Potassium and magnesium nutrition of tea plants and application effect of fertilizers

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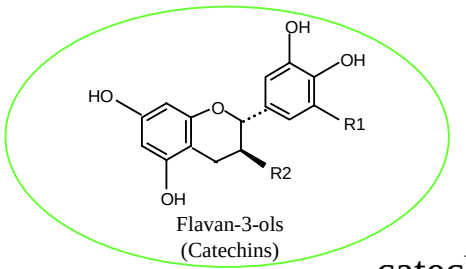
Major chemical components in tea

- Polyphenols (20-40%)
  - Catechins (10-30%)
- Free amino acids (1-5%)
  - Theanine (~2.5%)
- Alkaloids (2-5%)
  - Caffeine (2-5%)
- Carbohydrate (20-30%)
  - Soluble sugars (0.8-4%)
  - Polysaccharides (20-26%)
- Lipids (4-9%)
- Pigments (~1%)
  - Chlorophyll
- Minerals (~6%)
  - P, K, Ca, Mg, Al, F, …
- Aroma (0.01-0.02%)

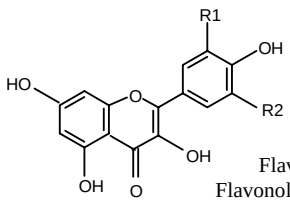
Main chemical components in tea

Polyphenols

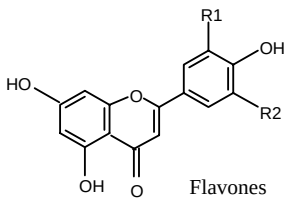


Flavan-3-ols
(Catechins)

catechins

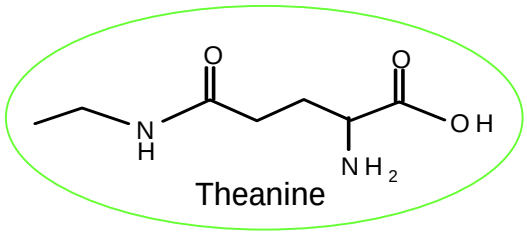


Flavonols
Flavonol glycosides

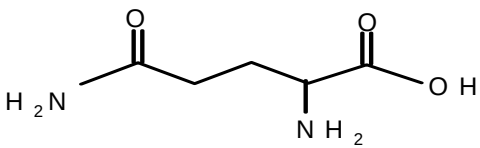


Flavones

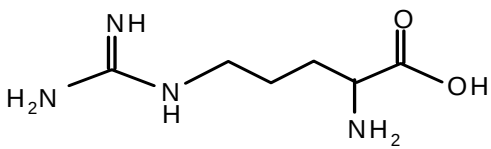
Amino acids



Theanine

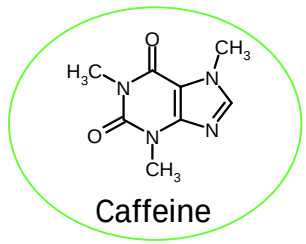


Glutamine

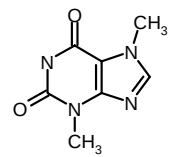


Arginine

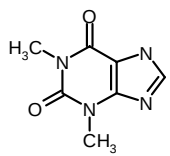
Alkaloids



Caffeine



Theobromine



Theophylline

Tea quality

- Appearance
- Color
  - Chlorophyll, carotenoids, xanthin, theaflavins, thearubigins, etc.
- Taste
  - Astringency: flavanoids (catechins), theaflavins, thearubigins,
  - Mellowness: free amino acids, etc.
  - Bitterness: caffeine, catechins, etc.
  - Sweetness: sugars, free amino acids, etc.
- Aroma
  - Grass: lipids (Z-3-hexenol, …)
  - Roast: furans, pyrazine, pyrroles (reaction products of sugars and amino acids, …)
  - Fragrance: volatiles (geraniol, linalool and their oxides, …)

Tea is a functional beverage

- Catechins：anti-oxidation, anti-cancer, …
- Theanine：improves human immunity, learning ability, …
- Caffeine：refreshing, reduces risk of skin cancer induced by UV irradiation
- ……

Concentrations of elements in teas

Element	Concentration (g/kg)	Element	Concentration (mg/kg)
N	35～60	Mn	300～1500
P	2～10	Fe	70～140
K	16～30	Zn	10～65
Ca	1.4～5.7	Cu	8～30
Mg	1.2～3.0	Mo	0.1～1.0
Cl	0.1～0.4	B	5～20
S	2～4	F	20～350
Al	0.1～1.0		

Potassium

- Potassium nutrition and nitrogen uptake, metabolism and free amino acids
- Response of yield and quality to potash fertilizer
- Effect of different K sources: KCl vs K_2SO_4
- Soil K status

N absorption rate as affected by K nutrition (nutrient solution experiment)

（μmol/g root dw·d^{-1}）

Treatment	NH_4^+	NO_3^-	Total
-K	12.0±4.6	1.4±1.6	13.3±4.7
+K	82.7±18.7	18.5±17.9	101.1±35.8

Effect of K nutrition on growth, free amino acid and nitrate reductase of tea plants (pot experiment)

	CK	NP	NPK
Biomass（g/pot）	14.2a	22.1b	27.4c
Leaf K concentration（mg/g）	—	3.0 a	6.6 b
Free amino acid in shoots（mg/g）	9.48a	9.67a	11.12b
Free amino acid in roots （mg/g）	1.50a	3.50b	3.92b
Nitrate reductase activity (μmol NO_2^-/g.fw.h^{-1})	236.2a	296.9ab	317.1b

(Ruan et al., 1998)

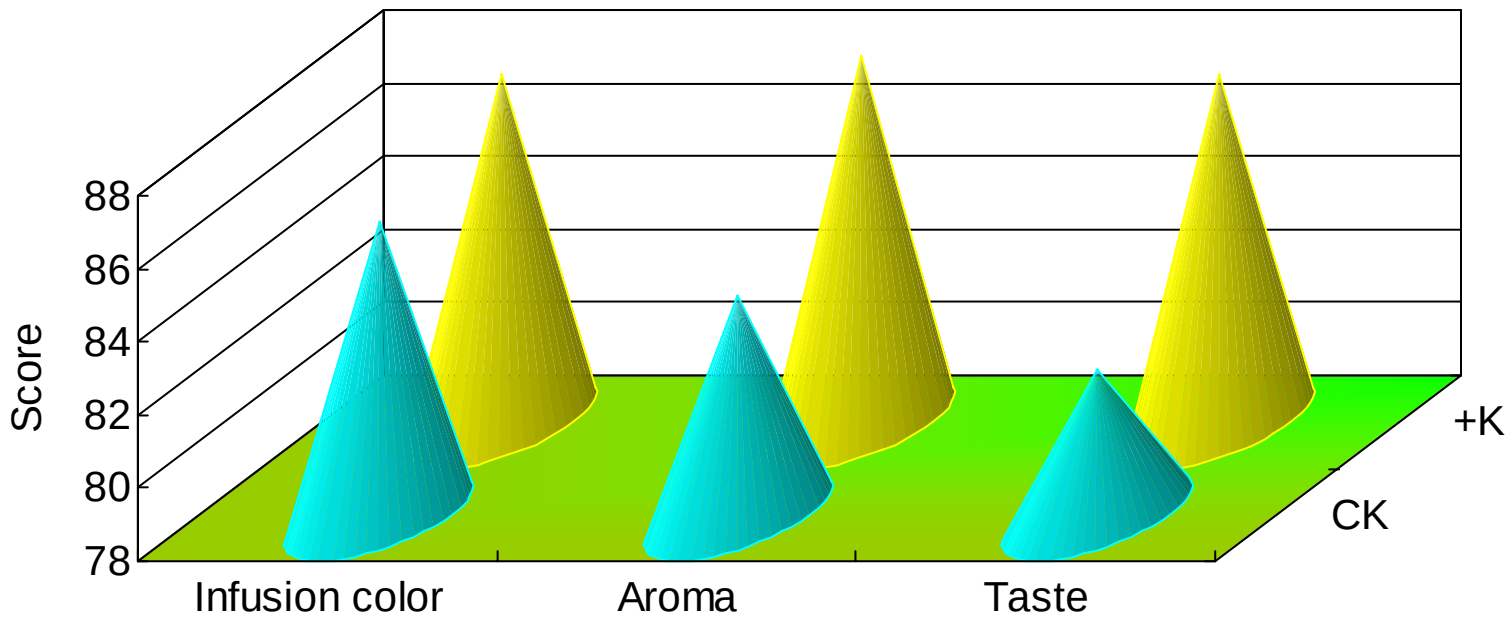
Effect of K supply on free amino acids in young shoots (μmol g^{-1}) (pot experiment)

