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Leaching and management of magnesium in typical soils of Southwest China

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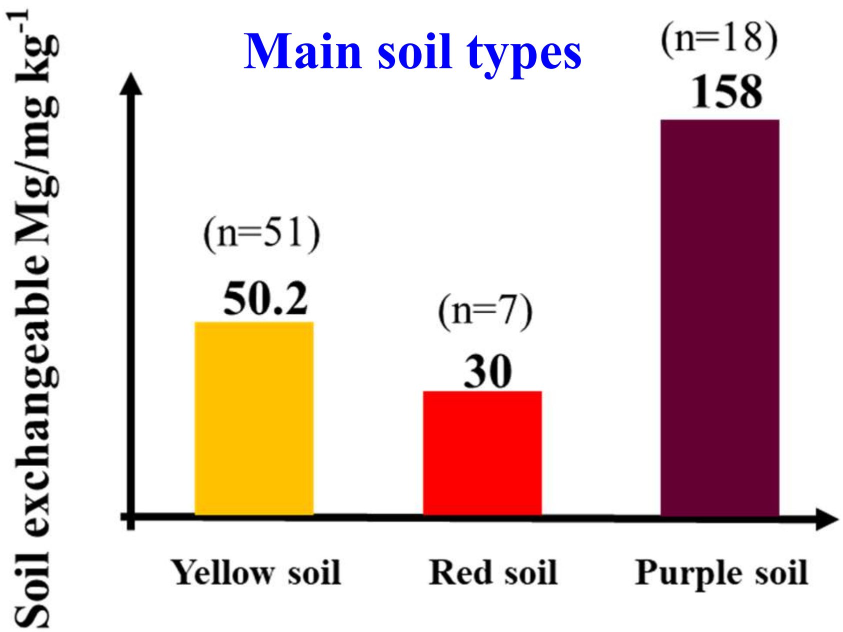
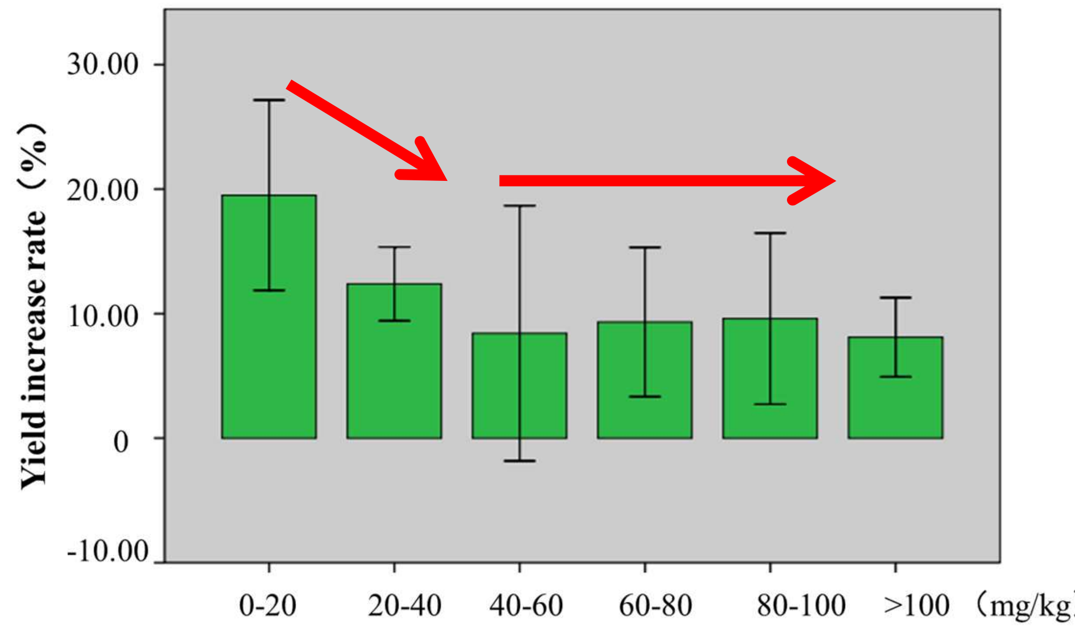
Outline

- Background
- Mg leaching in southwest China
  - Field measurement
  - Pot experiment
- Mg management approaches
  - Field measurement
  - Pot experiment
- Summary

Regional conditions - Soil



CEC cmol kg^{-1} | 9.16 | 6.63 | 24.3



Critical soil Ex-Mg: 40-60mg/kg

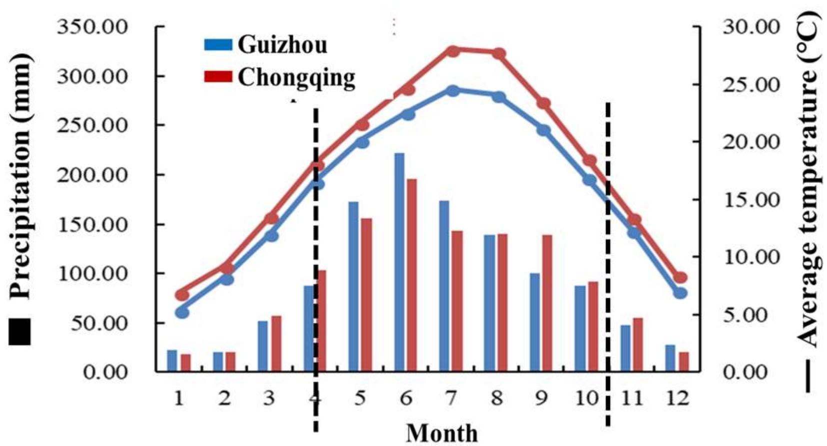
From Wang et al., unpublished

Poor soil properties: **acidic, highly weathering, poor retention of fertilizer and water.**

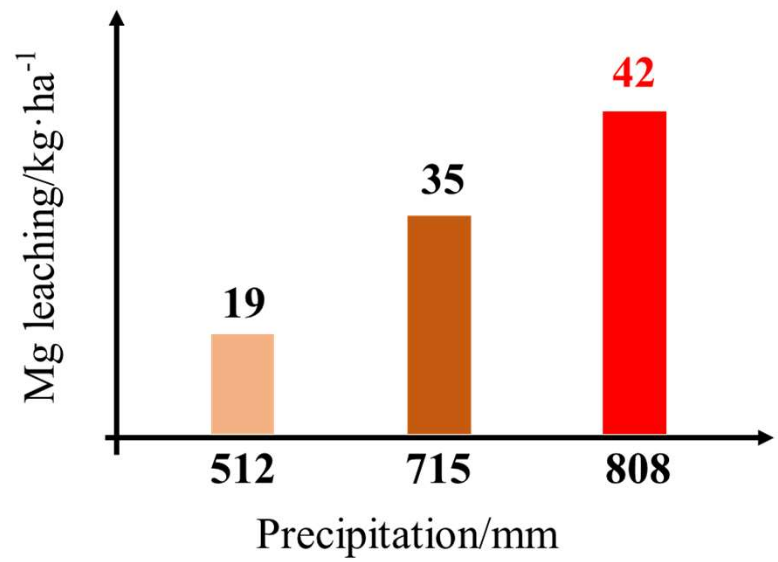
Regional conditions - Climate

High annual precipitation

Chongqing	Sichuan	Yunnan	Guizhou	Mean
1139	961	1091	1153	1086



Mg leaching is linear with precipitation



(Jakobsen, 1992)

Leaching is an important factor to lead soil Mg deficiency, especially under the poor soil properties and heavy precipitation conditions.

Mg leaching in cropland

Crop system	Precipitation (mm)	Mg leaching (kg/ha)	literature sources
Forest		9.5	Boysen, 1977
Arable land		20	Boysen, 1977
Grass	558	17.4	Di and Cameron, 2004
Winter wheat	512	19	Jakobsen, 1992
Winter wheat	715	35	Jakobsen, 1992
Winter wheat	808	42	Jakobsen, 1992
Maize	867	44	Jakobsen, 1992
Maize	1040	45	Poss and Saragoni,1992
Fallow	542	35	Ylaranta et al., 1996
Barley	542	87	Ylaranta et al., 1996
Grass	542	38	Ylaranta et al., 1996
Oilseed rape	808	42	Jakobsen, 1992
Soybean	814	45	Jakobsen, 1992
Apple		118	Neilsen, G.H. et al, 1983
Banana		79	Mauro W. O. et al, 2002

(Guan, unpublished)

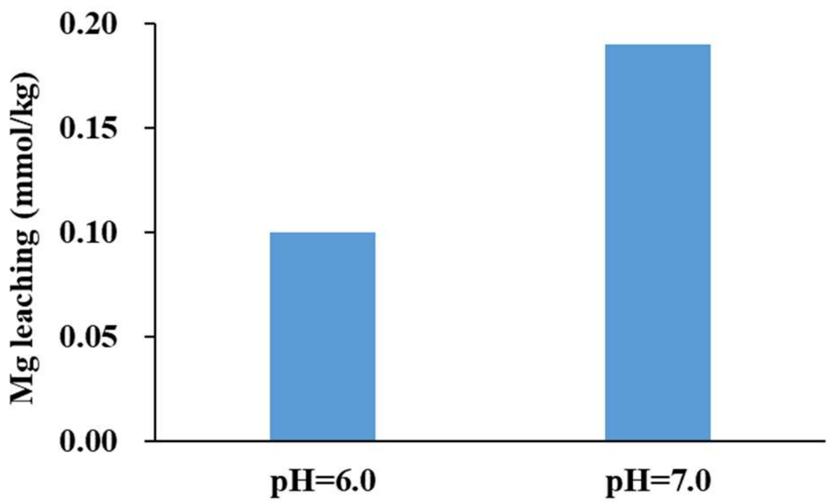
Globally, Mg leaching range widely, from 10 to more than 100 kg/ha. However, few studies focused on Mg leaching in the field in China.

As an intensive agricultural production area, soil Mg leaching in southwest China is unclear, and need to be quantified?

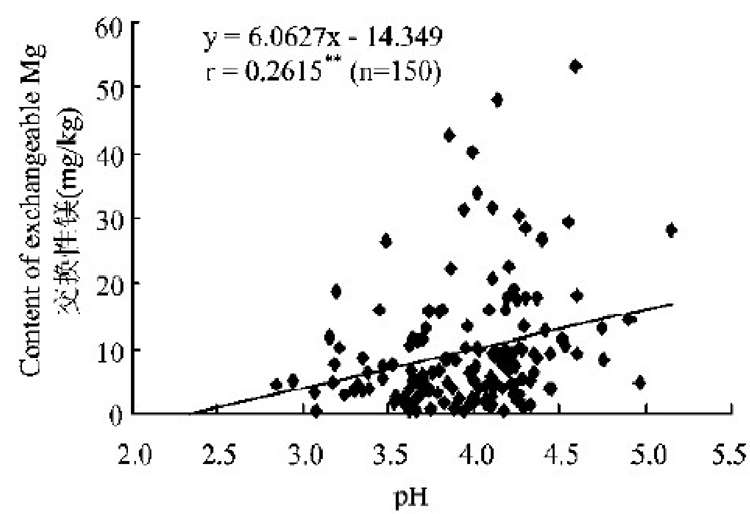
Control factors of Mg leaching: 1. soil pH

1) Soil exchangeable Mg dropped ＞50% when the soil pH increased from 5.5 to 7.5.
(Sumner et al.1978)

2) Effect of different pH of $Ca(OH)_2$ materials on soil Mg leaching in soil column



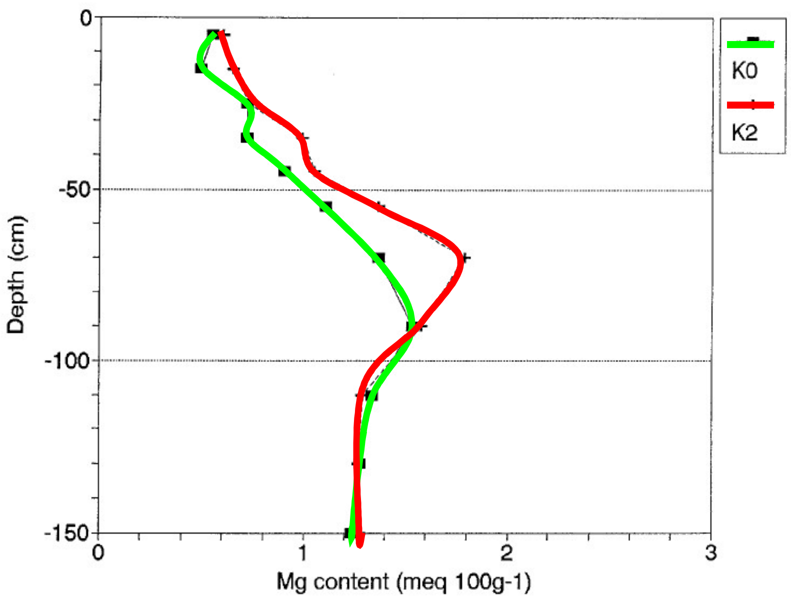
(Adapted from Phillips et al., 1988)



(Hou et al., 2009)

With the increasing of soil pH, Mg leaching increased.

