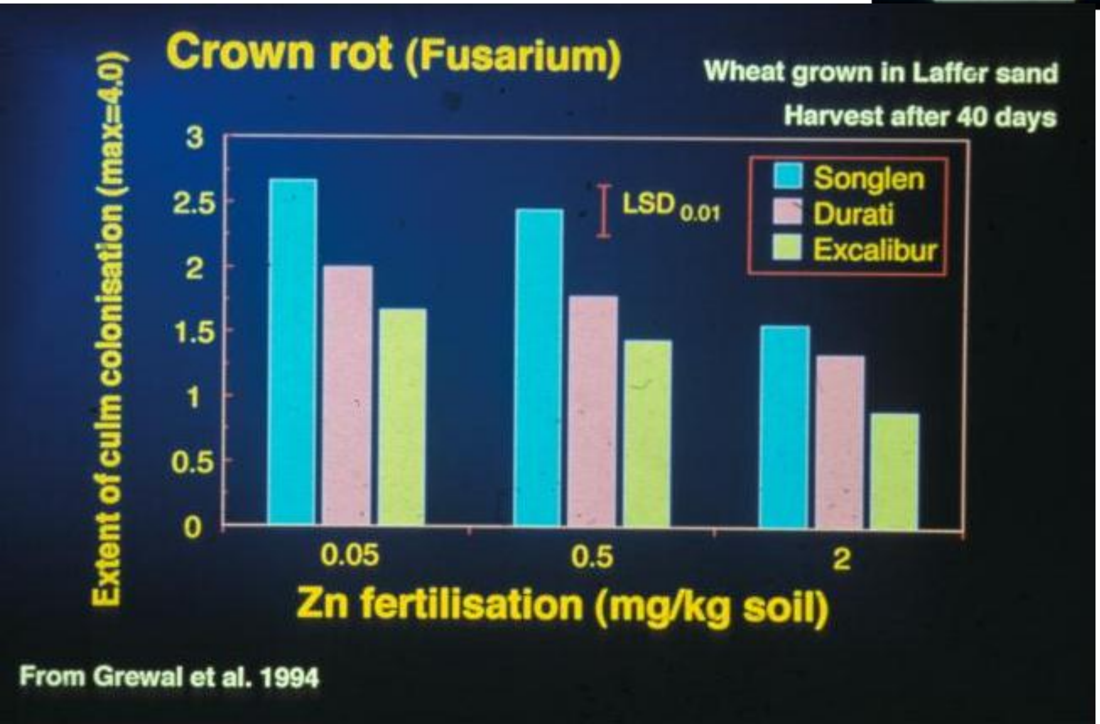
Reported* Effects of Nutrients on Disease

	Disease		
Mineral element	Decreased	Increased	Variable
Nitrogen ($N/NH_4/NO_3$)	168	233	17
Phosphorus (P)	82	42	2
Potassium (K)	144	52	12
Calcium (Ca)	66	17	4
Magnesium (Mg)	18	12	2
Manganese (Mn)	68	13	2
Copper (Cu)	49	3	0
Zinc (Zn)	23	10	3
Boron (B)	25	4	0
Iron (Fe)	17	7	0
Sulfur (S)	11	3	0
Other (Si, Cl, etc.)	71	6	8

*Based on 1,200 reports in the literature

(Don Huber, USA)

Potato leaves:
Alternaria solani



Yes, soil or foliar application of distinct nutrients (K, Ca Mn, Zn, B) or minerals (Si) can enhance disease/pest resistance!

Nutrient supply instead of toxic fungicides or insecticides!

Function of mineral nutrients in disease resistance

A better understanding of the function of distinct nutrients in disease/pest resistance is a prerequisite to develop adapted management strategies, including rhizosphere management for plant resistance and to suppress diseases or pests.

Example: C.V.C. (*Xylella fastidiosa*)

Traditional system (no mulching, use of herbicide)

Biological management system (mulching, no herbicides)

What is the main difference of both systems regarding C.V.C?

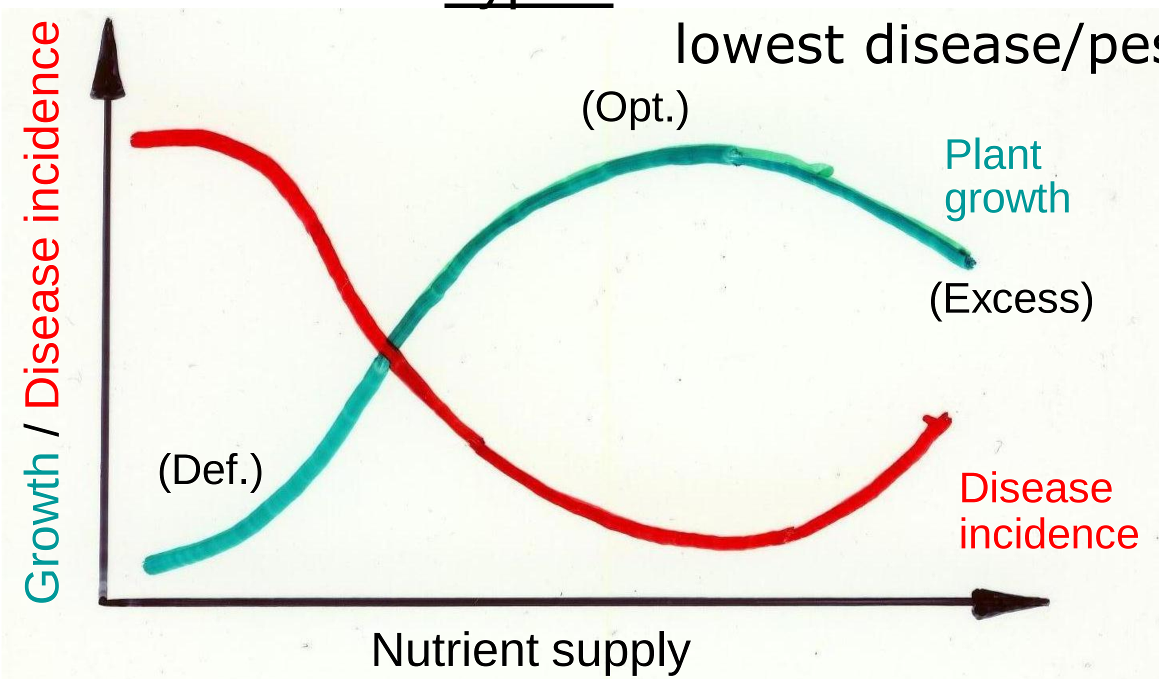
Take-all of wheat after wheat (front) versus wheat after oat (back).
(D. Huber)

What is the effect of oat as precrop regarding take-all suppression?

Function of mineral nutrients in disease/pest resistance

- Balanced mineral nutrition (nutritional status) might result in an unspecific higher resistance to stress (abiotic and biotic stress)
  A `balanced´ nutrient supply which ensure optimal growth is also considered optimal for plant resistance

Type I: "Balanced nutritional status " = lowest disease/pest incidence



Ideal situation

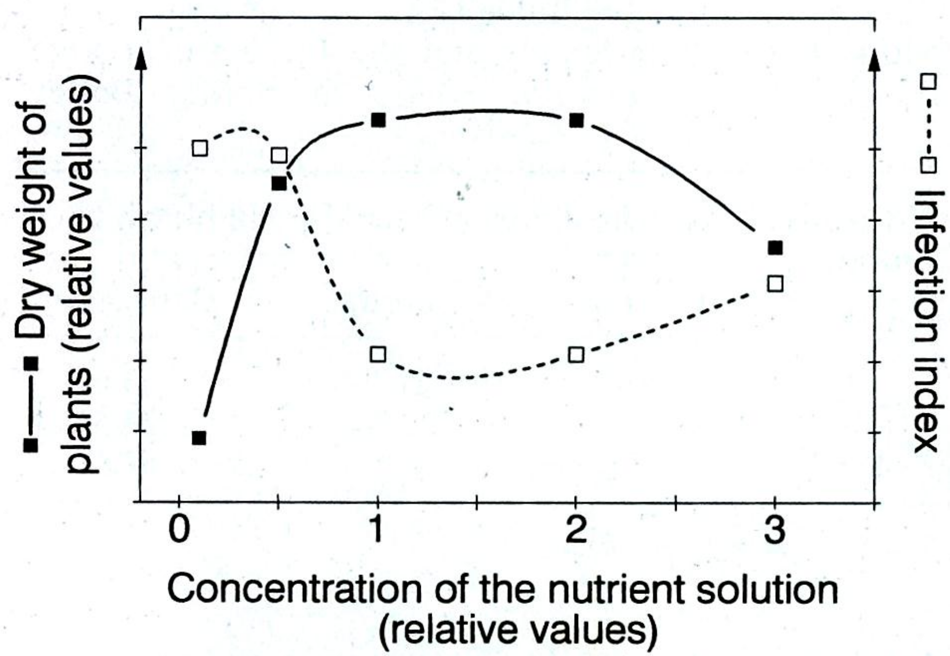
e.g.
Bacterial stem rot, or
Bacterial tomato wilt

Example:

Bacterial tomato wilt *(Clavibacter michiganense)*

N supply (ppm)	dry matter (g / plant) suscep*.	resistant*	disease incidence (% wilting leaves) suscep.	resistant
30	3.7	5.0	90	56
240	12.2	16.1	44	20
450	9.9	14.0	61	26

* Susceptible or resistant tomato cultivar



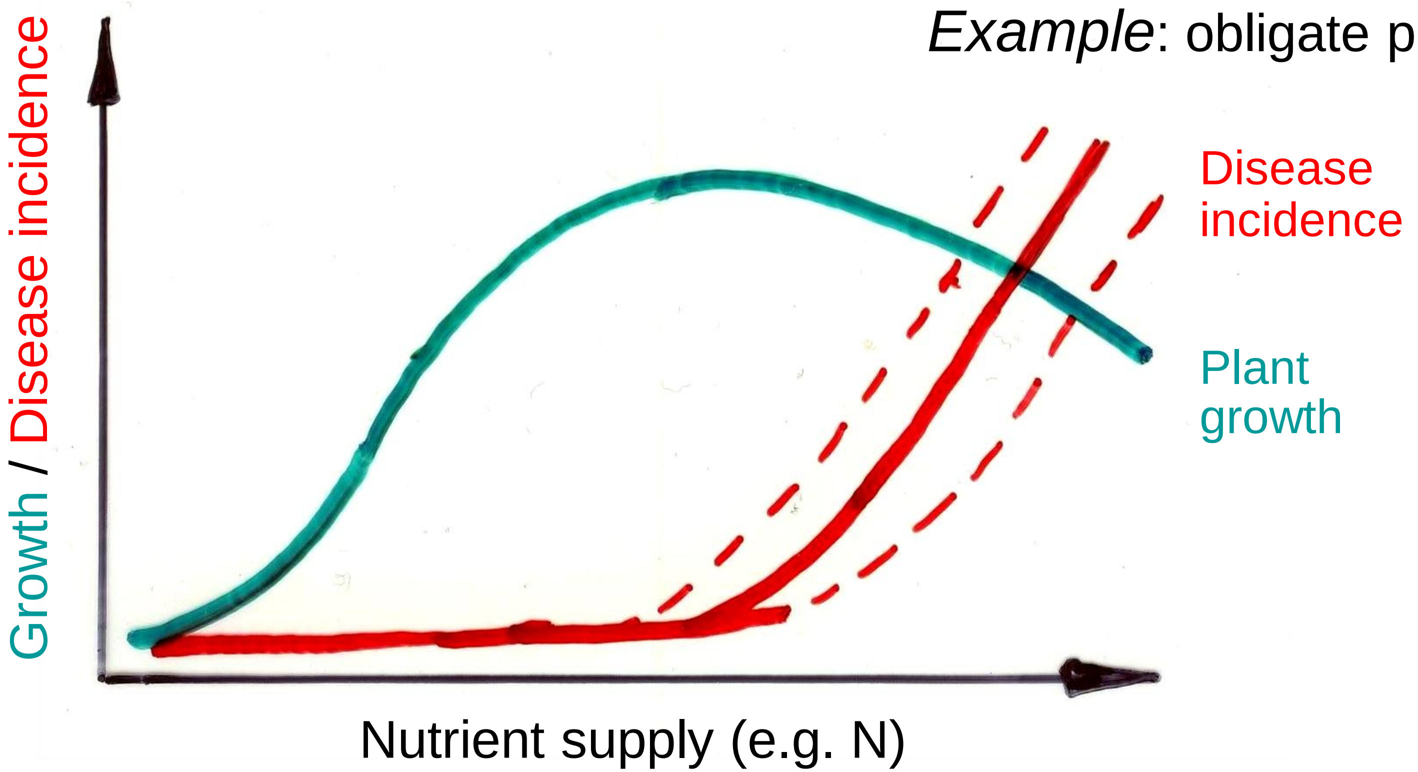
Example:

Bacterial stem rot (*Xanthomonas pelargonii*) in *Pelargonium* as affected by nutrient solution concentration (Marschner, 1995)

However, in many fungal diseases with obligate parasites an increase in nutrient supply, in particular of N, will result in an increased incidence.