	K_0	K_1	K_2
Thea	25.88±4.20a	28.80±3.41a	36.15±5.51b
Glu	7.30±2.21	9.44±1.22	7.44±0.44
Asp	2.99±0.97	4.60±1.01	3.39±0.79
Arg	0.83±0.53	0.90±0.33	0.71±0.29
Ala	1.75±0.55	1.67±0.19	1.47±0.20
Cys	2.83±0.20	3.04±0.36	2.69±0.24
Gly	0.33±0.40	0.31±0.35	0.23±0.39
His	1.79±0.62	1.50±0.31	1.74±0.41
Ile	0.82±0.13	0.77±0.03	0.70±0.04
Leu	1.09±0.12	0.92±0.15	1.00±0.02
Lys	0.88±0.05	0.86±0.10	0.59±0.22
Phe	0.87±0.08	0.78±0.07	0.89±0.05
Pro	1.63±1.26	1.87±1.48	1.11±0.67
Ser	3.61±0.76	3.41±0.41	4.69±1.21
Thr	4.59±2.69	2.98±1.72	5.65±0.70
Tyr	0.78±0.07	1.01±0.30	0.82±0.13
Val	2.95±0.73	2.68±0.83	2.99±1.75

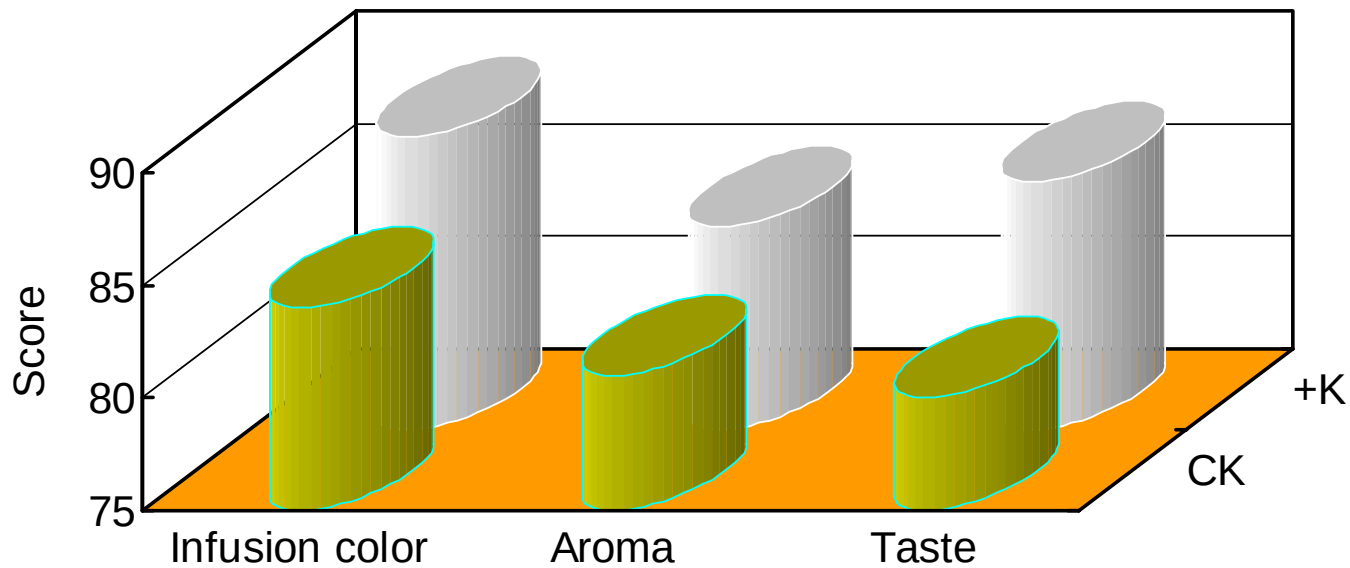
Yield response of tea to K fertilizer (field experiments)

Site	Year	Exch K mg/kg (*mg/ml)	Yield of CK ton/ha	K fertilizer (kg K_2O /ha)	Yield increment (%) Mean	Yield increment (%) Range
Hangzhou	1992-1998	106	9.70	150	16.6	9.9～25.6
Yingde	1992-1996	58	19.25	150	10.2	4.7～12.8
Anqi	1993-1994	50	6.57	150	19.5	1.1～37.8
Shenzhou	1995-1996	31*	24.25	168	8.6	6.6～10.2
Hangzhou	1995-1996	91	7.30	168	14.7	10.5～19.1
Yingde	1995-1997	43*	21.33	225	7.8	6.5～8.9
Hangzhou	1995-1997	160*	7.18	112	8.5	4.3～11.4
Shangrao	1995-1997	61*	3.03	75	13.2	8.7～19.5
Shaoxing	1995-1997	74*	17.13	225	6.1	0.0～10.1
Shanming	1995、1997	58	5.88	96	21.5	14.7～28.3
Hangzhou	1999-2000	86*	8.22	200	4.6	2.8～16.4
Yingde	1999-2001	31*	11.78	200	9.9	9.4～10.4
Yingde	1999-2002	44	11.67	187.5	13.8	11.0～16.6
Changsha	1999-2002	79	11.26	187.5	10.9	1.7～17.4
Wuhan	1999-2002	66	3.12	187.5	26.3	14.0～33.7
Hangzhou	1999-2002	68	3.81	187.5	11.0	7.1～13.2
Guilin	1999-2002	108	9.69	187.5	4.0	-0.7～9.4
Nanchang	2000-2001	85	11.04	187.5	-0.8	-3.9～1.0

Effect of K fertilizer on sensory scores of made green tea (field experiment)



Effect of K fertilizer on sensory scores of made black tea (field experiment)

