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Problems and solutions of fertilizer application in China

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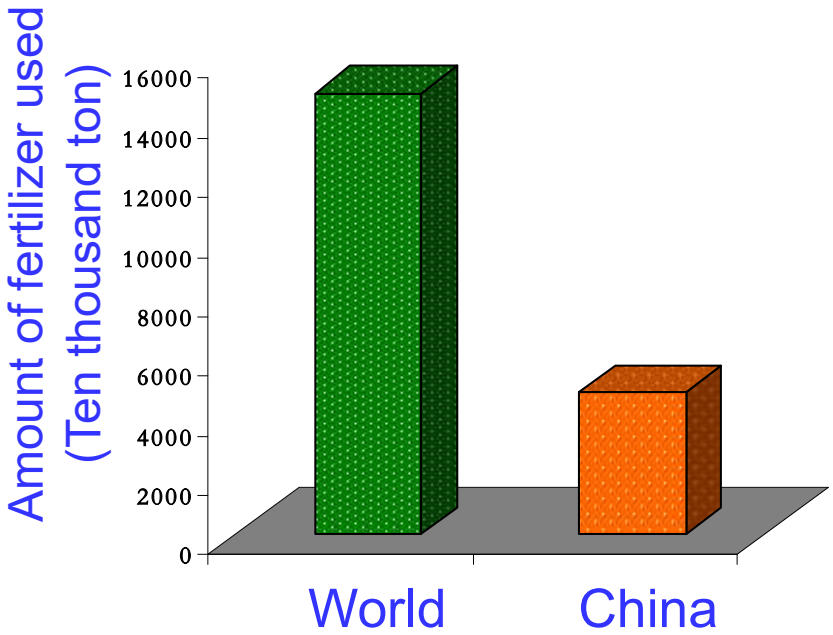
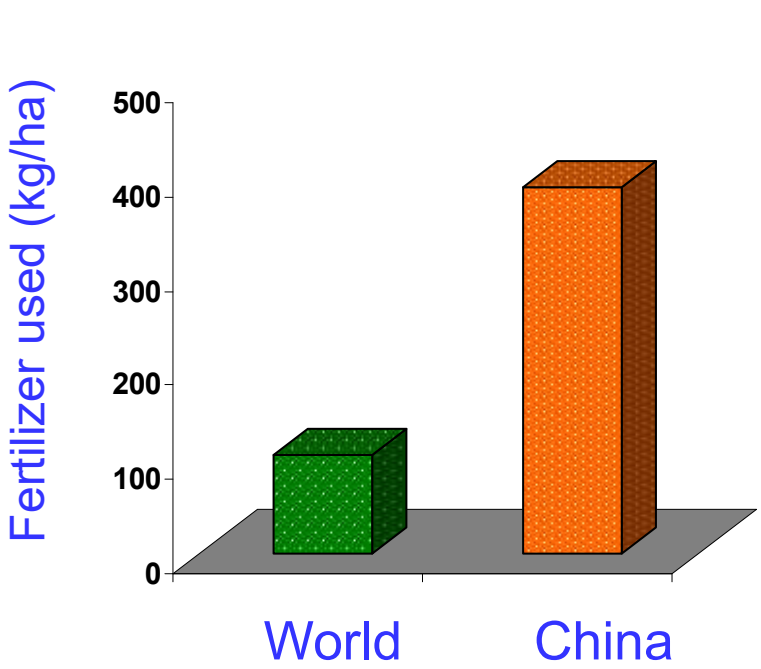
Problems and solutions

1. Problems caused by utilization of chemical fertilizer
2. Problems need to be solved for efficient fertilization
3. Prospects and suggestions

Problems caused by utilization of chemical fertilizer

Overused fertilizer and low FUE in China





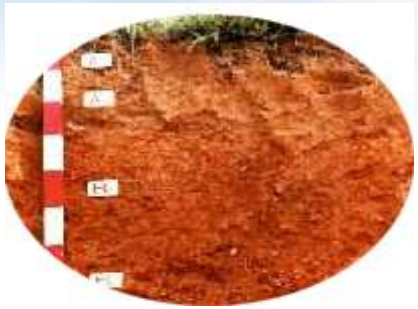
1/3 of the chemical fertilizer on 9% of the arable land.
Fertilizer dose is 3.7 times to the world average level which resulted in very low fertilizer use efficiency

Problems caused by utilization of chemical fertilizer

Environmental pollution caused by fertilization

Water eutrophication

Greenhouse gas emission



Soil acidification and degradation

Problems caused by utilization of chemical fertilizer

Environmental pollution caused by fertilization

Worldwide concern

Science AAAS

Galloway et al., Science, 320: 889 (2008)

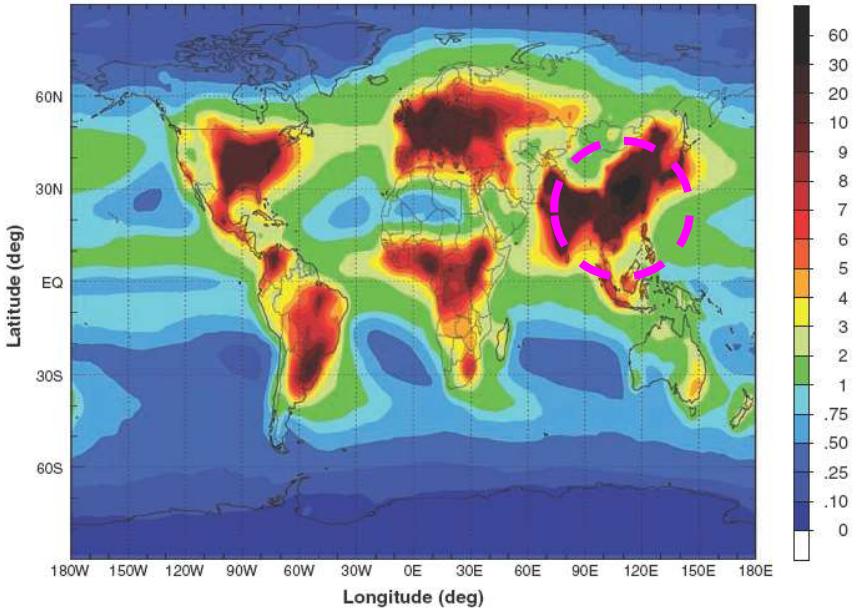


Fig. 2. Estimated N deposition from global total N (NOy and NHx) emissions, totaling 105 Tg N y^{-1}. The unit scale is kg N ha^{-1} y^{-1}, modified from the original units (mg m^{-2} y^{-1}) (*16*).

Science AAAS

J. H. Guo, *et al.*
Science **327**, 1008 (2010);
DOI: 10.1126/science.1182570

Significant Acidification in Major Chinese Croplands

J. H. Guo,[1]* X. J. Liu,[1]* Y. Zhang,[1] J. L. Shen,[1] W. X. Han,[1] W. F. Zhang,[1] P. Christie,[1,2] K. W. T. Goulding,[3] P. M. Vitousek,[4] F. S. Zhang[1]†

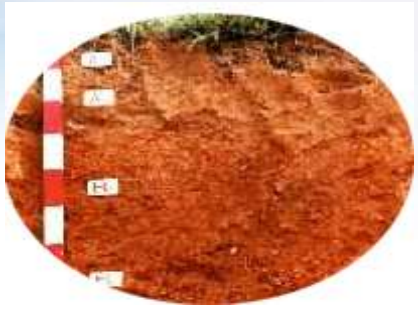
Soil acidification is a major problem in soils of intensive Chinese agricultural systems. We used two nationwide surveys, paired comparisons in numerous individual sites, and several long-term monitoring-field data sets to evaluate changes in soil acidity. Soil pH declined significantly ($P < 0.001$) from the 1980s to the 2000s in the major Chinese crop-production areas. Processes related to nitrogen cycling released 20 to 221 kilomoles of hydrogen ion (H^+) per hectare per year, and base cations uptake contributed a further 15 to 20 kilomoles of H^+ per hectare per year to soil acidification in four widespread cropping systems. In comparison, acid deposition (0.4 to 2.0 kilomoles of H^+ per hectare per year) made a small contribution to the acidification of agricultural soils across China.

