Role of Potassium and Magnesium in Carbon Allocation and Biomass Production

(Implications for Bioenergy Plants)

Ismail Cakmak

Sabanci University, Istanbul, Turkey

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Dependency on Fossil Fuels

Dependency on fossil fuels is still high, causing serious adverse environmental impacts such as high emission of greenhouse gases.

Reducing the dependency on this non-renewable fuel is now an important global challenge.

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Alternative to Fossil Fuels

- Converting plant-based biomass into fuel as a renewable energy source (e.g., biomass-based fuel) is a promising alternative to fossil fuel.
- Bioethanol and biodiesel are the major biomass fuels, and their widespread usage is expected to mitigate significantly greenhouse gas emissions.

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

The **sustainability and economics** of the biomass fuel production is dependent on the size of biomass and the concentrations and composition of carbohydrates or oils in the targeted plant organs.

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Theoretical gross energy yield of bio-fuels
- in l fossil fuel equivalents per ha

	Biomass yield (t/ha)	Yield of fossil fuel equivalents (l/ha)
Bio-ethanol		
Cereals	6 – 10 t grain	1500 – 2500
Sugar beet	50 – 70 t beet	3500 – 4900
Sugar cane	70 – 110 t cane	4000 – 6300
Straw (Cellulose, 2nd gen.)	3 - 4 t straw	670 - 900
Bio-diesel		
Oil seed rape	3 – 5 t grain	1250 – 2100
Oil palm	26 – 25 t FFB [1]	2500 - 4000
Wood [2] (BTL-diesel, 2nd gen.)	10 – 15 t dry wood	2600 – 3900

1) FFB = Fresh fruit bunches
2) Short rotation wood

Source: Dr. J. Küsters: Yara International

Role of Mineral Nutrition

Productivity of plants (e.g., size of biomass) is dependent on

i) the capacity of plants to fix atmospheric carbon into organic carbon through photosynthesis,
ii) translocation of the assimilated carbon from source into sink organs, and
iii) utilization of assimilated carbon in the sink organs for growth.

All these steps are greatly influenced by the mineral nutritional status of plants, **especially by Mg and K nutritional status of plants**

Mg and K Nutritional Status of Biofuel Plants

In this presentation several examples will be presented which suggest that a **particular attention should be paid to Mg and K nutritional status of biofuel plants** to achieve high biomass production and to maximize partitioning of the assimilated carbon in the desired plants organs (e.g., grains, stems or roots) for biofuel production.

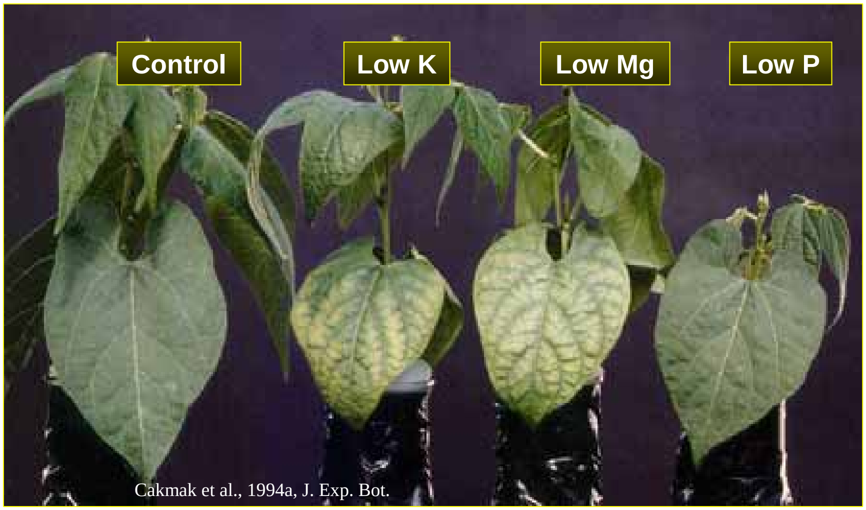
This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Mineral nutrients behave more or less similarly in their final effect on total dry matter production of plants, but distinctly differently in their final effect on dry matter partitioning between shoot and root organs,