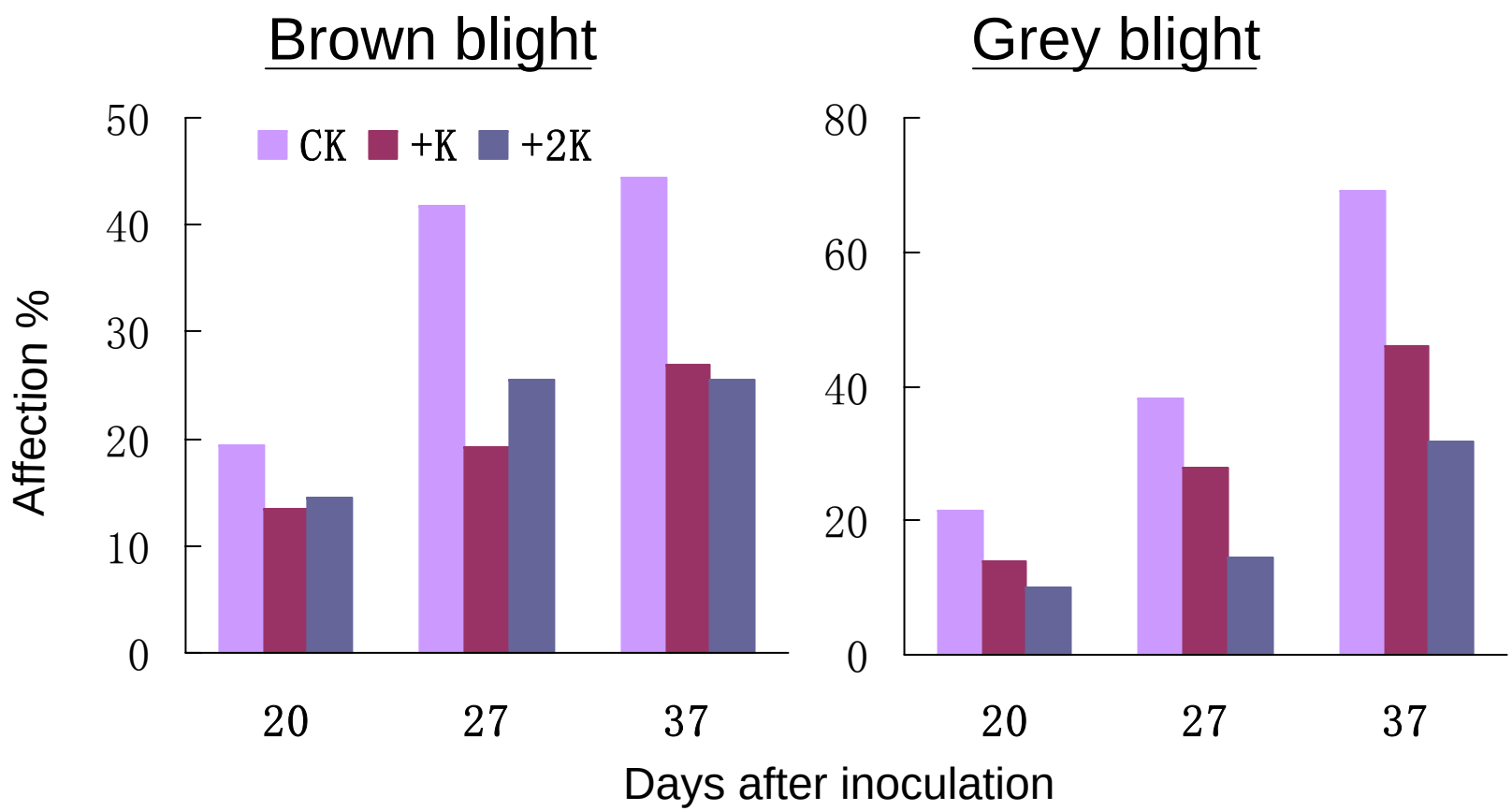


	NP	NPK_1	NPK_2
Total popyphenols (mg/g)	259.6	265.3	275.0
Theaflavins (mg/g)	4.78	6.16	7.02
Thearubigins (mg/g)	27.7	32.6	34.9

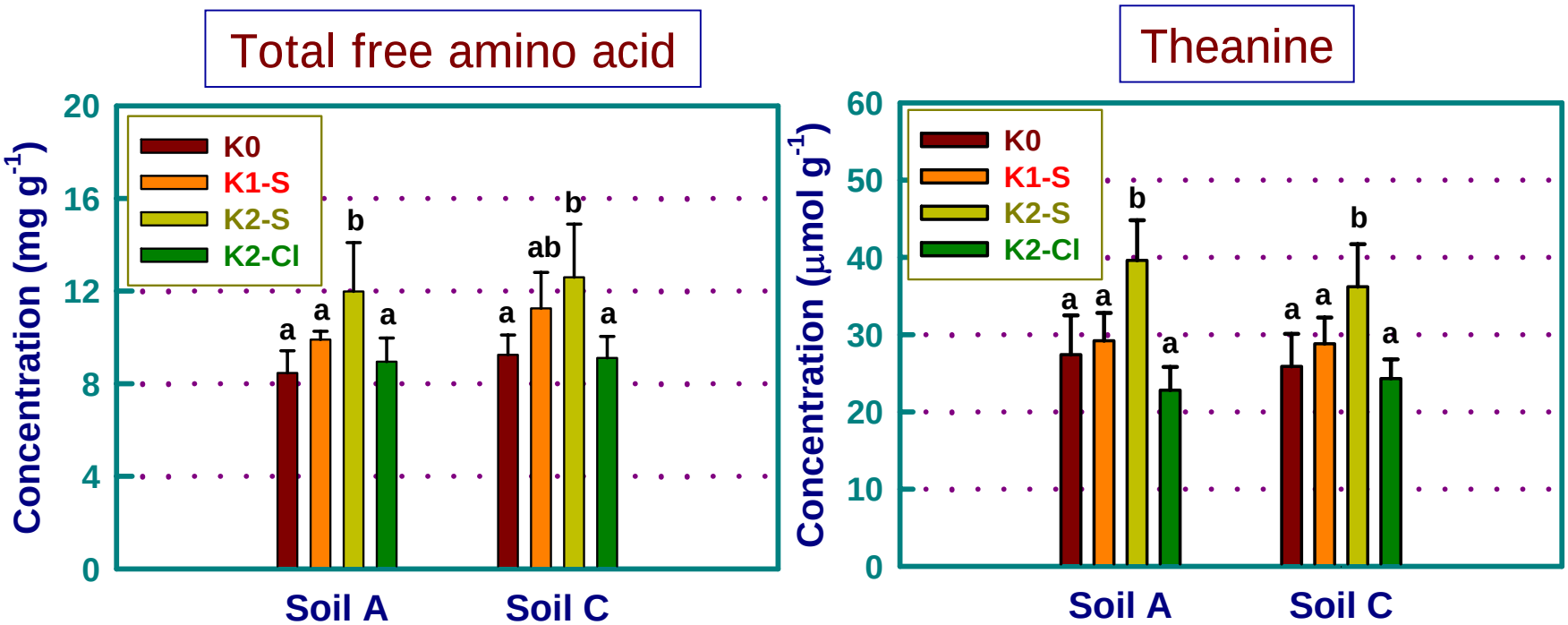
Effect of K supply on disease resistance of tea plants

Effect of K_2SO_4 on resistance of tea plant to anthracnose

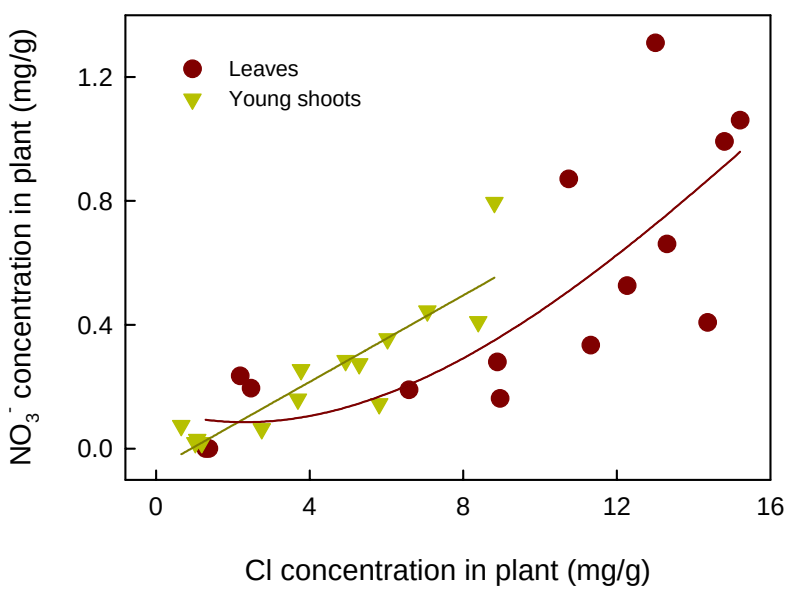
Effect of K supply on disease resistance of tea plants (pot experiment)

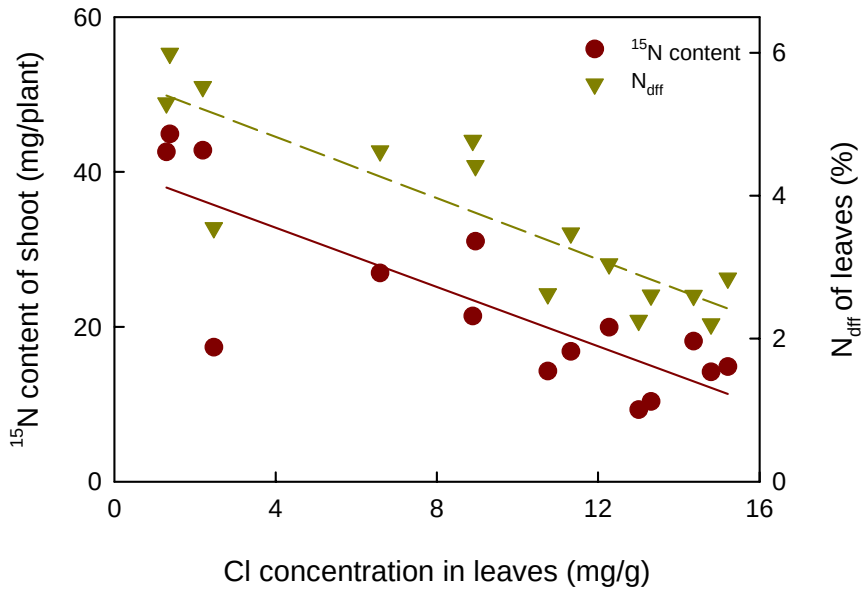


Total free amino acid and theanine in young shoots as affected by K sources (pot experiment)