Control factors of Mg leaching: 2. content of soil K and Ca



Exchangeable Mg profile distribution for treatment K0 and K2 (75kg/ha) (Poss & Saragoni, 1992)

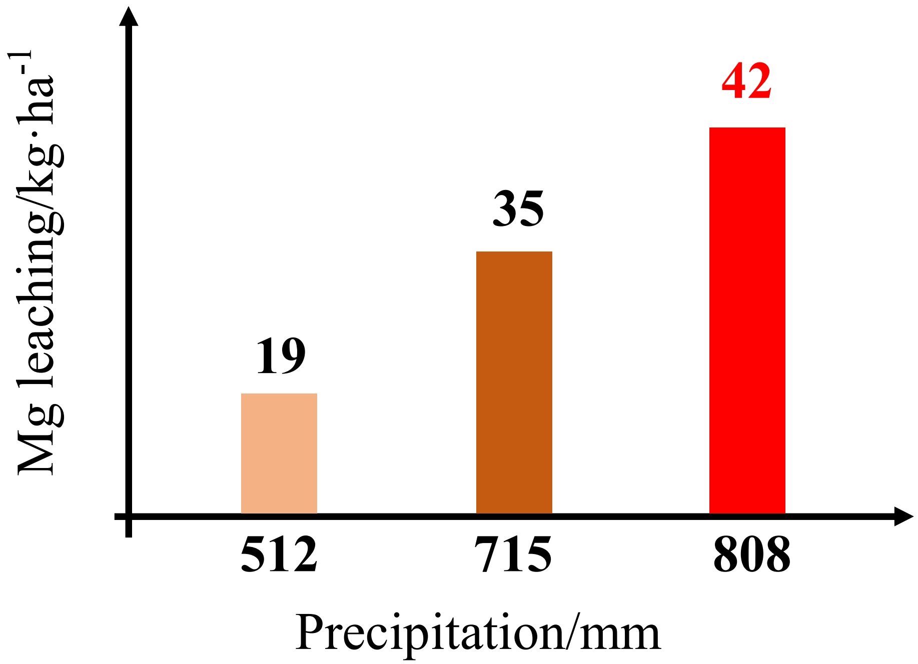
Effect of $Ca(OH)_2$ materials on soil Mg leaching in soil column

treatment	Mg Leaching ($mmol \cdot kg^{-1}$)
$-Ca(OH)_2$	0.06
$+Ca(OH)_2$ (pH=6.0)	0.10
$+Ca(OH)_2$ (pH=7.0)	0.19*

(Phillips I.R., Black A.S. & Cameron K.C.1988)

K and Ca application increased Mg leaching;
Soil K^+, Ca^{2+} and Mg^{2+} with similar cation radius, so with the increase of soil K and Ca, soil Mg easily leached out caused by isomorphous replacement.

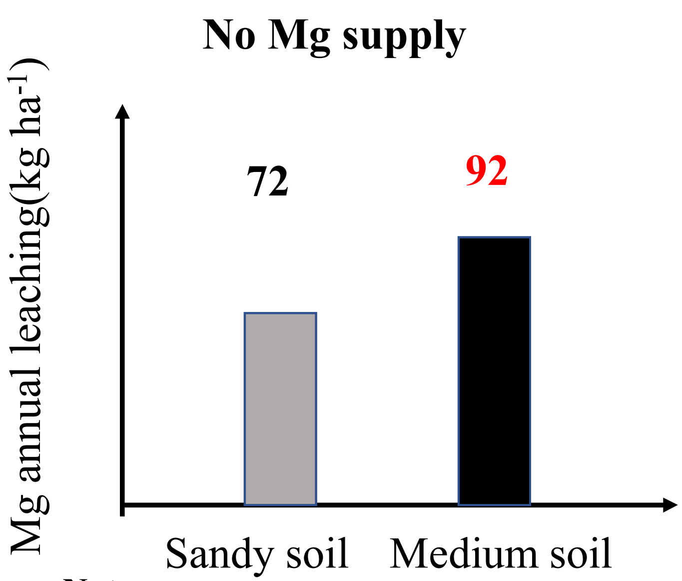
Control factors of Mg leaching: 3. Water supply (precipitation/irrigation)



Effect of precipitation on Mg leaching of winter wheat system

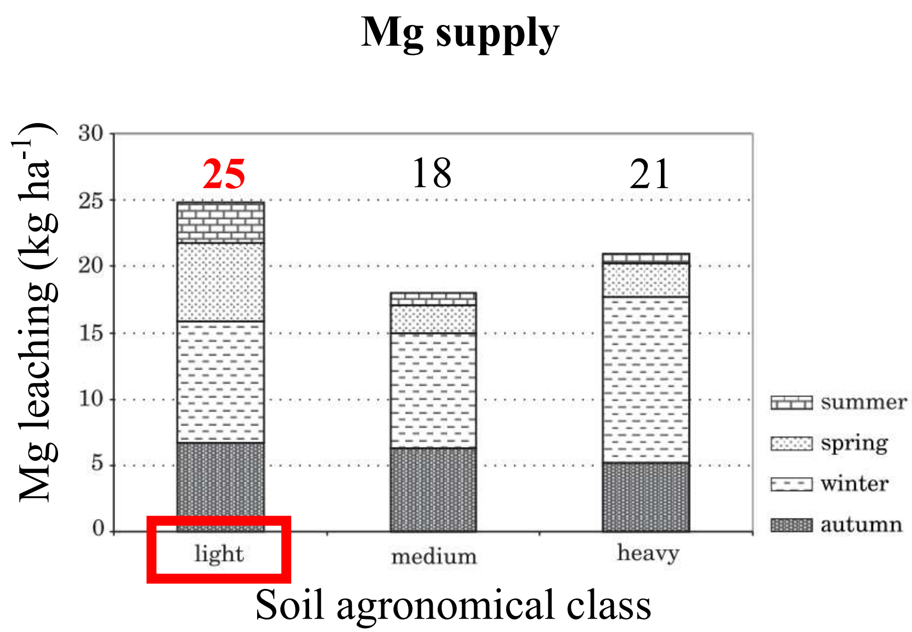
(Jakobsen1992)

Control factors of Mg leaching: 4. soil texture



Note:
Lysimetric experiments
During a 36-year-long period

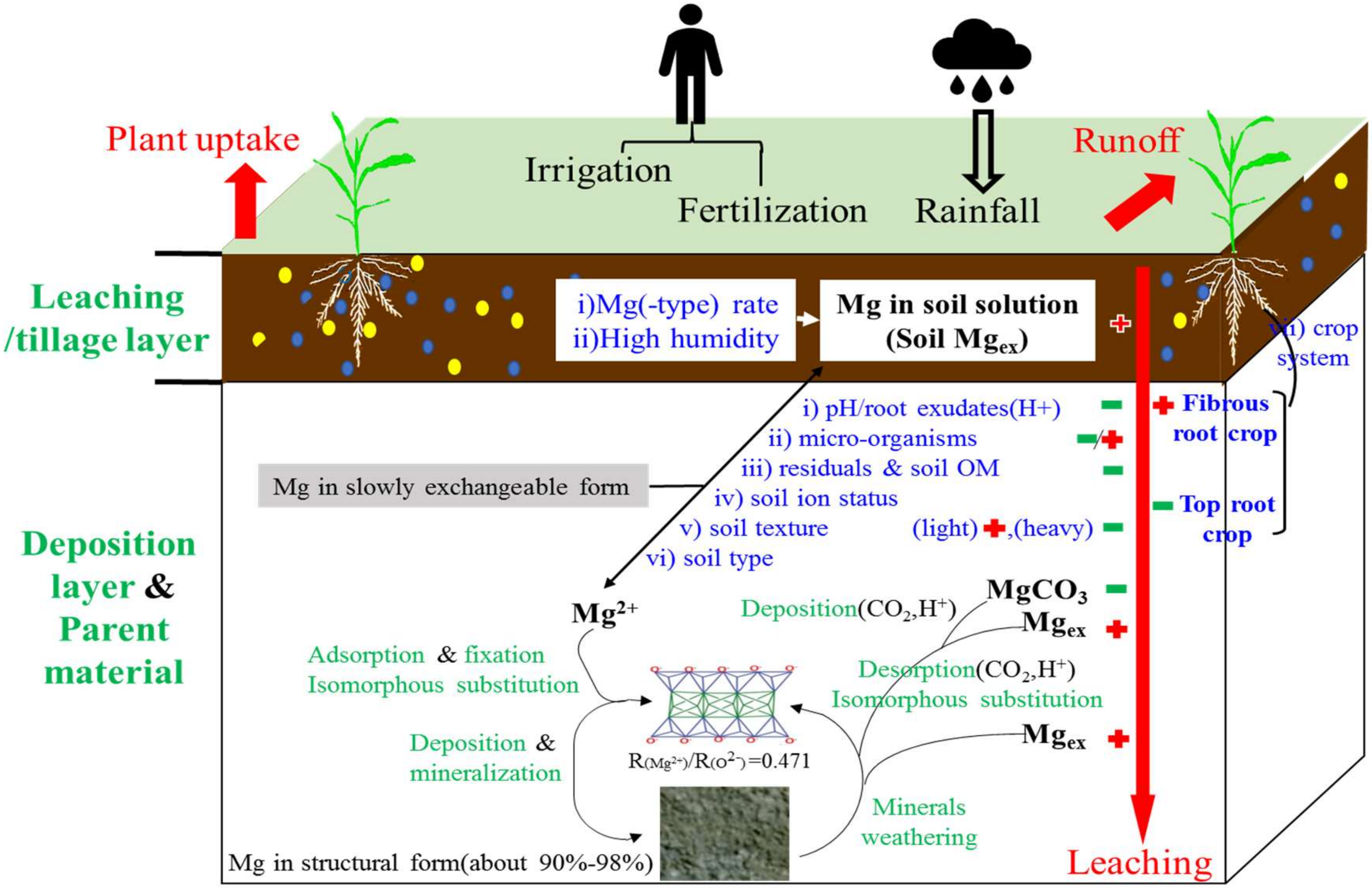
(Schweiger P. & Amberger A.1979)



(Koc J. & Szymczyk S. 2003)

Soil Mg leaching is affected by soil texture. From the parent material, Mg content in sandy soil is lower than that of medium soil, so there is more Mg leaching in medium soil. However, under Mg supply situation, there is more Mg leaching in light soil conversely caused by poor soil retention property.