an effect that needs a particular attention in production of bio-energy crops

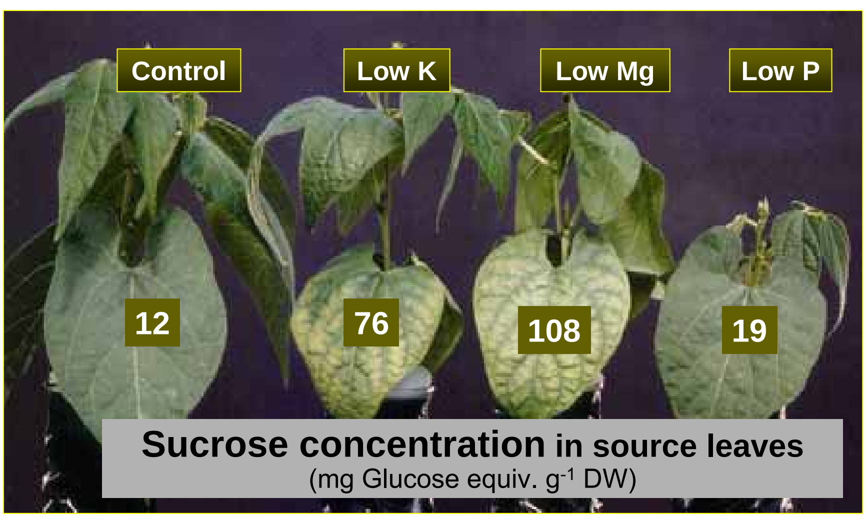
This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Growth of bean plants under low supply of K, Mg or P



This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Sucrose Accumulation in K and Mg deficient leaves

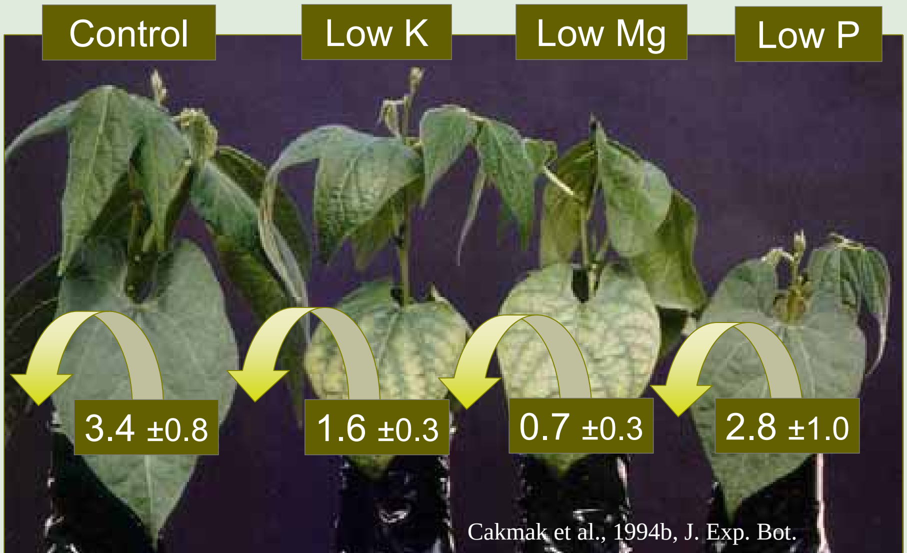


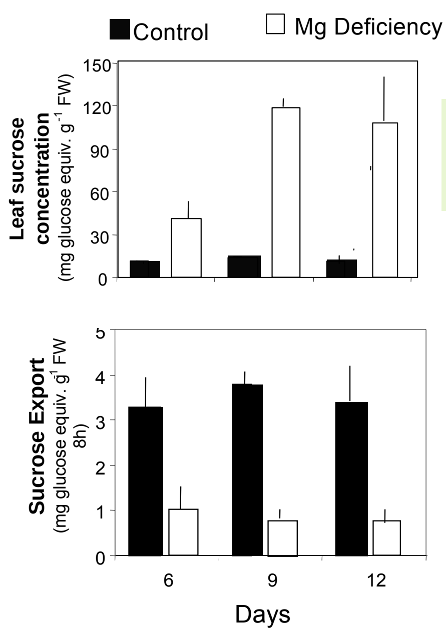
Cakmak et al., 1994b, J. Exp. Bot.

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Phloem Export of Sucrose from bean leaves

(mg Glucose equiv · g^{-1} DW · $8h^{-1}$)