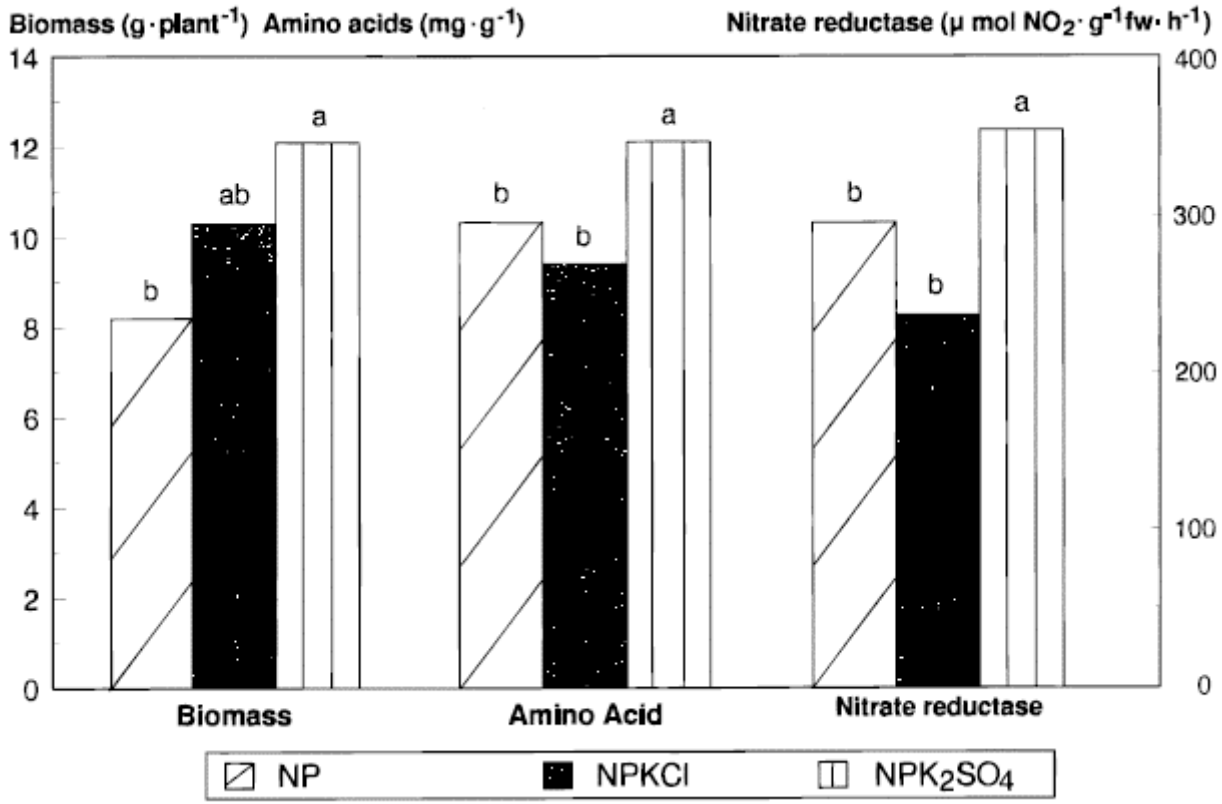


NO_3^- concentration and ^{15}N uptake as affected by Cl supply (pot experiment)





Cl affects NO_3^- assimilation by tea plants (pot experiment)



(Ruan et al., 1998)

Effect of Cl on tea plants supplied solely with NH_4^+ nutrition (nutrient solution experiment)

	-Cl	+Cl
Biomass (g pot^{-1})		
Young shoots	1.55±0.49	1.89±0.38
Root	3.79±0.82	2.52±0.70
Whole plant	15.58±2.95	12.04±0.90
Cl^- concentration in mature leaves (mg g^{-1})	1.49±0.22	3.84±0.35
Chlorophyll (μg cm^{-2})	252.6±8.4	228.7±11.1
Glutamine synthetase activity (μmol g^{-1} fw min^{-1})		
Young fully expanded leaves	1.34±0.06	1.54±0.29
Fibrous roots	0.35±0.03	0.42±0.07
NH_4^+ uptake rate (μmol g^{-1} root dw d^{-1})	165.9±21.8	171.9±8.5
Total free amino acid (μmol g^{-1})		
Young shoots	226.6±71.5	135.7±29.1
Fibrous roots	598.5±196.9	631.9±102.9
Theanine (μmol g^{-1})		
Young shoots	87.3±28.1	33.5±8.4
Fibrous roots	278.9±65.7	232.2±24.7

Effect of K_2SO_4 and KCl on tea yields in field experiments

Site	Year	Exch K mg/kg(*mg/ml)	Treatment		
			K0	K2SO4	KCl
Yingde	1995-1997	43*	20.6	23.0	22.3
Hangzhou	1995-1997	160*	6.8	7.8	7.8
Shangrao	1995-1997	61*	2.9	3.4	3.3
Shaoxing	1995-1997	74*	16.6	18.2	18.1
Yingde	1999-2002	44	11.67	13.24	12.67
Changsha	1999-2002	79	11.26	12.35	12.17
Wuhan	1999-2002	66	3.12	3.92	3.38
Hangzhou	1999-2002	68	3.81	4.28	4.44

Effect of K_2SO_4 and KCl on chemical components of tea in field experiments

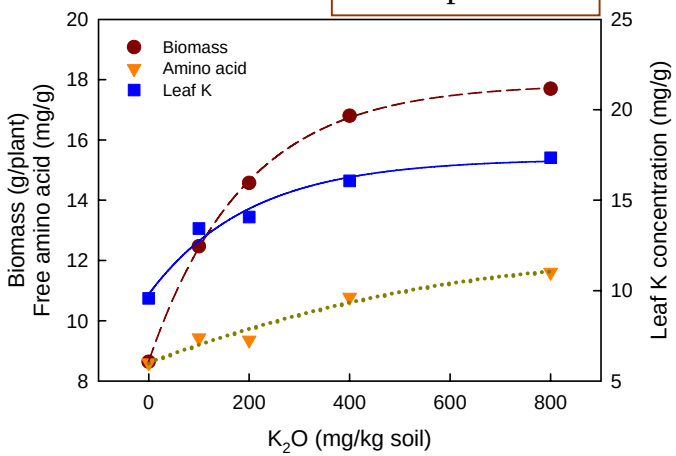
	Site	Spring tea			Autumn tea		
		K0	K2SO4	KCl	K0	K2SO4	KCl
Polyphenols	Hangzhou	263.0	269.2	253.6	180.8	204.5	203.4
	Shangrao	271.0	279.8	282.0	205.4	218.9	216.8
	Shaoxing	279.2	306.0	308.0	312.2	324.1	325.5
	Yingde	298.8	312.5	310.7	216.5	241.2	232.5
Amino acid	Hangzhou	40.1	42.9	42.2	25.5	31.2	31.7
	Shangrao	36.2	39.1	38.8	28.8	30.2	29.8
	Shaoxing	38.8	42.6	42.0	31.1	33.1	32.8
	Yingde	35.4	38.9	39.0	27.7	29.6	28.9
Caffeine	Hangzhou	25.3	26.6	26.0	20.7	20.5	21.3
	Shangrao	27.0	28.2	26.9	21.2	23.2	21.9
	Shaoxing	28.6	30.2	30.5	20.6	20.5	20.8
	Yingde	27.8	28.6	29.7	22.7	26.2	25.4
Water extract	Hangzhou	310.0	326.0	330.0	367.0	383.0	387.0
	Shangrao	353.0	370.0	357.0	367.0	393.0	397.0
	Shaoxing	347.0	368.9	367.8	373.0	380.0	373.0
	Yingde	332.5	350.2	356.1	333.0	356.5	358.8