Problems caused by utilization of chemical fertilizer

Environmental pollution caused by fertilization

Water eutrophication

Greenhouse gas emission



Soil acidification and degradation

Prevent loss of fertilzer

?

Are the problems caused by chemical fertilizer inevitable or evitable?

Problems caused by utilization of chemical fertilizer

Soil acidification is inevitable for plant growth, but evitable for proper fertilization

Plant growth is the main factor for soil acidification

Plant root release H^+ when absorb cations, and release OH^- when absorb anions. Plant tissue normally produce more negative charge after assimilation of CO_2. Thus the root will always absorb more cations than anions. More cations uptake by root, more H^+ released in rhizosphere.

Acidification of soil resulted by plant growth closely related to the amount of alkaline produced as the plant tissue burned or biologically decomposed. Plant bring out alkaline and leave acid in the soil.

Problems caused by utilization of chemical fertilizer

Soil acidification is inevitable for plant growth, but evitable for proper fertilization

Plant growth is the main factor for soil acidification

Soil acidification resulted by plant growth is a nature process. In a nutrient solution culture system, we need to apply alkaline for a stable pH. Similarly for the soils without alkaline buffer capacity, acidification need to be remediated continually.

The essence for soil acidification remediation is to replenish the cations exhausted by plant growth. Application of straw or manure somewhat like returning alkaline back to the field.

Problems caused by utilization of chemical fertilizer

Soil acidification is inevitable for plant growth, but evitable for proper fertilization

Improper form of fertilizer will sure lead to soil acidification. But urea will not lead to irreversible soil acidification

Urea $\longrightarrow$ NH_4HCO_3 $\longrightarrow$ NH_4NO_3 $\longrightarrow$ HNO_3

As the plant absorb NO_3^-, OH^- will be released, As NO_3^- converted into N_2, OH^- will also be left. HNO_3 somewhat like organic acids, the acidification will disappear as they disappear from soil.

Problems caused by utilization of chemical fertilizer

Soil acidification is inevitable for plant growth, but evitable for proper fertilization

While the fertilizer contain Cl^- or SO_4^{2-} will easily get soil irreversible acidification if plant will not uptake the anions as much as we applied, It's difficult to remove these non-degradable anions from the soil which will easily lead to soil acidification or salinization.

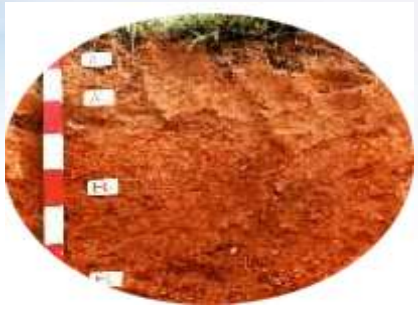
The soil acidification are mainly resulted from plant growth, The proper fertilizer form should be exactly what plant need and should be physiological alkalinity for soils suffering acidic problem

Problems caused by utilization of chemical fertilizer

Environmental pollution caused by fertilization

Water eutrophication

Greenhouse gas emission



Soil acidification and degradation

Prevent loss of fertilizer

Proper fertilizer

The bad problems caused by chemical fertilizer are evitable!

Problems need to be solved for efficient fertilization

How to judge the fertilization is efficient enough or not?

What's the key step for efficient fertilization?

Problems need to be solved for efficient fertilization

How to judge the fertilization is efficient enough or not?

Reported ARE of main crops in China

	N	P	K	Data resouce
1997	30%-35%	10%-20%	35%-50%	Li et al., 1997
2008	28%	12%	31%	Zhang et al., 2008
2013	33%	24%	42%	CAM, 2013

ARE is a bad FUE index

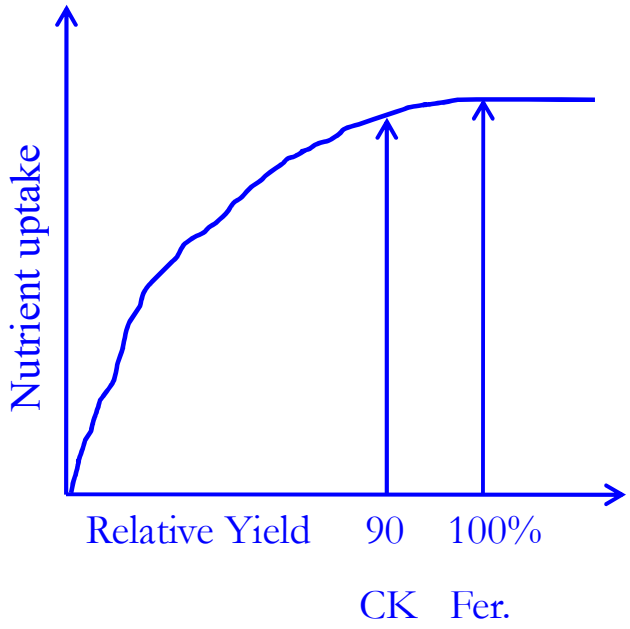
How to judge the fertilization is efficient enough or not?

ARE is a bad FUE index

It's very good even the ARE is low!

FUE (ARE) calculation：

$$NU_{fertilized} - NU_{control})/ NF * 100\%$$



For example, P uptake of CK and P applied treatments were 60 and 75 kg/ha，respectively, P fertilizer dose was 75kg/ha, the PUE was calculated as 20%。

For P applied treatment, if the P loss in running off or leaching was very low. P input and output kept balance, soil P fertility could maintained, the high yield could be sustained, it was already perfect.

What's the problem with ARE of 20%?

How to judge the fertilization is efficient enough or not?

ARE is a bad FUE index

It's very good even the ARE is low!

Calculation of FUE for NPK treatment of Fengqu long-term field experiment:

For NPK treatment during 16 yr, amount of K fertilizer: 3984 kg/ha, Soil K reserve increased: 462 kg/ha, plant K uptake: 3471 kg/ha, plant K uptake of NP treatment: 2352 kg/ha. The ARE of K is:

（3471–2352）/3984×100% = 28.1 %

The RKUE is：

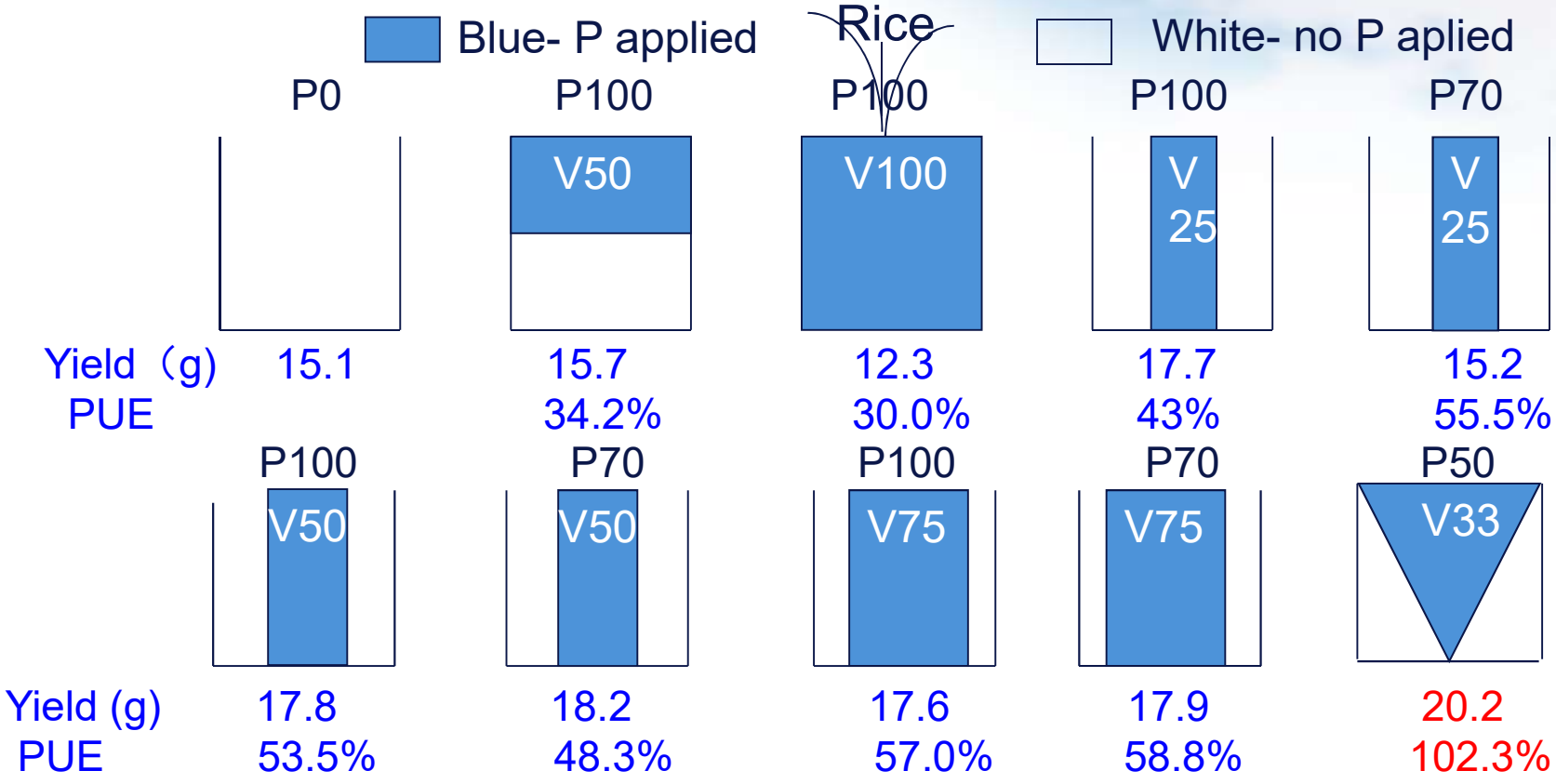
3471 /（3984 – 462）× 100% = 98.6 %　　Loss rate 1.4%

（Wang and Zhou. Acta Pedologica Sinica, 2014(2)）

How to judge the fertilization is efficient enough or not?

ARE is a bad FUE index

High ARE is not sustainable !



Rice yield and PUE as affected by various P application pattern (pot culture).

How to judge the fertilization is efficient enough or not?

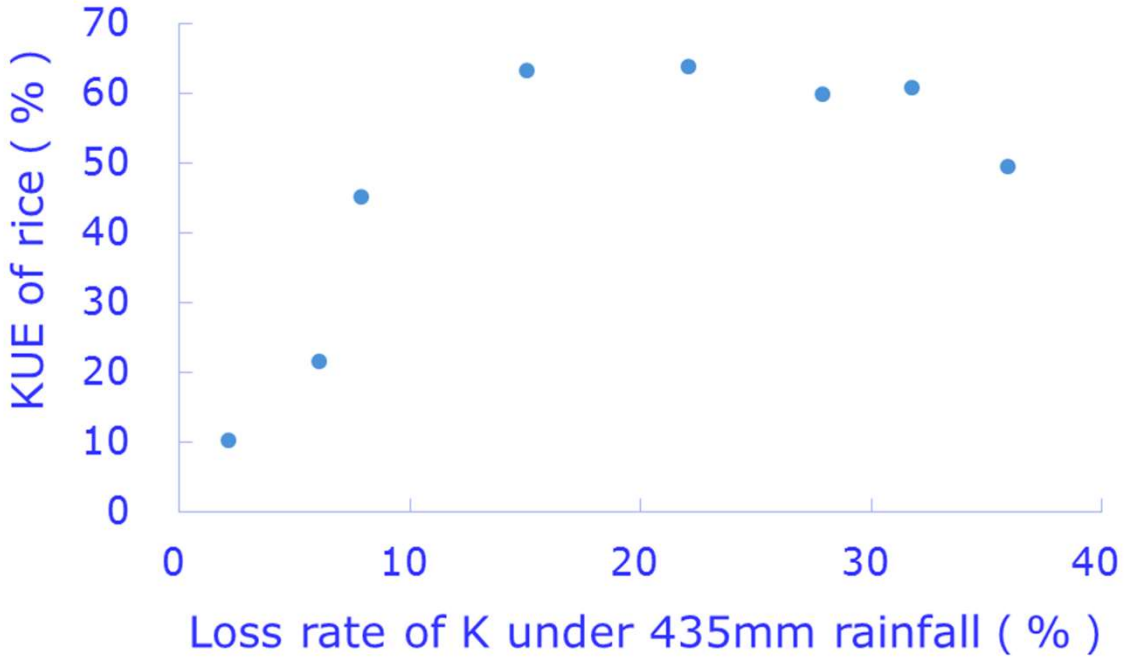
ARE is a bad FUE index

People never know what's the best ARE value for the best fertilization !

For different soil-plant systems, what's the best FUE, how to judge it's the best? So far there is no answer for this question.

How to judge the fertilization is efficient enough or not?

ARE can not reflect nutrient loss rate



The relation between KUE of rice (pot culture) and the K loss rate (column leaching) of different soils （unpublished data）

The higher the ARE of K, the lower the soil K holding capacity and the higher the K loss risk

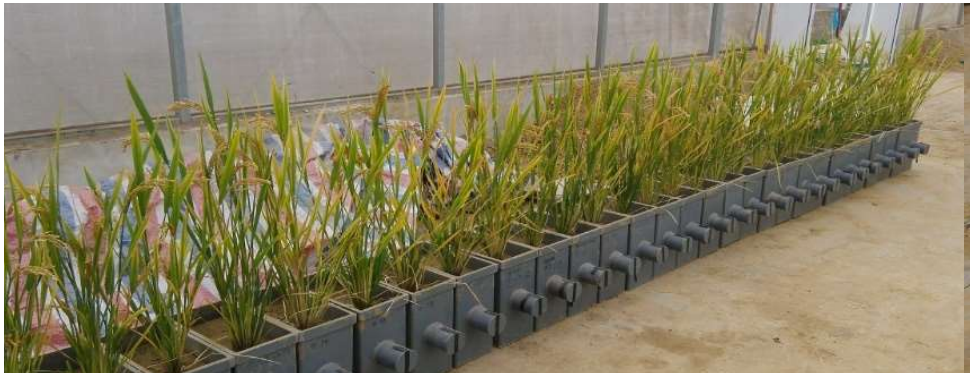
How to judge the fertilization is efficient enough or not?