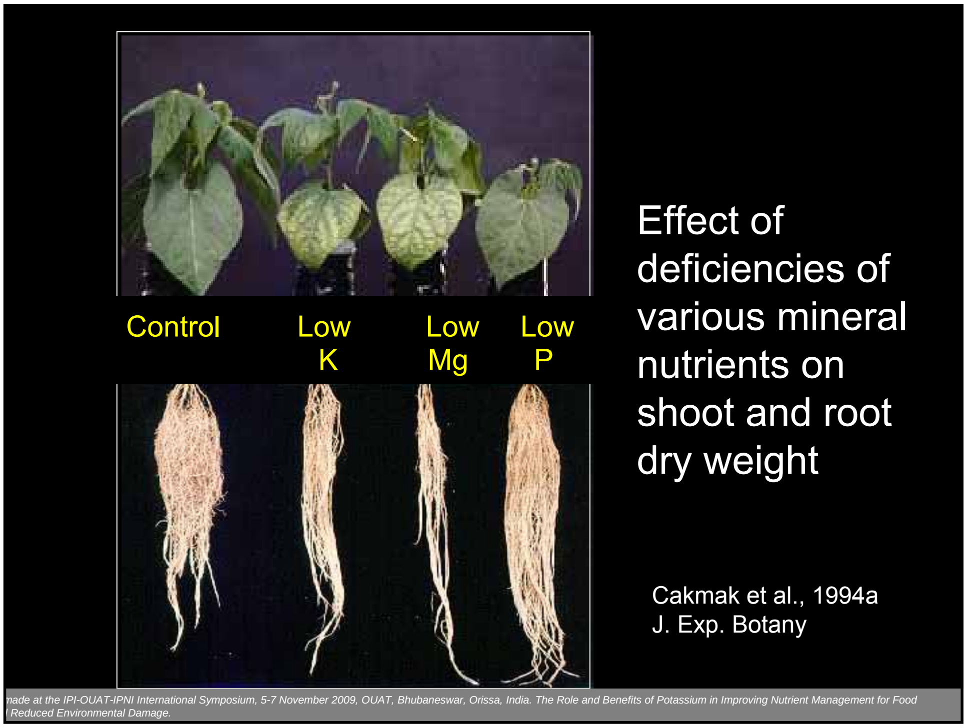


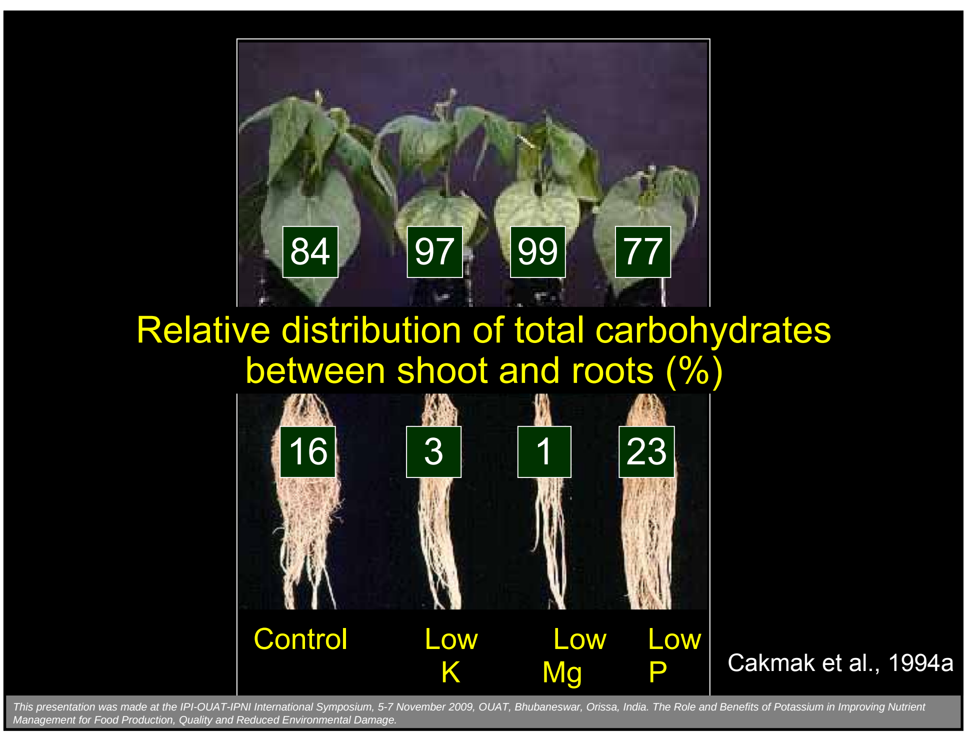


Sucrose Concentration in Source Leaves
(mg Glucose equiv. g^{-1} DW)

Sucrose Export in Phloem
(mg Glucose equiv . g^{-1} DW. $8h^{-1}$)

Cakmak et al., 1994b J. Exp Bot.