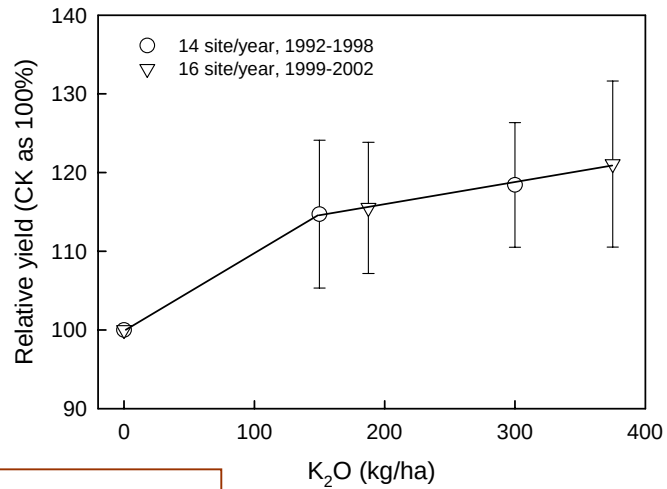
Effect of K_2SO_4 and KCl on sensory score of made teas in field experiments

Site	Treatment	Spring tea				Autumn tea			
		Inf. color	aroma	taste	Inf. leaf	Inf. color	aroma	taste	Inf. leaf
Hangzhou	K0	86	87	85	89	85	84	86	82
	K2SO4	84	85	85	87	83	85	83	81
	KCl	88	88	88	88	84	86	85	84
Yingde	K0	85	86	89	—	86	90	84	85
	K2SO4	86	85	87	—	86	87	91	84
	KCl	83	85	91	—	85	88	86	85
Guilin	K0	86	83	83	85	90	86	83	87
	K2SO4	88	85	86	85	91	90	86	85
	KCl	86	86	86	84	91	86	85	85
Changsha	K0	89	91	91	88	95	90	83	87
	K2SO4	91	90	89	90	94	91	84	86
	KCl	87	87	86	89	96	90	86	88
Nanchang	K0	86	83	84	85	89	88	89	85
	K2SO4	88	89	89	87	89	88	86	85
	KCl	85	89	88	87	86	88	87	84
Wuhan	K0	—	—	—	—	87	85	89	89
	K2SO4	—	—	—	—	89	90	86	89
	KCl	—	—	—	—	88	86	88	90

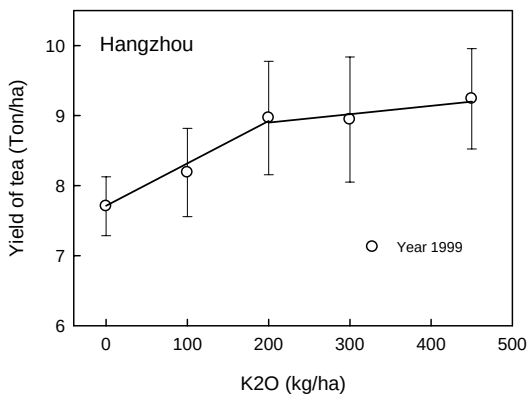
Effect of K application amount on tea

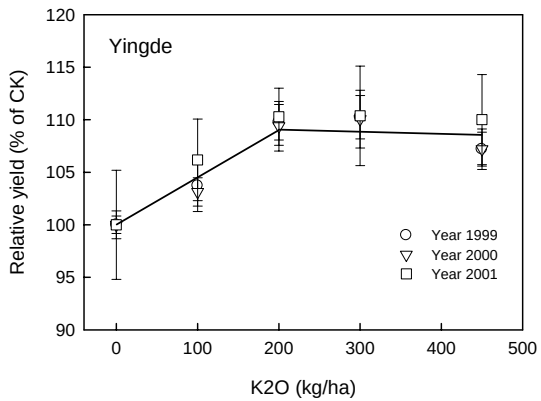
Pot experiment





Field experiments





Profile of exchangeable K in soil samples (1998-2003)

Depth	Range		Grade (mg/kg)			
(cm)	(mg/kg)		⩽80	81～120	>120	Total
0-20	9～427	Number	365	104	99	568
(0-15)		Percentage (%)	64.3	18.3	17.4	100.0
		Mean (mg/kg)	50	92	176	80
20-40	9～341	Number	449	75	44	568
(15-30)		Percentage (%)	79.0	13.2	7.7	100.0
		Mean (mg/kg)	41	93	186	59

Magnesium

- Magnesium nutrition and N uptake, metabolism and free amino acids accumulation
- Mg and long distance transport of amino acids in tea plants
- Response of yield and quality to Mg fertilizer
- Soil Mg status

Mg concentrations in tea plants

	Mg (g/kg)
Absorption root	2.67
Feeding root	1.77
Young shoots	1.80
Mature leaves	1.61
Stem	0.67

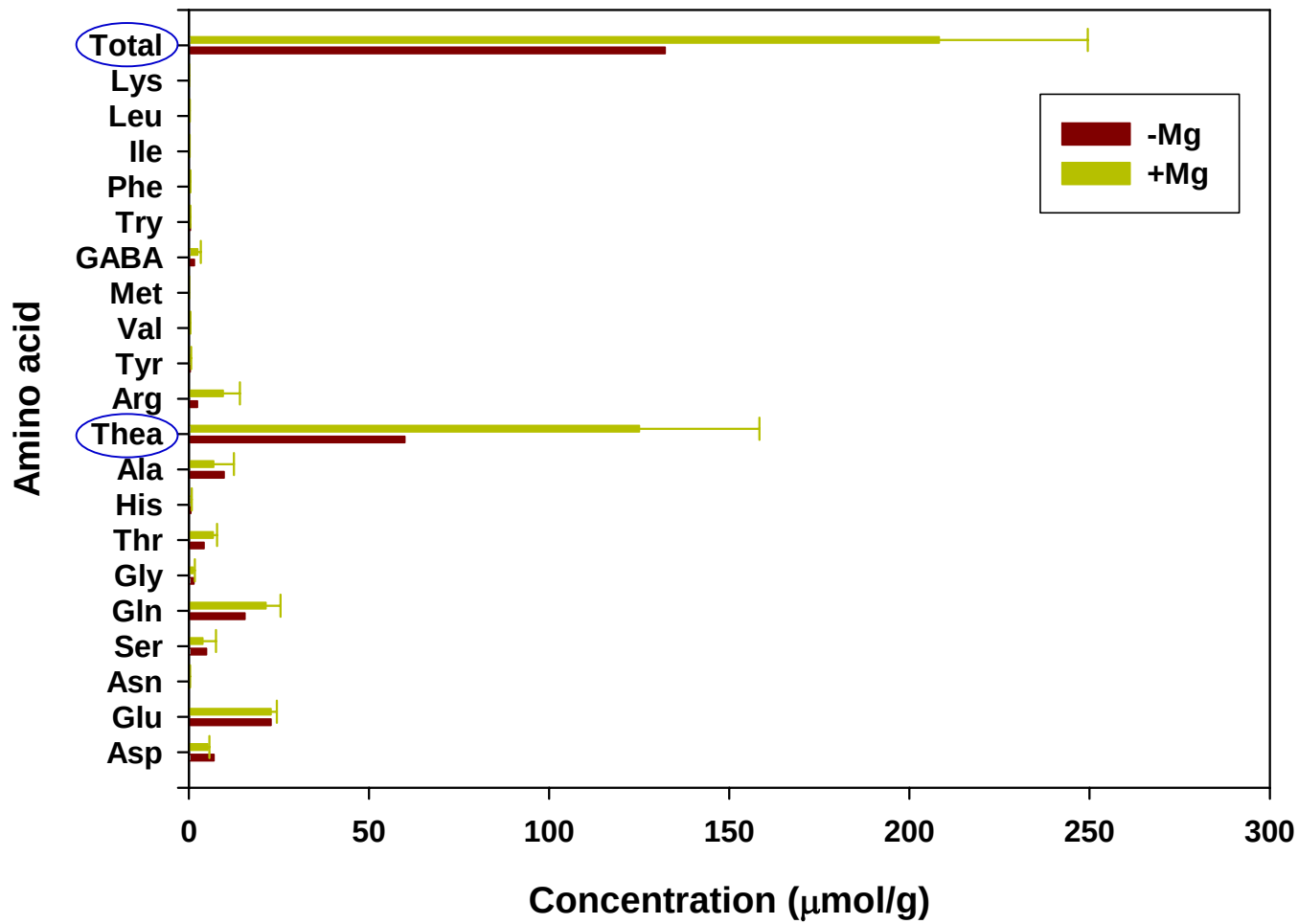
(Wu, 1994)