Type II: Increasing disease/pest incidence with increasing nutrient (N) supply, especially at excessive supply.

Example: obligate parasites



Nitrogen fertilizer supply and the incidence of leaf blotch (*Rynchosporium scalis*) in spring barley cultivars (Jenkyn, 1976; see Marschner, 1995)

N supply kg/ha	Flag leaf area infected by leaf blotch (%)		
	Proctor*	Cambrinus	Deba Abed
0	0.4	15.4	3.6
66	1.3	21.3	20.5
132	4.5	30.5	57.3

* Resistent cultivar

This negative N effect is particularly expressed in the non-resistant cultivars <u>as a general rule</u>.

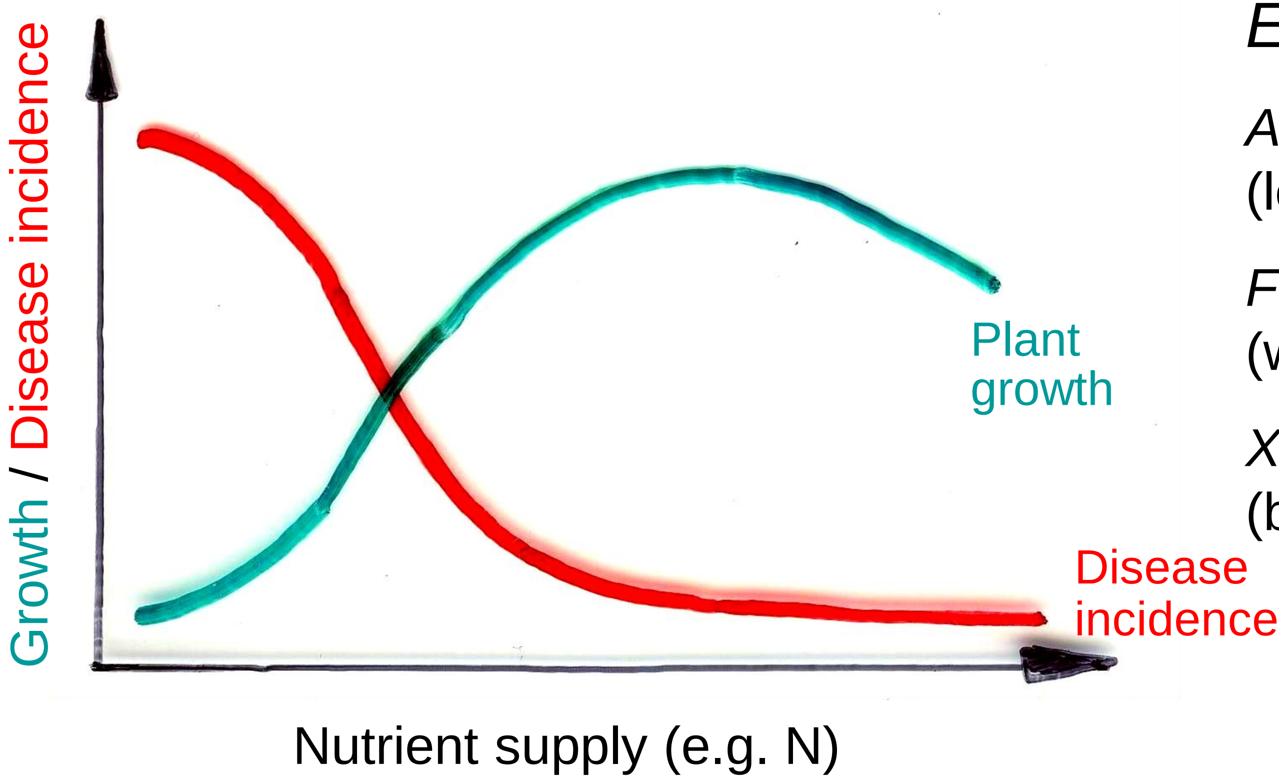
This negative effect of increasing N supply (at excessive level) can not only found for obligate fungal parasites but also for pests.

Effect of increasing N supply on N concentration in barley plants and population density of aphides
(Results of a practical class, Hohenheim 2001)

N supply	Content of amino acids (relative, %)	Nitrate content In stems (ppm) (NO_3 quick test)	No. of aphides per plant after 0	7	21d
deficient	58	10	5	45	470
optimal	81	1100	5	86	2434
excess	100	5000	5	77	8360

In contrast to the before mentioned obligate parasites, the facultative parasites get often suppressed with increa-sing nutrient (N) supply

Type III: Decreasing disease/pest incidence with increasing nutrient (N) supply (facultative parasites)

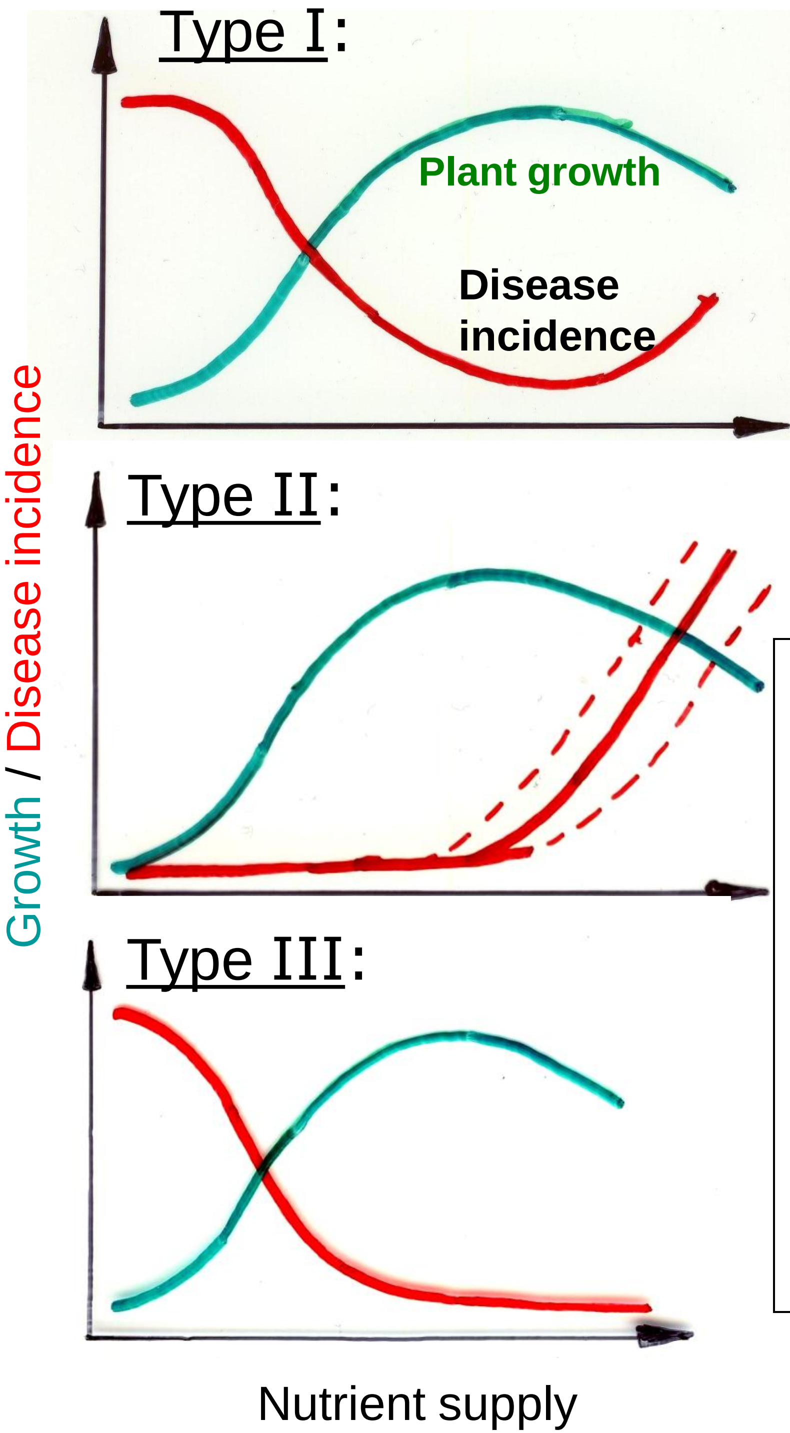


Examples:

Alternaria ssp.
(leaf spot disease)

Fusarium oxysporum
(wilt and rot disease)

Xanthomonas ssp.
(bacterial spots and wilt)



These principal different relationships between nutritional status and disease susceptibility (Type I-III) might already explain the various contracting data of the above shown literature review.

Reported* Effects of Nutrients on Disease

Mineral element	Disease Decreased	Disease Increased	Disease Variable
Nitrogen (N/NH_4/NO_3)	168	233	17
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Boron (B)	25	4	0
Iron (Fe)	17	7	0
Sulfur (S)	11	3	0
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(Don Huber, USA)

Different effect of N supply dependent on kind of pathogen

Effect of N and K supply on disease susceptibility

Pathogen/disease	N-level		K-level	
	low	high	low	high
Obligate parasite				
Puccinia sp	+	+++	++++	+
Erysiphe graminis	+	+++	++++	+
Facultative parasite				
Alternaria sp	+++	+	++++	+
Fusarium oxisporum	+++	+	++++	+
Xanthomonas sp	+++	+	++++	+

+ → ++++ increase in disease susceptibility

(Kiraly, 1976; Perrenoud, 1977)