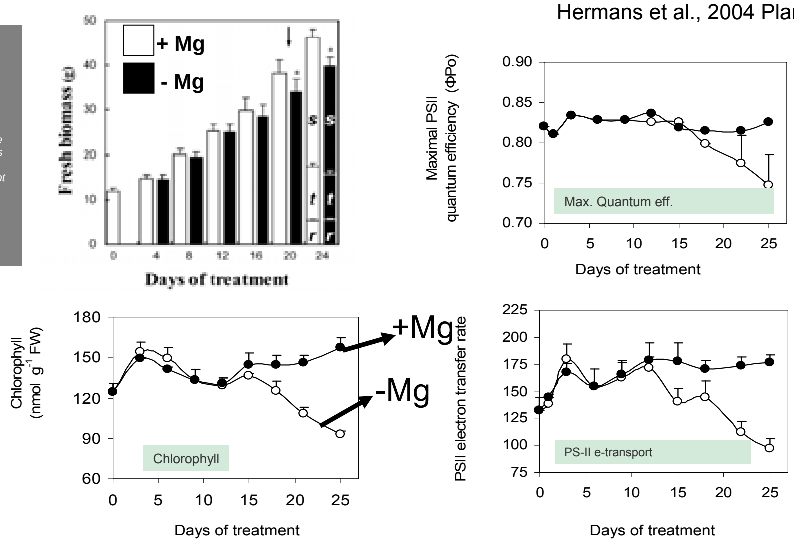

Control
Low K
Low Mg
Low P
Effect of deficiencies of various mineral nutrients on shoot and root dry weight
Cakmak et al., 1994a
J. Exp. Botany
nade at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food
Reduced Environmental Damage.


84
97
99
77
Relative distribution of total carbohydrates between shoot and roots (%)
16
3
1
23
Control
Low K
Low Mg
Low P
Cakmak et al., 1994a
This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Growth, chlorophyll and maximal quantum efficiency and electron transport rate of PSII in sugar beet plants with deficient and adequate Mg supply.

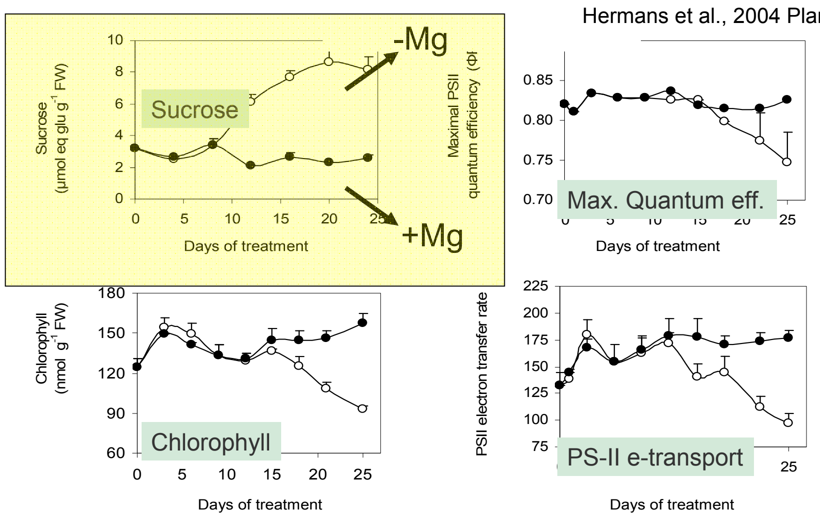
Hermans et al., 2004 Planta

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.



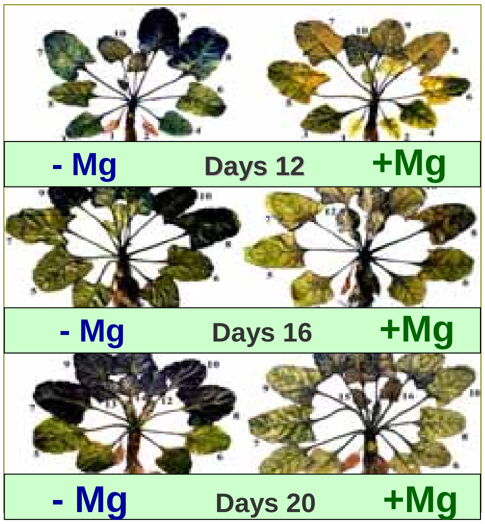
Sucrose, chlorophyll and maximal quantum efficiency and electron transport rate of PSII in sugar beet plants with deficient (O) and adequate (●) Mg supply.