Core processes and control factors of soil Mg leaching---Summary



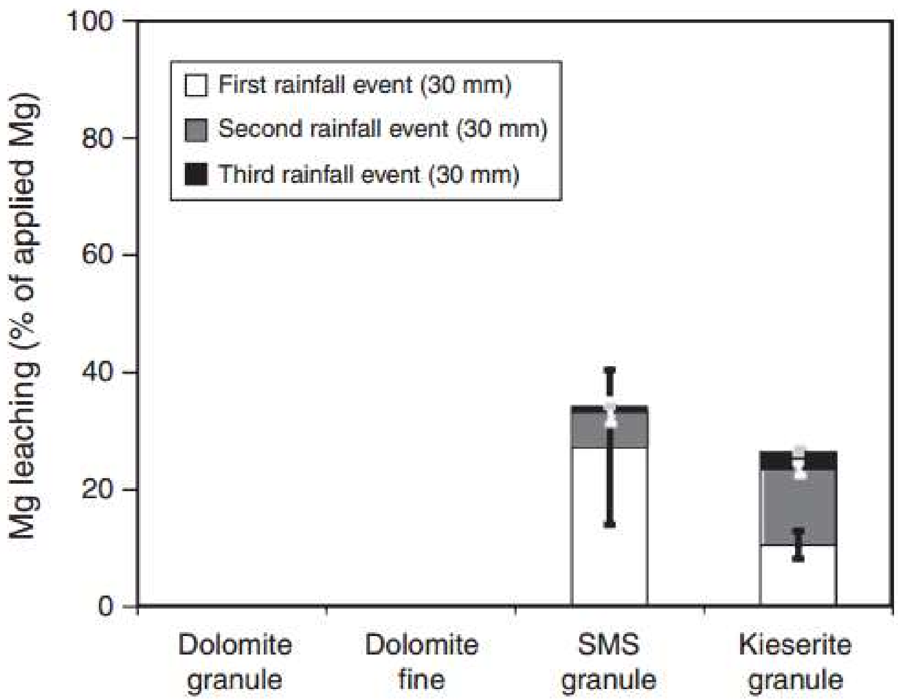
- **Soil property**
- **Environment**
- **Management**

Solubility Values of Potential Mg Sources at 25°C

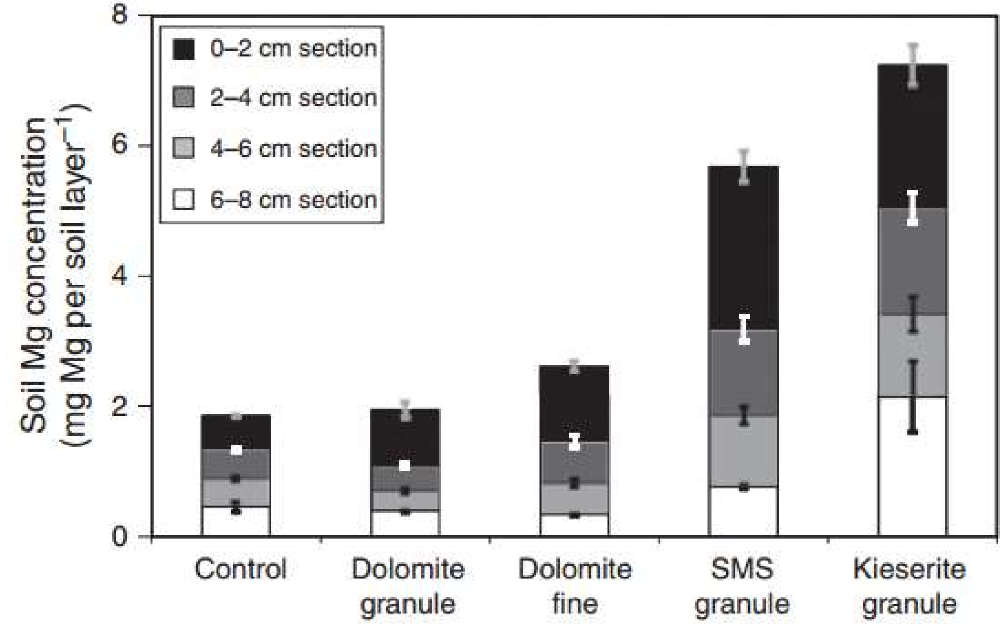
	Mineral	Chemical formula	Magnesium content	Solubiloty, g/L
	Magnesium choloride	$MgCl_2$	25%	2560
Easy-soluble	Magnesium nitrate	$Mg(NO_3)$	9%	1250
	Magnesium sulfate	$MgSO_4 \bullet 7H_2O$	9%	357
	kieserite	$MgSO4 \bullet H_2O$	17%	342
	Dolomite	$CaMg(CO_3)_2$	6-20%	0.01
Slow-release	Magnesium hydroxide	$Mg(OH)_2$	42%	0.009
	Magnesium oxide	MgO	56%	0.006
	Polyhalite	$K_2Ca_2Mg(SO_4)_4 \bullet 2H_2O$	3.6%	

(J.Baltrusaitis et al.,2016;Robert Mikkelsen et al.,2010)

The solubility values of Mg vary in a large range, the Mg source with low solubility could be a consideration to prevent mg from leaching.

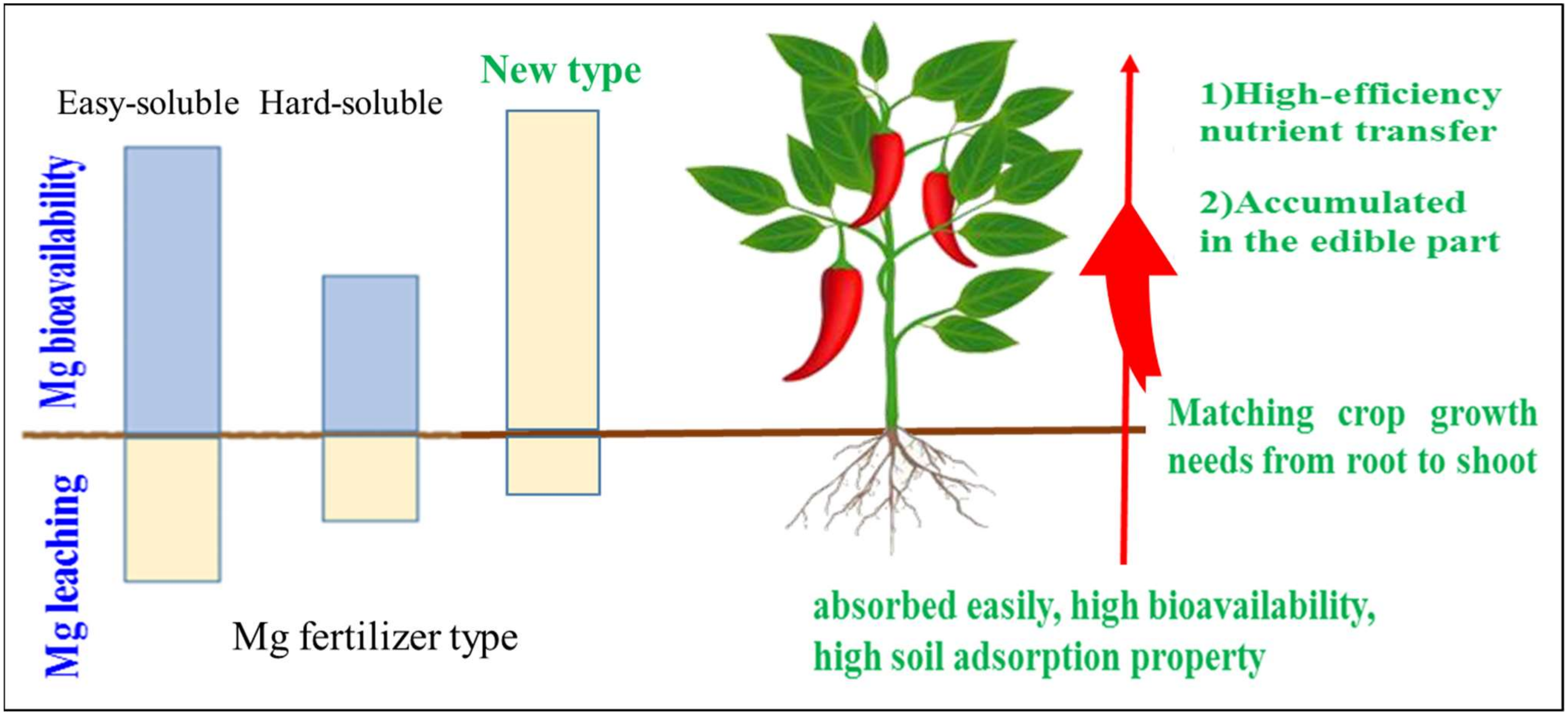


$CaMg(CO_3)_2$ **$MgSO_4$ x $1H_2O$**



$CaMg(CO_3)_2$ **$MgSO_4$ x $1H_2O$**

There could be a contradiction with leaching risk and bioavailability soil.



Some new type Mg fertilizers may take overall consideration in these two sides.

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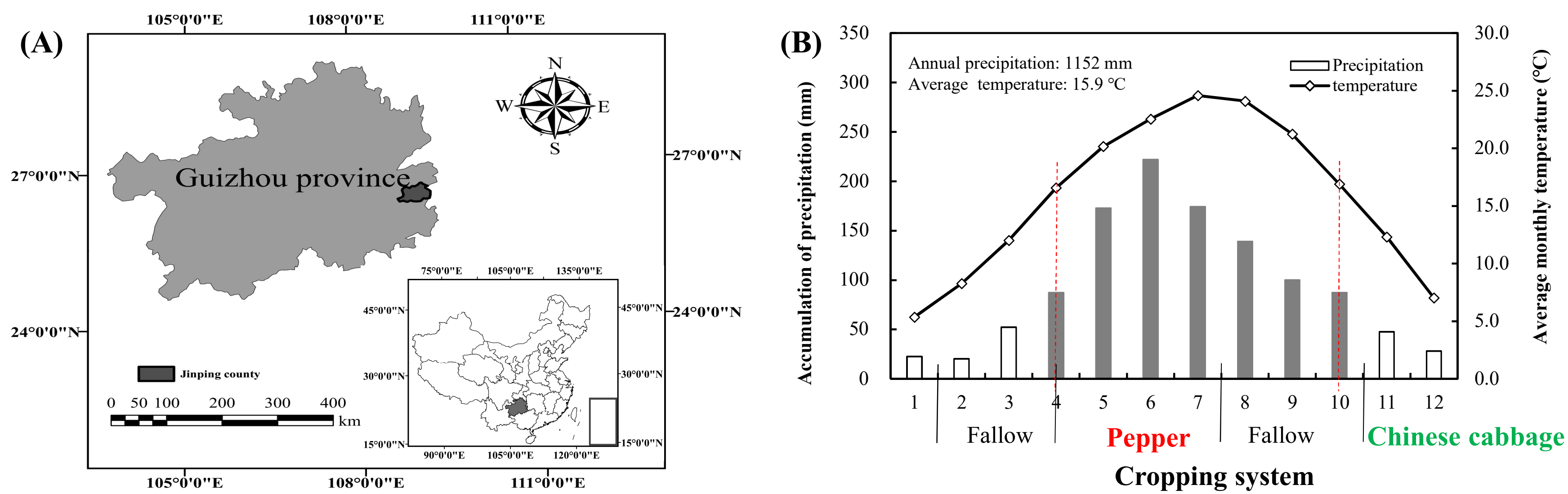
Field measurement

Method： field lysimeter experiment under soil Mg fertilizer supply

Site： yellow soil (pH 4.87， CEC 9.16 cmol kg^{-1}, exchangeable Mg 48.8 mg kg^{-1}), Jinping county

Crop material： pepper and Chinese cabbage



Location (A), meteorological condition (average value from 2007 to 2017) and vegetable rotation system design(B) of the studied area.