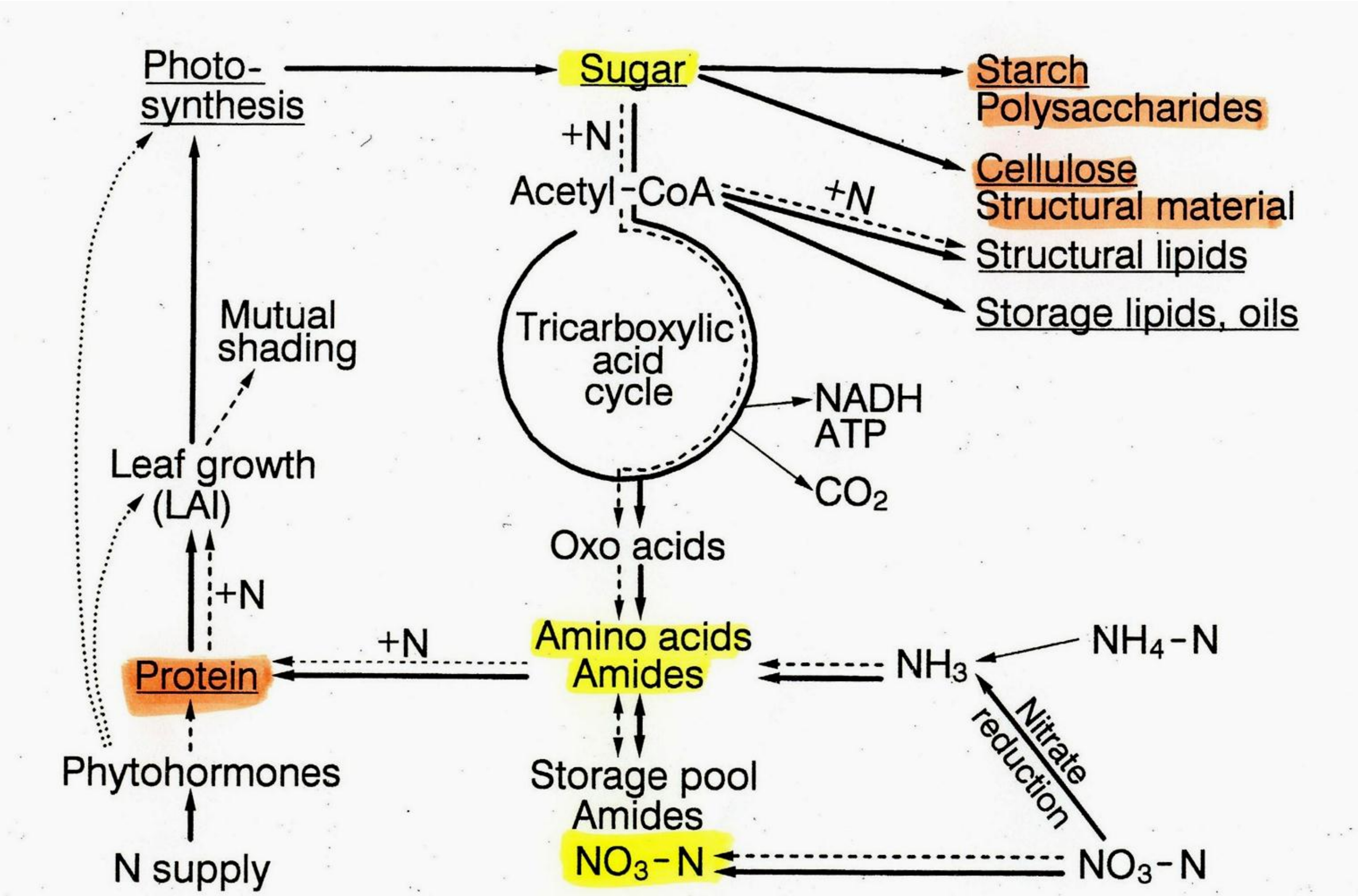
→ enhanced K supply can counteract negative effects of a high N supply on stress resistance e.g. disease resistance!

Possible explanations for the different behavior of obligate and facultative parasites with N supply

- *Promotion of obligate parasites at excessive N supply*
  - higher biomass density affecting microclimate
  - higher concentration of soluble N compounds in the shoot
  - enhanced efflux of low molecular compounds into the apoplast
  - a higher share of young leaf tissue
  - lower content of lignin, phenolics and Si in young leaves.
  - thinner cell walls and less stabilizing tissues
  - more lodging problems of cereals
  - delayed senescence

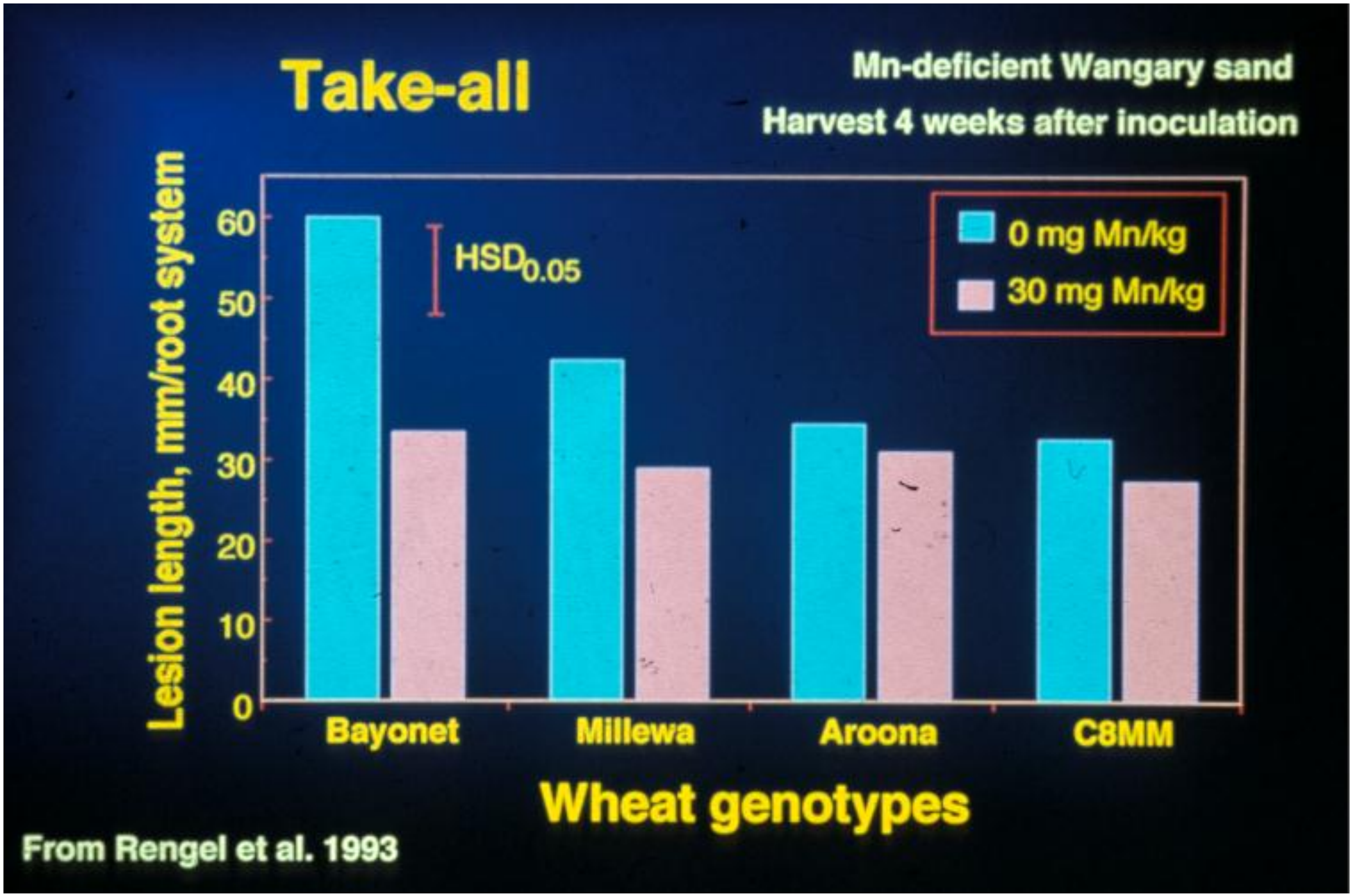
- *Inhibition of facultative (semisaprophytic) parasites at excessive N supply*
  - delayed senescence
  - increased content of toxins / phytoalexins

Effect of supply of a **high** or **low** N supply or K / N ratio on soluble (low molecular weight) constituents (amino acids, sugars) and high molecular weight proteins, starch and cellulose (Marschner,1995)



Specific effects of micronutrients in disease/pest resistance

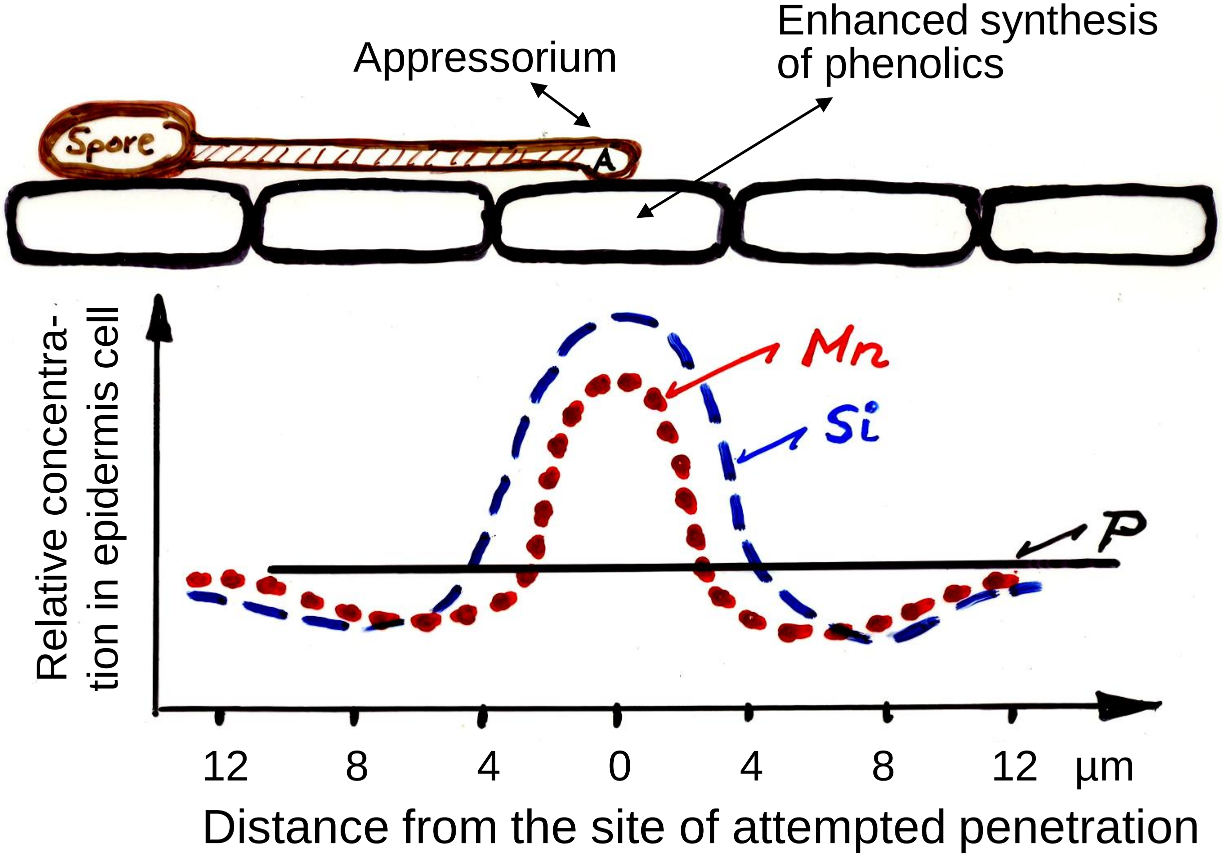
Suppression of take-all by an improved Mn nutritional status of wheat via Mn fertilization or selection of Mn efficient cultivars.



(Rengel et al., 1993; Plant Soil 151, 255 - 263)

Of specific interest is the short term, very localized redistribution of Mn and Si in leaves in relation with the attempted penetration of a pathogen hyphae in a leaf cell and the subsequent rapid enhanced biosynthesis of phenolics for increased disease resistance. (Leusch and Buchenauer, 1988)

This interaction of Si, Mn and phenolics, however, is not well studied, yet.