ARE can not reflect nutrient loss rate

Effect of fertilization methods on NUE of rice (^{15}N isotope)

Treat.	Yield (g/pot)	N residue %	N loss %	NUE of ^{15}N	ARE	RNUE
CK	12.7±0.6 c					
FP4-3-3	21.9±0.6 ab	28.4±0.4 b	37.6±0.7 a	34.0±0.5 b	40.9±1.6 b	47.5±0.8 c
RZF1	22.0±1.6 ab	42.8±4.6 a	18.1±1.4 b	39.1±4.4 ab	40.3±3.6 b	68.1±3.0 b
RZF2	24.9±0.8 ab	34.4±2.4 ab	17.5±0.5 b	48.2±2.8 a	49.0±3.4 a	73.3±1.7 b
RZF3	20.5±0.7 a	39.8±3.4 a	10.4±3.1 c	49.8±3.5 a	51.4±4.8 a	82.8±4.7 a

（N fertilizer：Urea，Dose：0.9g N/pot，RZF: one-time hole application）（unpublish）



How to judge the fertilization is efficient enough or not?

ARE can not show goodness of soil nutrient holding capacity

ARE has negative relation to soil fertility and soil NHC

FUE (ARE) calculation：

$$NU_{fertilized} - NU_{control}) / NF * 100\%$$

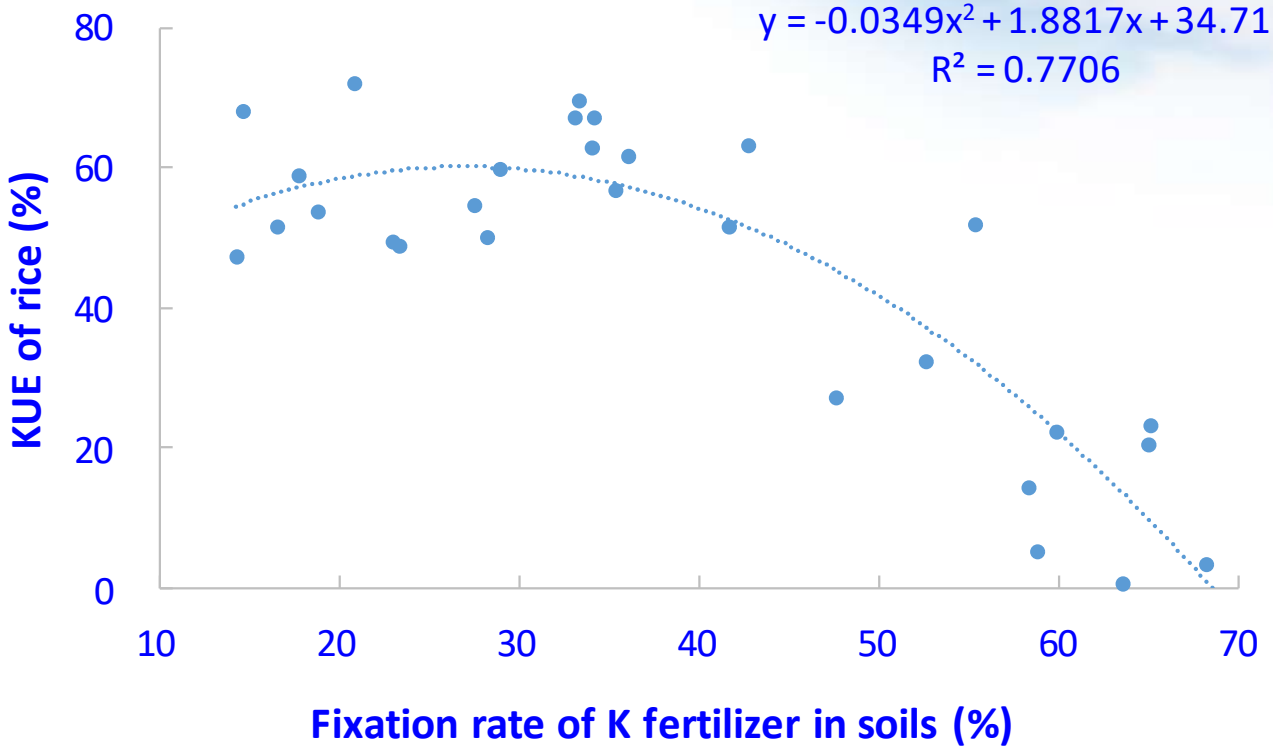
The higher the soil fertility and nutrient holding capacity (NHC), the higher nutrient supply buffering capacity, and the higher nutrient uptake without fertilization, which lead to lower FUE.

Different FUE were reported in literature. The FUE of the soil with low NHC (sandy, sloppy or low yield soils) was higher than FUE of the soil with higher NHC (high yield, high fertility)

For different nutrients, the rule is the same: The higher the soil NHC for the nutrient, the lower the FUE, such as FUE of NPK.

How to judge the fertilization is efficient enough or not?

ARE can not show goodness of soil nutrient holding capacity



The relationship between KUE of rice and K fixation rate for 10 soils

The higher K fixed rate in soil, the lower the KUE!

How to judge the fertilization is efficient enough or not?

ARE can not show goodness of soil nutrient holding capacity

Fixation rate of K and K recovered by successive 8 seasons of ryegrass

Soil	K fixation rate %	K recovery rate%
Shandong, Laiyang	86.6 ± 3.4	92.1 ± 0.4
Hunan, Wangcheng	31.4 ± 2.8	18.4 ± 5.3
Henan, Fengqiu	41.3 ± 3.5	47.2 ± 6.5
Jiangsu, Changshu	64.5 ± 1.2	60.6 ± 0.7

Nutrients fixation is very good, but not bad!

Fixation results in NHC, which explains why soil is good than sand!

Low ARE but high NHC, why should we improve ARE?

How to judge the fertilization is efficient enough or not?

Simply reduce fertilizer dose for higher ARE may not be correct

The most easy way to improve ARE is just reduce amount of fertilizer. It's of course right when some farmer do over-fertilization. But some recommended reduced fertilizer dose may not correct since most of the results were based on one or two seasons of data. If the nutrients exhaustion occurred in soil, it can not be sustainable. Thus, simply reduce the fertilizer dose may not be correct.

How to judge the fertilization is efficient enough or not?

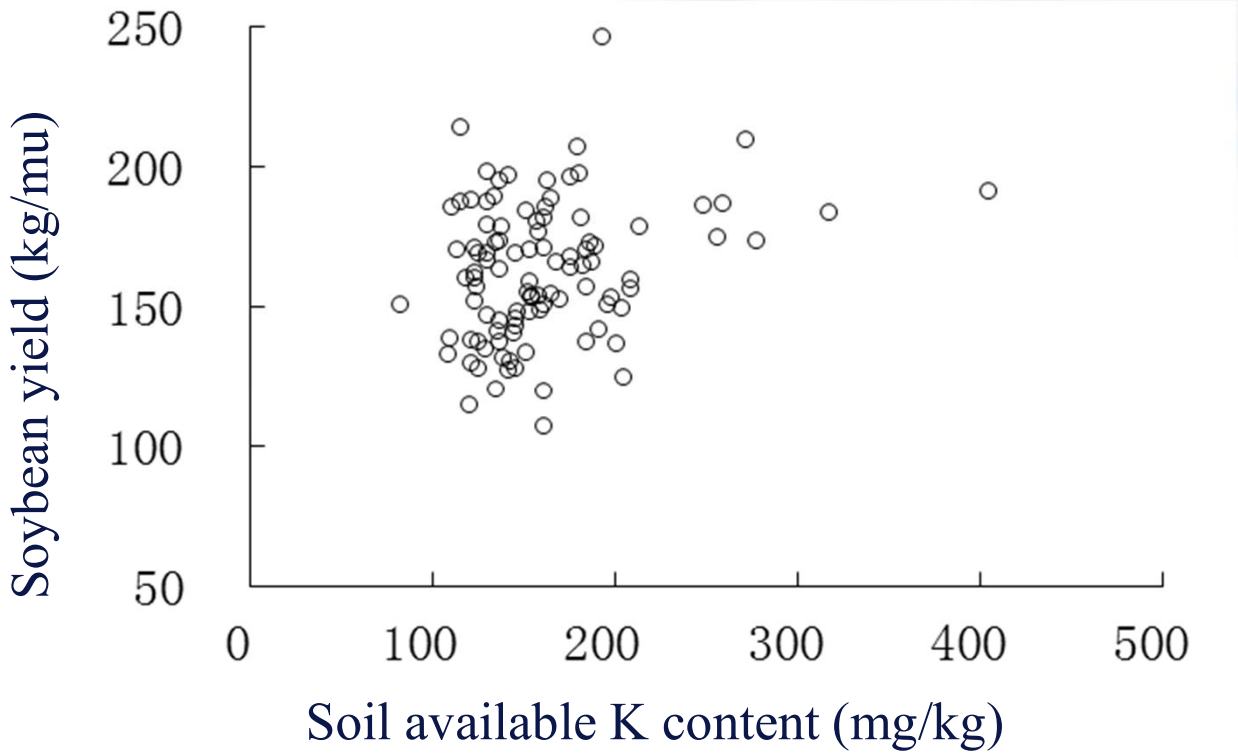
Simply reduce fertilizer dose for higher ARE may not be correct