Treatments： 5 Mg fertilizer supply rates, 4 repeats; details as follows,

Optimal design for NPK fertilizers:

(1) Pepper: N(urea), 250 kg ha^{-1}; P_2O_5, 140 kg ha^{-1}; K_2O(potassium sulfate), 300 kg ha^{-1};

(2) Chinese cabbage: N, 250 kg ha^{-1}; P_2O_5, 120 kg ha^{-1}; K_2O,190 kg ha^{-1};

Mg rates:

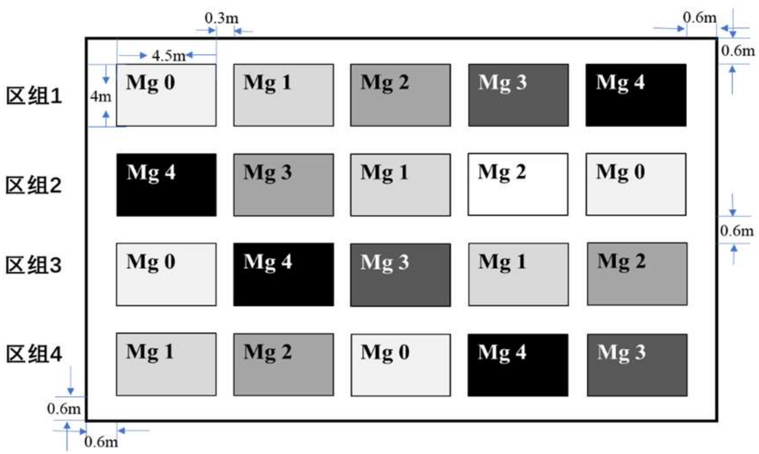
Mg0: 0 kg MgO ha^{-1} (source: $MgSO_4 \cdot 7H_2O$)

Mg1: 37.5 kg MgO ha^{-1}

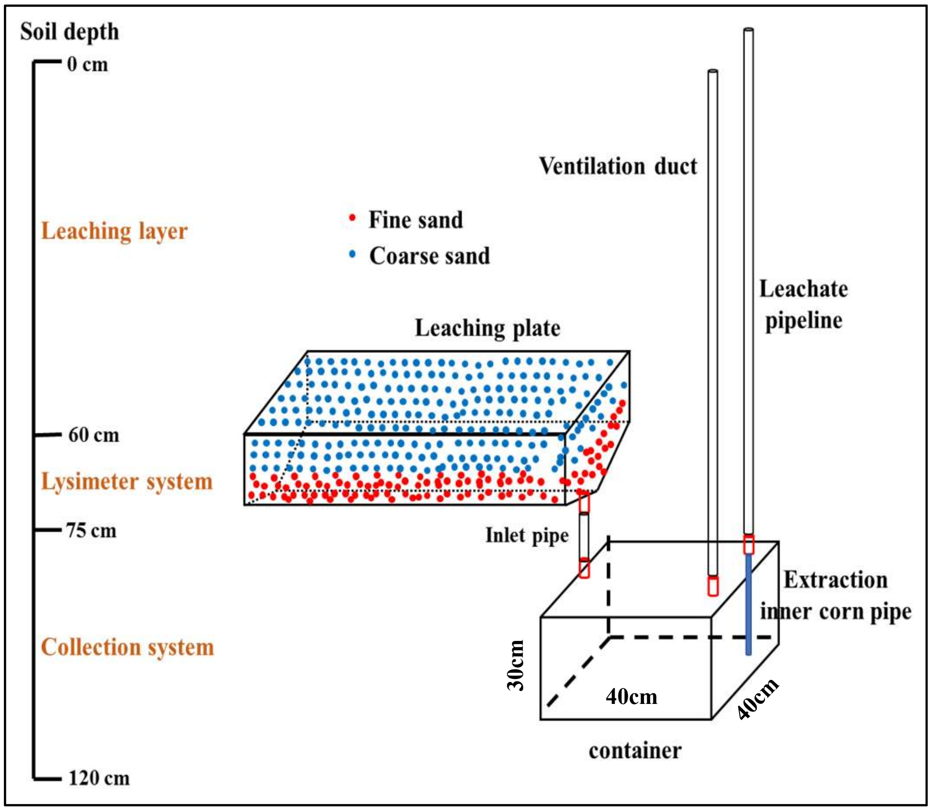
Mg2: 75 kg MgO ha^{-1}

Mg3: 112.5 kg MgO ha^{-1}

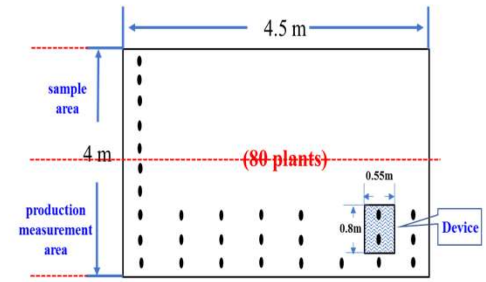
Mg4: 150 kg MgO ha^{-1}



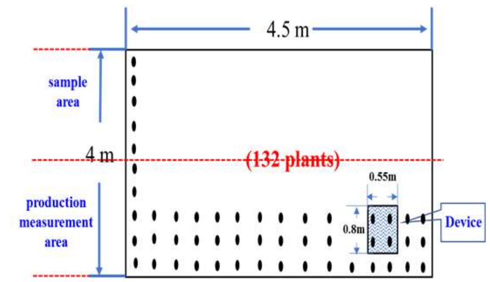
Structure of field experiment lysimeter



Functional partition of unit plot



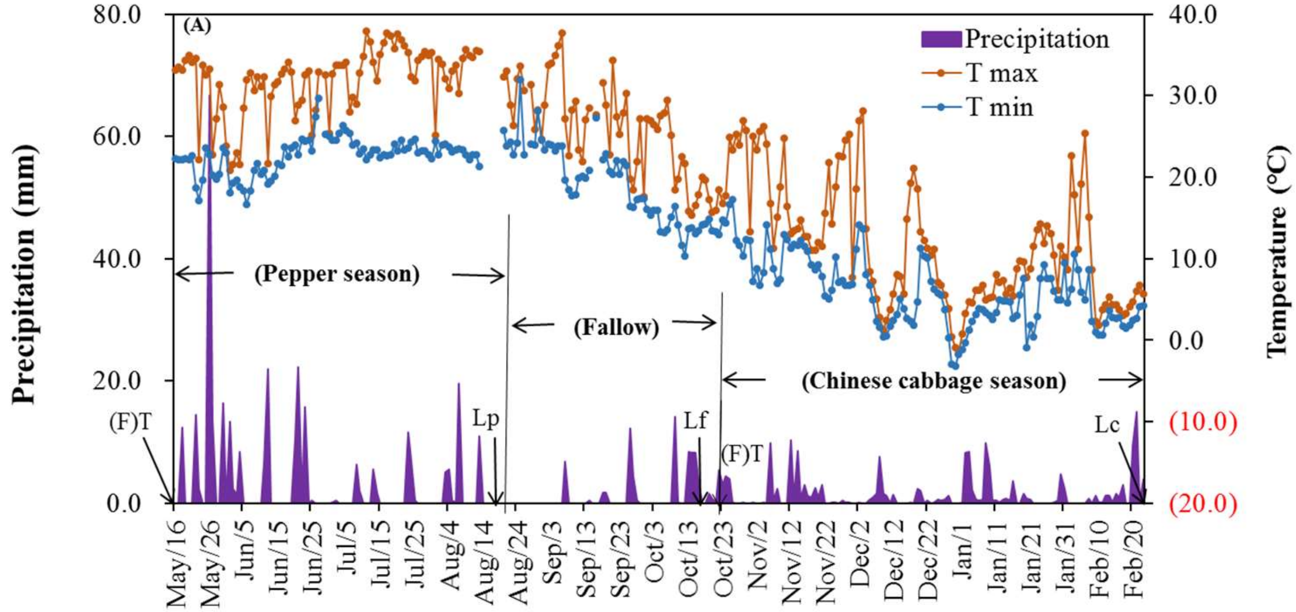
pepper season



Chinese cabbage season

Determination: **E**xtract leachate after 2-3 times of rainfall **(accumulated precipitation ≤80mm)**, **volume and Mg, K, Ca concentration of leachate were detected.**

Climate characteristics

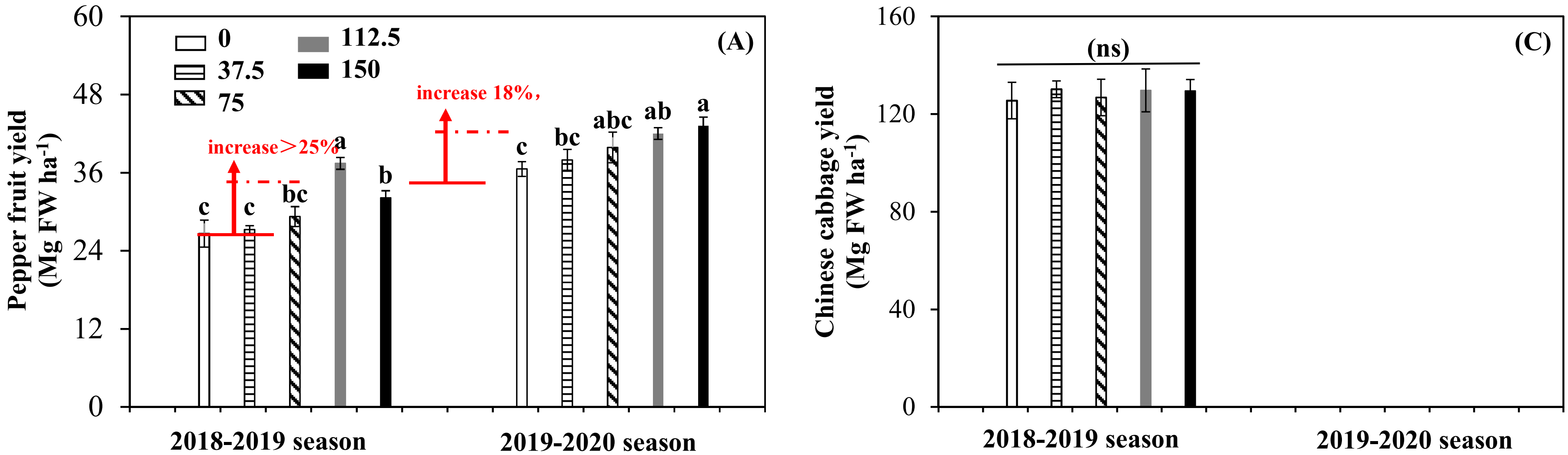


Daily precipitation and temperature during the whole open-field pepper-Chinese cabbage rotation period in 2018~2019.
F: fertilization date for basal fertilizer
T: crop transplanting date
L: last date for leachate sampling in each crop season. Lp, Lf and Lc represents last sampling date in the pepper season, fallow period and Chinese cabbage season, respectively.

(M. Lu, Y. Liang & D. Y. Liu, unpublished)

In 2018, accumulated precipitation in pepper season is 308mm， and 181mm for Chinese cabbage.

