The importance of potassium in citrus production in China

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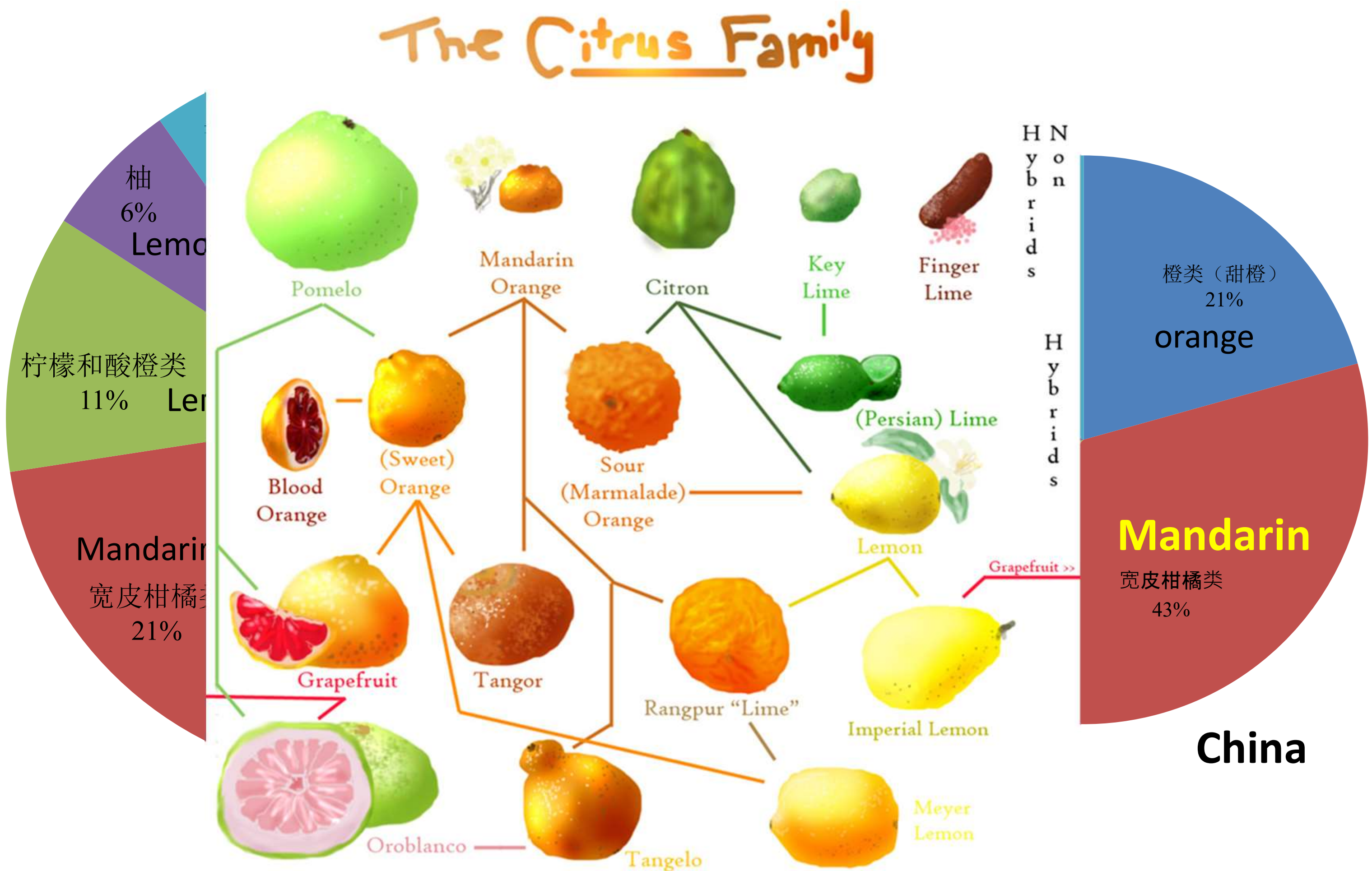
Outline

1. Overview of citrus production in China
2. Functions of K in citrus production
3. Importance of K in citrus production in China
4. Balanced use of K in citrus: An example of Mg vs K

Mandarin is the major citrus product in China



Nutritional and health benefits of citrus fruits

C. Economos and W.D. Clay

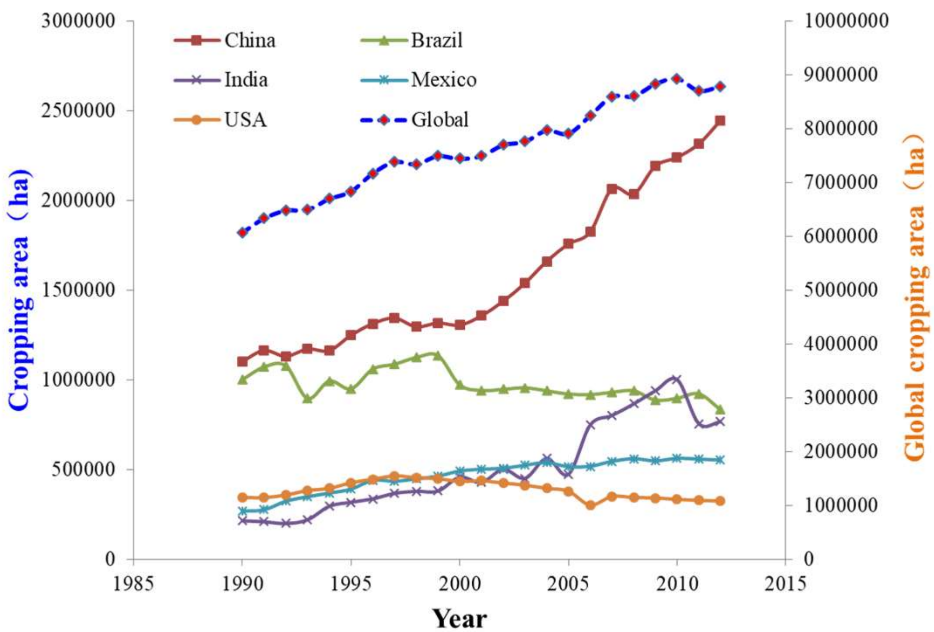
Citrus is most commonly thought of as **a good source of vitamin C**. However, like most other whole foods, citrus fruits also contain an impressive list of other essential nutrients, including both glycaemic and non-glycaemic carbohydrate (sugars and fiber), **potassium**, **folate**, **calcium**, thiamin, niacin, vitamin B_6, phosphorus, **magnesium**, copper, riboflavin, pantothenic acid and a variety of **phytochemicals**. In addition, citrus contains **no fat** or sodium and, being a plant food, no cholesterol. The average energy value of fresh citrus is also low (see Table), which can be very important for consumers concerned about putting on excess body weight.

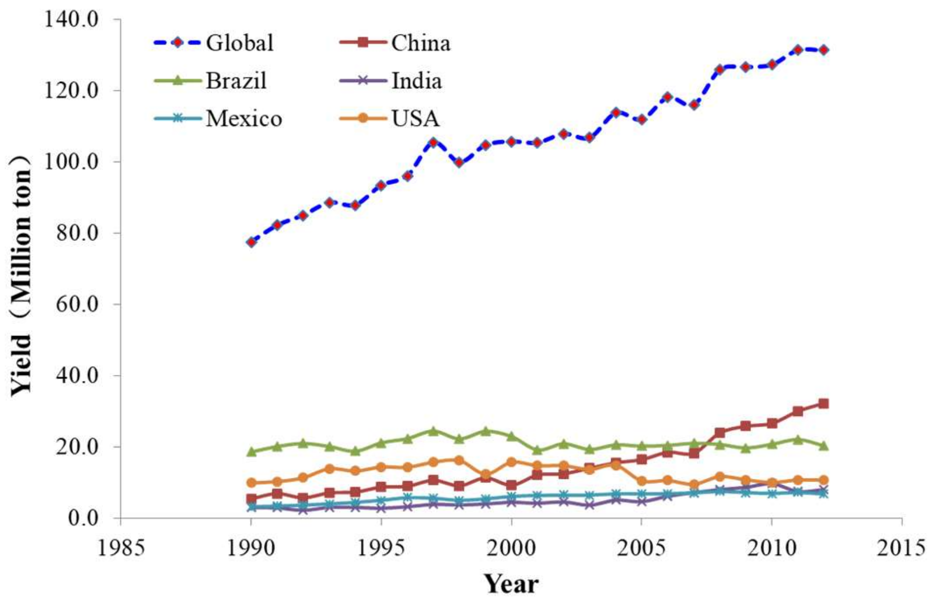
Nutritional facts about citrus fruit

	Orange	Grapefruit	Tangerine
Weight *(g)*	131	236	84
Energy *(kcal)*	62	78	37
Fibre content *(g)*	3.1	2.5	1.7
Ascorbic acid *(mg)*	70	79	26
Folate *(mcg)*	40	24	17
Potassium *(mg)*	237	350	132