Hermans et al., 2004 Planta



This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Effect of Mg deficiency on starch accumulation in sugar beet leaves, as detected by lugol staining

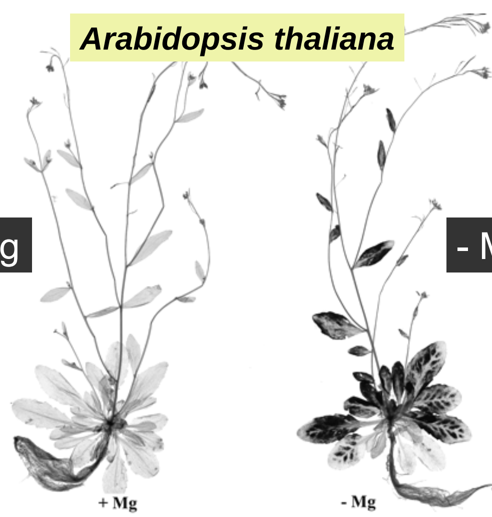


Adverse consequences for bioethanol crops

Hermans et al., 2005 Planta 220: 541-549

Arabidopsis thaliana

+ Mg

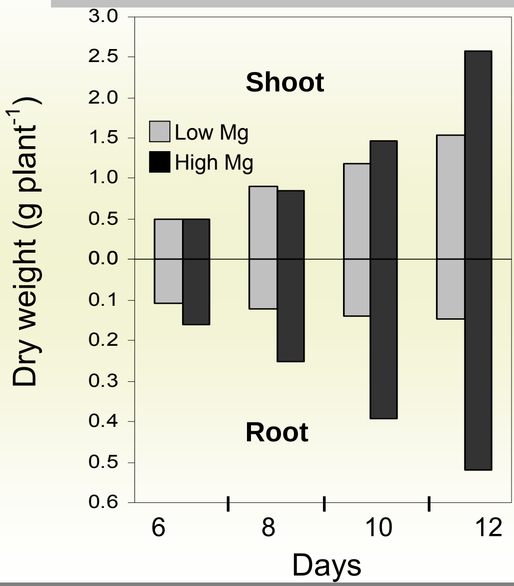


- Mg

Iodine staining of starch in ***Arabidopsis thaliana*** to reveal the presence of starch before the appearance of chlorotic symptoms

Hermann and Verbruggen, 2005, J. Exp. Botany.

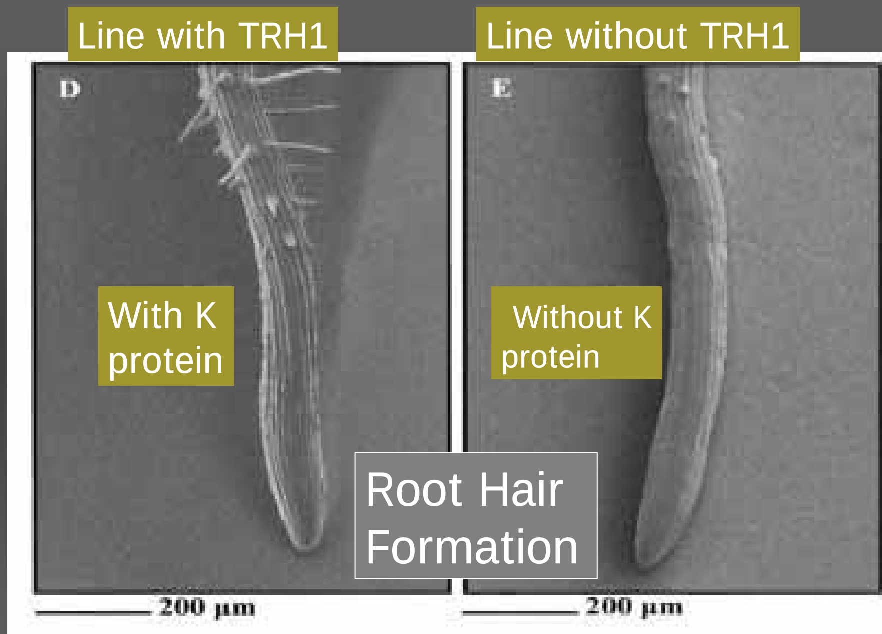
Shoot and root dry weight of bean plants with deficient and adequate Mg supply



Before any visible change occurs in shoot, root growth is impaired under low Mg supply.

Cakmak et al., 1994a J. Exp Bot.