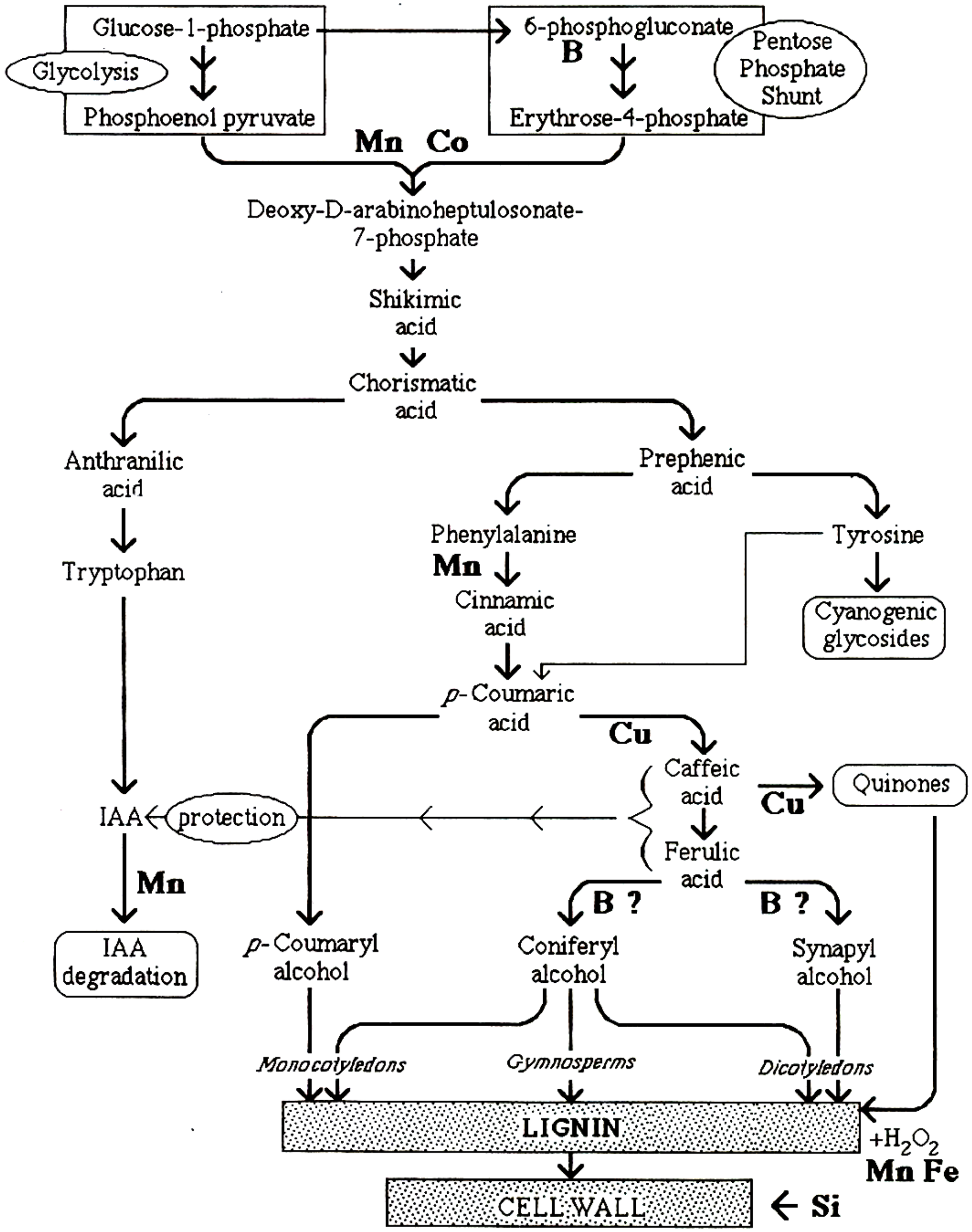
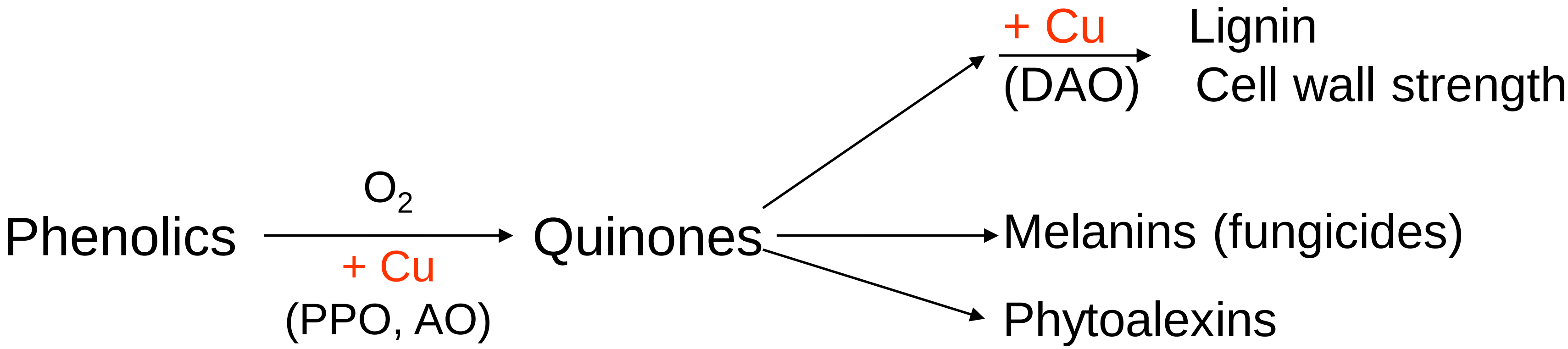


Fig. 10-2. Some pathways for lignin and phenol synthesis centered around the shikimic acid pathway. Information presented here has been derived from Burnell (1988), Bidwell (1979), Goodwin and Mercer (1972), Graham (1983), and Gross (1980).

Beside Mn, also Cu, B and Co are involved in the shikimate pathway, responsible for biosynthesis of phenolics, lignin and phytoalexins

(Graham and Webb, 1991)

The role of Cu in disease resistance



Cu containing enzymes: Ascorbate oxidase (AO)
Diamine oxidase (DAO)
Polyphenol oxidase (PPO)

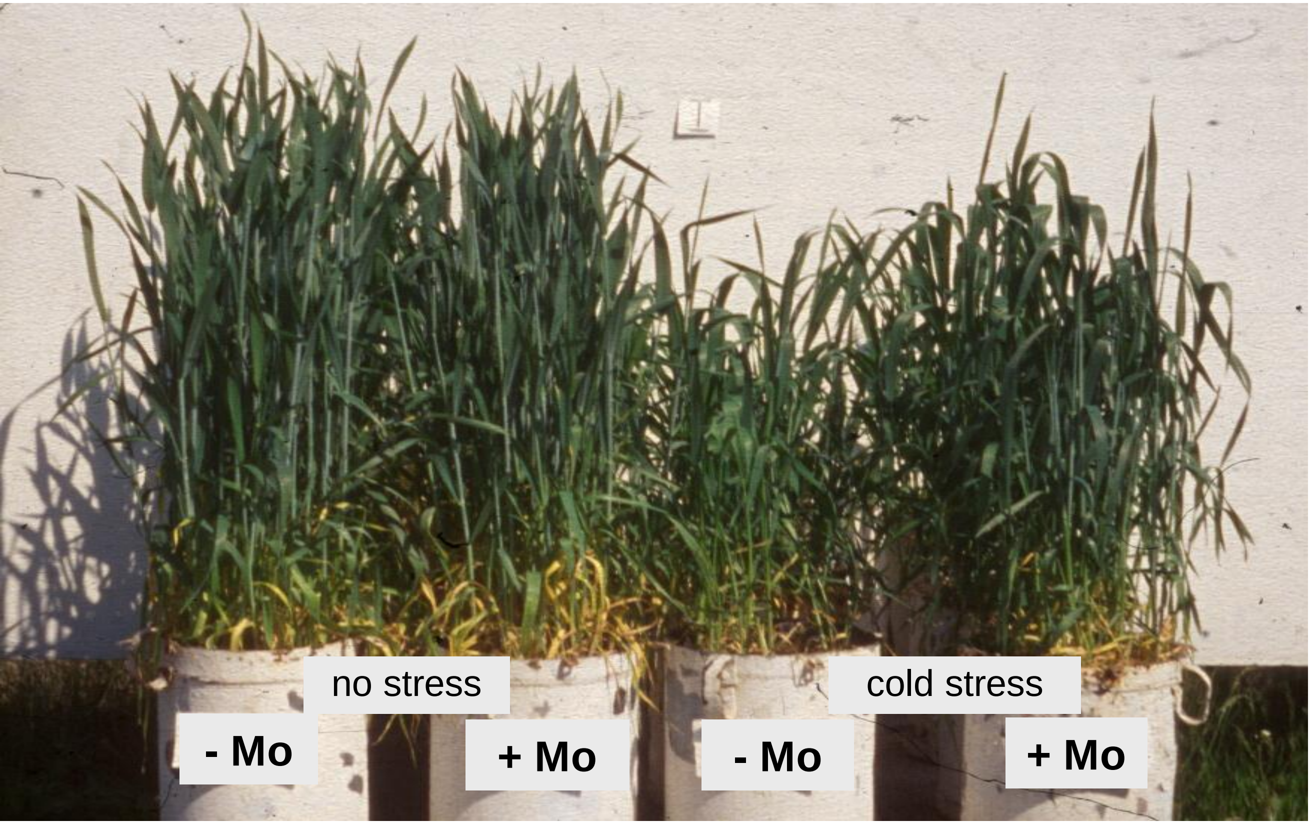
Influence of Cu supply on cell wall composition of young wheat leaves *(Robson et al., New Phytol. 89, 361-373; 1981)*

Treatment	Cu concentration (mg/kg DW)	cell wall content (%)	cell wall composition (% of cell wall)		
			cellulose	hemicellulose	lignin
– Cu	1.0	42.9	55.3	41.4	3.3
+ Cu	7.1	46.2	46.8	46.7	6.5

Function of mineral nutrients in disease/pest resistance

- Balanced mineral nutrition (nutritional status)
- Specific nutrient effects

An increased requirement for Mo under various stress conditions!



(Vunkova-Radeva et al., Plant Physiol. 87, 1988)

In general, a higher demand for such specific mineral nutrients (Mo, Mn, Zn, B and K) is also required under biotic stress conditions (e.g. at high pathogen pressure or high temperature stress)

☐ Function of mineral nutrients in disease/pest resistance

- Balanced mineral nutrition (nutritional status)
- Specific nutrient effects

Examples:

Potassium (K):

Affecting the organic constituents of a plant, and, thus, resistance to parasites

Magnesium (Mg)

Calcium (Ca)

Phosphorus (P)

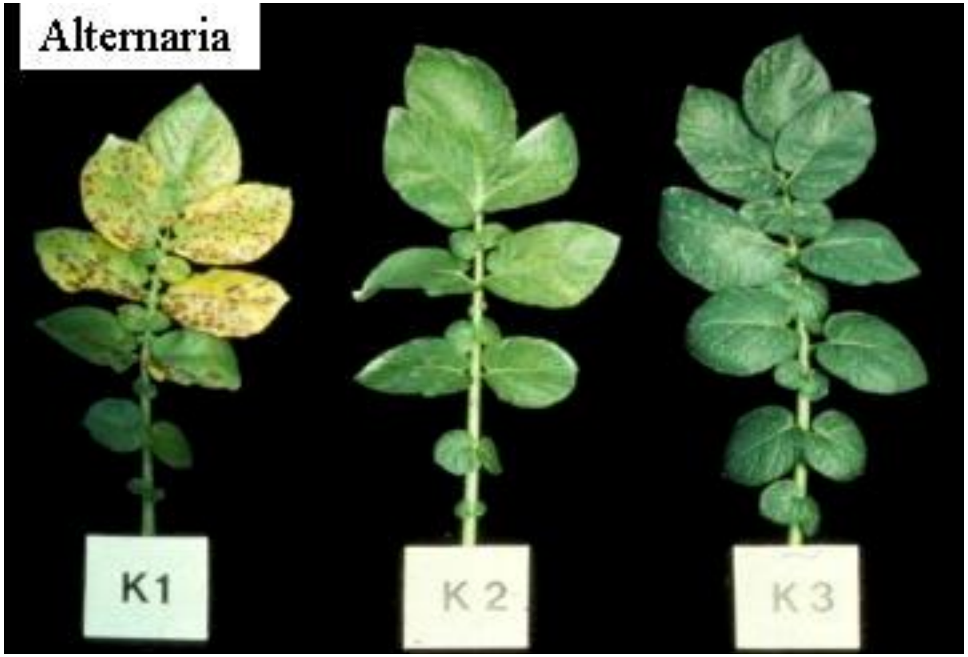
Specific effect of K on disease/pest resistance

Effect of N and K supply on disease susceptibility

(Kiraly, 1976; Perrenoud, 1977)

Pathogen/disease	N-level		K-level	
	low	high	low	high
Obligate parasite				
Puccinia sp	+	+++	++++	+
Erysiphe graminis	+	+++	++++	+
Facultative parasite				
Alternaria sp	+++	+	++++	+
Fusarium oxisporum	+++	+	++++	+
Xanthomonas sp	+++	+	++++	+

+ → ++++ increase in disease susceptibility



Potato leaves

→ enhanced K supply can counteract negative effects of a high N supply on stress resistance e.g. disease resistance!