http://www.fao.org

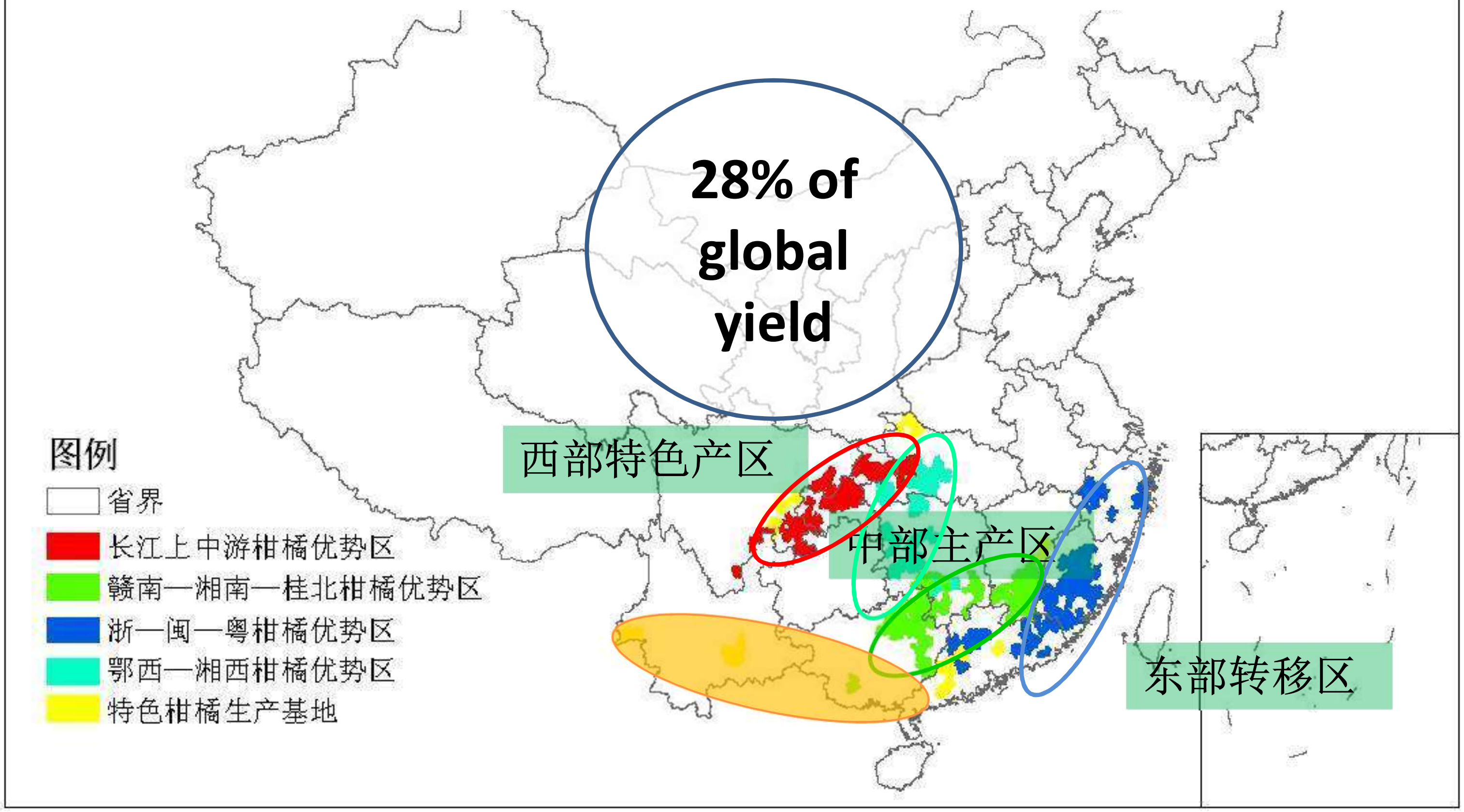
Increasing citrus planting areas and total yield especially in China





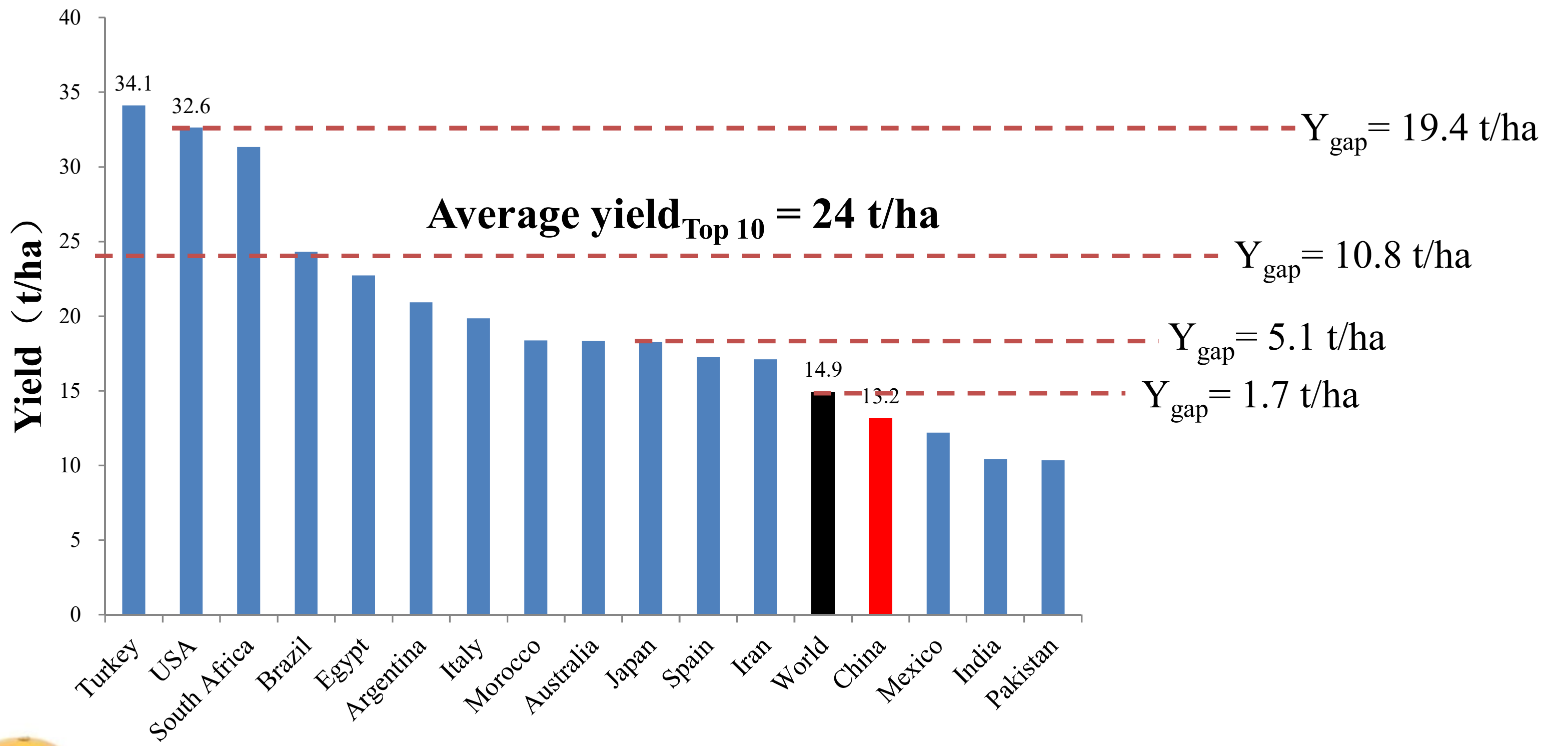
There is a growing trend in the area of citrus cultivation worldwide, reaching 87.78 million hectares (130 million mu) in 2012. Among them, China's citrus planting area grows rapidly, reaching 2.44 million hectares in 2012, ranking first in the world. The above five countries account for 56% of the world's citrus cultivation area.

Dominant regions of citrus producing areas in China



Guangxi, Sichuan, and Yunnan are provinces with fast citrus planting.

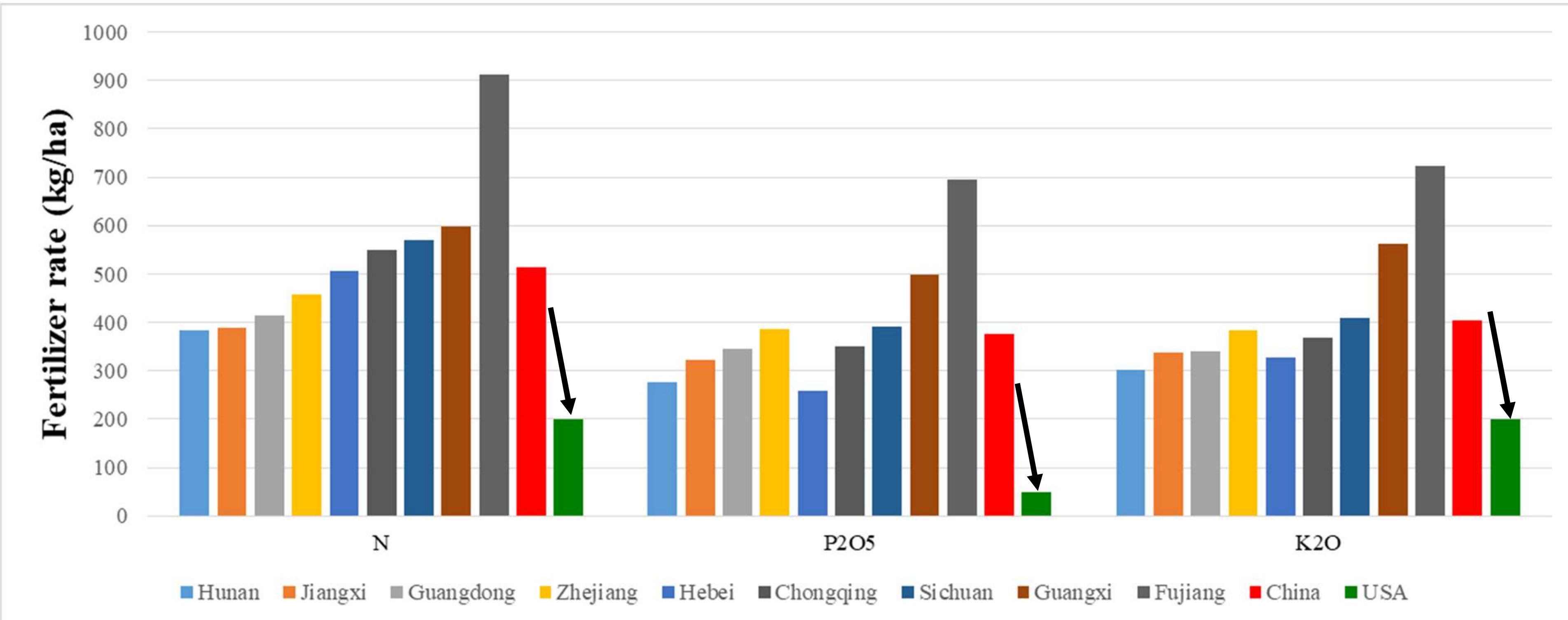
Low citrus yield in China



The average yield in China is 13.2 t/ha, accounting 40% of that in USA

(FAO, 2016)

NPK fertilizer are overused by farmers in China



A large number of farmers survey shows that China's citrus orchard is generally over-fertilized (Zhou, 2017), resulting low nutrient use efficiency.

Great potential for fertilizer saving of citrus producing in China

地区	面积（千公顷）	农户施肥量（万吨）			肥料需求量（万吨）			节肥量（万吨）		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
湖南	400.0	18.6	8.0	10.6	8.0	4.8	6.4	10.6	3.2	4.2
广东	254.7	10.5	5.1	8.1	5.1	3.1	4.1	5.4	2.1	4.0
湖北	243.6	11.3	4.9	6.5	4.9	2.9	3.9	6.5	1.9	2.6
广西	217.1	9.0	4.4	6.9	4.3	2.6	3.5	4.6	1.8	3.4
四川	271.6	12.5	6.7	7.5	5.4	3.3	4.3	7.0	3.4	3.2
江西	317.3	14.8	6.3	8.4	6.3	3.8	5.1	8.4	2.5	3.4
福建	179.6	7.9	3.7	4.1	3.6	2.2	2.9	4.3	1.6	1.3
浙江	109.4	5.9	2.5	2.4	2.2	1.3	1.8	3.7	1.2	0.7
重庆	161.4	7.4	4.0	4.5	3.2	1.9	2.6	4.2	2.0	1.9
云南	39.5	1.8	1.0	1.1	0.8	0.5	0.6	1.0	0.5	0.5
总计	2194	100	47	60	44	26	35	56	20	25

全国4%

56% 43% 42%

注：（1）农民习惯施肥量来自前10种植省市已发表文献的均值；（2）推荐用量采用按生产1 t 鲜柑橘需氮量7-10 kg计算，N：P2O5：K2O比例为1：0.5：0.8，推荐用量200-120-160 kg/ha；

It's estimated that 40~50% of fertilizers used by farmers could be saved if recommended NPK rate by Chinese experts is applied. But how to achieve this target?