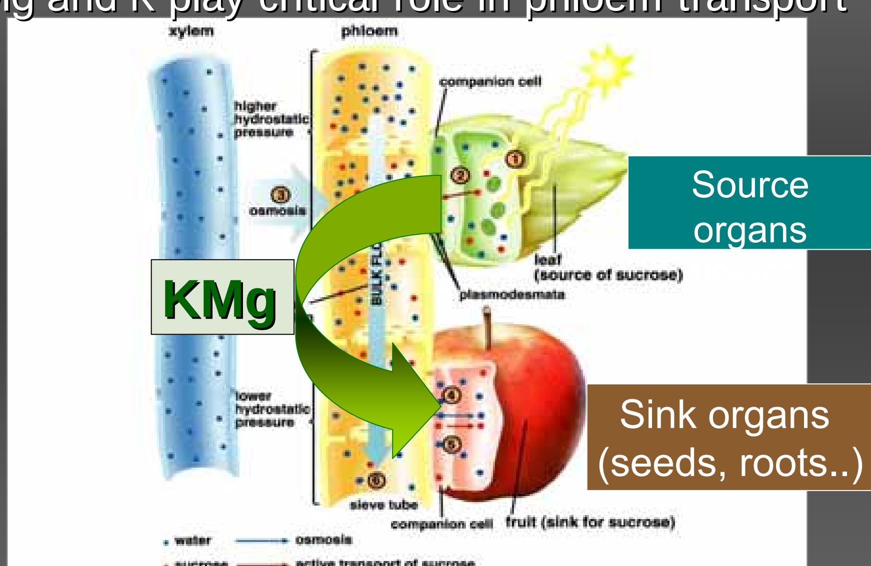
This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.



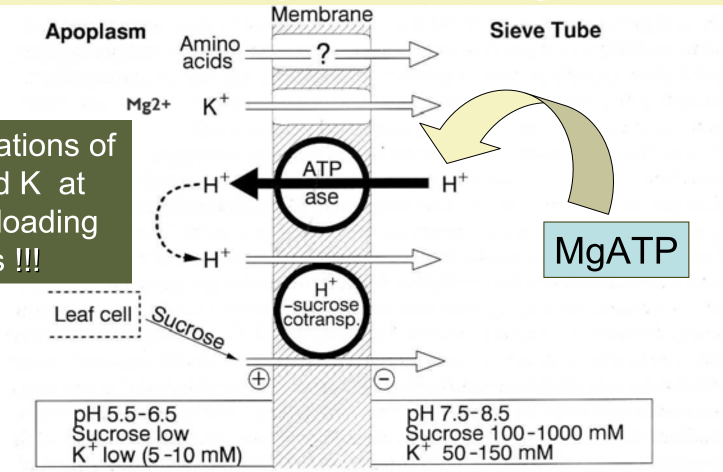
Rigas et al., 2001, Plant Cell, 13: 139-151

PHLOEM TRANSPORT

Mg and K play critical role in phloem transport



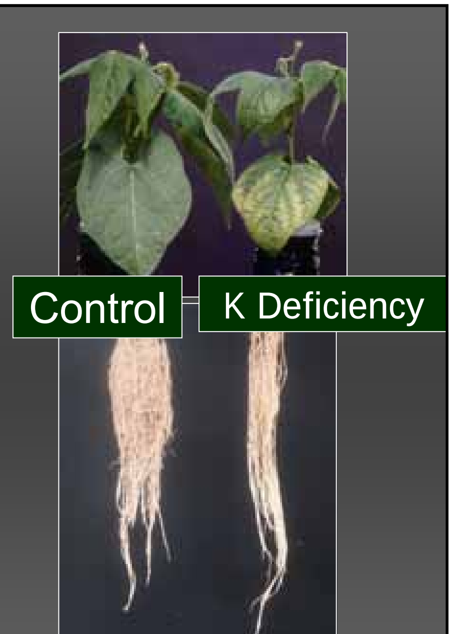
Mg plays a key role in phloem loading of sucrose



Concentrations of Mg and K at phloem loading sites !!!

MgATP

Model of phloem loading of sucrose mediated by proton-sucrose co-transport



Sink Organs are very sensitive to Mg and K deficiencies

Cakmak and Kirkby, 2008, Physiol. Plant.

Effect of N P K combinations on root/tuber production in in Potatoes

at 92 (Expt 1) and 58 days (Expt 2) after emergence

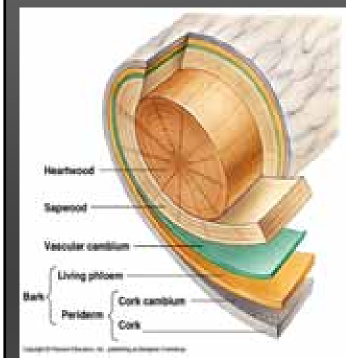
Treatment combinations	Root dry wt fraction (%)		Tuber number per plant		Tuber wt. (g $plant^{-1}$)	
	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
high N P K	2.0	2.9	11.2	27.5	701	629
low N / high P K	2.0	3.1	11.5	21.3	370	465
low P / high N K	2.1	2.4	11.0	27.3	490	587
low K / high N P	1.6	2.2	10.8	17.8	338	418