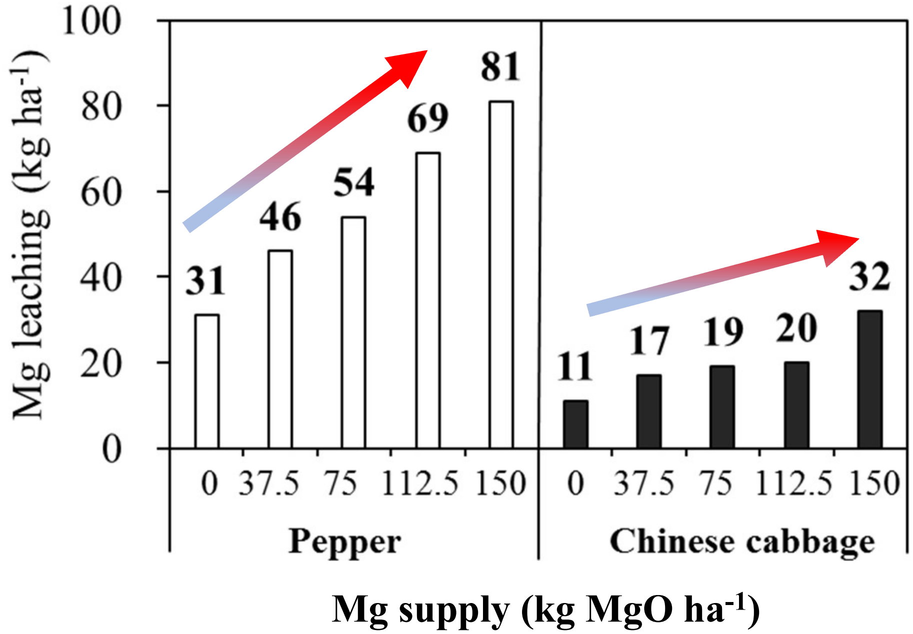
Result 1: Mg supply & crop yield

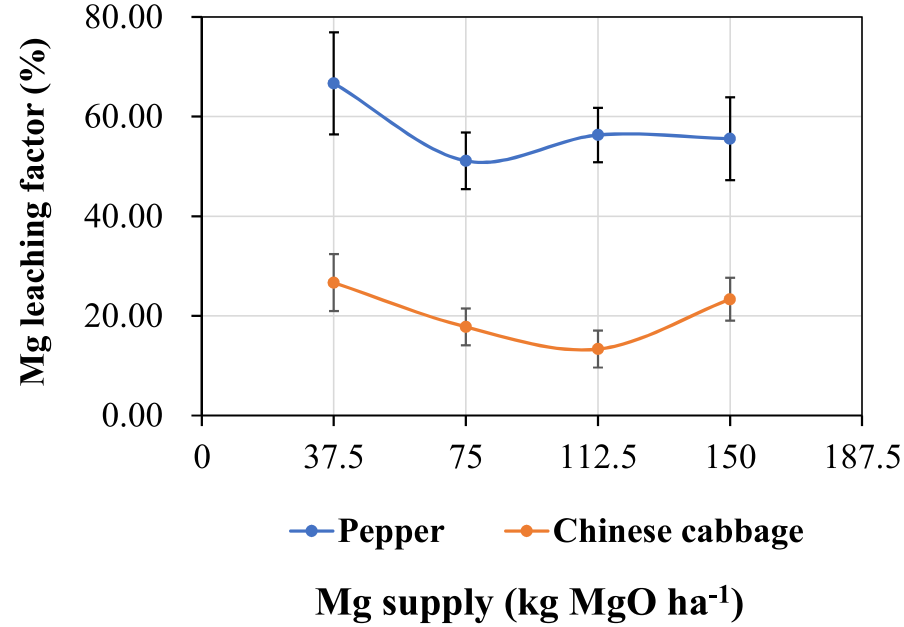


Mg deficiency is an important limiting factor for the increase of pepper yield.

No significantly effect on the yield of Chinese cabbage.

Result 2: Soil Mg leaching



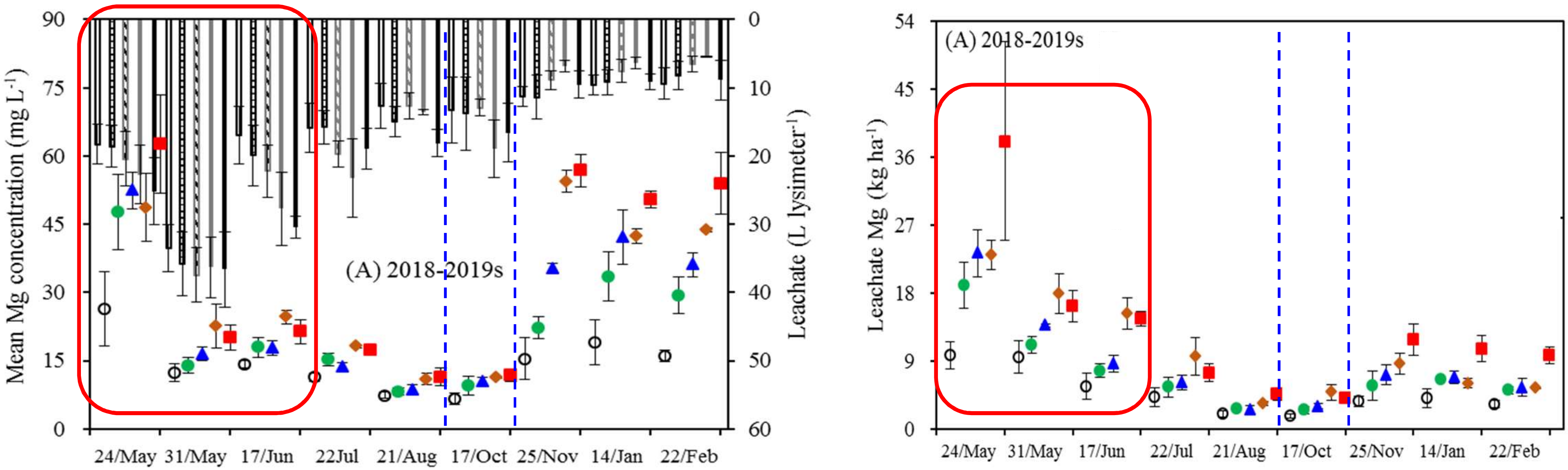


Note: Mg leaching factor (%)=(Mg leaching loss of Mg treatment - Mg leaching loss of CK)*100 / Mg supply rate

Mg leaching in pepper and Chinese cabbage was 31 and 11 kg ha^{-1}, respectively. With the application of Mg fertilizer, Mg leaching loss is increased.

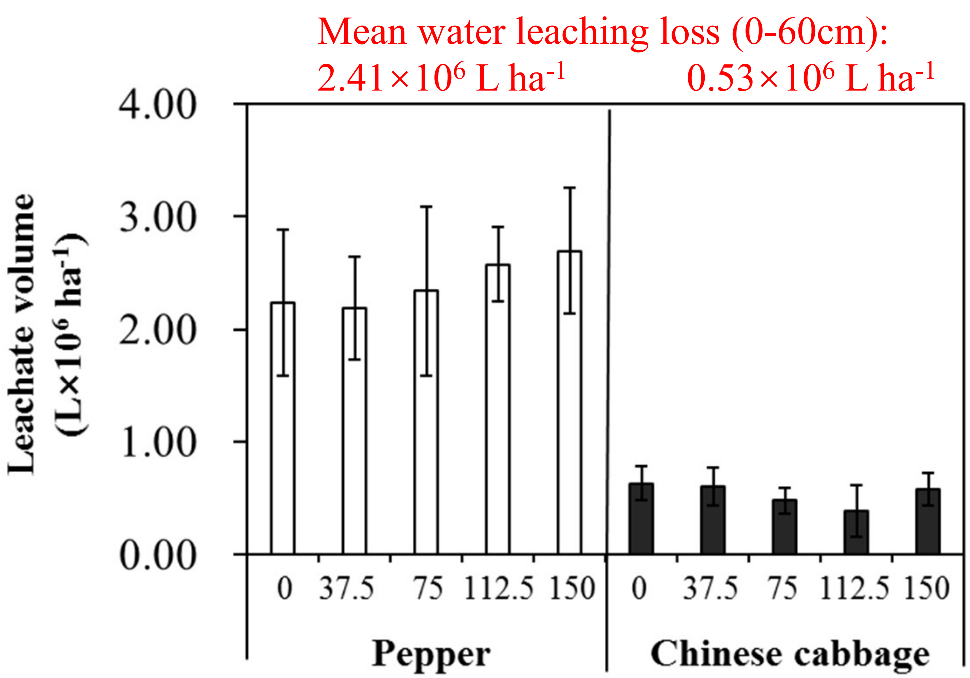
The Mg leaching factor was 55-66% in pepper season, and 13-27% in Chinese cabbage season.

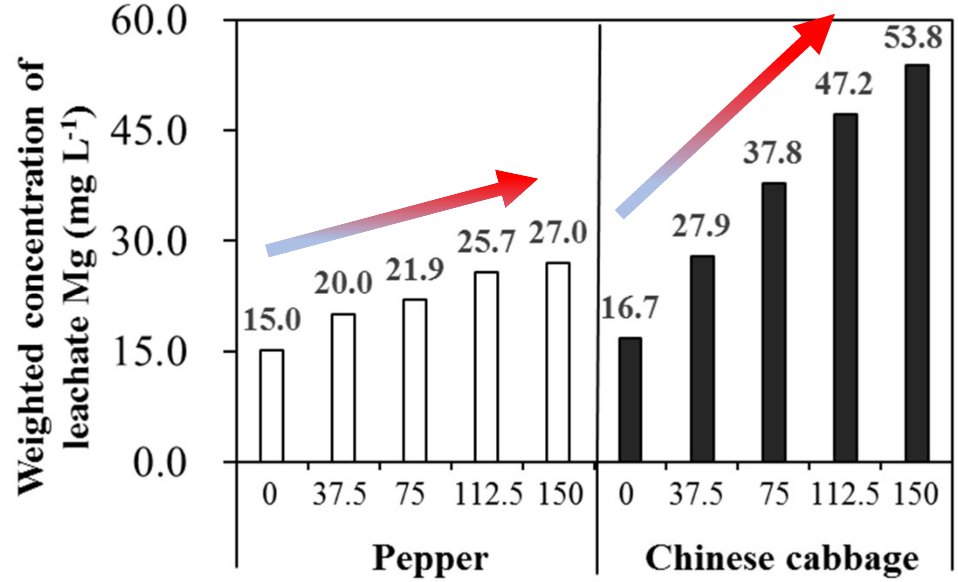
Result 2: Dynamic change characteristics of Mg leaching



High intensity of rainfall in the early stage of pepper planting leaded to the high quantity Mg leaching loss, which was the main reason why the total loss of Mg leaching in Chinese cabbage season was lower than that in the pepper season.