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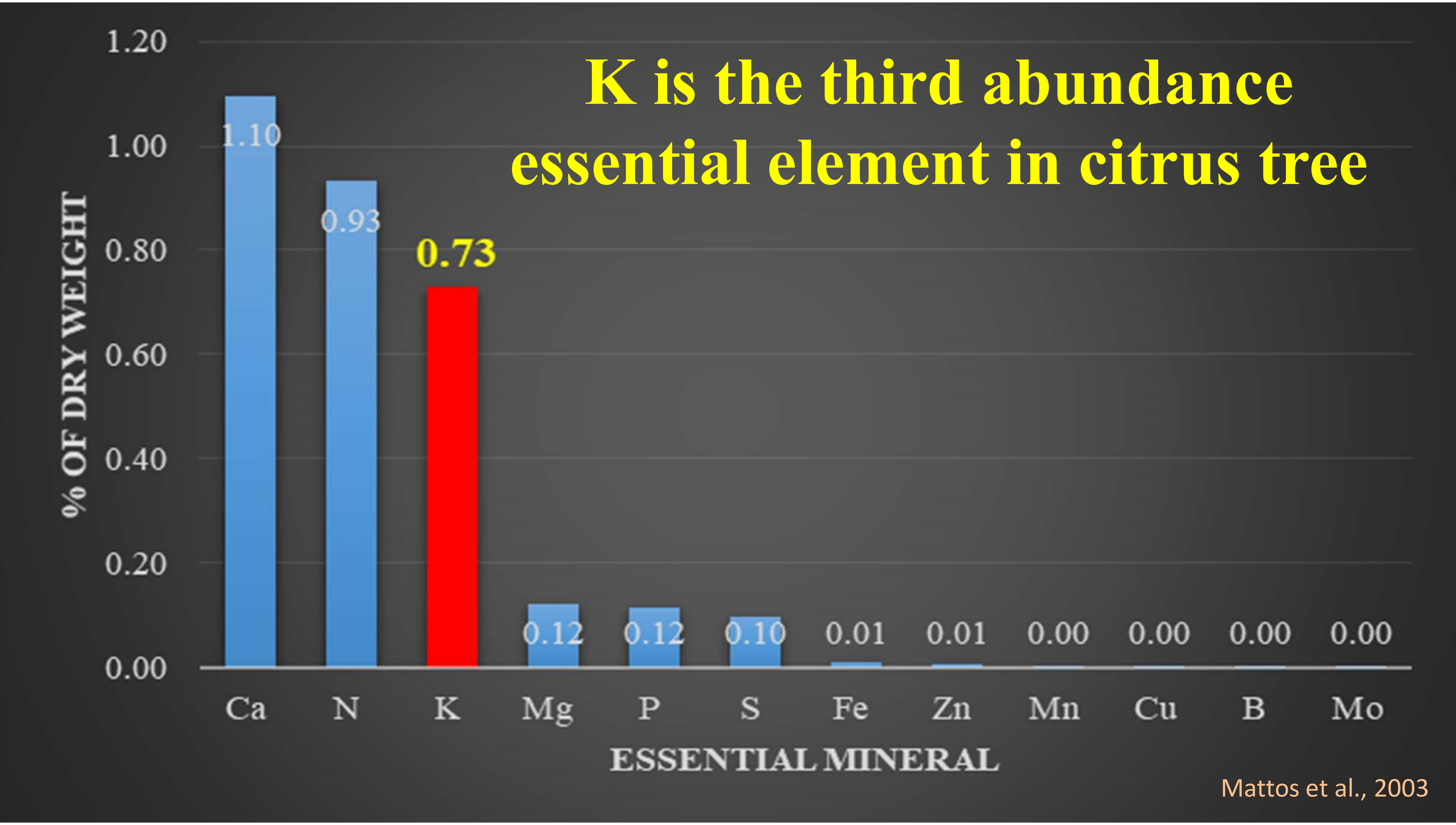

K is the third abundance essential element in citrus tree
% OF DRY WEIGHT
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1.10
0.93
0.73
0.12
0.12
0.10
0.01
0.01
0.00
0.00
0.00
0.00
Ca
N
K
Mg
P
S
Fe
Zn
Mn
Cu
B
Mo
ESSENTIAL MINERAL
Mattos et al., 2003

The general functions of K in plant

1. It is characterized by high mobility in plants at all levels – within individual cells, within tissues, as well as in long-distance transport via the xylem and phloem.
2. Potassium is not metabolized and it forms only weak complexes in which it is readily exchangeable. And its high concentrations in the cytosol and chloroplasts, it balances the charge of and insoluble anions and thus facilitates stabilizing the pH between 7 and 8 in these compartments, which is the optimum for most enzyme reactions.

- Enzyme Activation
- Protein Synthesis
- Photosynthesis
- Osmoregulation

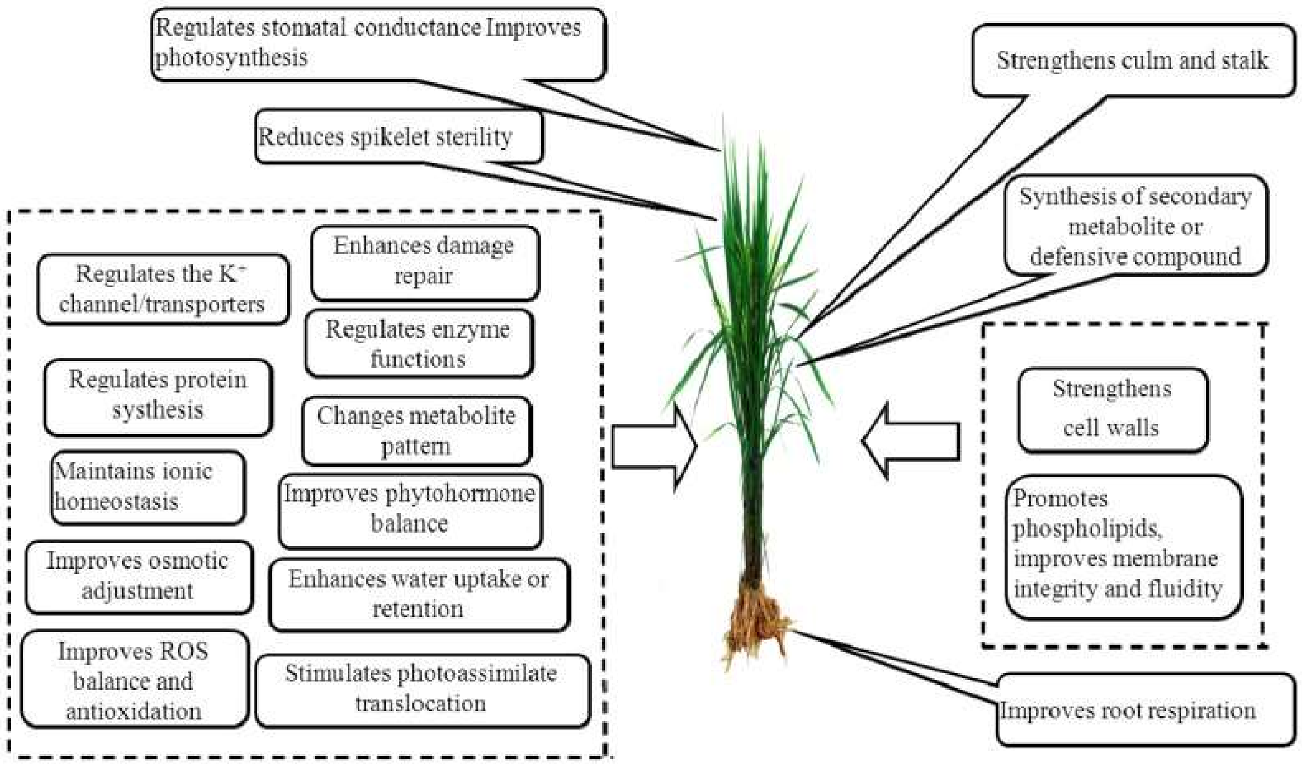
(Marschner, 1995)

	Leaf K concentration ($mg\ g^{-1}$ dw)		
	12.8	19.8	38.4
Stomata resistance ($s\ cm^{-1}$)	9.3	6.8	5.9
Photosynthesis ($mg\ CO_2\ dm^{-2}\ h^{-1}$)	11.9	21.7	34.0
RUBP carboxylase activity ($\mu mol\ CO_2\ mg^{-1}$ protein h^{-1})	1.8	4.5	6.1
Photorespiration ($dpm\ dm^{-2}$)	4.0	5.9	9.0
Dark respiration ($mg\ CO_2\ dm^{-2}\ h^{-1}$)	7.6	5.3	3.1

From Peoples and Koch (1979).

Potential roles of K in stress response

K also contributes to the survival of plants exposed to various biotic and abiotic stresses.