Effect of supply of a **high** or a **low** K supply or K / N ratio on soluble (low molecular weight) constituents (amino acids, sugars) and high molecular weight proteins, starch and cellulose (Marschner,1995)

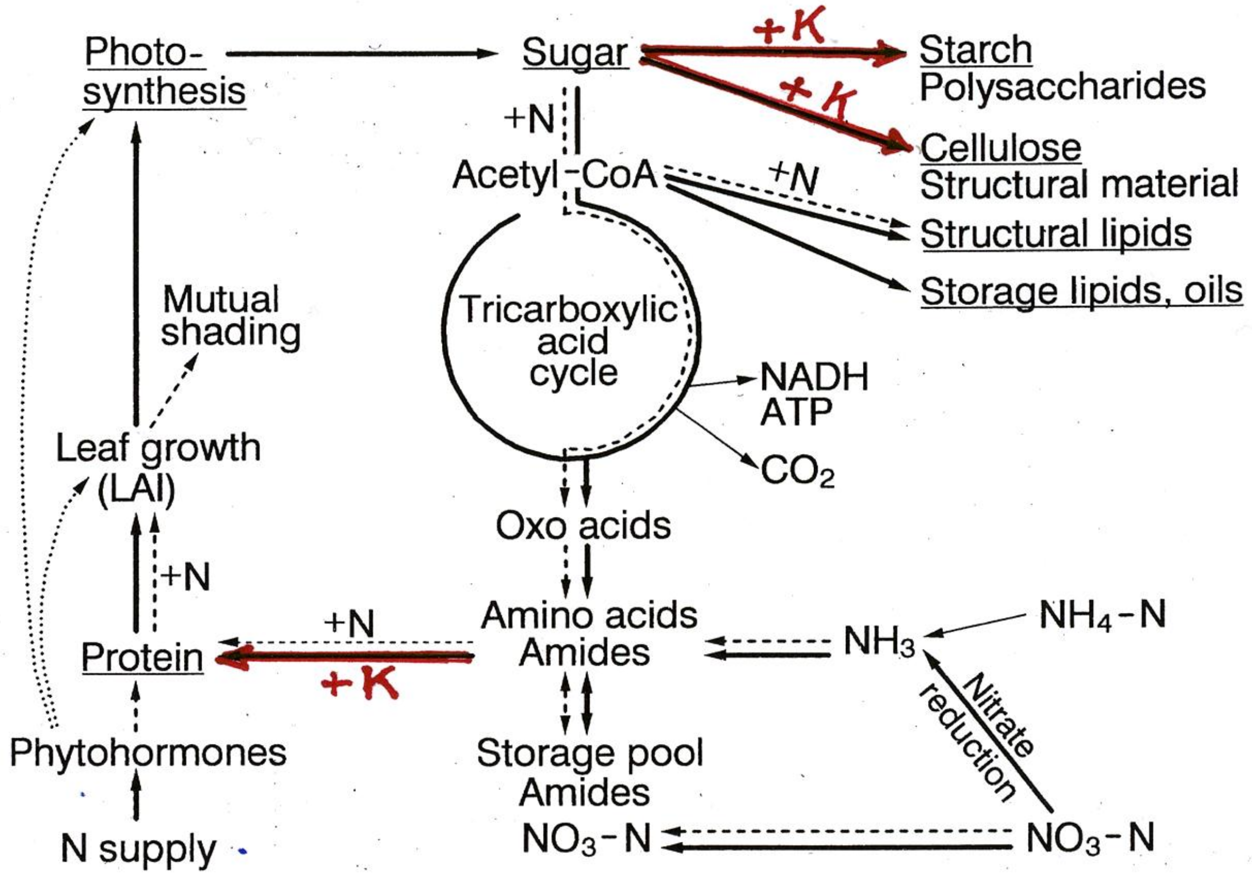
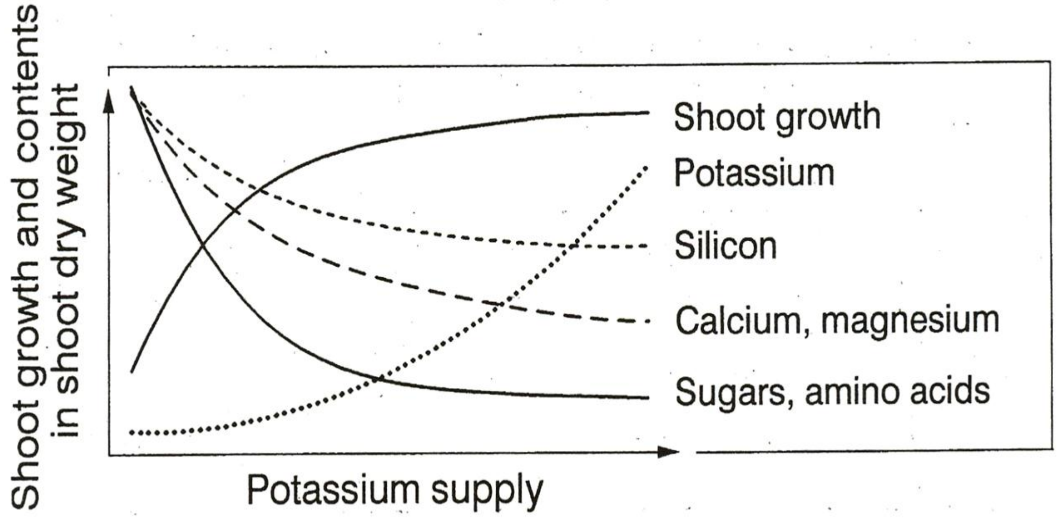
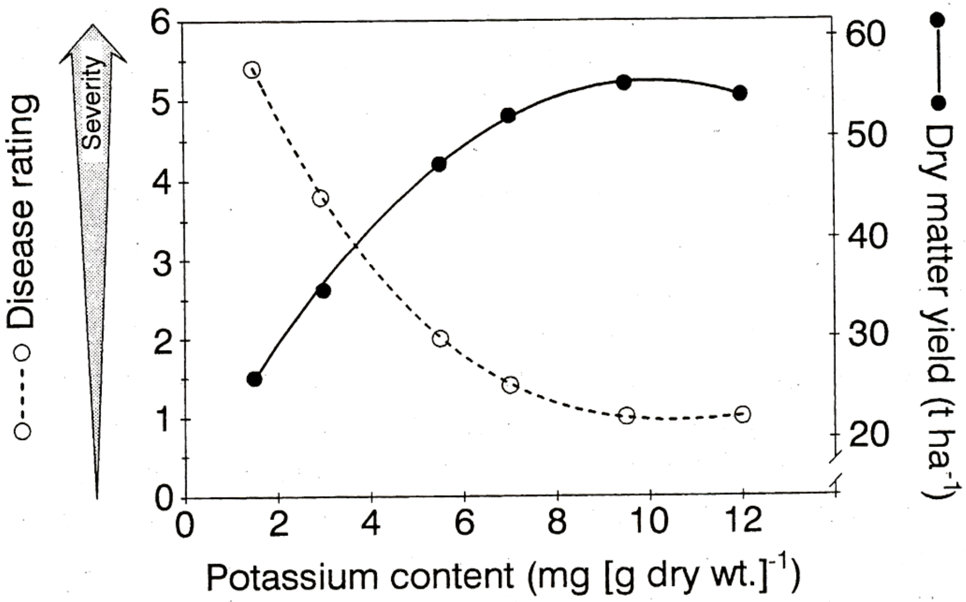


Fig. 8.17 Model of the effects of nitrogen supply on leaf growth and on various plant constituents. Key: ———→, suboptimal to optimal nitrogen supply; – – – →, high to excessive nitrogen supply. ⟶ adequate K supply

Marschner, 1995



Tentative scheme of growth response and major changes in plant composition with increasing potassium supply.



(Marschner,1995)

Fig. 11.8 Severity of leaf spot disease (*Helminthosporium cynodontis*) and dry matter yield in 'Coastal' bermudagrass (*Cynodon dactylon* L. Pers.) versus leaf potassium content. (Reproduced from Matocha and Smith, 1980, by permission of the American Society of Agronomy.)

Low nutritional status of K (but also of P and S) results in enhanced soluble nitrogen in leaves and, thus, in attraction of sucking insects such as rice plant hoppers or squash bugs

Table 11.8

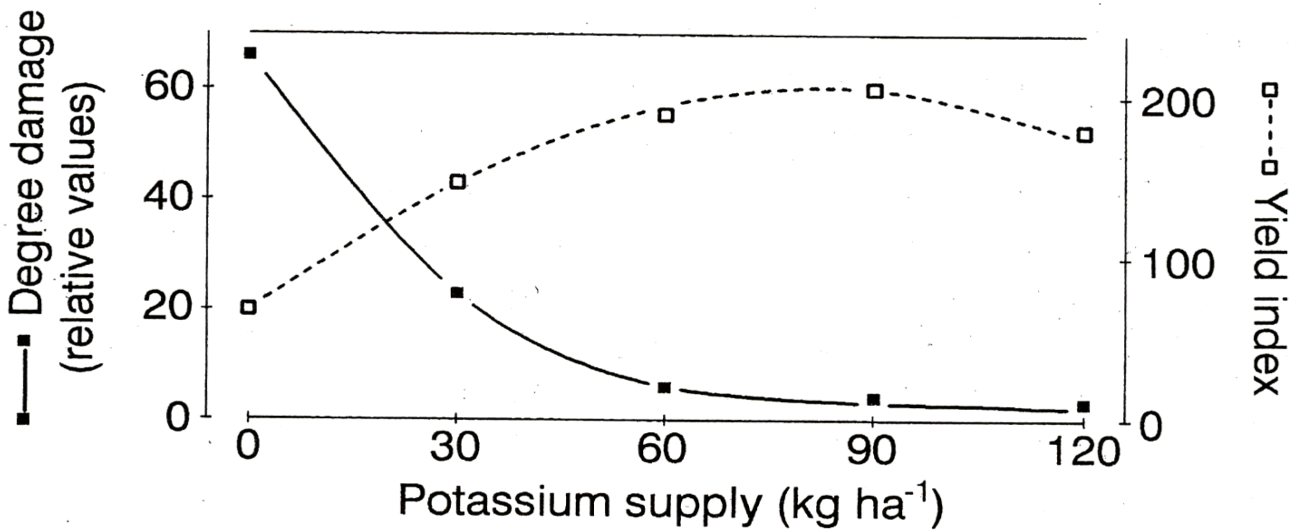
Relationship between Mineral Nutrient Deficiencies, Number of Squash Bugs (*Anasa tristis*) per Plant, and Soluble Nitrogen Content of Squash[a]

Nutrient supply	Squash bugs (no. per plant)	Soluble nitrogen ($\mu g\ g^{-1}$ fresh wt)
Complete	1.70	32.1
−N	0.66	4.5
−P	2.11	93.7
−K	2.45	98.9
−S	3.42	143.7

[a]From Benepal and Hall (1967).