If the fertilizer dose recommended is lower than the amount nutrient harvest, it is may not be correct even for some soil with rational higher fertility:

According to soil testing and fertilizer recommendation system, a lower fertilizer dose will be recommended on the fertile soil. Eventually, the fertile soil with very good nutrients buffering capacity which was not sensitive to fertilization will be changed into the soil with low fertility and sensitive to fertilization, which is opposite to the target of soil fertility improvement, thus it also may not be correct.

How to judge the fertilization is efficient enough or not?

Simply reduce fertilizer dose for higher ARE may not be correct



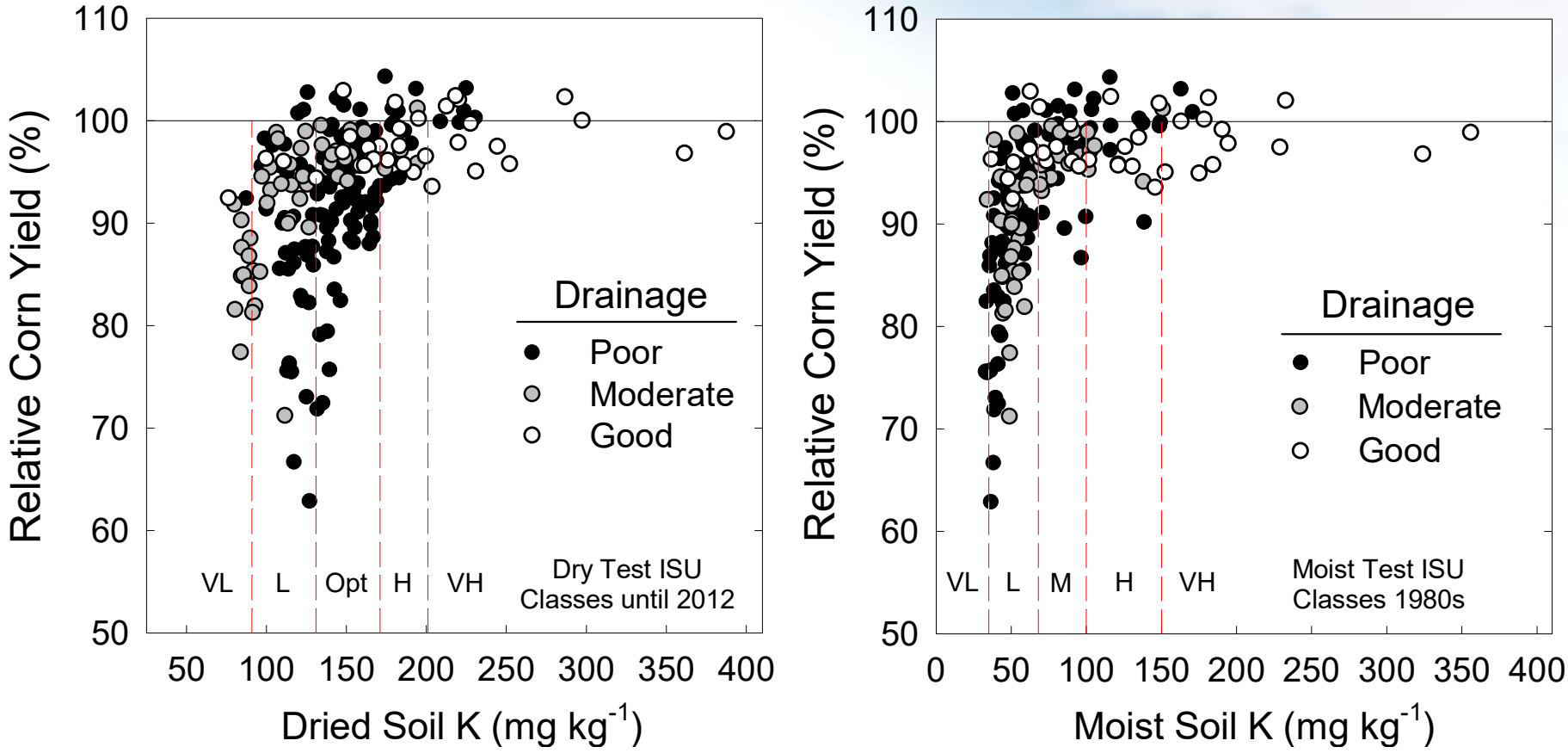
The relationship between soil available K and soybean yield

Higher soil K fertility is good for stable and higher crop yield

How to judge the fertilization is efficient enough or not?

Simply reduce fertilizer dose for higher ARE may not be correct

Adapted from Barbagelata & Mallarino 2012 (data 2001 to 2006)



The lower soil K fertility will decline yield under bad climate

Problems need to be solved for efficient fertilization

How to judge the fertilization is efficient enough or not?

ARE is a bad index we should discard in future!

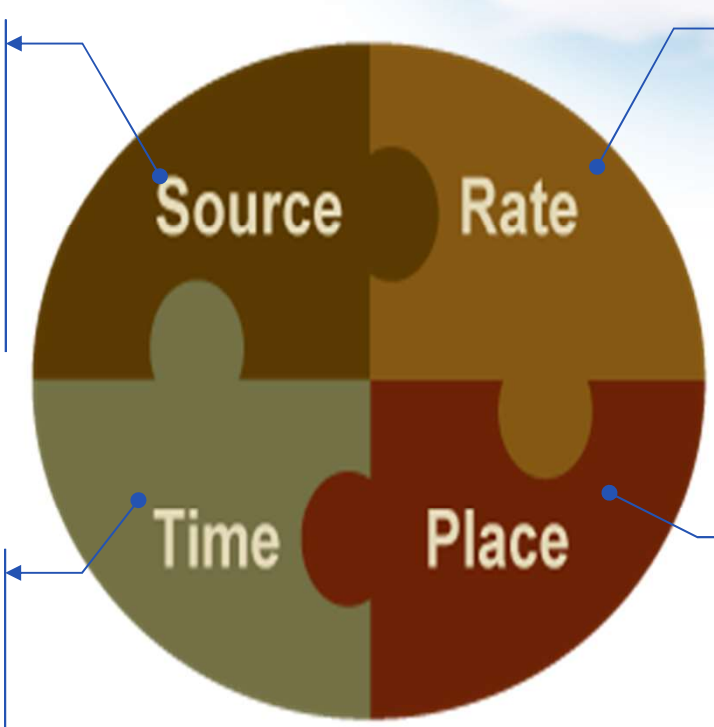
The efficient fertilization aim to not only the higher stable crop yield, high quality of product, sustainable soil quality, but also the lowest loss rate of fertilizer!