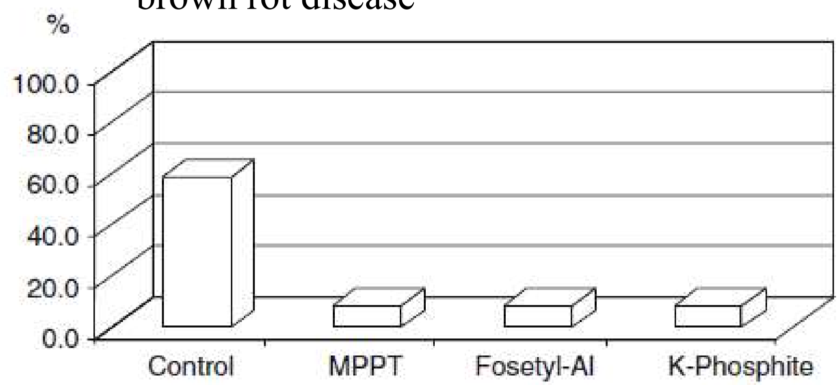


Cakmak, 2007; Wang et al., 2013

Potential roles of K in the control of plant diseases

	Decrease in disease	Increase in disease	No effect	Total
Fungi	89	33	8	130
Bacteria	18	5	0	23
Viruses	9	5	3	17
Nematode	3	6	1	10

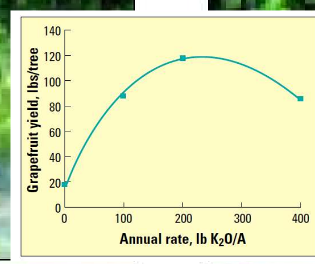
Percentage of citrus trees affected by gummosis brown rot disease



Application of Nutrient-Related Products to Disease Control in Citrus

Wang et al., 2013; Garcia-Mina, 2012

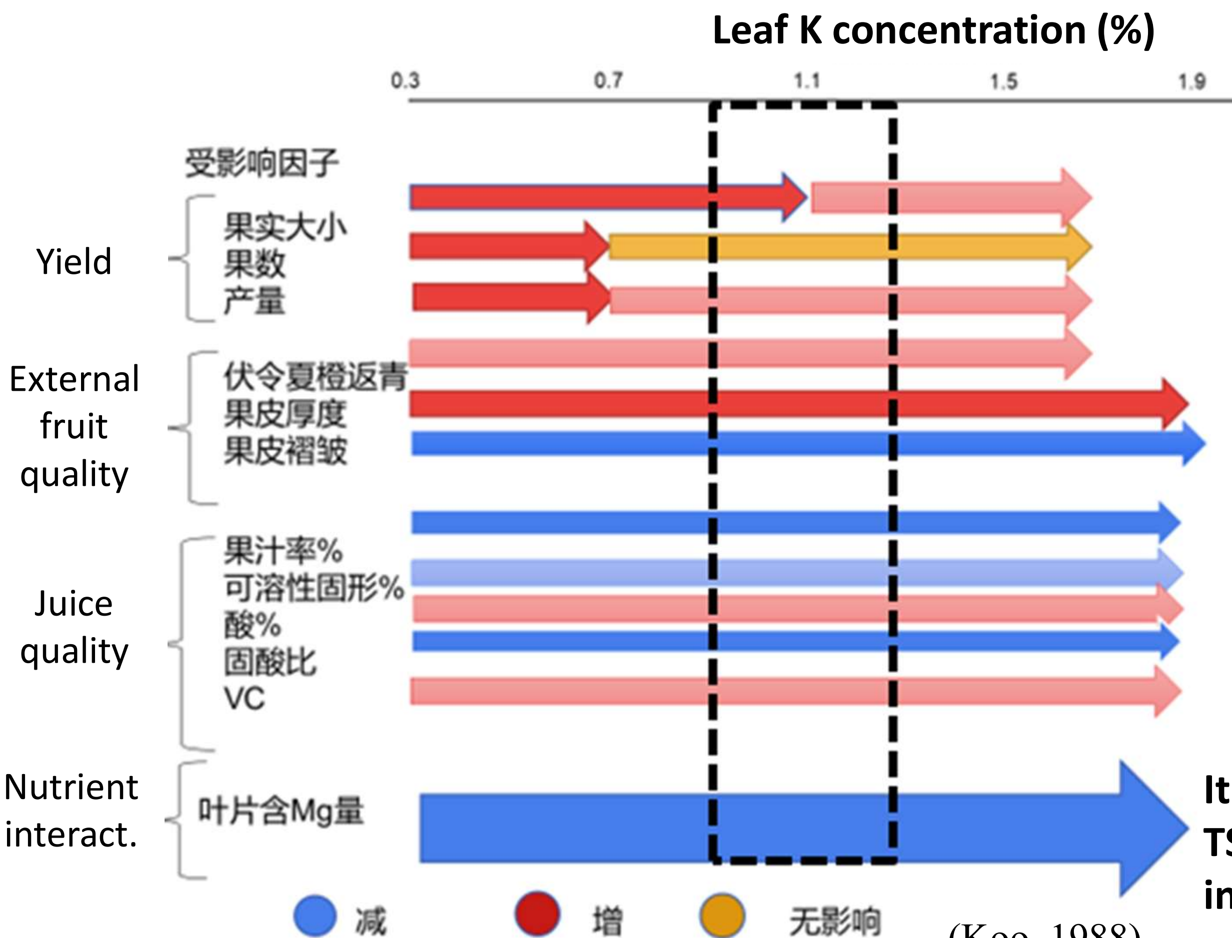
Low canopy growth and yield of citrus tree when without sufficient K application



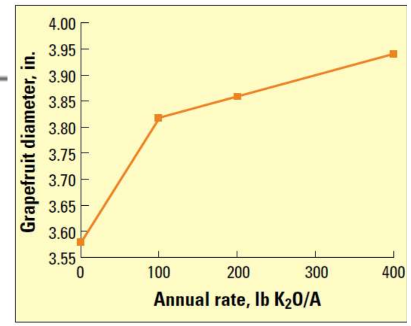
	Deficient	Low	Optimum	High	Excessive
Potassium	<0.7	0.7–1.1	1.2–1.7	1.8–2.4	>2.4

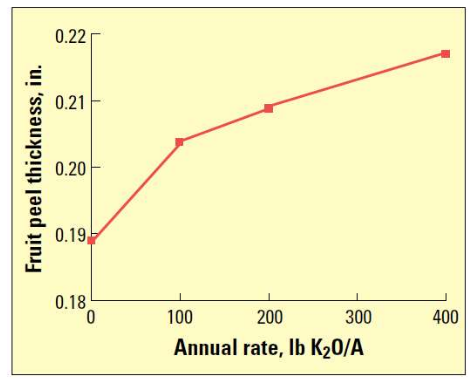
The tree at left received no K fertilizer – note the tight, compact growth and no visible fruit. The tree at right received 200 lb K2O/A each year – note the increased branching and expansive tree canopy with visible grapefruit (Obreza, 2012).

K—quality element



(Koo, 1988)





(Obreza, 2003).

It’s noticeable that overuse of K will decrease TSS, but increase acid and peel thickness, indicating lower quality.

(Obreza and Morgan, 2008)

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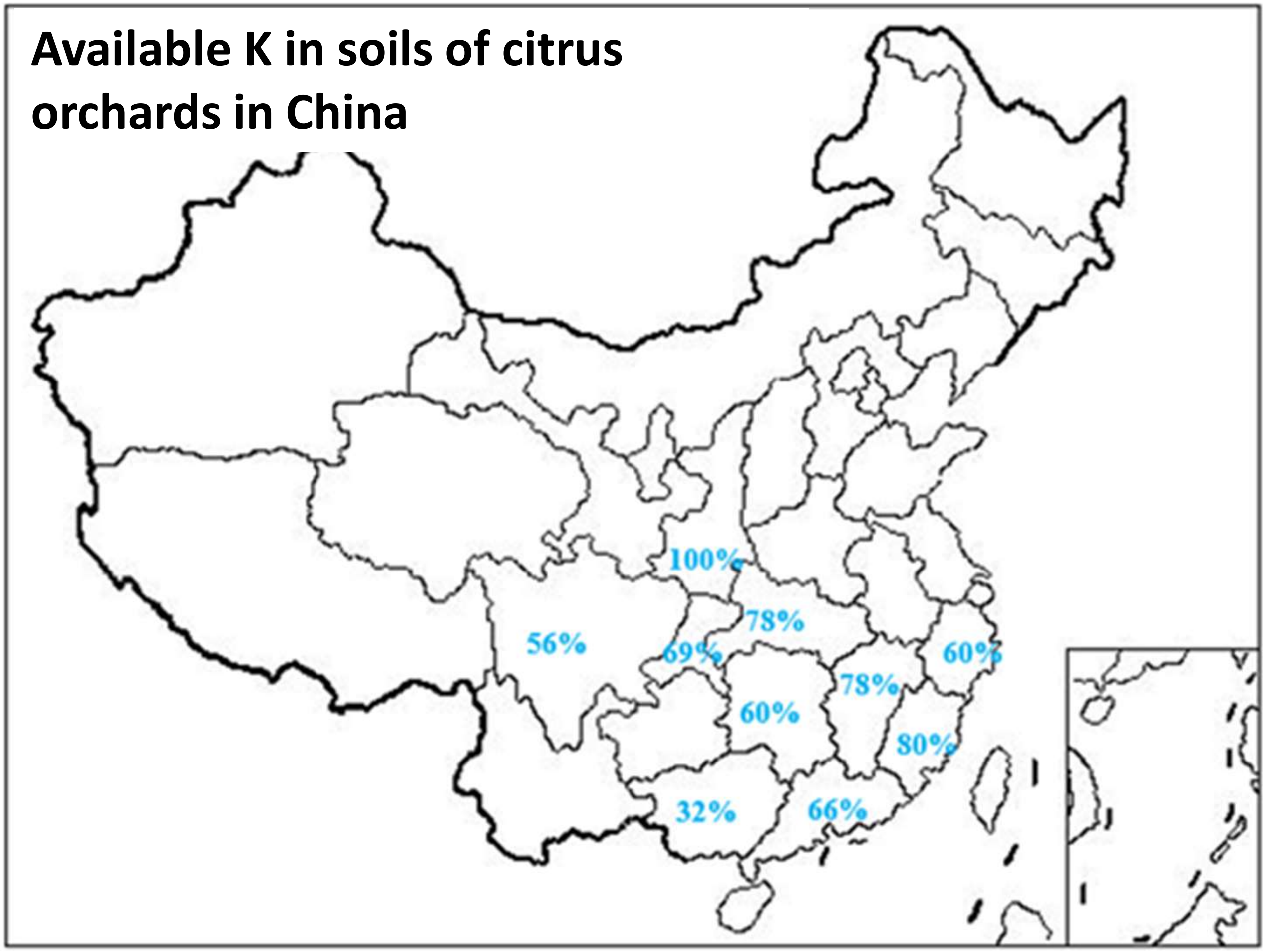
Buildup of soil available K in Chinese citrus orchards