(Marschner, 1995)

Effect of potassium supply on grain yield of wetland rice and incidence of stem rot (*Helminthosporium sigmoideum*). Basal dressing of nitrogen and phos-phorus constant at 120 and 60 kg ha^{-1}, respectively. (Based on Isunadji,1976)



Effects of Fertilizers Applied on a Soil Low in Available on Infestation of Oak Trees (*Quercus pendula*) by Cup-Shield Lice (Eulecanium refulum Ck11.)

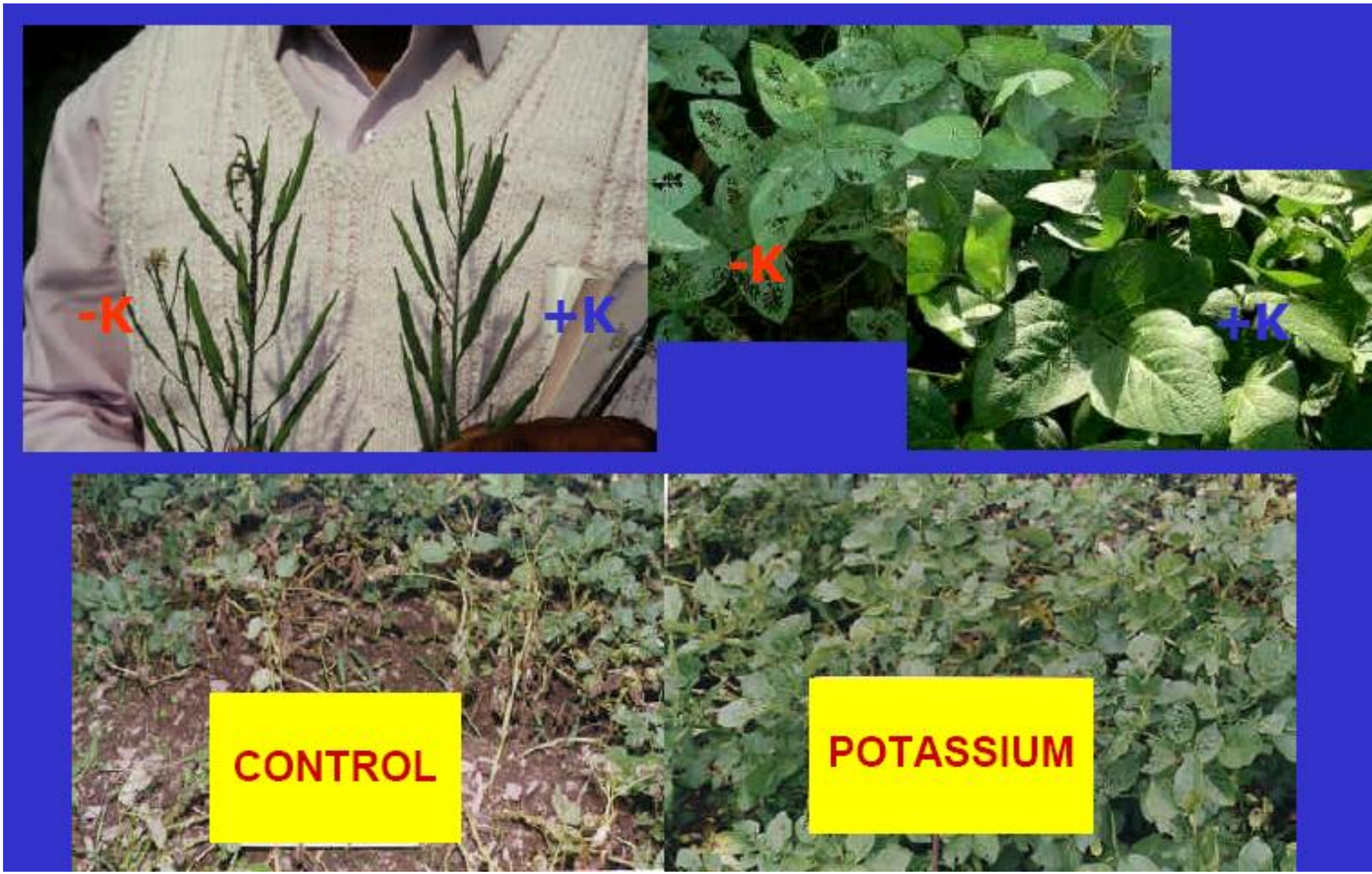
	Fertilizer			
	K + Mg	N + P + K + Mg	Mg	N + P + Mg
No. of lice per 10-cm stem section	0.72	0.82	4.32	8.78

Based on Brüning (1967)

A better K supply might also increase mycorrhizae infection rate and thus disease resistance.

(Marschner,1995)

<u>Potassium keeps plant healthy</u> (A. Krauss,2004)



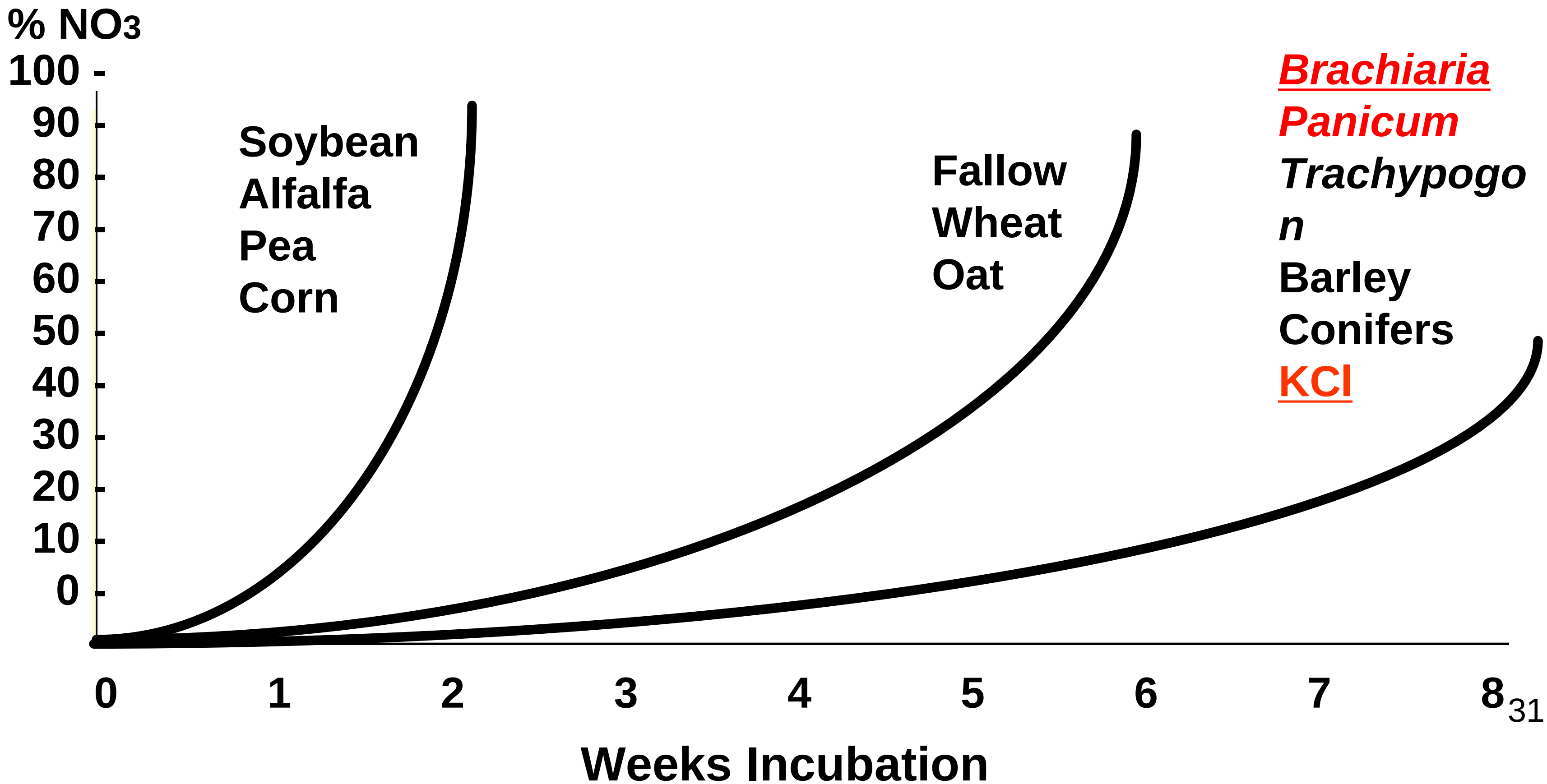
In addition potassium as chloride (Cl) can effect disease resistance via:

a) suppression of the pathogen (take-all common root rot, yellow rust

b) increase in hist tolerance (take all)

(Fixen, Adv. Agron. 50, 107-150;1993)

Effect of different crop residues on inhibition of nitrification in a soil (D. Huber, 2002)



Effect of KCl on incidence of take-all in wheat applied with ammonium-N

KCl treatment (kg/ha) Autumn	Spring	% infected roots	Grain yield (t/ha)
0	0	45	5.3
56	0	34	5.7
56	185	11	6.5

(Chlorid might inhibit nitrifying bacteria with subsquent rhizosphere acidification)

Christensen et al.,
Agron, J. 73, 1053-1058; 1981

Lowering rhizosphere pH inhibits the fungus of take-all

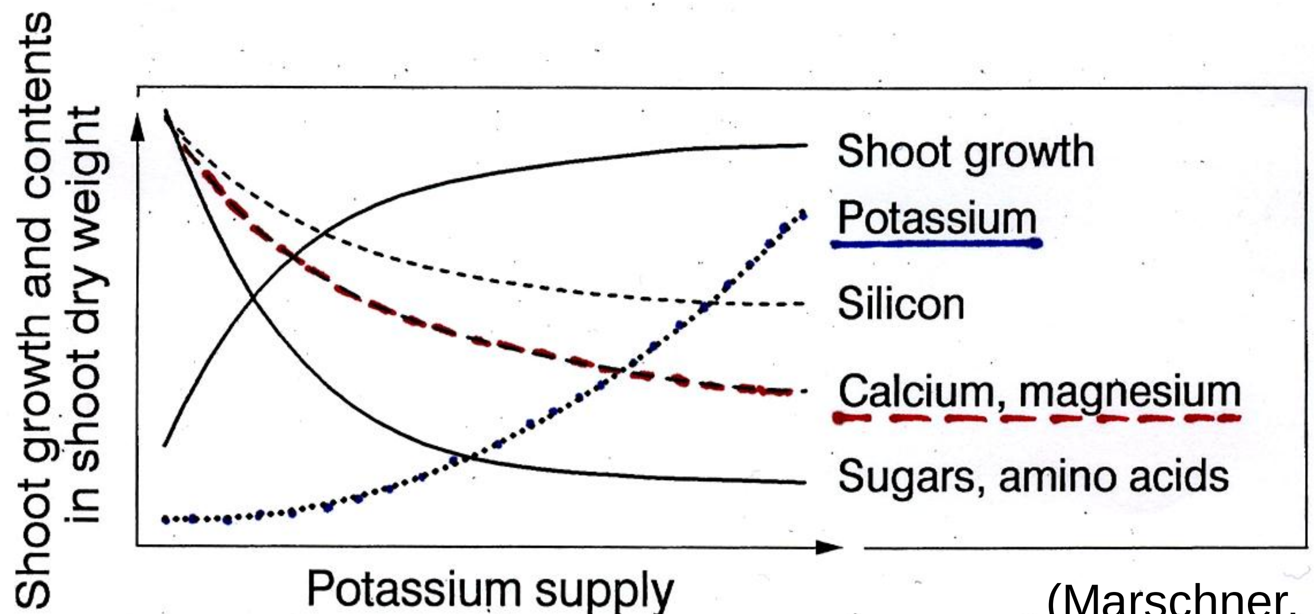
(D. Huber, USA)

– N serve   + N serve

- <u>Specific mineral nutrient effects</u>

Examples:

<u>Magnesium</u> (Mg): No specific reports available, but Mg deficiency (e.g. induced by a high K supply or low pH) will result in an unbalanced nutritional status and, thus, in an enhanced disease susceptibility.