Can we reduce the fertilizer N, P and K loss rate to 20%, 1% and 10% respectively, in China in future?

Problems need to be solved for efficient fertilization

What's the key step for efficient fertilization?

Right fertilizer source



Right fertilizer rate

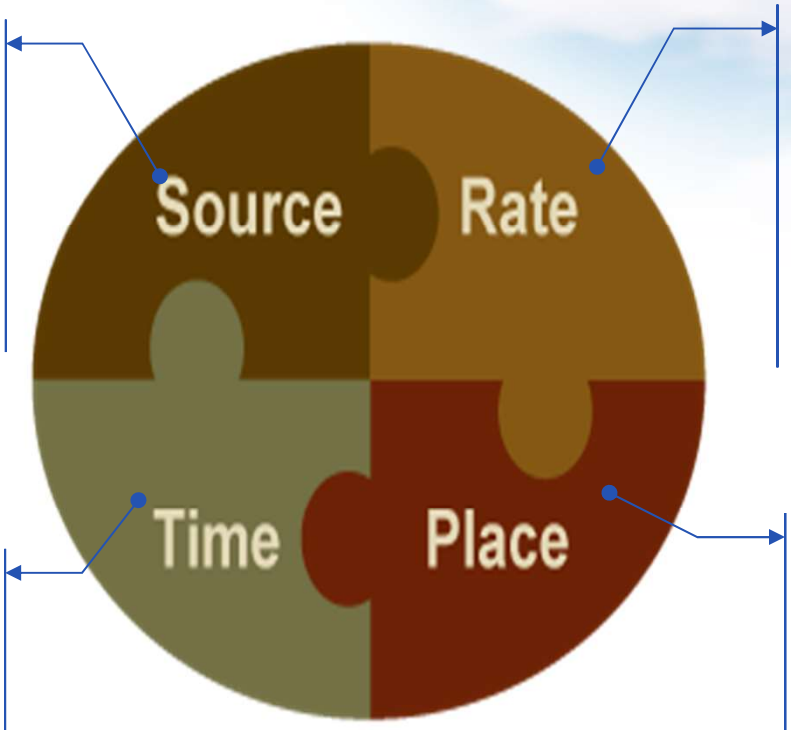
Right fertilizer time

Right fertilizer place

Problems need to be solved for efficient fertilization

What's the key step for efficient fertilization?

Right fertilizer source



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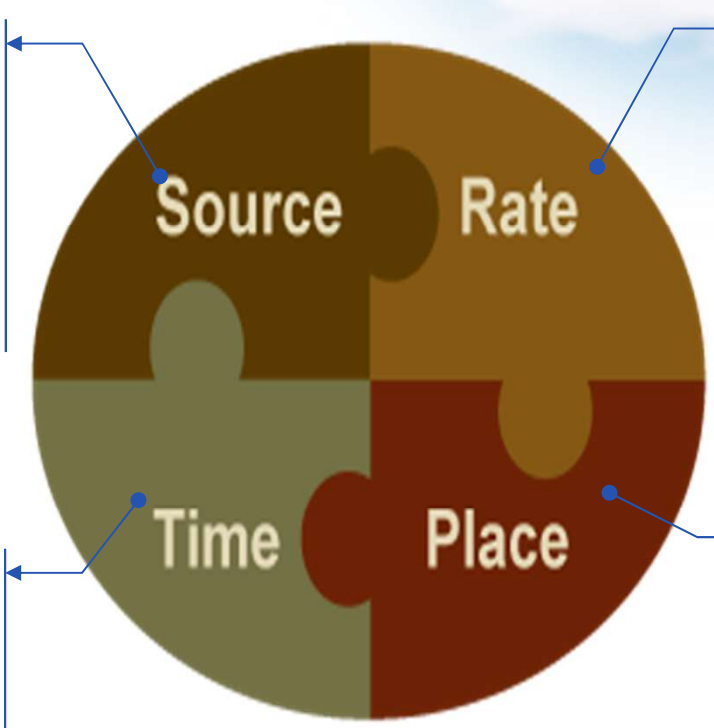


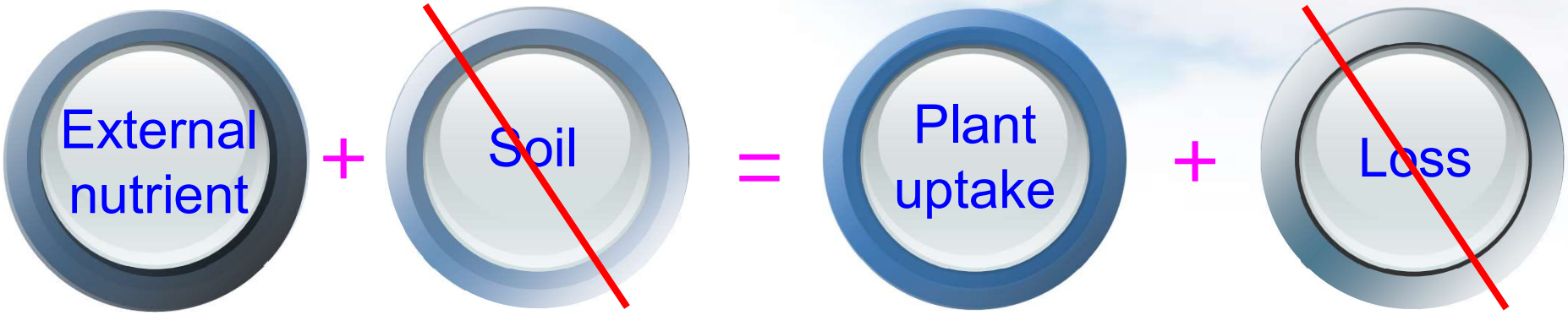
Right fertilizer rate

Right fertilizer time

Right fertilizer place

Problems need to be solved for efficient fertilization

How to decide the fertilization dose?



For a stable crop field, the target for fertilization management are: Higher and stable crop yield, higher economic efficiency

The RNUE as higher as 100%, that is the loss rate is zero,

Soil fertility do not over accumulated or exhausted, generally maintain balance, that is the fertility change is also zero,

Thus: Fertilization dose = Plant nutrient uptake （removal）

Problems need to be solved for efficient fertilization

How to decide the fertilization dose?

The ideally dose = nutrients removed by plant harvest

The rational dose = nutrients harvest + loss

The minimum of fertilizer dose equals to nutrients harvest. How much fertilizer could be reduced depends on how much the loss could be saved. Thus the loss rate is a key factor to decide the rational fertilizer dose!

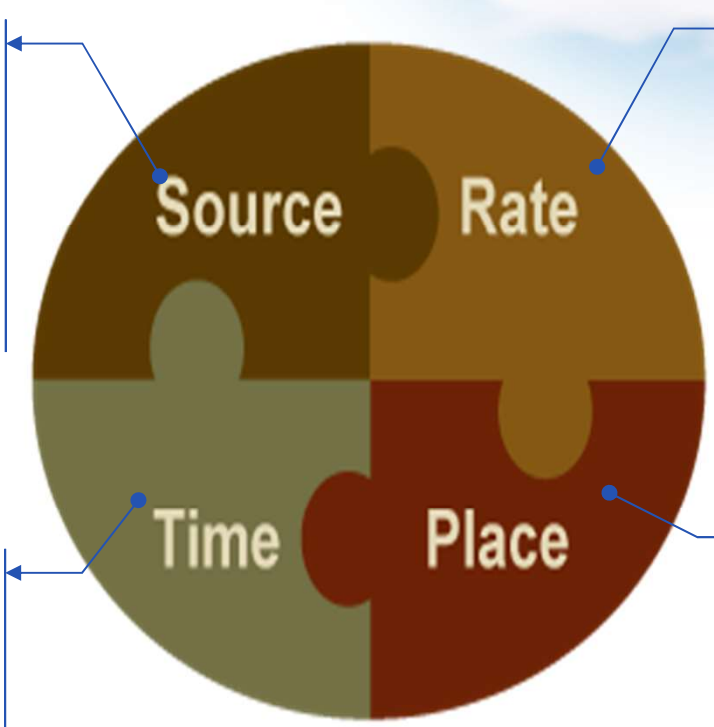
To decide a proper fertilizer dose is not so difficult!