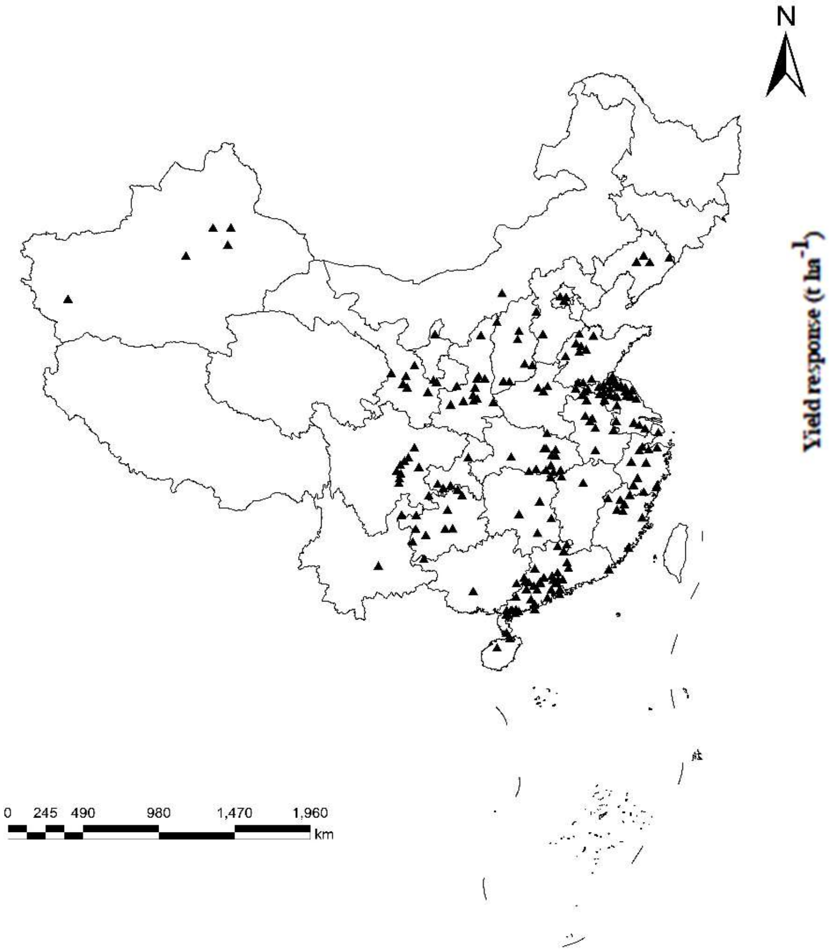


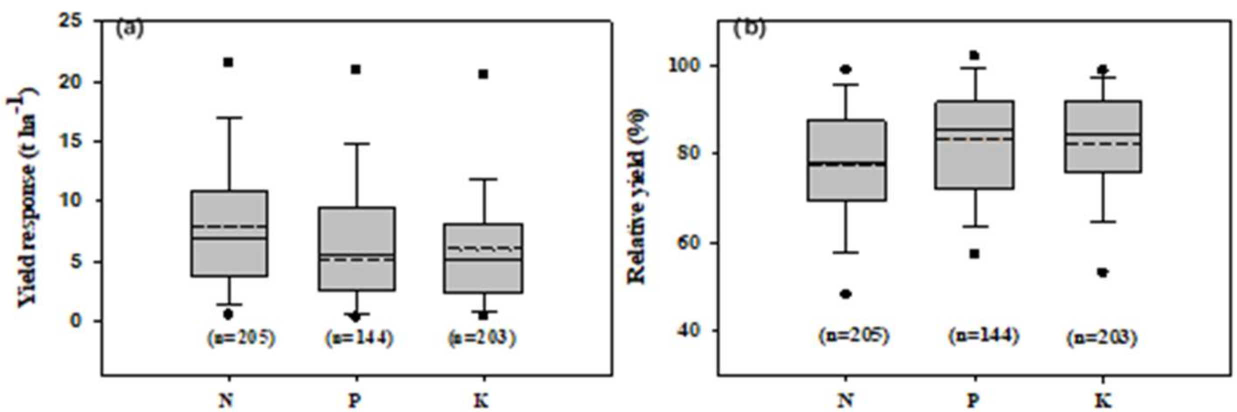
During last three decades, overuse of K fertilizer by farmers has substantially increased the soil K supply capacity in orchards.

Do we need further K application?

Adopted from Hu Chengxiao (2018)

Agronomic response of K fertilization to fruit crops



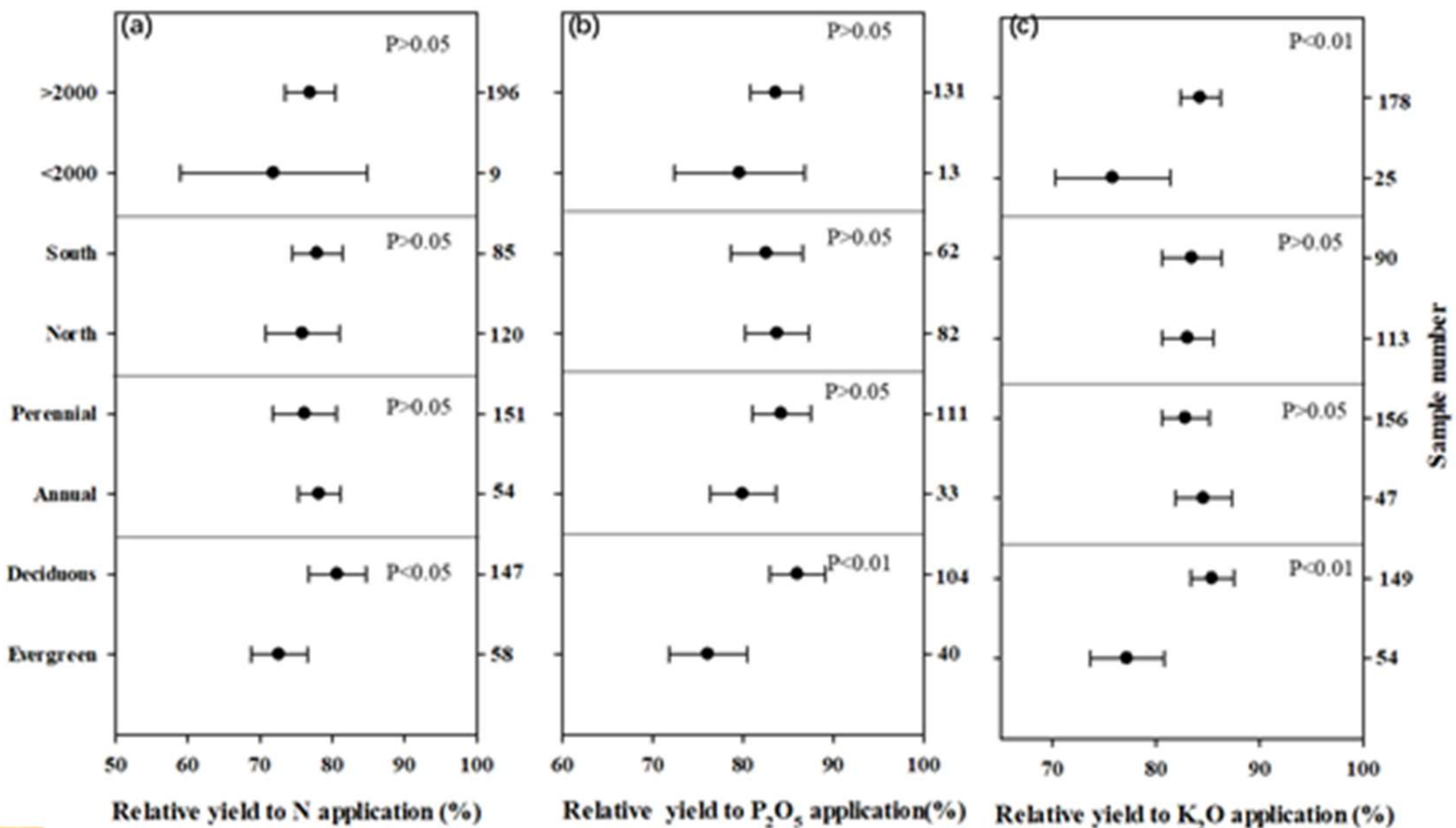


Meta analysis showed that YR-K value was 5.9 with CI of 5.6-7.9 t ha^{-1} in China.

On the other hand, the RY-K value was 82.4 with CI of 81.3-85.1 %, respectively.

Li and Zhang et al. unp

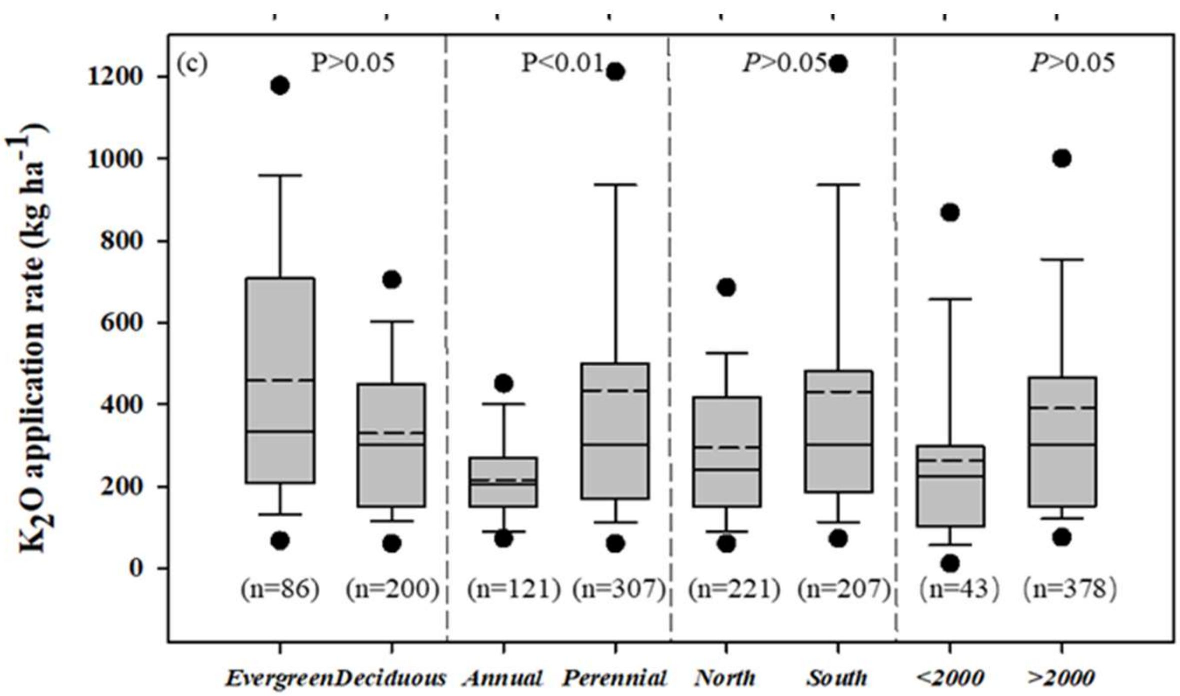
Agronomic response of K fertilization to fruit crops

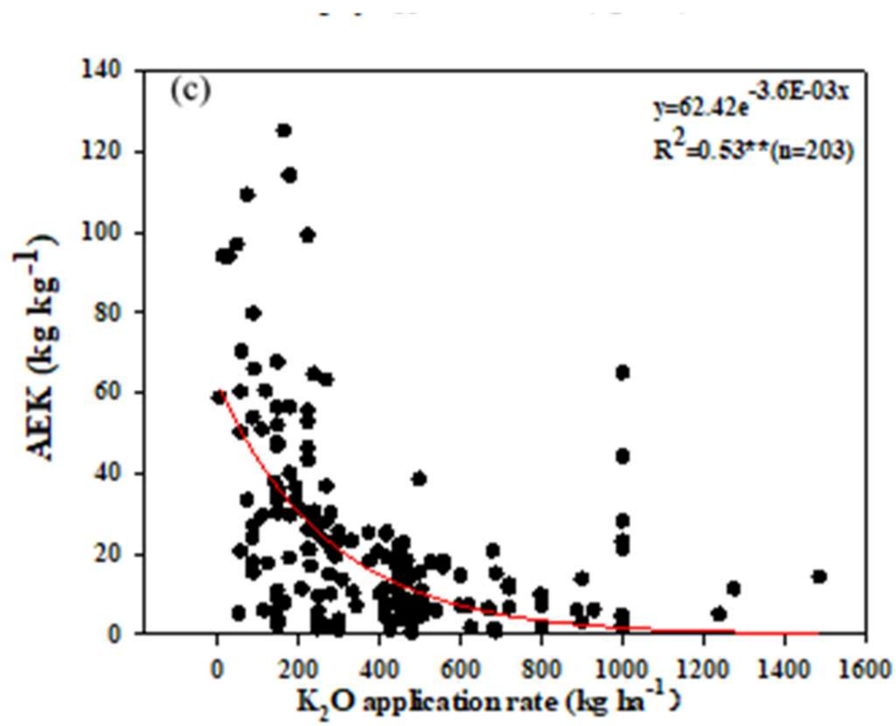


Zhang et al. unp

The contribution of K fertilization is decreasing with Eras, and is higher for evergreen fruit crops.