Result 2: Leachate volume and weighted concentration of leachate Mg

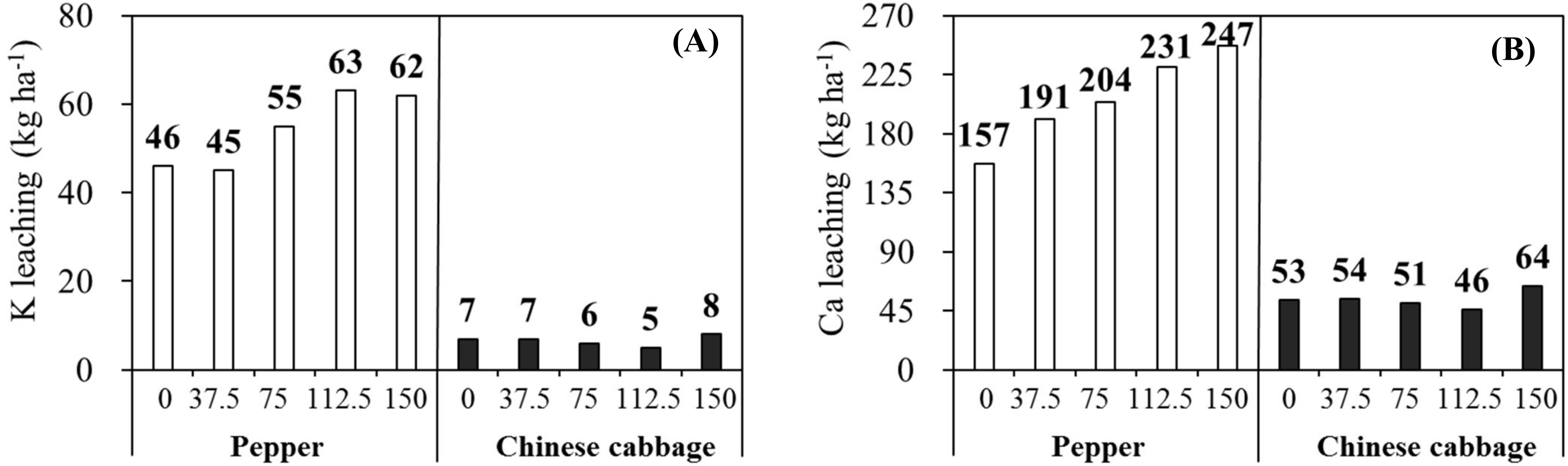




There were 241 mm and 53 mm leachate loss at 0-60 cm soil depth in the pepper season and Chinese cabbage season on a rain-fed condition, respectively.

The concentration of leachate Mg increased with increasing Mg application.

Result 2: Mg supply & soil K and Ca leaching



K and Ca leaching were increased with the increasing Mg application rate in pepper season.

Pot experiment

Method： soil pot lysimeter experiment under soil Mg fertilizer supply

Soil materials： yellow soil (pH 4.87, CEC 9.16 cmol kg^{-1}, Mg_{ex} 48.8 mg kg^{-1}), red soil (pH 5.32, CEC 6.63 cmol kg^{-1}, Mg_{ex} 24.0 mg kg^{-1}), air-dry soil 6 kg/pot

plant material： pepper and Chinese cabbage

Treatments： 7 rates of Mg fertilizer supply, 6 repeats. Details of water and fertilizers management as follows:

(1) 800 ml/pot deionized water every week; (2) Mg, NPK supply. (N source, urea; P_2O_5 source, monoammonium phosphate; K_2O source, potassium sulfate.)

24 hours after irragation, the **volume and concentration of leachate Mg, K, Ca be determined.**

Mg supply

mg MgO kg^{-1}soil	Source: $MgSO_4$ $7H_2O$						
Pepper	0	15	30	60	120	240	480
Chinese cabbage	0	10	20	40	80	160	240

NPK supply

g kg^{-1} soil	N	P_2O_5	K_2O
pepper	0.58	0.29	0.59
Chinese cabbage	0.30	0.15	0.225

Chinese cabbage pot experiment

Principles of water supply:

(1) 60% of field water capacity for early growth requirements of crops,

(2) Total amount of water supply equal the growth period rainfall (mean, 130mm) in the Chinese cabbage production.

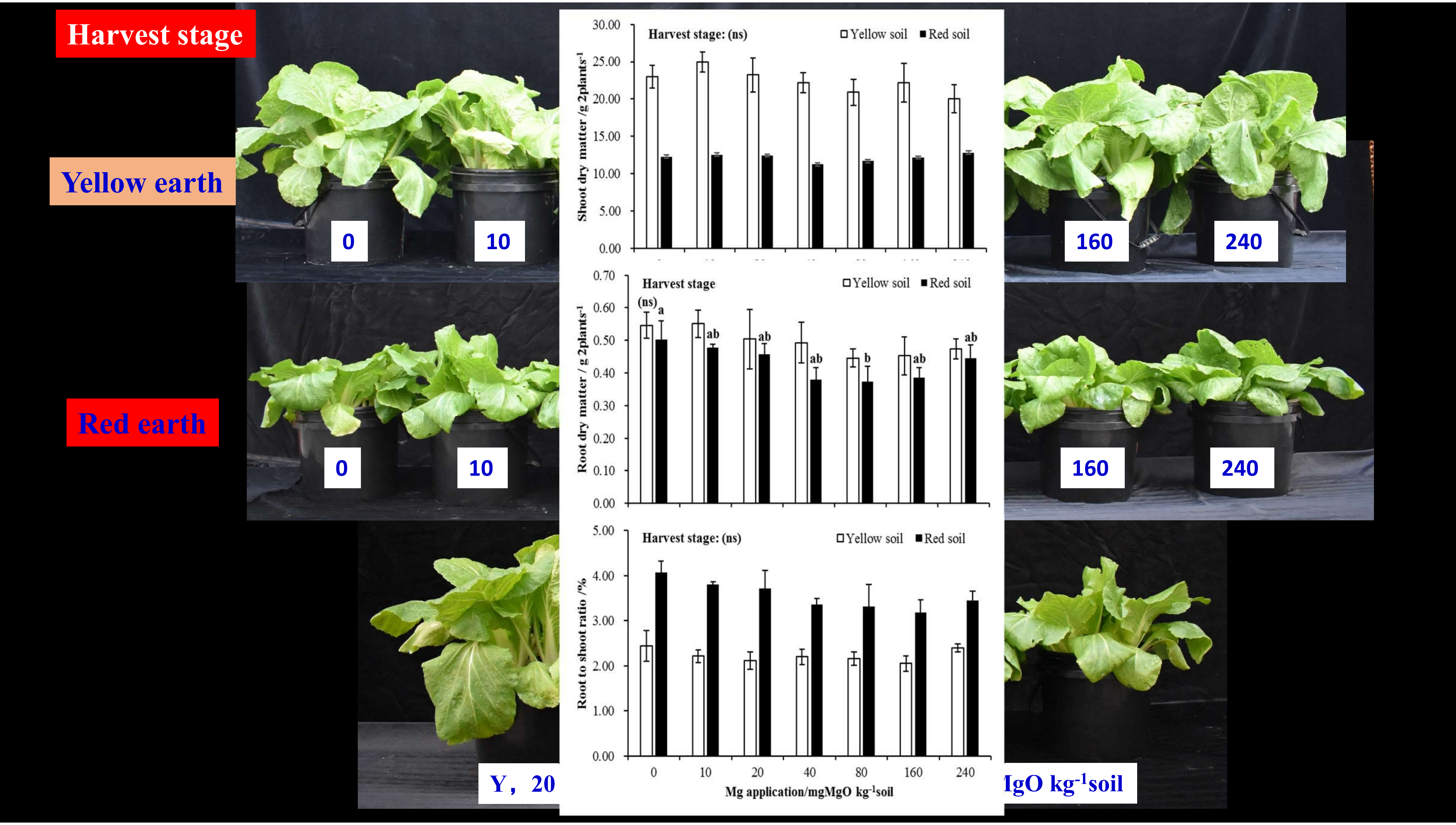
Growth period: 20181104 - 1219

Red soil   Yellow soil

Rosette stage

Deionized water supply

20181219	Both 1400 ml
20181226	Both 900 ml
20190103	Both 900 ml
20190110	Both 800 ml
20190117	Both 800 ml


Harvest stage
Yellow earth
Red earth
0
10
160
240
0
10
160
240
Y，20
lgO kg-1soil
Harvest stage: (ns)
Yellow soil
Red soil
Shoot dry matter /g 2plants-1
Harvest stage
Root dry matter / g 2plants-1
(ns)
a
ab
b
Harvest stage: (ns)
Root to shoot ratio /%
0
10
20
40
80
160
240
Mg application/mgMgO kg-1soil

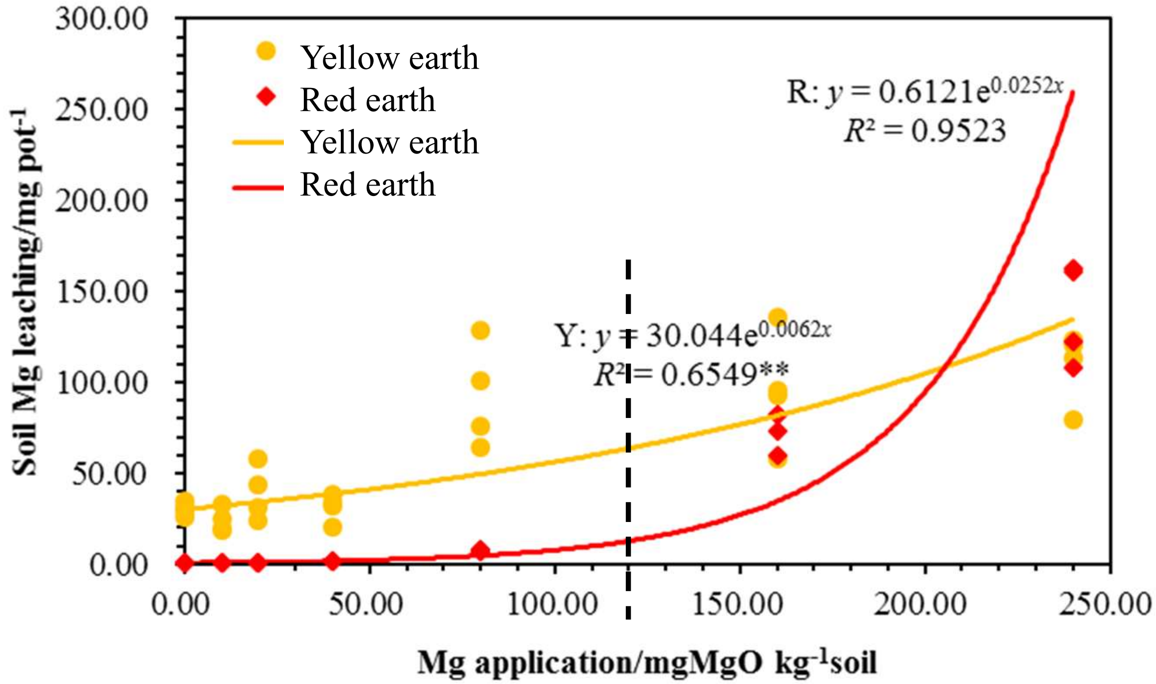
Result 1: Dynamic change characteristics of Mg leaching

Leachate volumes of Chinese cabbage pot experiment in different soil types

mL	20181219		20181226		20190103		20190110		20190117	
	Yellow	Red	Yellow	Red	Yellow	Red	Yellow	Red	Yellow	Red
MgO 0	701	623	394	584	415	524	188	460	278	444
MgO 10	793	657	377	593	370	573	224	488	221	428
MgO 20	958	758	363	556	375	542	250	456	236	382
MgO 40	920	900	385	615	418	593	289	523	293	473
MgO 80	696	919	347	609	492	579	306	525	311	480
MgO 160	810	860	430	590	444	558	304	504	369	453
MgO 240	885	688	492	580	404	533	312	475	335	417

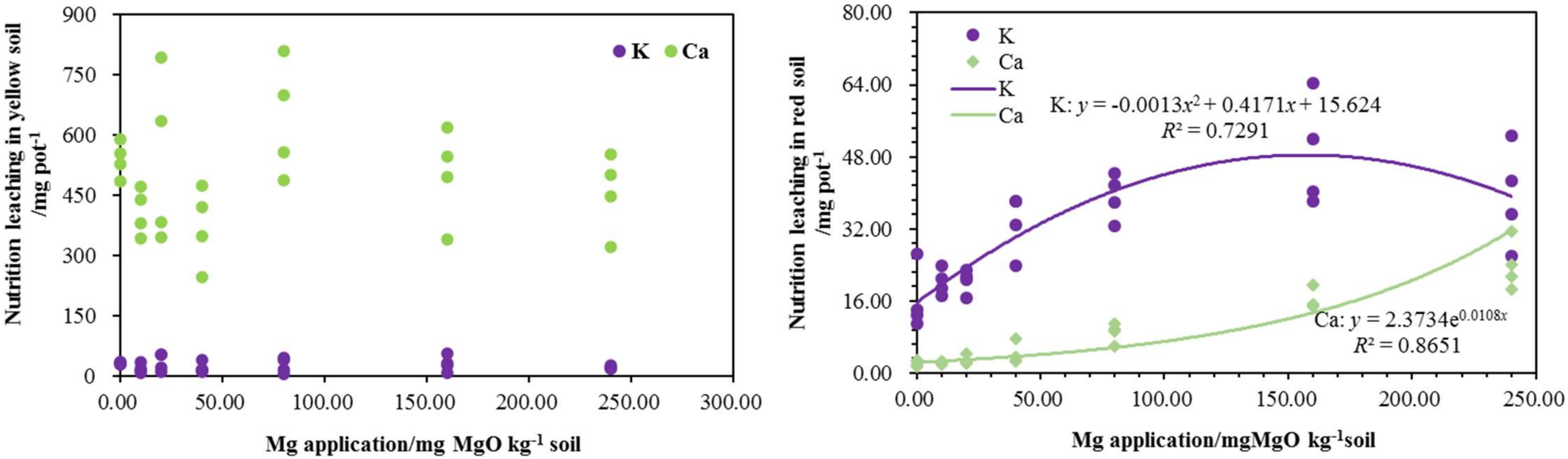
With growth of Chinese cabbage, leachate volume of two soil types were different due to differences of plant water-bioavailability and soil water retention property.