Biomass, free amino acid and nitrate reductase activity as affected by Mg supply (pot experiment)

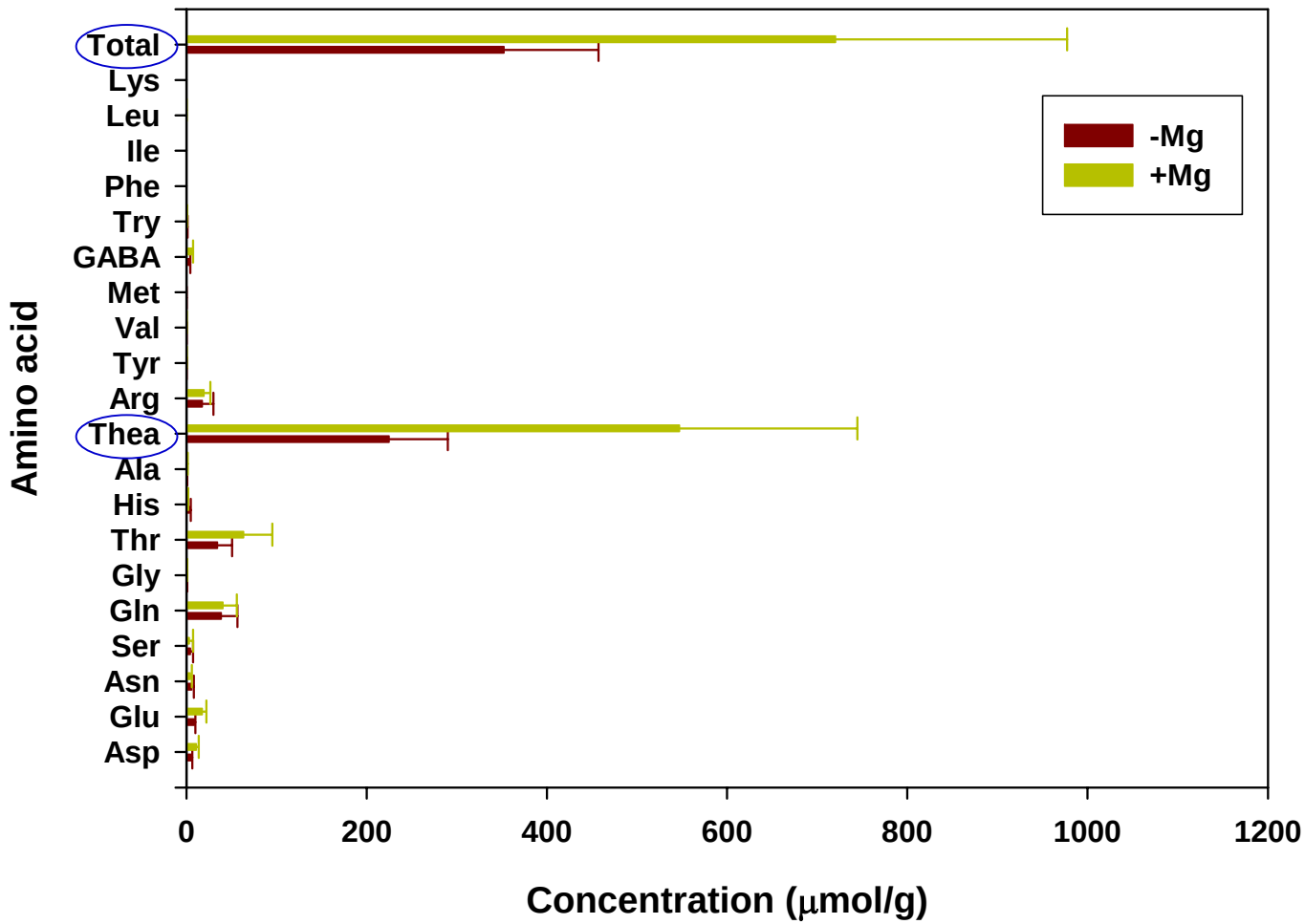
	NPK	NPKMg
Biomass (g/plant)	27.4 a	33.8 b
Free amino acid in leaves (mg/g)	11.12 a	13.24 b
Free amino acid in root (mg/g)	3.92	4.20
Activity of nitrate reductase (μmol NO_2^-/g fw. h^{-1})	317.1 a	391.3 b

(Ruan et al., 1998, J. Sci. Food Agric., 76, 389-396)

Profile of free amino acids in young shoots of tea plants supplied with different Mg in nutrient solution



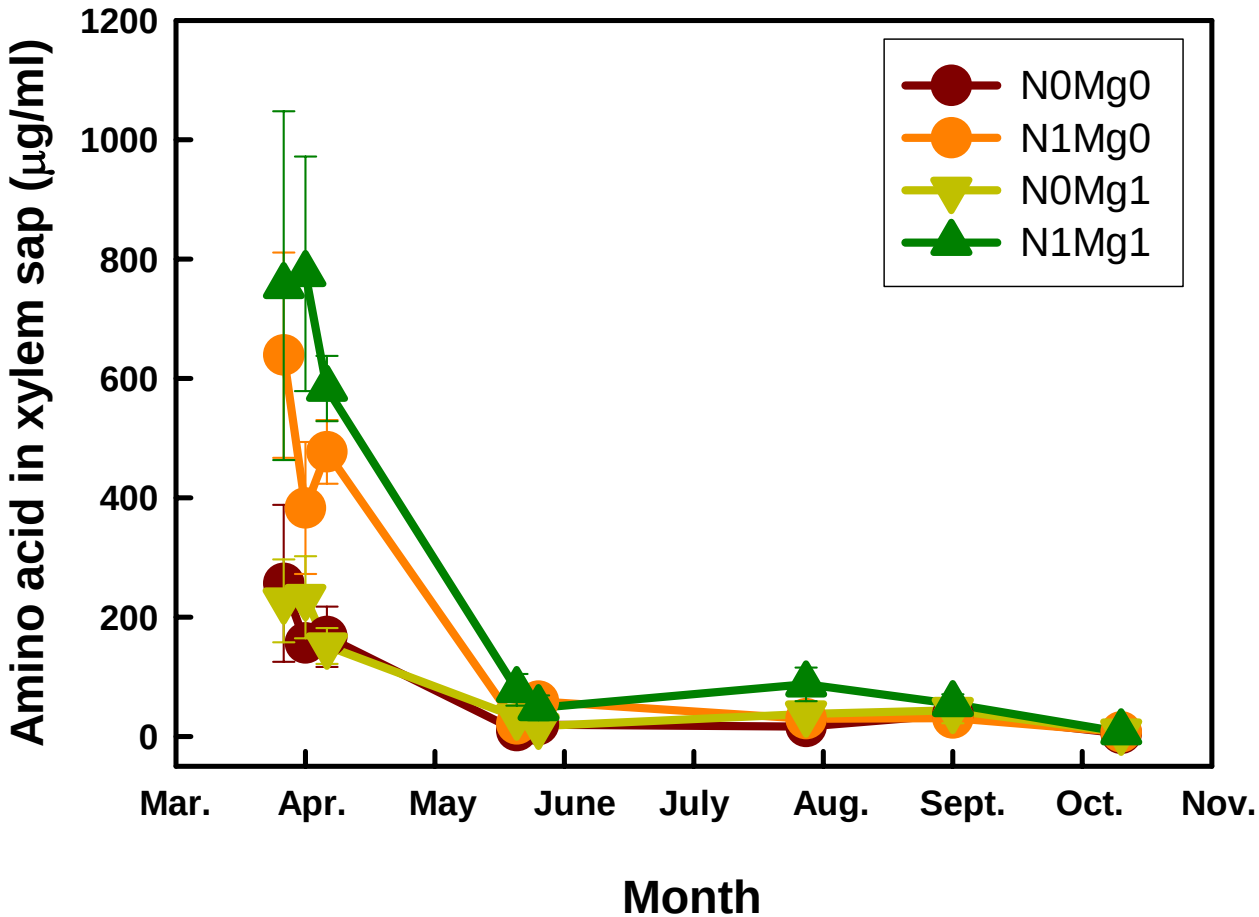
Profile of free amino acds in root of tea plants supplied with different Mg in nutrient solution