(Marschner, 1995)

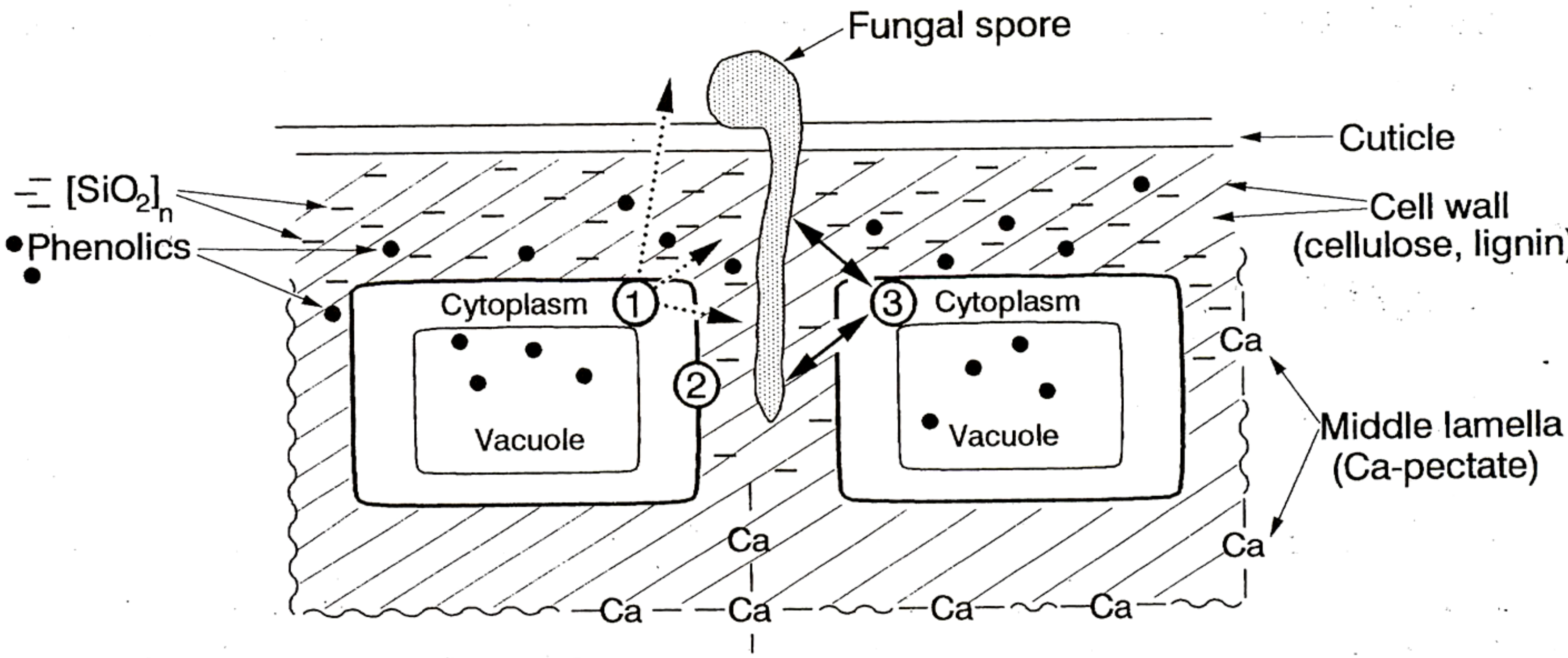
Fig. 11.9 Tentative scheme of growth response and major changes in plant composition with increasing potassium supply.

Also Mg deficiency-induced accumulation of assimilates in leaves can promote leaf pathogens via an enhanced release of sugars into the leaf apoplast as substrate.

- <u>Specific mineral nutrient effects</u>

Examples:

<u>Calcium</u> (Ca): Important role in stabilizing plasma membranes and cell walls (middle lamella, Ca pectate)



1 Diffusion of low-molecular-weight assimilates (sugars, amino acids)
2 Plasma membrane permeability
3 Interactions between fungus/epidermal cell (formation of toxins, phenolics)

Fig. 11.2 Schematic representation of the penetration of a fungal hypha on the leaf surface into the epidermal cell layer (apoplasm), and some factors which affect the penetration and growth rate of the hypha and are closely related to mineral nutrition.

Marschner, 1995

Particularly under abiotic stress conditions enhanced Ca supply is required to suppress membrane leakiness and thus assimilate losses into the apoplast for pathogenes

Table 8.28

Influence of Calcium on Carbohydrate Loss from Cotton Roots[a]

Treatment			
Aeration	Temperature (°C)	Solution	Carbohydrate loss (μg per seedling $(4\ h)^{-1}$)
O_2	31	Distilled water	18
O_2	5	Distilled water	57
O_2	5	10^{-5} M Ca^{2+}	7
N_2	31	Distilled water	89
N_2	31	10^{-5} M Ca^{2+}	7

[a]Based on Christiansen *et al*. (1970).

Marschner, 1995

Potassium / Calcium interaction

High Ca leaf concentration as prerequisite to suppress activity of the extracellulare polygalacturonase for dis-solving the middle lamella as a prerequisite for invasion of the parasite

Table 11.3
Relationship Between Cation Content and Severity of Infection with *Botrytis cinerea* Pars. in Lettuce[a]

Cation content (mg g^{-1} dry wt)			Infection with *Botrytis*[b]
K	Ca	Mg	
14.4	10.6	3.2	4
23.8	5.4	4.1	7
34.2	2.2	4.7	13
48.9	1.8	4.2	15

[a]Based on Krauss (1971).
[b]Infection index: 0–5 slight infection; 6–10 moderate infection; 11–15 severe infection.

(Marschner 1995)

Table 11.5
Relationship between the Calcium Content of Bean, the Activity of Pectolytic Enzymes in the Plant Tissue, and the Severity of Soft Rot Disease Caused by *Erwinia carotovora*[a]

	Pectolytic activity (relative units)[b]				
	Polygalacturonase		Pectate transeliminase		
Calcium content ($mg\ g^{-1}$ dry wt)	−	+	−	+	Severity of symptoms[c]
6.8	0	62	0	7.2	4
16	0	48	0	4.5	4
34	0	21	0	0	0

[a]From Platero and Tejerina (1976).
[b]+, Bacterial inoculation; −, no inoculation.
[c]4 = Complete decay of plants within 6 days; 0 = no symptoms.

(Marschner 1995)

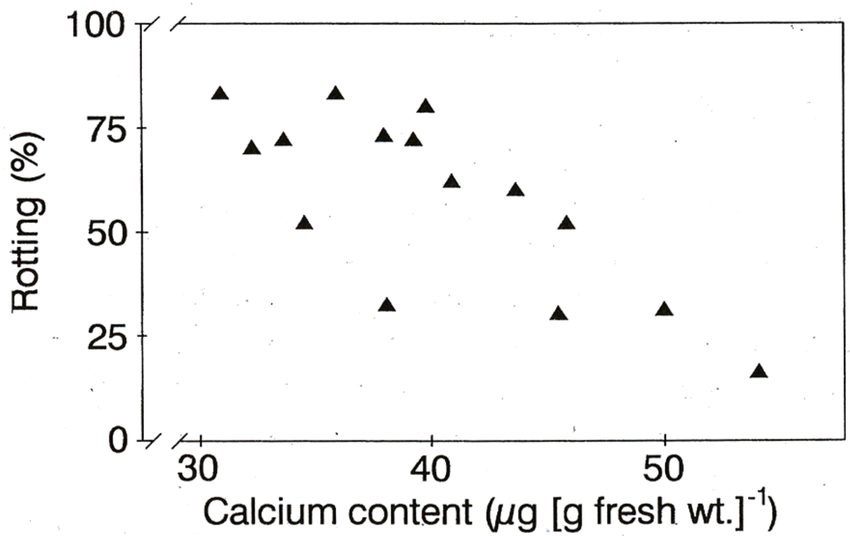


Fig. 11.10 Relationship between the calcium content of apples (cv. Cox orange) and the incidence of rotting due to *Gloesporium perennans* infection after the apples were stored for 3 months at 3°C. (Modified from Sharpless and Johnson, 1977.)

Table 11.6
Relationship between Calcium Supply, Calcium Content and Bacterial Canker Disease (*Clavibacter michiganense* ssp. *michiganense* (Smith)) in a Susceptible and a Resistant Tomato Cultivar[a]

Ca supply ($mg\ l^{-1}$)	Ca content (% in shoot dry matter)		Disease development (% wilted leaves)	
	Moneymaker	Plovdiv 8/12	Moneymaker	Plovdiv 8/12
0	0.12	0.14	84	56
100	0.37	0.42	27	12
200	0.43	0.55	37	6
300	0.44	0.58	27	8

[a]Based on Berry *et al*. (1988).

Marschner, 1995

Effects of Ca as lime and via Cu desorption on take-all (*Gaeumannomyces graminis*)

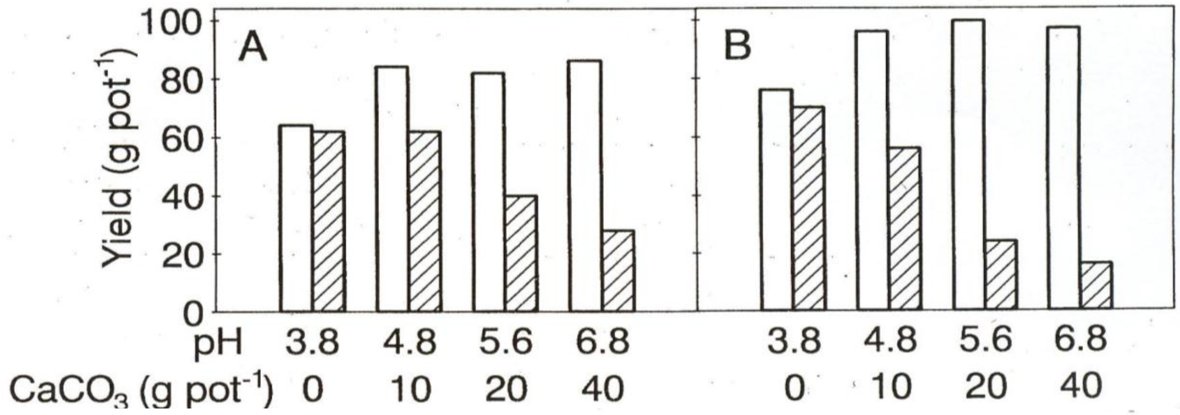


Fig. 11.11 Effect of liming and inoculation with *Gaeumannomyces graminis* var. *tritici* (take-all) on (A) straw yield and (B) grain yield of spring wheat (*Triticum sativum*). Open bars, noninoculated; striped bars, inoculated. (Modified from Trolldenier, 1981.)

Table 11.7
Effect of Copper and Gypsum Application on Growth, Yield and on Root Infection with Take-All (*Gaeumannomyces graminis*) of Winter Wheat Grown in Copper Deficient Soil[a]

Treatment	Dry weight (g per pot)	Ears (no. per pot)	Grain (g per pot)	Infected plants (%)
Nil (control)	8.54	2.80	4.33	100
$CuSO_4$, soil	12.68	3.70	6.51	83
$CuSO_4$, foliar	12.82	3.33	6.06	100
$CaSO_4$, soil	9.81	2.70	5.41	83
$CuSO_4$ + $CaSO_4$, soil	16.96	4.67	8.98	0

[a]Based on Gardner and Flynn (1988).