Result 2: Mg leaching



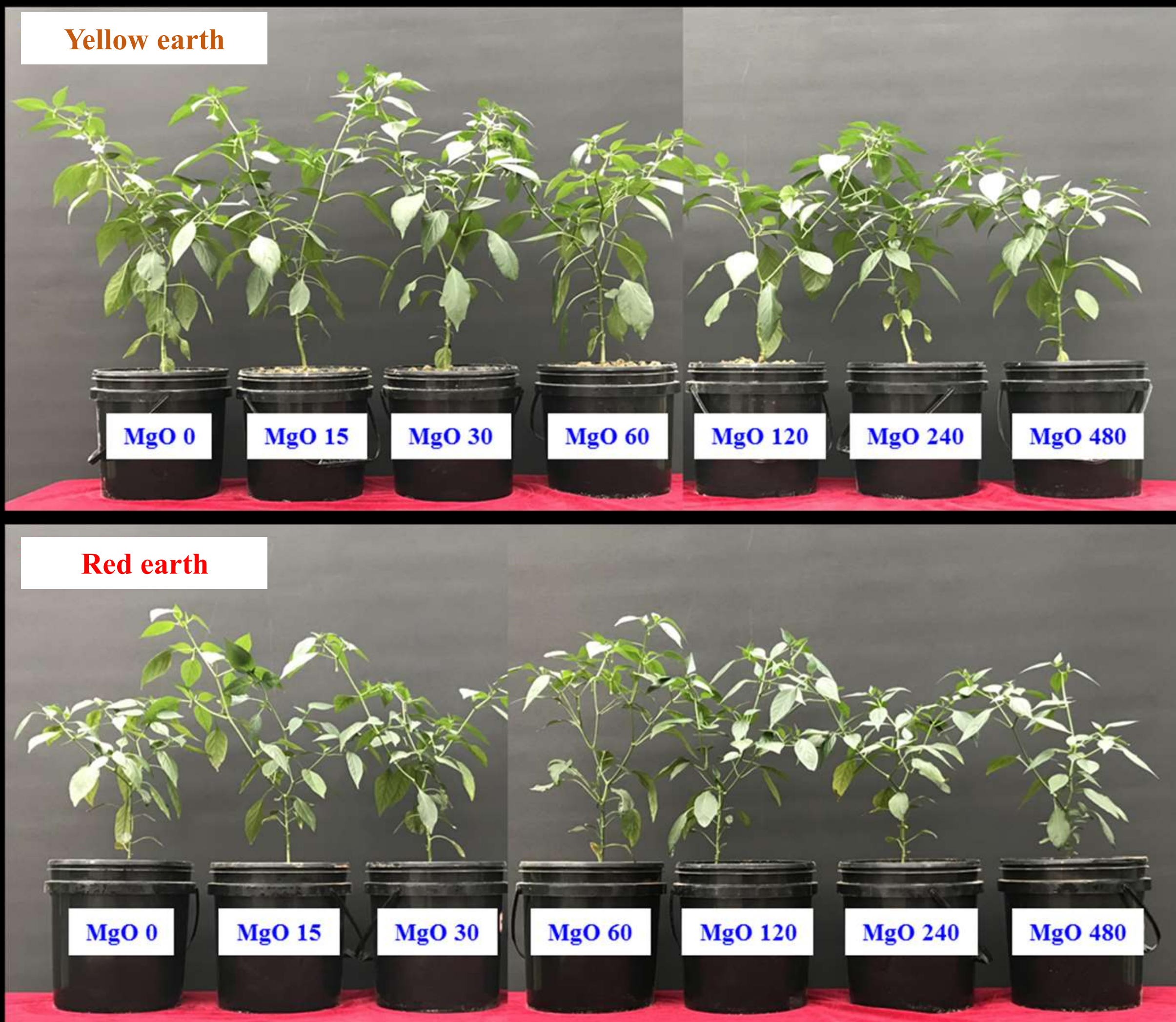
Mg leaching shows a significant near linear relationship with Mg application rate.

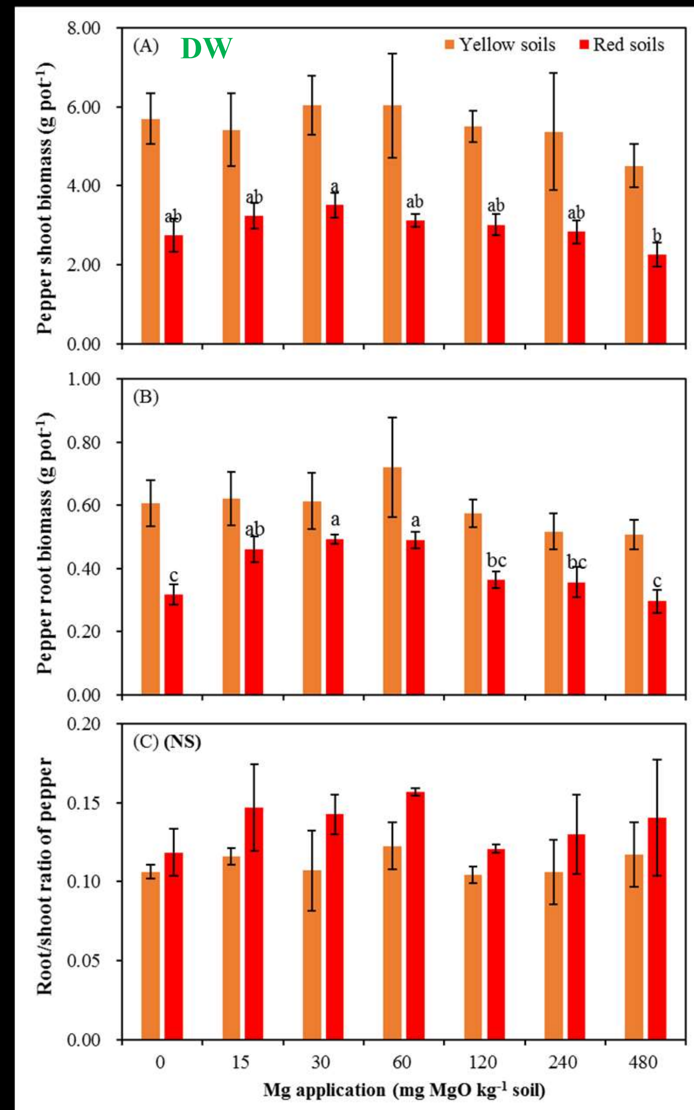
The difference in red soil is mainly caused by Mg deficiency of basic soil (before the black line) and low CEC (6.63 cmol kg^{-1}, after the black line).



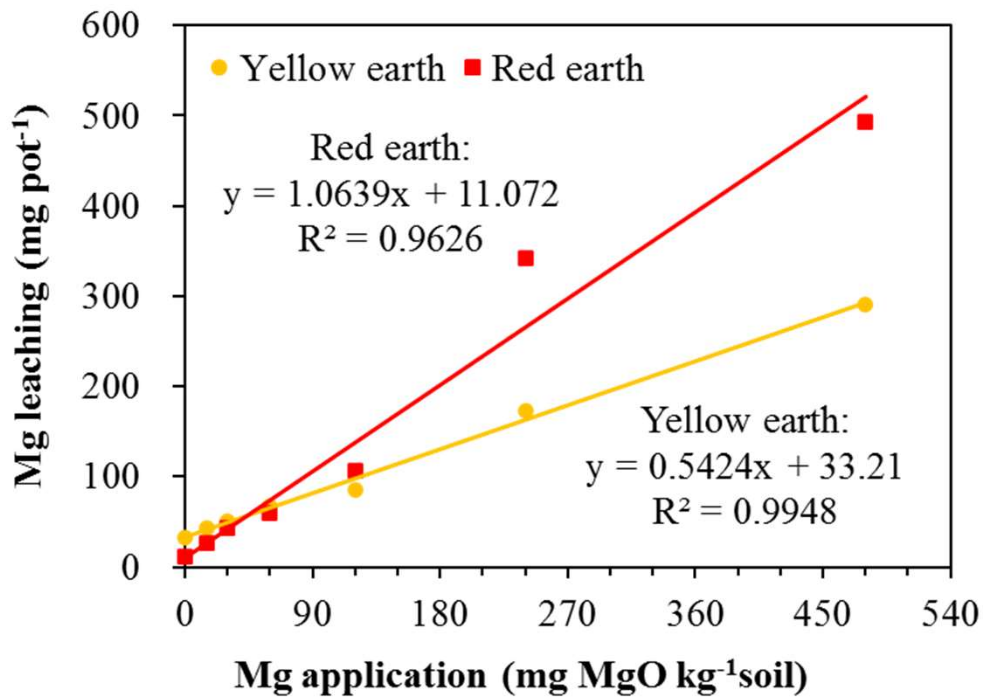
K and Ca leaching are anabatic with increasing Mg supply in red earth.

Pepper pot experiment





Mg leaching



Significant linear relationship showed between Mg leaching and Mg supply on two soil types. And Mg leaching factor of red earth is higher than that of yellow earth.

Different Mg leaching loss models for different cropping systems.