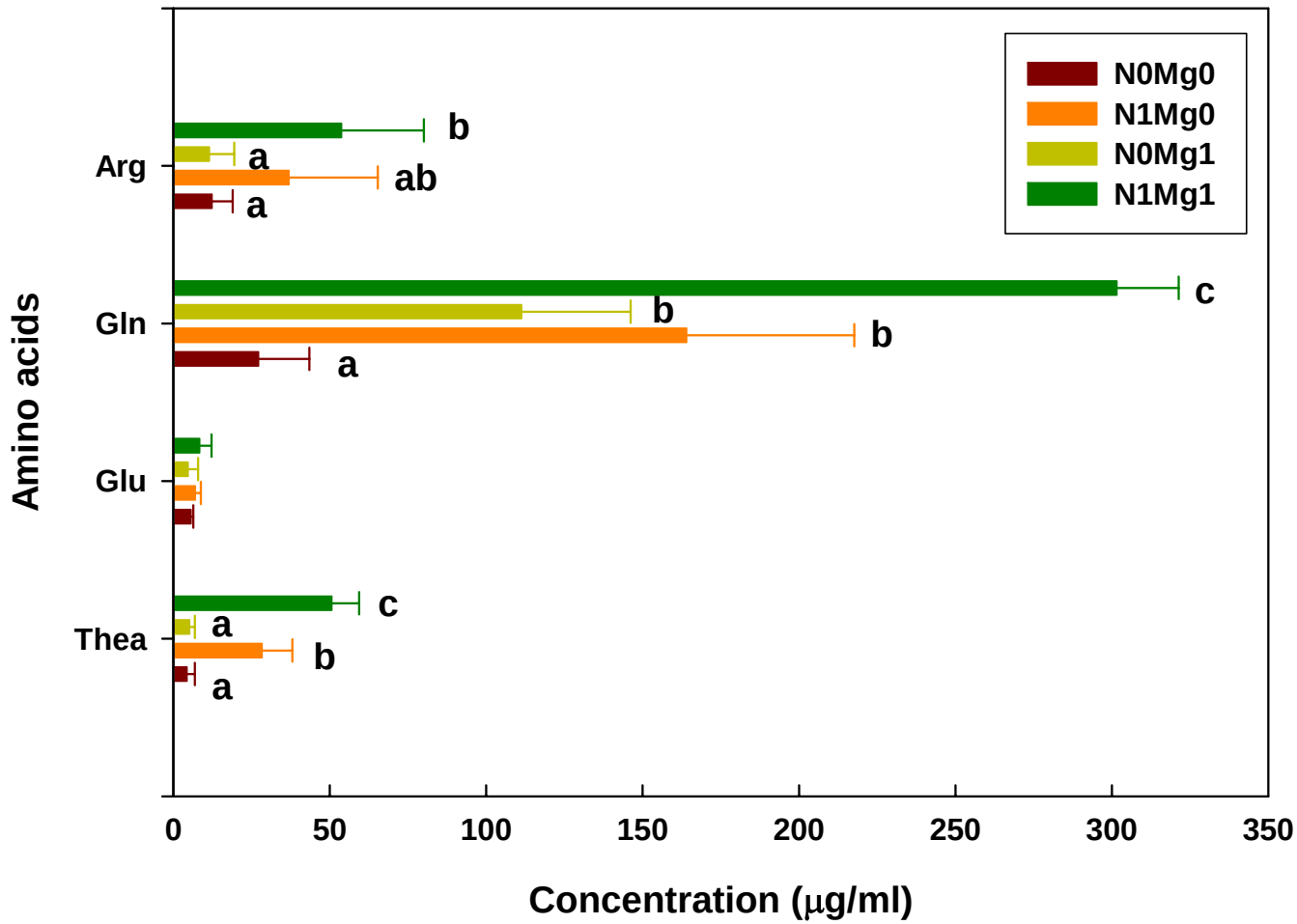
Plant growth, N uptake and glutamine synthetase activity in tea plants as affected by Mg supply in nutrient solution

	Treatment	
	-Mg	+Mg
Biomass (g/pot)	6.11±1.05	25.65±3.65
Mature leaf chlorophyll (μg/cm^2)	133.0±10.8	211.1±11.3
Glutamine synthetase (μmol/g FW.min^{-1})		
Leaf	1.45±0.16	1.27±0.38
Root	0.35±0.06	0.37±0.18
Nitrogen uptake rate (μmol/g dry root.d^{-1})		
NH_4^+	38.4±7.4	44.1±9.2
NO_3^-	3.1±0.8	7.8±5.3
Total N	41.4±7.4	51.9±13.2

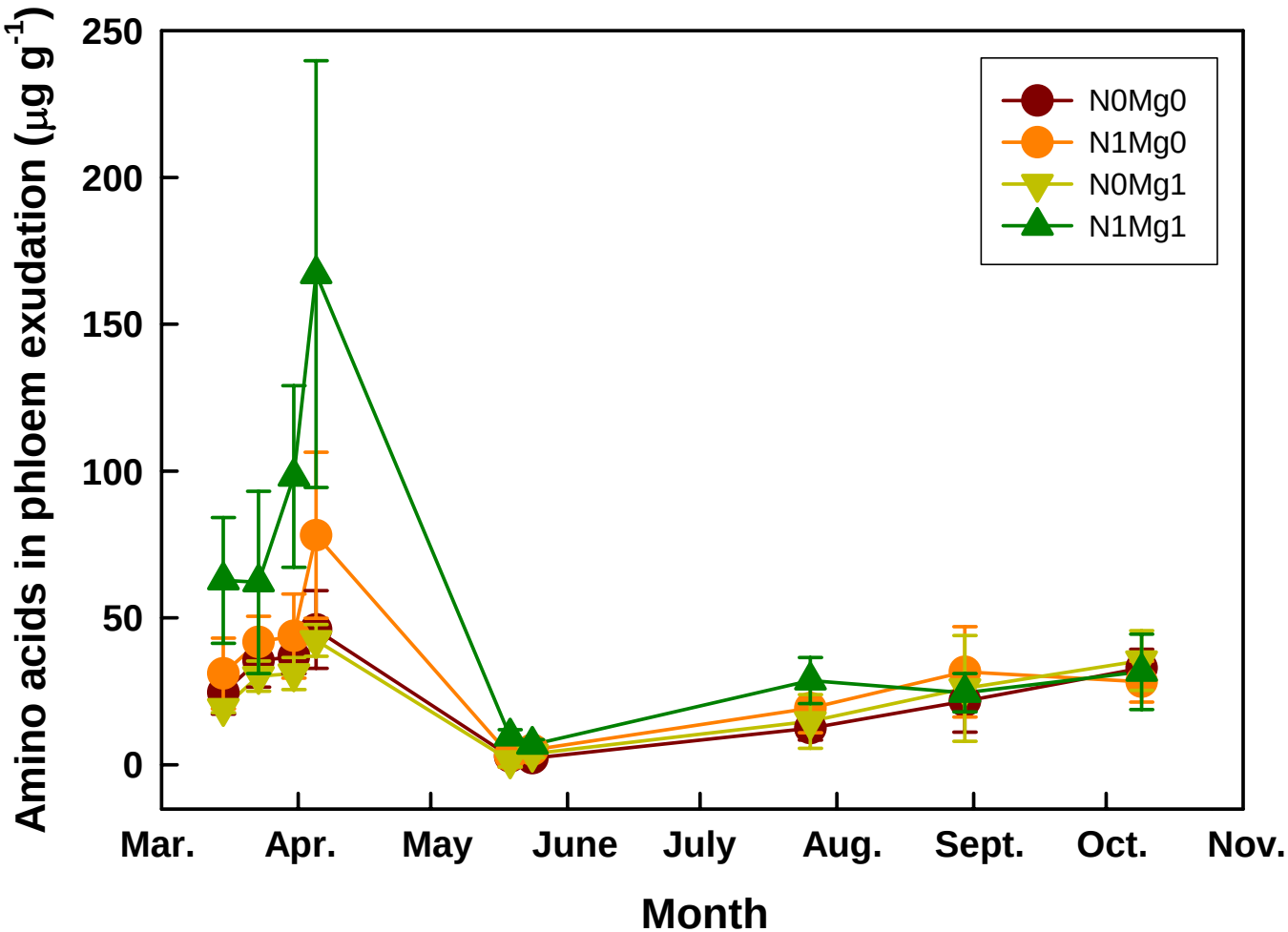
Total amino acid in collected xylem sap of plants supplied with different N and Mg nutrition (pot experiment)