It's not the key technique for efficient fertilization!

Problems need to be solved for efficient fertilization

What's the key step for efficient fertilization?

Right fertilizer source



Right fertilizer rate

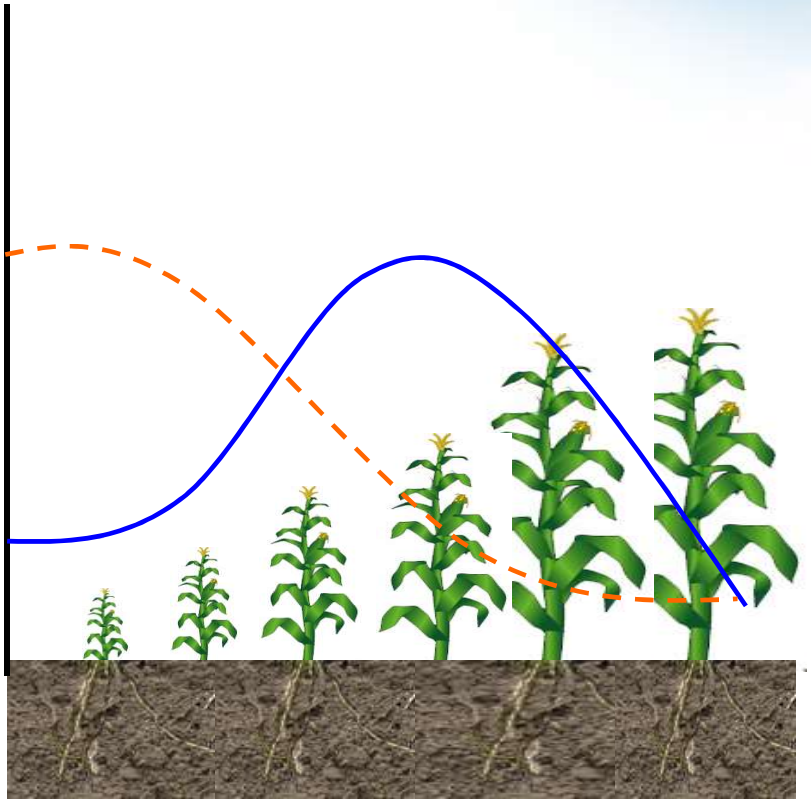
Right fertilizer time

Right fertilizer place

Problems need to be solved for efficient fertilization

What's the key step for efficient fertilization?

How to decide the proper time?



Idea model:

Supply less when plant need litter, supply more when plant need more

For sandy culture, that's the truth.

It's different for the soils owning good buffer capacity.

Mismatching of supply and uptake?

Problems need to be solved for efficient fertilization

What's the key step for efficient fertilization?

How to decide the proper time?

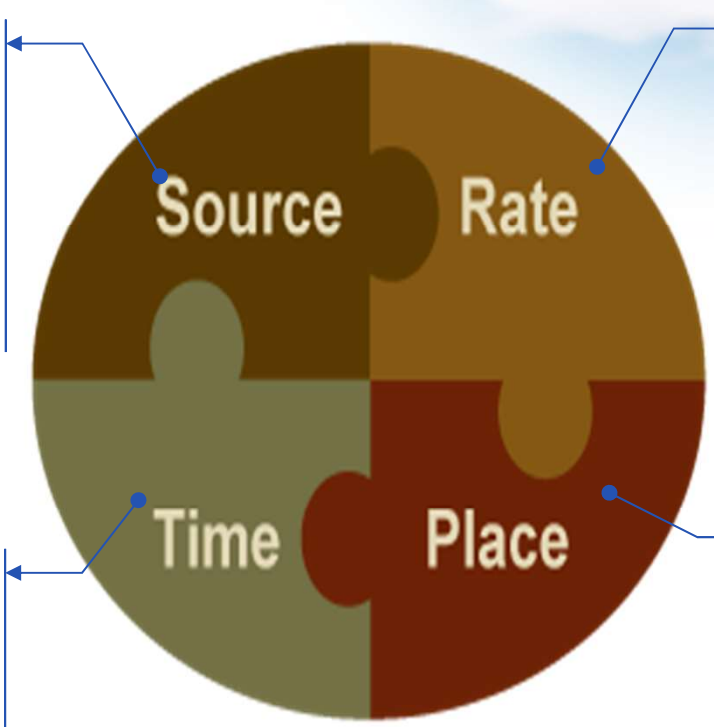
If the nutrient will neither leave the root zone nor be lost for a comparatively long time. After the basal fertilization, plant roots will absorb the nutrient when they need. This is the simple and ideal model for plant nutrients uptake. In this case, there is no need for later or split fertilization, Thus fertilizer time is not a key factor for fertilization.

Split fertilization on time is mainly necessary for the case that nutrients could be easily lost in soil.

Problems need to be solved for efficient fertilization

What's the key step for efficient fertilization?

Right fertilizer source



Right fertilizer rate

Right fertilizer time

Right fertilizer place

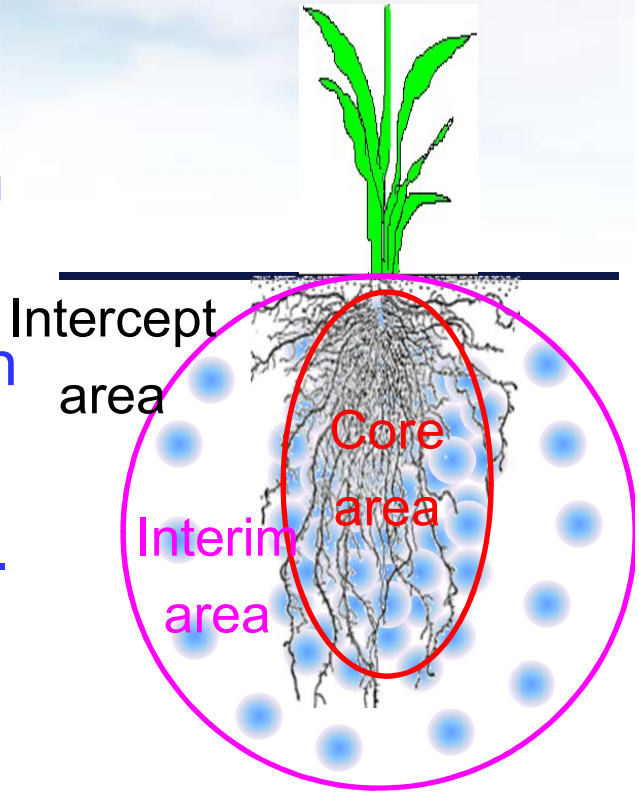
Problems need to be solved for efficient fertilization

Root zone fertilization– a necessary and key step for efficient fertilization

What is RZF?