Jenkins and Mahmood, 2002, Ann. App. Biology

Impairments in in phloem export under K or Mg deficiency has consequences for the size and quality of the plant organs which used for biofuel production

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Potassium is involved in wood formation (lignocellulose production)



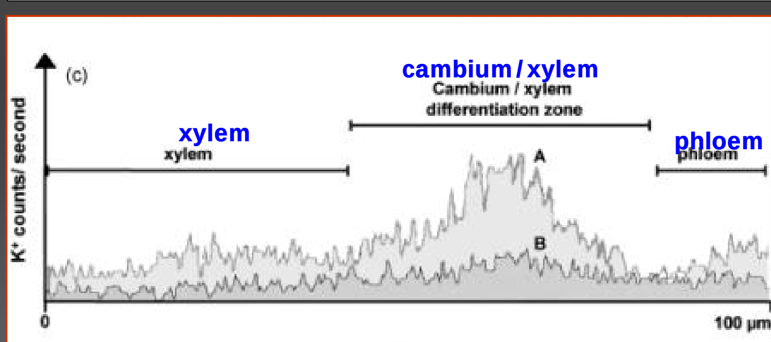
In the cambial region and xylem differention zone, existence of a strong potassium demand has been shown.

Differentiating xylem cells involved in wood formation represent a strong sink for potassium that provides the driving force for cell expansion (reduced assimilate transport)

Langer et al., 2002; Plant Journal, 32: 997-1009

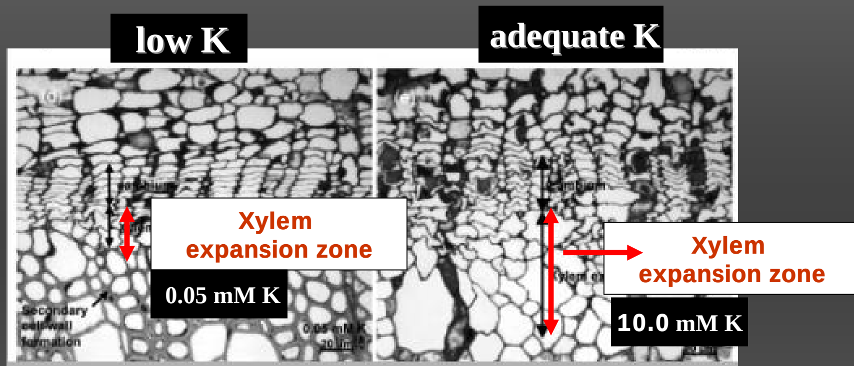
K nutritional status strongly affects development of wood producing cells

Potassium concentration in xylem tissue, cambium / xylem differention zone and phloem tissue



Langer et al., 2002; Plant Journal, 32: 997-1009

Under K deficiency cambial and cell-expansion zones lack 2-3 cell layers each



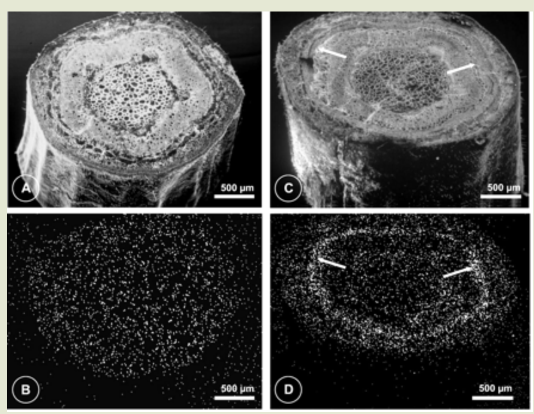
Langer et al., 2002; Plant Journal, 32: 997-1009

Lack of cell divisions in the vessel development region results in reduced wood production

Potassium distribution in twigs of poplar plants

Low K+ supply during cambial growth markedly reduced.

Cambial zone represents the major sink for K in the stem



B: Mapping of potassium-specific x-ray signals indicating a strong accumulation of potassium in the activated cambial zone

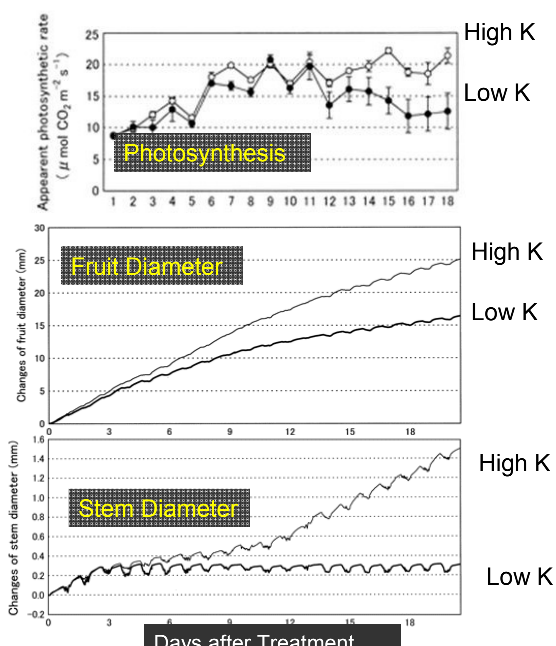
Arend et al., 2002, Plant Physiol, 2002, 129: 1651-1663