Increasing K fertilization in new Era decreases KUE

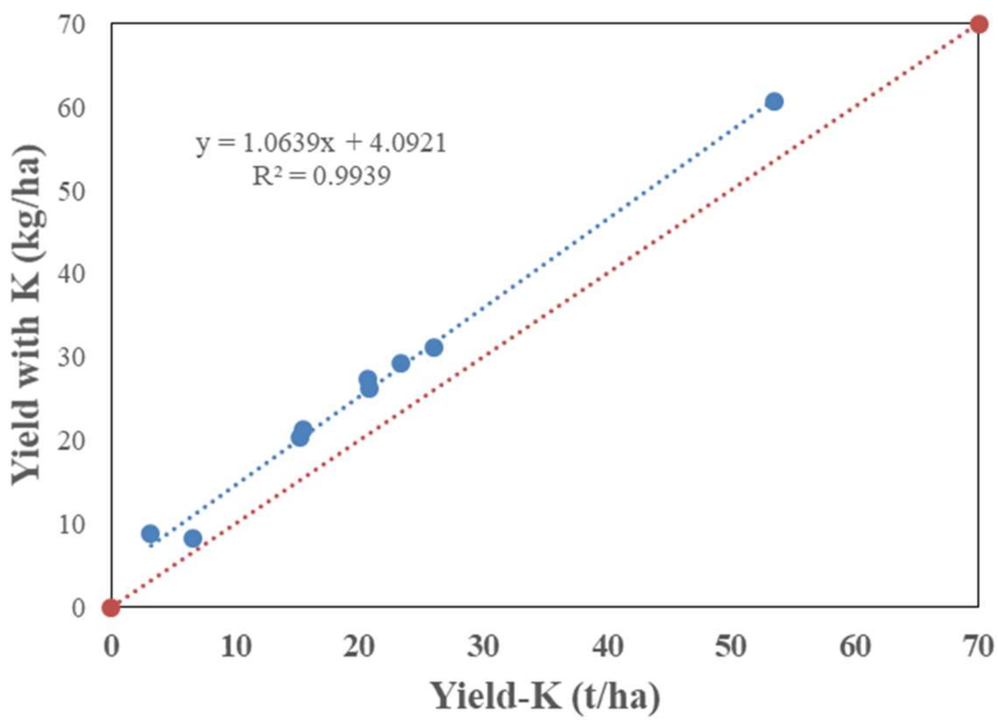


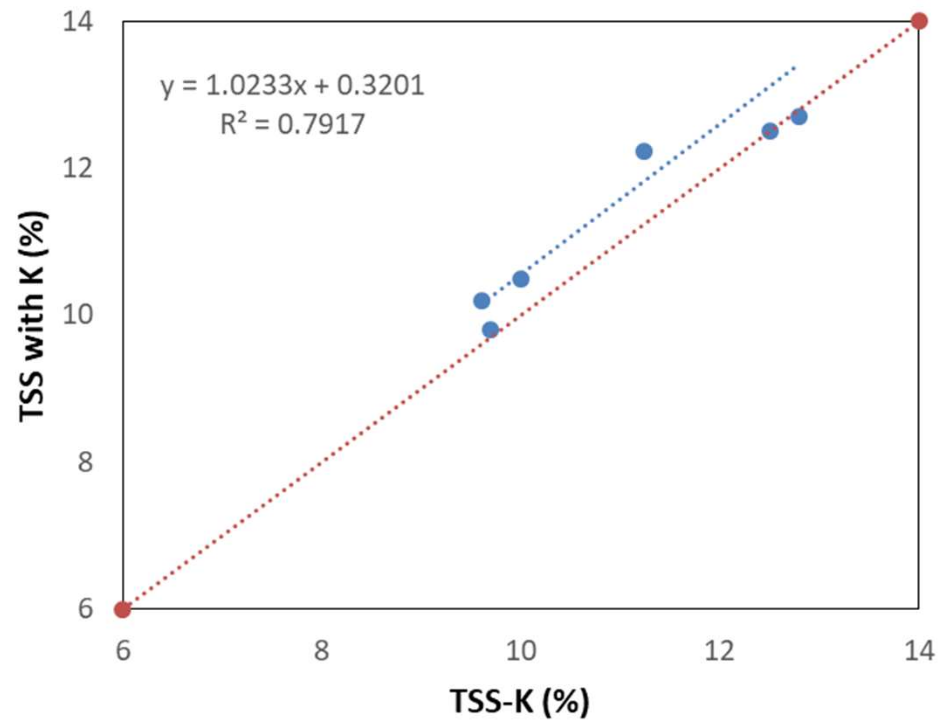


There is increasing trend of K application after year 2000.
And K rates was significantly and negatively correlated with AEK

Li and Zhang et al. unp

Yield and quality response of K fertilization to citrus





In average, K application can increase yield with 6%, and has positive effects on TSS and others. Don't use too much K fertilizer.

Zhang et al. unp

Strategy of integrative nutrient recommendation of citrus production for high yield and high efficiency

Step 1-Yield based fertilizer recommendation: to quantify the basic fertilizer rate of NPKCaMg according to target yield, fruit nutrient remove (FNR), and nutrient harvest index of fruit (NHI).

Estimated fertilizer rate = FNR/(NUE*NHI）

NHI: 30-50% for N, 45-71% for P and 50-72% for K

Step 2-Soil test and leaf analysis based modification of FR: to modify fertilizer rate and formula according to soil test and leaf analysis by standard of nutrient classification;

Step 3-Individual (tree level) based modification of FR: to modify fertilizer rate and formula according to varieties, age of trees, combination of rootstock and scion, and tree vigor.

Step 1-Yield based fertilizer recommendation

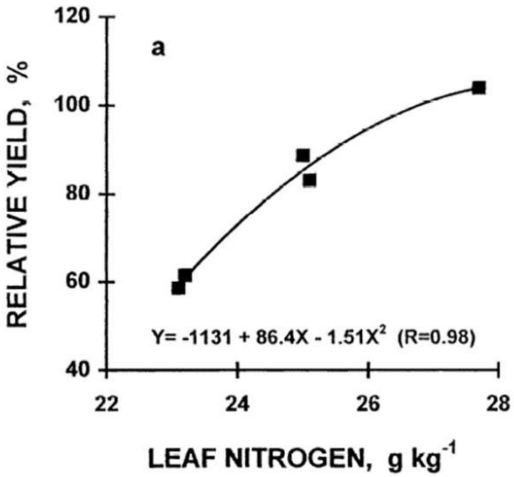
Varieties	fruit nutrient remove (kg/t fresh fruit)					Estimated fertilizer rate (kg/ t fresh fruit)		
	N	P_2O_5	K_2O	CaO	MgO	N	P_2O_5	K_2O
甜橙	1.46	0.54	2.95	0.97	0.32	6.6-13.1	3.2-9.7	7.2-12.5
脐橙	1.78	0.51	2.09	0.89	--	8.0-16.0	3.1-9.2	5.1-8.9
柑	1.70	0.50	2.80	0.30	0.10	7.7-15.3	3.0-9.0	6.8-11.9
温州蜜柑	1.69	0.40	2.06	0.92	0.33	7.6-15.2	2.4-7.2	5.0-8.8
蕉柑	1.90	0.40	1.60	0.30	0.20	8.6-17.1	2.4-7.2	3.9-6.8
金柑	1.36	0.53	2.71	--	--	6.1-12.2	3.2-9.5	6.6-11.5
Mean	1.58	0.52	2.36	0.83	0.26	7.1-14.2	3.1-9.4	5.7-10.0

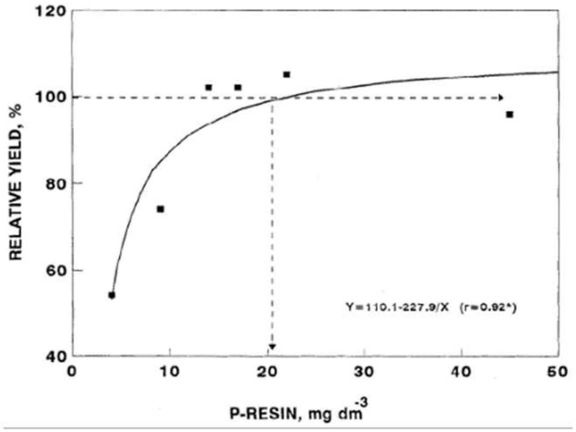
The basic nutrient recommendation for citrus production in China:

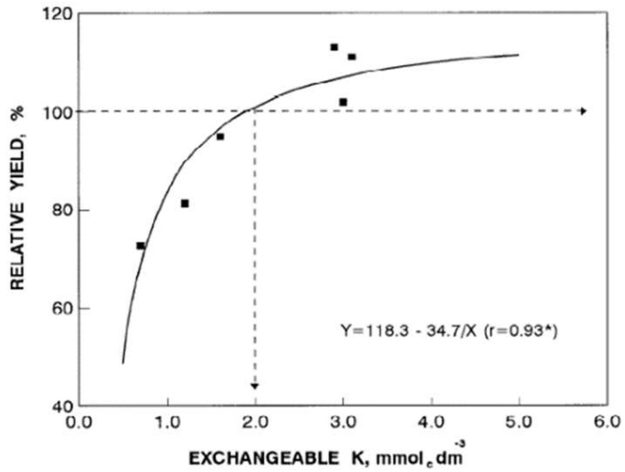
N: 7-10 kg/t; P_2O_5: 2-3 kg/t; K_2O: 5-7 kg/t