Outline

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Field measurement

Method: open-field experiment with different Mg fertilizers

Soil material: yellow earth (pH 4.87, Mg_{ex} 48.8 mg kg^{-1}), Jinping county, Guizhou province

plant material: pepper (2019 season) and Chinese cabbage (CC, 2018 season)

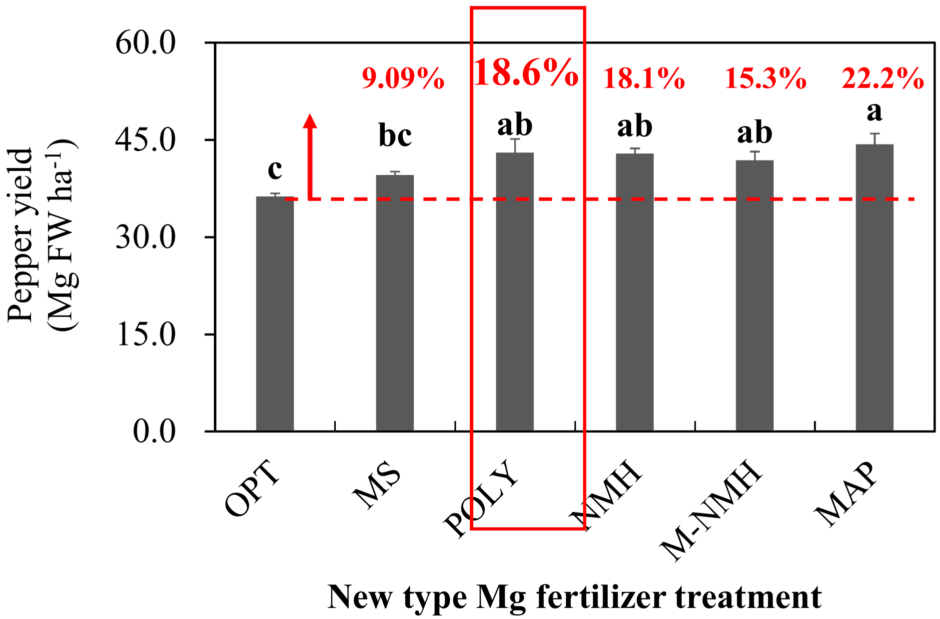
Treatments: 5 different types of Mg fertilizer supply: magnesium sulfate (MS), polyhalite (POLY), nano-magnesium hydroxide (non-soluble, NMH), modified nano-magnesium hydroxide (water-soluble, M-NMH), and magnesium ammonium phosphate (MAP). Same rate of MgO (75 kg ha^{-1}), 4 repeats; details as follows,

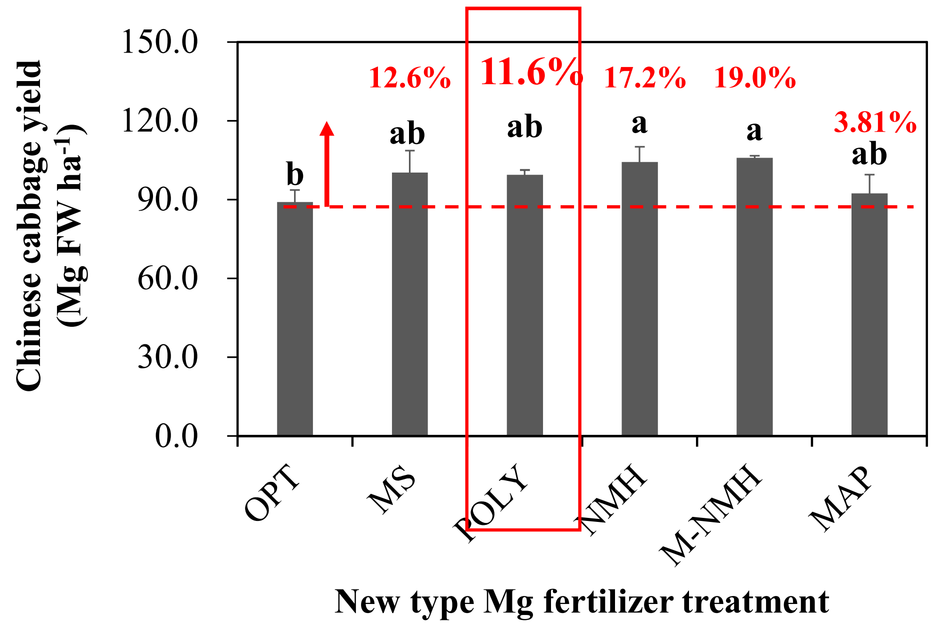
Pepper (kg ha^{-1})	OPT	New-type Mg treatment
N	250	250
P2O5	140	140
K2O	300	300
MgO	-	75

CC (kg ha^{-1})	OPT	New-type Mg treatment
N	250	250
P2O5	120	120
K2O	190	190
MgO	-	75

Note: OPT, NPK optimized fertilization; CC, Chinese cabbage. N source, urea; P_2O_5 source, monoammonium phosphate; K_2O source, potassium sulfate.

Result: New type Mg fertilizer & crop yield





Note: **OPT:** NPK optimized fertilization; **POLY:** polyhalite; **MS:** magnesium sulfate; **NMH:** nano-magnesium hydroxide (non-soluble); **M-NMH:** modified nano-magnesium hydroxide (water-soluble); **MAP:** magnesium ammonium phosphate

On the basis of OPT, pepper yield increased by 9.09% for conventional Mg fertilizer application (MS), and 18.5% for new type Mg fertilizer.
Application of new type Mg fertilizer has significant yield-increasing effect on pepper and Chinses cabbage production.

Pot experiment

Objectives: To explore effects of new types of Mg fertilizer application on the control of soil base cation leaching loss.

Method： soil pot lysimeter experiment

Soil types： yellow earth (pH 4.87， Mg_{ex} 48.8 mg kg^{-1}), 6 kg air-dry soil for each pot

Crop material： pepper and Chinese cabbage

Treatments： Different type of Mg fertilizer supply, 3 rates, 6 repeats. Details of water and fertilizers management as follows:

(1) 800 ml/pot deionized water every week; (2) Mg, NPK supply. (N source, urea; P_2O_5 source, monoammonium phosphate; K_2O source, potassium sulfate.)

24 hours after watering, the **volume and Mg, K, Ca concentration of leachate be determined.**

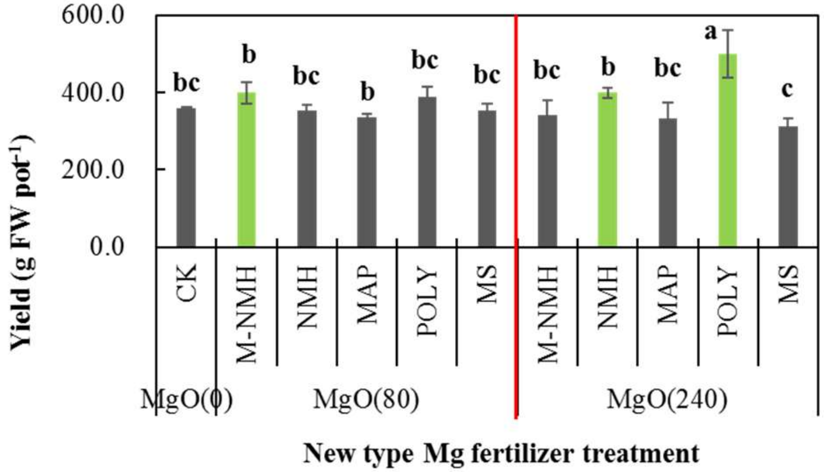
Mg supply

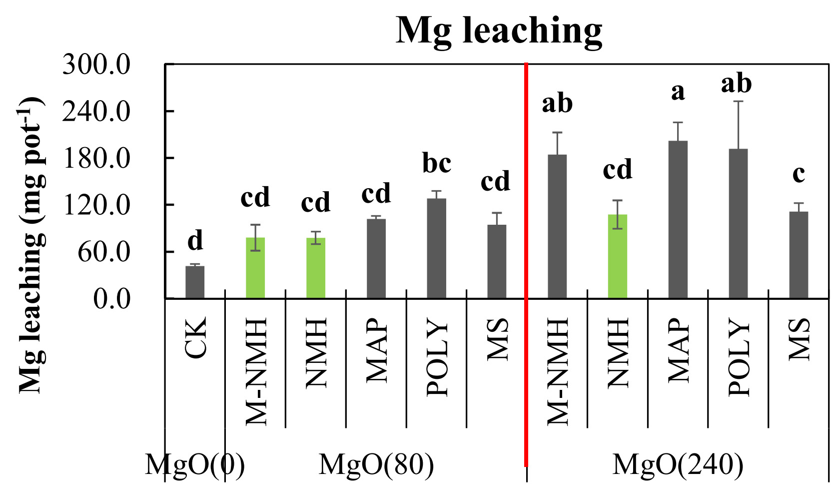
mg MgO kg^{-1}soil			
Pepper	0	80	240
Chinese cabbage	0	80	240

NPK supply

g kg^{-1} soil	N	P_2O_5	K_2O
pepper	0.3	0.15	0.35
Chinese cabbage	0.3	0.15	0.225

Chinese cabbage pot experiment

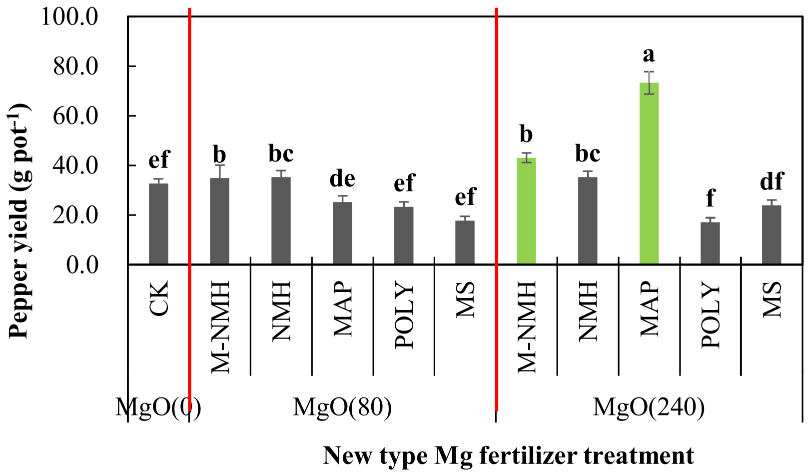


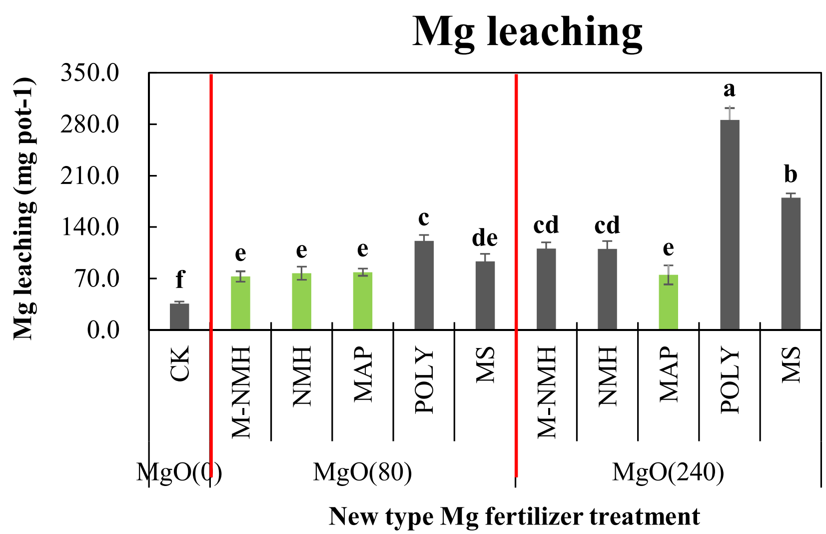


Compared with conventional Mg fertilizer (MS), POLY fertilization can significantly increase crop yield, but increase soil Mg leaching because of the trait of high content of Ca and K. Mg leaching factor decreased for (M-)NMH fertilization in Chinese cabbage production

Note: Mg leaching factor (%)=(Mg leaching loss of Mg treatment - Mg leaching loss of CK)*100 / Mg supply rate

Pepper pot experiment





Applying (M-)NMH and MAP are better for controlling Mg leaching loss in pepper production.

Summary

1. As a intensive agricultural production area, there is a serious Mg leaching problem in southwest China, especially in pepper season (Leaching factor: 55-66%).

2. Application of PLOY can increase yield of pepper and Chinese cabbage by 18.6% and 11.6%, respectively.

3. New type Mg fertilizers can effectively control the Mg leaching loss and improve crop productivity simultaneously.

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Thanks for your attention!