Marschner, 1995

- Specific mineral nutrient effects

Examples:

Phosphorus (P): no specific interactions with diseases and pests reported

P deficiency: higher efflux of soluble carbohydrates into the leaf apoplast
→ higher disease/pest susceptibility

Low P status: enhanced infection rate by AM fungi
→ increased plant health

Increasing P fertilizer supply: better growth, less take-all incidence and severity

Increasing supply of an acidifying P fertilizer: lower soil pH, higher Mn and Si uptake, less take-all incidence;

Low nutritional status of P (but also of K and S) results in enhanced soluble nitrogen in leaves and, thus, in attraction of, sucking insects such as rice plant hoppers or squash bugs

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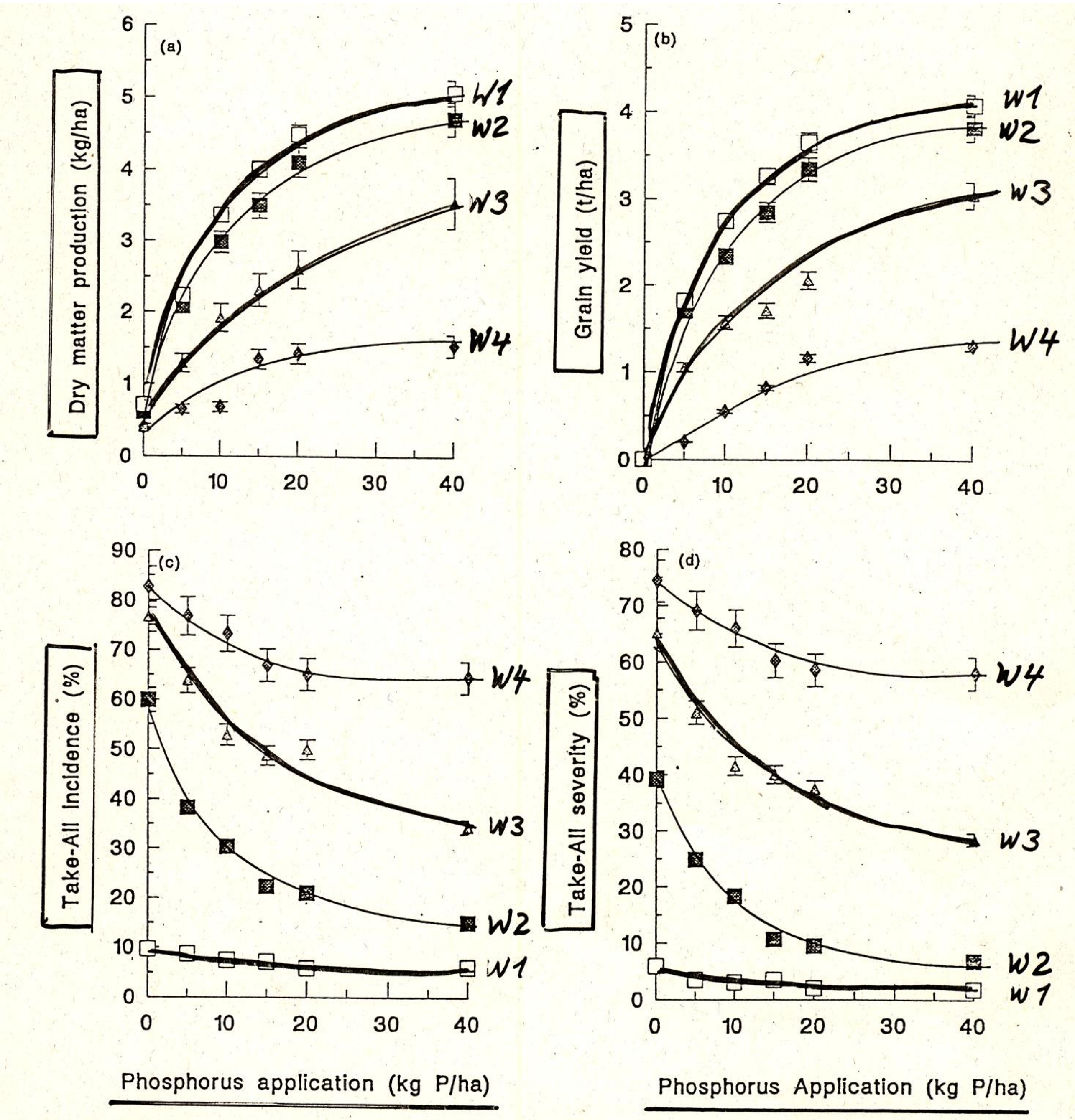
Nutrient supply	Squash bugs (no. per plant)	Soluble nitrogen ($\mu g\ g^{-1}$ fresh wt)
Complete	1.70	32.1
−N	0.66	4.5
−P	2.11	93.7
−K	2.45	98.9
−S	3.42	143.7

[a]From Benepal and Hall (1967).

Marschner, 1995



Effect of an increasing P supply on growth, grain yield and incidence and severity of take-all depending on the frequency of wheat culture in the rotation. (Brennan, J. Plant Nutr. 18, 1159- ; 1995)

Suppression of replant disease by AM-fungi

- Specific mineral nutrient effects

Examples:

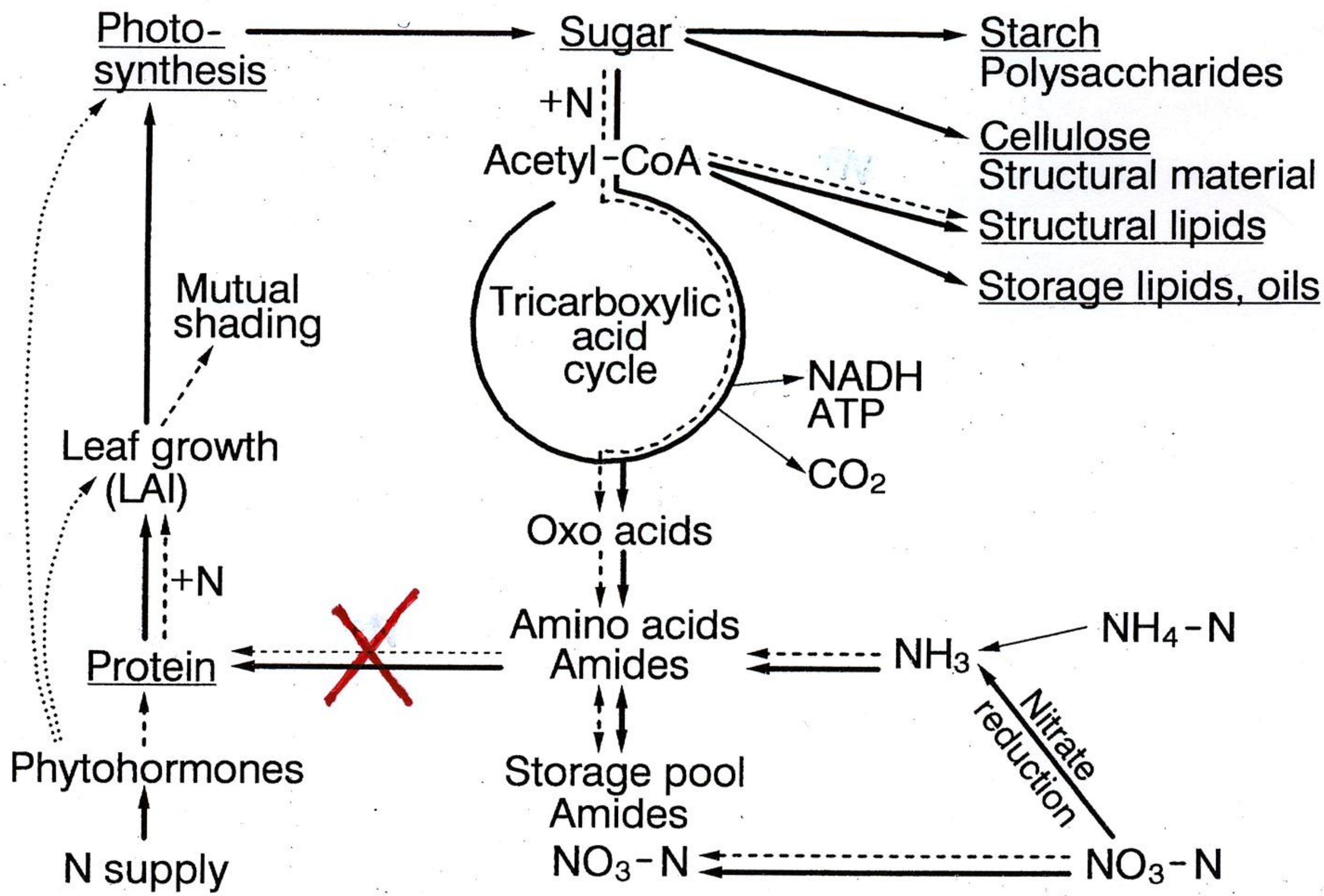
Sulfur (S): indirect by inhibited protein synthesis, S deficiency result in accumulation of soluble organic N, which might promoted parasites

Table 8.10
Effect of Sulfur Deficiency on Leaf Composition in Tomato[a]

	Content in leaves (mg (100 g)$^{-1}$ dry wt)			Sulfur content of protein (μg mg^{-1} protein)	
Treatment	Chlorophyll	Protein	Starch	Cytoplasm	Chloroplast
Control (+SO_4^{2-})	5.8	48.0	2.8	13.5	6.5
S-Deficiency	0.9	3.5	27.0	3.8	5.2

[a]Based on Willenbrink (1967).

Marschner, 1995



S deficiency results in an inhibited protein synthesis and thus in accumulation of soluble N compounds

Table 11.8
Relationship between Mineral Nutrient Deficiencies, Number of Squash Bugs (*Anasa tristis*) per Plant, and Soluble Nitrogen Content of Squash[a]

Nutrient supply	Squash bugs (no. per plant)	Soluble nitrogen ($\mu g\ g^{-1}$ fresh wt)
Complete	1.70	32.1
−N	0.66	4.5
−P	2.11	93.7
−K	2.45	98.9
−S	3.42	143.7

[a]From Benepal and Hall (1967).

Table 8.11
Effect of Sulfate Concentration in the Nutrient Solution on Plant Fresh Weight and Sulfur and Nitrogen Content of Cotton Leaves[a]

		Sulfur or Nitrogen (% dry wt)				
Supply (mg $SO_4^{2-}\ l^{-1}$)	Leaf dry wt (g per plant)	Sulfate S	Organic S	Nitrate N	Soluble organic N	Protein N
0.1	1.1	0.003	0.11	1.39	2.23	0.96
1.0	2.4	0.003	0.12	1.37	2.21	1.28
10.0	3.4	0.009	0.17	0.06	1.19	2.56
50.0	4.7	0.10	0.26	0.00	0 51	3.25
200.0	4.7	0.36	0.25	0.10	0.45	3.20

[a]Based on Ergle and Eaton (1951).

Marschner, 1995

■ Conclusion/Prospects

- An adequate nutritional status can improve resistance/ tolerance to diseases/pests
- Beside balanced plant nutrition some distinct nutrients (K, Ca, Mn, Cu) play a key role in resistance/tolerance to disease/ pests.
- Under high disease pressure plants require a higher nutritional status
- By an adapted crop and fertilization management including rhizosphere management, plants can be supported in their disease resistance.
- In particular, interactions between the use of agrochemicals (e.g. glyphosate), micronutrient acquisition and enhanced disease susceptibility have to be considered much more carefully in relation to plant, soil and ecosystem health in future.

Muito obrigado! *Thank you for your attention !*