Step 2- Establish standard of soil and leaf nutrient classification

Example: to quantify NPK rate by multi years and sites field trials using soil and leaf analysis







Step 3- local standard of soil and leaf nutrient classification

Element	Unit of measure	Deficient	Low	Optimum	High	Excess
N	%	< 2.2	2.2 – 2.4	2.5 – 2.7	2.8 – 3.0	> 3.0
P	%	< 0.09	0.09 – 0.11	0.12 – 0.16	0.17 – 0.30	> 0.30
K	%	< 0.7	0.7 – 1.1	1.2 – 1.7	1.8 – 2.4	> 2.4
Ca	%	< 1.5	1.5 – 2.9	3.0 – 4.9	5.0 – 7.0	> 7.0
Mg	%	< 0.20	0.20 – 0.29	0.30 – 0.49	0.50 – 0.70	> 0.70
Cl	%	---	---	< 0.2	0.20 – 0.70	> 0.70[1]
Na	%	---	---	---	0.15 – 0.25	> 0.25
Mn	mg/kg or ppm[2]	< 18	18 – 24	25 – 100	101 – 300	> 300
Zn	mg/kg or ppm	< 18	18 – 24	25 – 100	101 – 300	> 300
Cu	mg/kg or ppm	< 3	3 – 4	5 – 16	17 – 20	> 20
Fe	mg/kg or ppm	< 35	35 – 59	60 – 120	121 – 200	> 200
B	mg/kg or ppm	< 20	20 – 35	36 – 100	101 – 200	> 200
Mo	mg/kg or ppm	< 0.05	0.06 – 0.09	0.10 – 2.0	2.0 – 5.0	> 5.0

[1]Leaf burn and defoliation can occur at Cl concentration > 1.0%.
[2]ppm = parts per million.

（USA, Koo et al.,1984）

产量	叶片氮（g kg^{-1}）			土壤 resin-磷（mg dm^{-3}）				土壤交换性钾（mmol dm^{-3}）			
	<23	23-27	>27	<5	6-12	13-30	>30	<0.7	0.8-1.5	1.6-3.0	>3.0
t/ha	N (kg/ha)			P2O5 (kg/ha）				K2O (kg/ha)			
<15	100	70	60	50	40	20		60	40	20	0
16-20	120	80	70	70	50	30		80	60	40	0
21-30	140	120	90	90	70	40		120	80	60	0
31-40	200	160	130	130	100	50		140	120	80	40
41-50	220	200	160	160	120	60		180	140	100	50
>50	240	220	180	180	140	70		200	160	120	60

（Brazil, Quaggio et al., 1998）

K recommendation of citrus orchard in China

Ex. K（mg/kg）	Yield level (kg/mu)			
	2000	3000	4000	5000
＜50	20～30	23～40	26.5～43	--
50～100	16.5～20	20～30	23～40	26.5～43
100～150	10～13	16.5～20	20～30	23～40
150～200	6.5～10	10～13	16.5～20	20～30
＞200	＜6.5	6.5～10	10～13	16.5～20

Zhang et al., 2011

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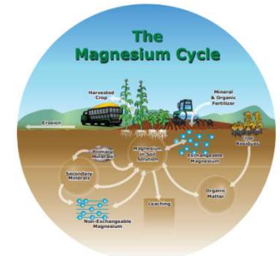
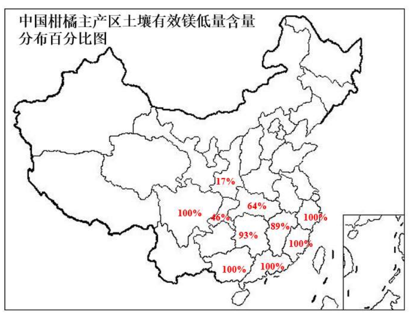
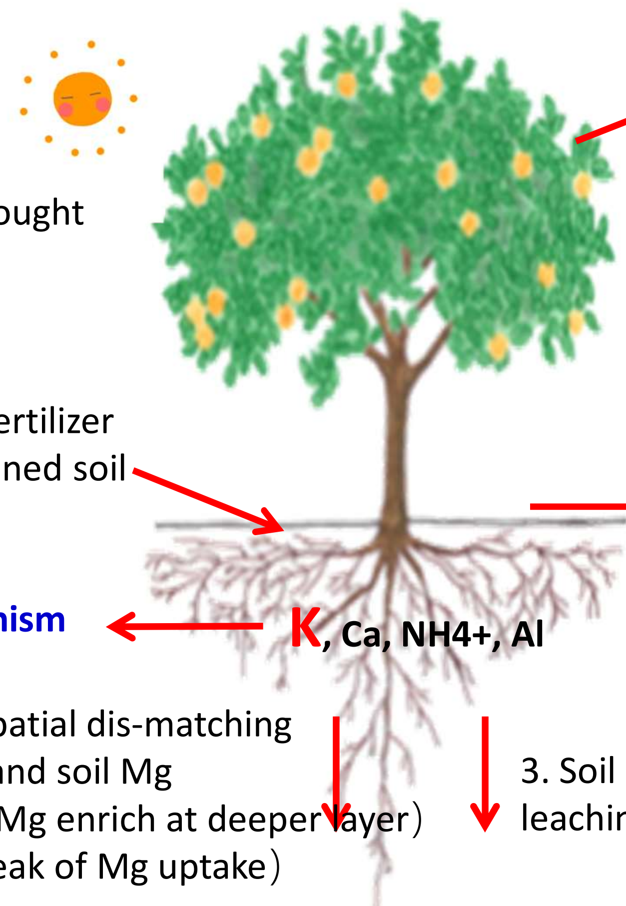
Comprehensive reasons of orchard Mg deficiency



Surplus K vs use-up Mg





1. Many years' harvest and pruning resulted in soil Mg exhausting

2. Sloping orchards and poor management resulted in Mg runoff.

3. Soil acidification accelerated Mg leaching.

4. The temporal and spatial dis-matching between root system and soil Mg
（e.g., topdressing vs Mg enrich at deeper layer）
（root dormancy vs peak of Mg uptake）

5. Strong antagonism ← **K, Ca, NH4+, Al**

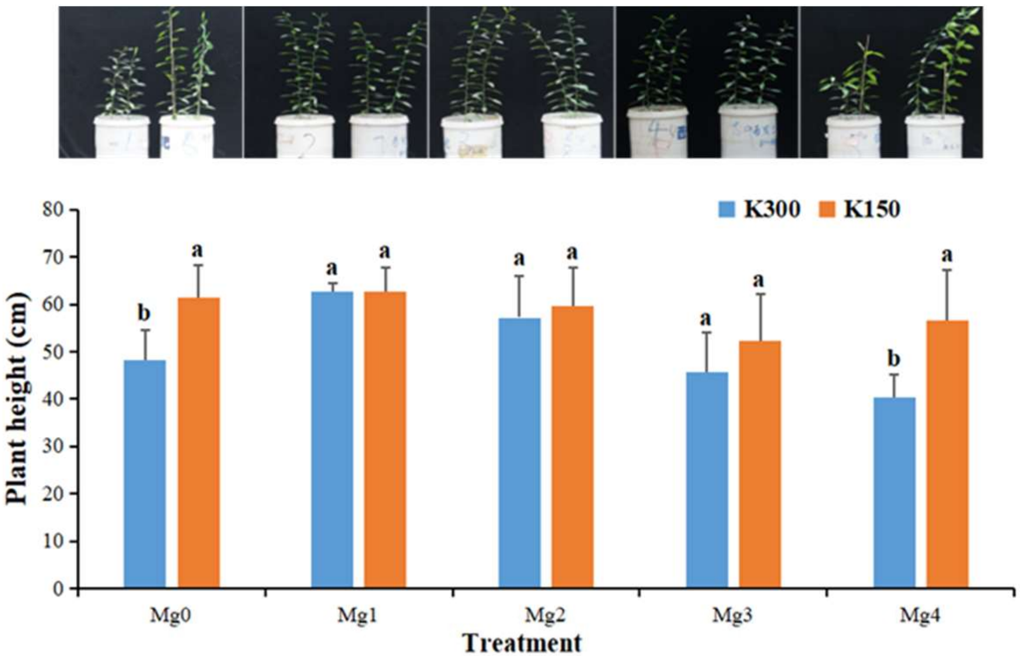
6. less organic fertilizer resulted in declined soil fertility

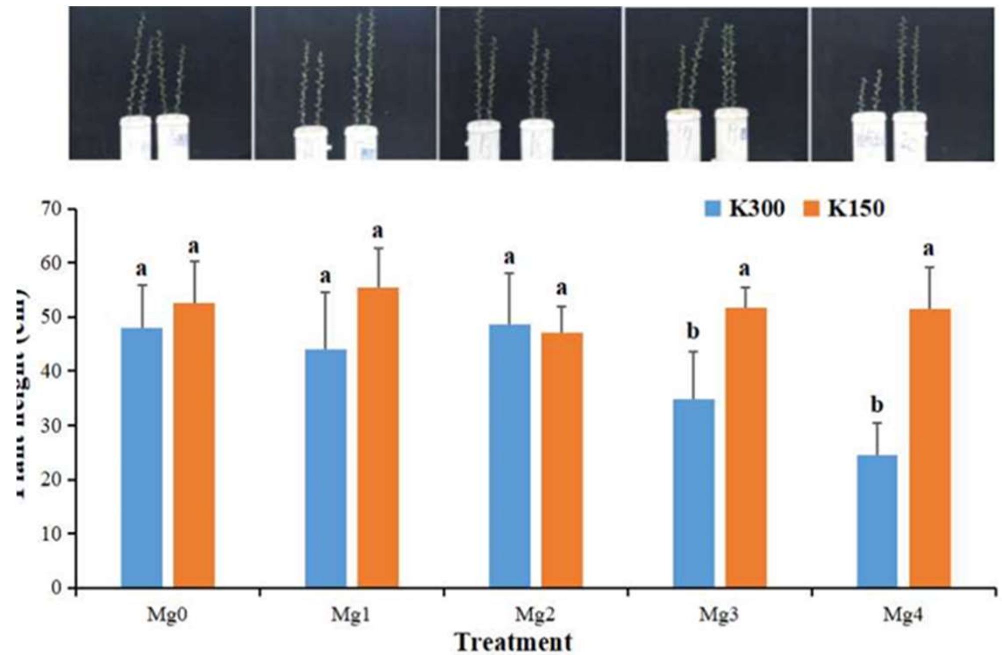
7. Seasonal drought

The effect of K/Mg ratio on the growth of citrus seedling

K/Mg ratios:
CK, 10/0,
T1, 10/2.5,
T2, 10/5,
T3, 10/7.5,
T4, 10/10
Two K levels:
150 and 300 mg/kg soil
Two rootstock:
Xiangcheng and Zhike

K/Mg ratio on the growth of citrus seedling- Height





High K application decrease the height of seedling in soil without Mg application, while normal K application has no effect.