Amino acids in collected xylem sap of plants supplied with different N and Mg nutrition (pot experiment)



Total free amino acid in phloem exudate of plants supplied with different levels of N and Mg (pot experiment)



Yield response to Mg fertilizer in field experiments

Site	Year	Exch Mg	Mg fertilizer	Yield of CK**	Increment (%)	
		mg/kg(*mg/ml)	MgO kg/ha	ton/ha	Mean	Range
Hangzhou	1992-1998	62	35	11.43	6.1	3.4～7.9
Yingde	1992-1996	20	35	21.22	3.5	0～7.0
Anqi	1993-1994	35	35	7.55	13.8	11.0～16.6
Shaoxing	1996-1997	63*	42	3.32	5.0	1.8～8.1
Shengzhou	1996-1997	90*	42	20.25	6.6	5.5～7.7
Hangzhou	1999-2001	47	37.5	6.19	3.0	-0.3～6.4
Yingde	1999-2001	34	37.5	11.70	7.3	5.7～8.8

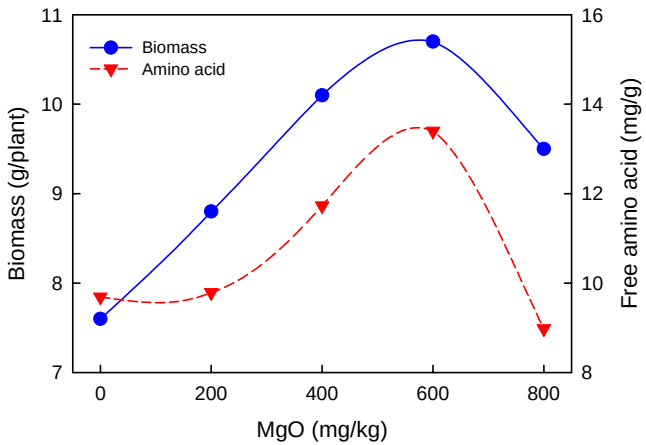
Effect of Mg application on chemical components in tea in field experiments

Site	Season	Amino acid (mg/g)			Polyphenols (mg/g)			Caf. (mg/g)		
		CK	+Mg	Mg effect (%)	CK	+Mg	Mg effect (%)	CK	+Mg	Mg effect (%)
Yingde	Spring	27.92	29.77	+6.2	265.3	257.7	-2.9	37.90	37.91	0
	Autumn	12.56	13.78	+8.8	254.3	223.2	-13.9	27.12	27.06	-0.2
	Spring	20.17	21.58	+6.5	316.4	316.4	0	37.50	38.76	+3.2
	Autumn	20.50	20.75	+1.2	327.5	335.3	2.3	32.16	38.58	+16.6
Hangzhou	Spring	30.71	32.47	+5.4	266.4	262.6	-1.4	36.19	37.36	+3.1
	Autumn	14.20	15.40	+7.8	241.8	239.4	-1.0	29.12	31.30	+7.0
	Spring	21.90	22.80	+3.9	—	—	—	—	—	—
	Autumn	9.90	11.90	+16.8	—	—	—	—	—	—
Anqi	Spring	27.85	28.18	+1.2	251.3	235.9	-6.5	37.68	38.49	+2.1
	Autumn	9.75	11.62	+16.1	259.5	250.5	-3.6	24.95	25.56	+2.4
Shenzhou	Spring	21.80	23.10	+6.0	268.7	266.1	-1.0	22.8	22.5	-1.3
	Autumn	18.90	20.10	+6.3	265.4	272.4	+2.6	19.7	19.9	+1.0
Shaoxing	Spring	32.20	34.50	+7.1	296.5	298.8	+0.7	29.8	29.7	-0.3
	Autumn	19.10	19.90	+4.2	298.5	296.6	-0.6	24.1	24.6	+2.1

Effect of Mg fertilizer on sensory scores of made tea in field experiments

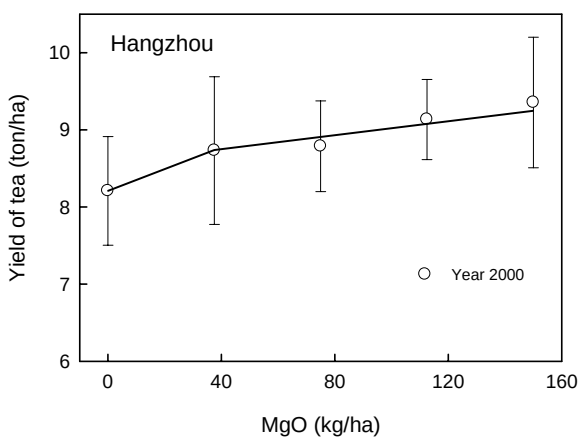
Site	Mg fertilizer	Spring tea				autumn tea			
	(MgO kg/ha)	Infusion	Aroma	Taste	Inf. leaf	Infusion	Aroma	Taste	Inf. leaf
Hangzhou	0	89	87	84	87	89	83	86	83
	37.5	89	87	87	87	92	88	87	85
Dongzhi	0	89	92	90	88	—*	—	—	—
	37.5	90	94	92	90	—	—	—	—
Shaoxing	0	87	82	86	83	86	88	83	85
	75	90	87	87	84	86	88	87	87
Yingde	0	—	—	—	—	89	87	89	85
	37.5	—	—	—	—	90	88	88	90

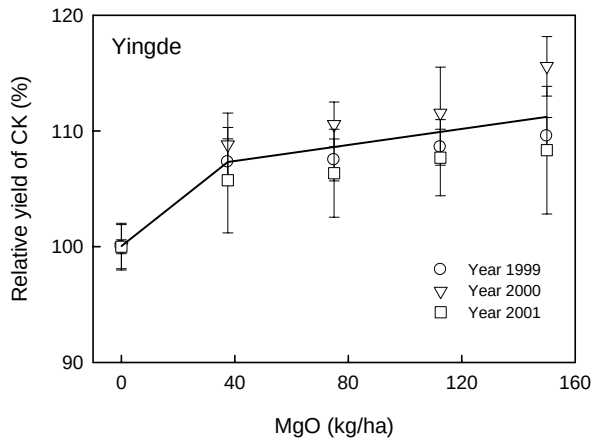
Effect of Mg fertilizer amount on tea



Pot experiment

Field experiments





Profile of exchangeable Mg in tea soils (1998-2003)

Depth	Range		Grade (mg/kg)				
(cm)	(mg/kg)		≤20	21～40	41～80	>80	总计
0-20	9～427	Number	150	153	144	121	568
(0-15)		Percentage (%)	26.4	26.9	25.4	21.3	100.0
		Mean (mg/kg)	14	27	53	143	56
20-40	9～341	Number	179	160	124	107	569
(15-30)		Percentage (%)	31.4	28.1	21.7	18.8	100
		Mean (mg/kg)	12	26	54	154	52

Summary

- Potassium deficiency decreases nitrogen uptake and utilization by tea plants, and reduces free amino acids concentrations.
- Application of K fertilizer increases tea yield averagely by 11.7%, i.e. one kg K_2O increases 1.42 kg made tea.
- Application of K fertilizer improves tea quality (chemical and sensory).
- Pot experiments revealed negative effect of Cl on accumulation of free amino acid (esp. theanine) in tea plants possibly by inhibiting NO_3^- reduction and interfering transport of theanine from root to shoot and further metabolism therein. However, there are no significant difference of SOP and MOP under field conditions.
- About 64% surface soil samples and 79% subsoils contained exchangeable K $\leqslant$ 80 mg/kg.
- Appropriate K application amounts (K_2O) are between 150-200 kg/ha.

Summary

- Mg deficiency reduces NO_3^- utilization, decreases long distance transport of amino acids via xylem and phloem, and diminishes free amino acids in tea plants.
- Application of Mg fertilizer increases tea yield averagely by 6.5%, i.e. one kg MgO increases 4.3 kg made tea.
- Application of Mg fertilizer improves tea quality (chemical and sensory).
- About 53% surface soil samples and 60% sub-soils contained exchangeable Mg $\leqslant$ 40 mg/kg.
- Appropriate Mg application amount (MgO, Kieserite or Sul-Po-Mag) is about 35-37.5 kg/ha.

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