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Stem growth is highly sensitive to K deficiency (less production of **lignocellulose** material for biofuel production)

The effect of K deficiency on changes in in stem diameter of tomato plants

Stem development is highly sensitive to K deficiency and related to reduced carbon partitioning in the stem



Kanai et al., 2007, J. Experimental Bot.

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Reduced 14C partitioning in the stem under K deficiency

The effect of K deficiency on 13C atom percentage excess in various parts of tomato plants

Plant part	7 days after treatment		14 days after treatment	
	Control	**K deficiency**	**Control**	**K deficiency**
Fed leaf	0.629±0.048	0.880±0.056	1.250±0.089	1.327±0.096
Other leaves	0.005±0.000	0.004±0.000	0.003±0.000	0.002±0.000
Fruits	0.248±0.016	0.155±0.009	0.080±0.022	0.060±0.013
Stem	0.032±0.002	0.018±0.002	0.035±0.005	0.023±0.002
Root	0.029±0.002	0.026±0.007	0.068±0.017	0.015±0.007

Kanai et al., 2007, J. Experimental Bot.

In K-deficient tomato plants, growth inhibition in stem and fruit occurred prior to depression of photosynthetic activity

Stem and fruits are the strongest sink for both photoassimilates and K.

Demand for K during rapid fruit growth might be above the root uptake capacity or the capacity of leaves to remobilize adequate K..**Needs for foliar K application.**

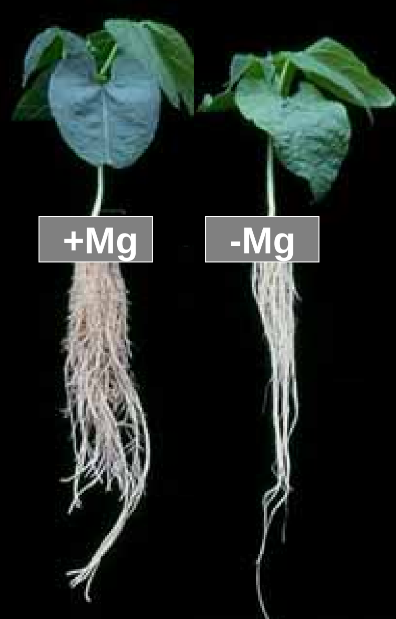
These effects are important for plant materials harvested for lignocellulose production.

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Conclusions

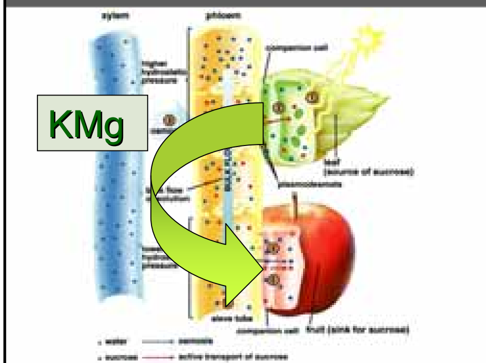
Impairments in maintenance of phloem transport of sugars into the sink organs (e.g., roots and seed) by Mg or K deficiency may affect the size and number of sink organs and consequently yield.

Mg deficiency-induced decreases in single grain weight and number of grains per ear are well-known (Beringer et al..)



Very early impairments in root growth and related decline in root surface by Mg and K deficiencies may have serious impacts on the acquisition of mineral nutrients and uptake of water by roots, **especially under water-limited and nutrient-deficient soil conditions.**

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.



Due to their fundamental roles in phloem export of carbohydrates, nutritional status of plants with Mg or K is important during the reproductive growth stage of biofuel plants, especially under stress conditions which restrict root uptake of Mg and K such as drought stress, low pH, excess N….

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

To maximize biomass/starch production

Topdressing or late foliar application of Mg and K (just before or after flowering) might be required to guarantee efficient retranslocation of photo-assimilates/sucrose into harvest products (e.g. grains, stems, tubers),

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.


Thank you…
Sabanci University
SABANCI ÜNİVERSİTESİ
This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.