Liu and Zhang et al. inpr.

K/Mg ratio on the growth of citrus seedling- biomass

Treatment	Leaf (g/plant)	Stem (g/plant)	Root (g/plant)	Shoot (g/plant)	Root/shoot ratio
Varieties(V)					
Xiangcheng	2.05a	1.46a	1.47a	3.52a	0.418b
Zhike	0.61b	1.39a	1.33a	1.99b	0.668a
K level(K)					
K300	1.14b	1.20b	1.23b	**2.34b**	0.526a
K150	1.52a	1.65a	1.57a	**3.17a**	0.521a
Mg level(Mg)					
Mg0	1.30bc	1.40bc	1.46a	2.70b	0.541a
Mg1	1.55a	1.74a	1.67a	3.28a	0.509a
Mg2	1.51ab	1.64ab	1.51a	3.15a	0.479a
Mg3	1.25cd	1.23cd	1.19b	2.48bc	0.480a
Mg4	1.04d	1.10d	1.17b	2.14c	0.290a
Significance of ANOVA					
Varieties(V)	***	0.361	0.0898	***	***
K level(K)	***	***	***	***	0.550
Mg level(Mg)	***	***	***	***	0.369
V*K*Mg	0.786	1.00	0.233	0.980	*

High K application decreased the biomass of seedlings compared with normal K application. Mg applications decreased the R/S ratio.

Liu and Zhang et al. inpr.

K/Mg ratio on the growth of citrus seedling- K, Mg

Treatment	Leaf-K (g/kg)	Leaf-Mg (g/kg）	Stem-K (g/kg)	Stem-Mg (g/kg)	Root-K (g/kg)	Root-Mg (g/kg)
Varieties (V)						
Xiangcheng	5.31a	1.91b	9.88a	1.76b	2.43a	1.47a
Zhike	4.53b	3.05a	8.55b	2.53a	2.43a	1.19b
K level (K)						
K300	5.18a	3.00a	9.73a	2.31a	2.38a	1.35a
K150	4.65b	1.96b	8.70b	1.97b	2.47a	1.31a
Mg level (Mg)						
Mg0	6.10a	1.09e	10.0a	1.46e	2.91a	0.88c
Mg1	5.24b	1.73d	8.64c	1.75d	2.13a	1.03c
Mg2	4.56c	2.45c	8.75c	2.10c	2.39a	1.36b
Mg3	4.24c	3.02b	9.22bc	2.46b	2.43a	1.61ab
Mg4	4.45c	4.14a	9.43b	2.95a	2.29a	1.76a
Significance of ANOVA						
Varieties(V)	***	***	***	***	0.987	**
K level(K)	***	***	***	***	0.811	0.662
Mg level(Mg)	***	***	***	***	0.767	***
V*K*Mg	**	*	**	0.0724	0.237	0.760

K application increased shoot K concentration, but decrease shook Mg concentration, while Mg applications could reverse this trend.

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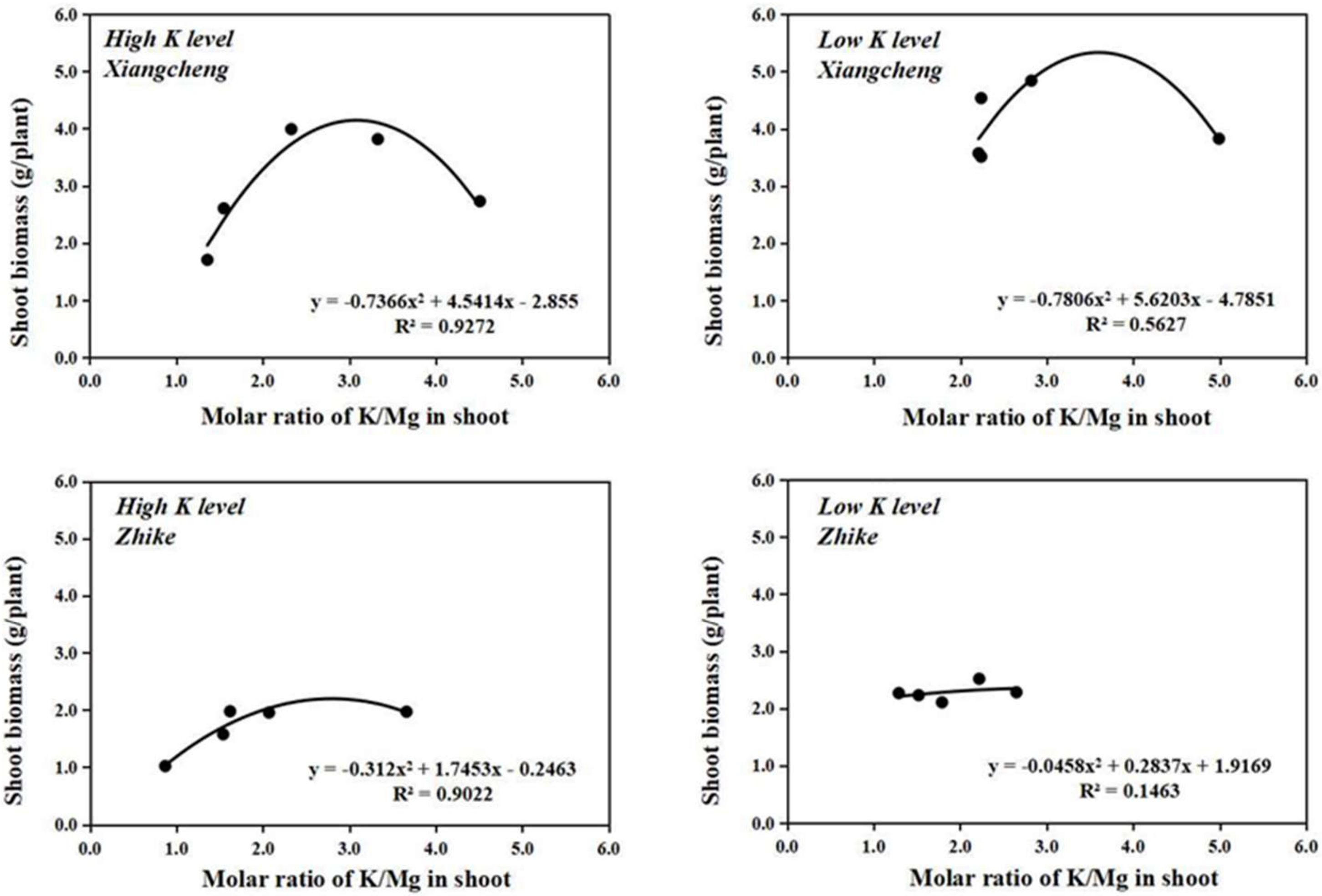
K/Mg ratio on the growth of citrus seedling- K/Mg ratio



-The biomass is significantly affected by K/Mg ratio in shoot.

-When K/Mg ratio is around 3, the shoot biomass is highest.

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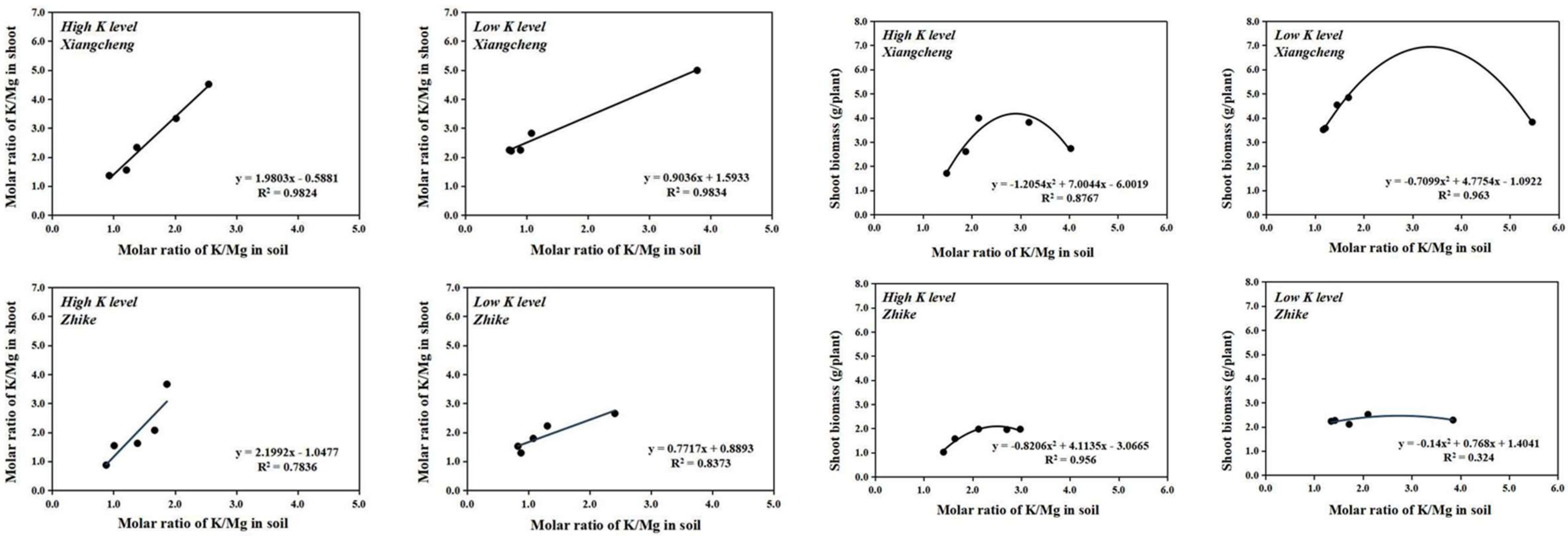
K/Mg ratio on the growth of citrus seedling- K, Mg



-The K/Mg in shoot is linearly correlated with that in soil.
-When K/Mg in soil is between 2 and 3, the shoot biomass is higher.

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Summary

1. K market in Chinese citrus producing region is huge, although K input per hectare should be reduced by a half.
2. As “quality element”, K is important for both yield and quality. But K overuse may also reduce fruit quality.
3. Long-term K overuse resulted enhanced soil K supply capacity, while less yield and quality response to additional K application. This indicates the need of rational strategy of K application.
4. High K application may aggravate Mg deficiency in Chinese citrus orchards, indicating unguent need for balanced application of K, Mg and others.


Thanks for your attention!