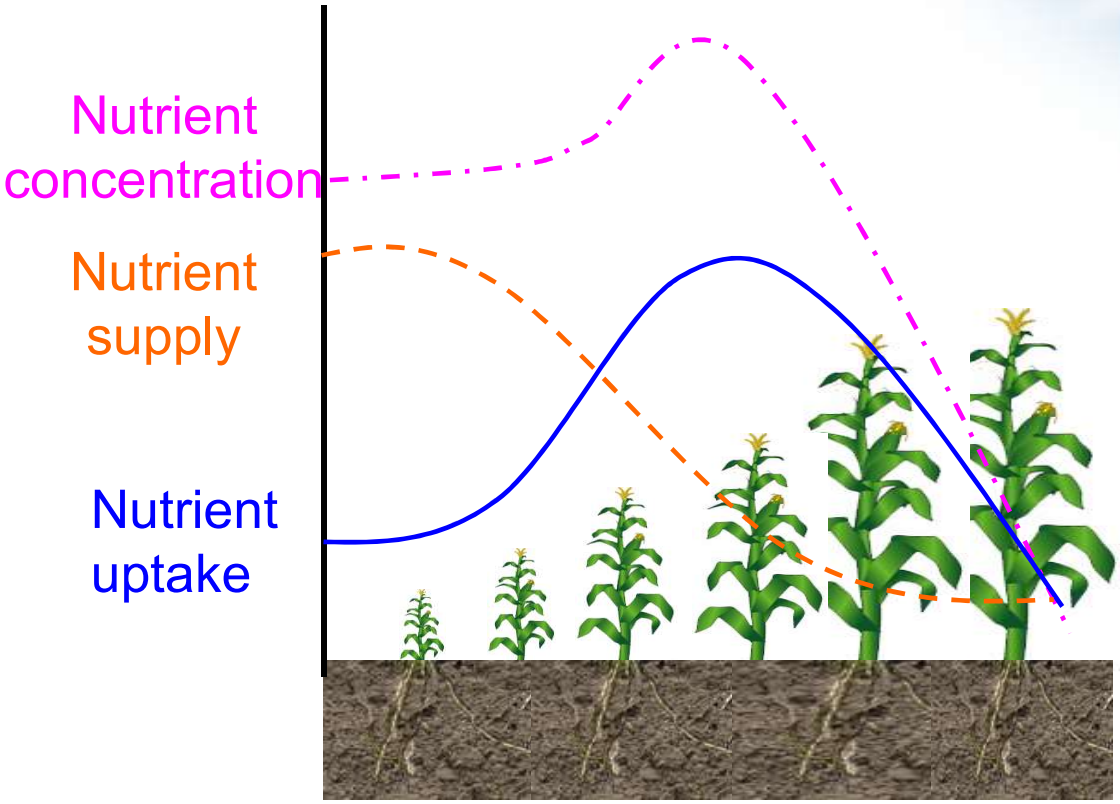
Apply proper amount of fertilizer with certain technique to crop active-root zone. To make the dynamic diffusion zone of fertilizer match well to the extension zone of active roots of the crops. This fertilization technique is RZF.

RZF aims to match well the concentration, amount and space of nutrients fertilized to what crops need, and prevent nutrient loss in situ.



Problems need to be solved for efficient fertilization

Why RZF is a key step for efficient fertilization



(Wang and Zhou, 2013, Soils (In Chinese)

The high concentration of nutrients in root zone is an important factor for sufficient nutrient supply and higher yield.

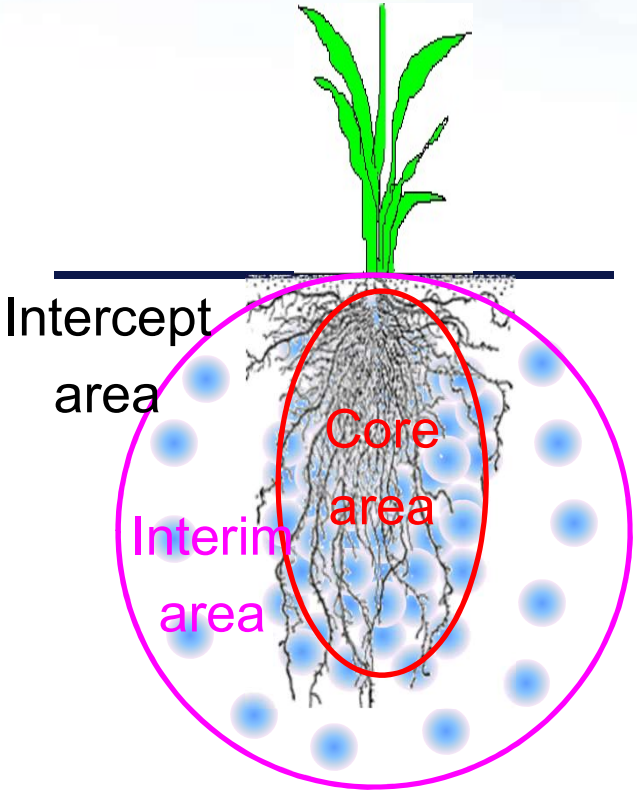
More fertilizer is needed for non-RZF technique to reach such a higher nutrients concentration in root zone.

Problems need to be solved for efficient fertilization

Why RZF is a key step for efficient fertilization

The loss of nutrient can not be prevented without RZF

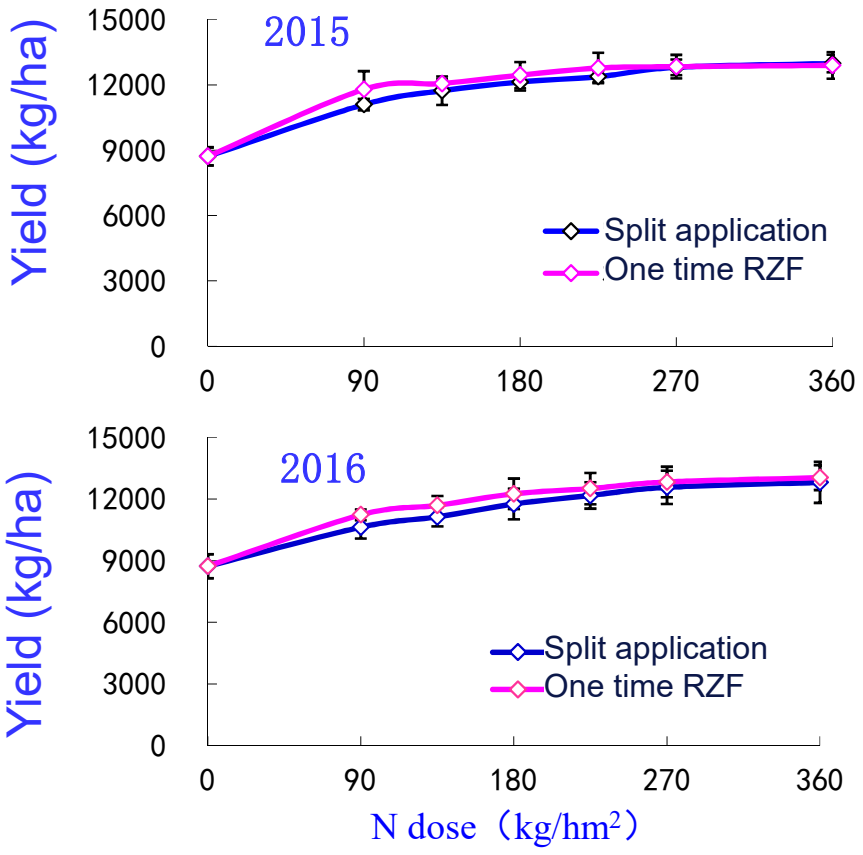
The loss of some nutrient in soil is a nature course. The nutrient in bulk soil will easily subject to loss, while the loss of nutrient from root zone will be efficiently prevented by both root and the surrounding soil.



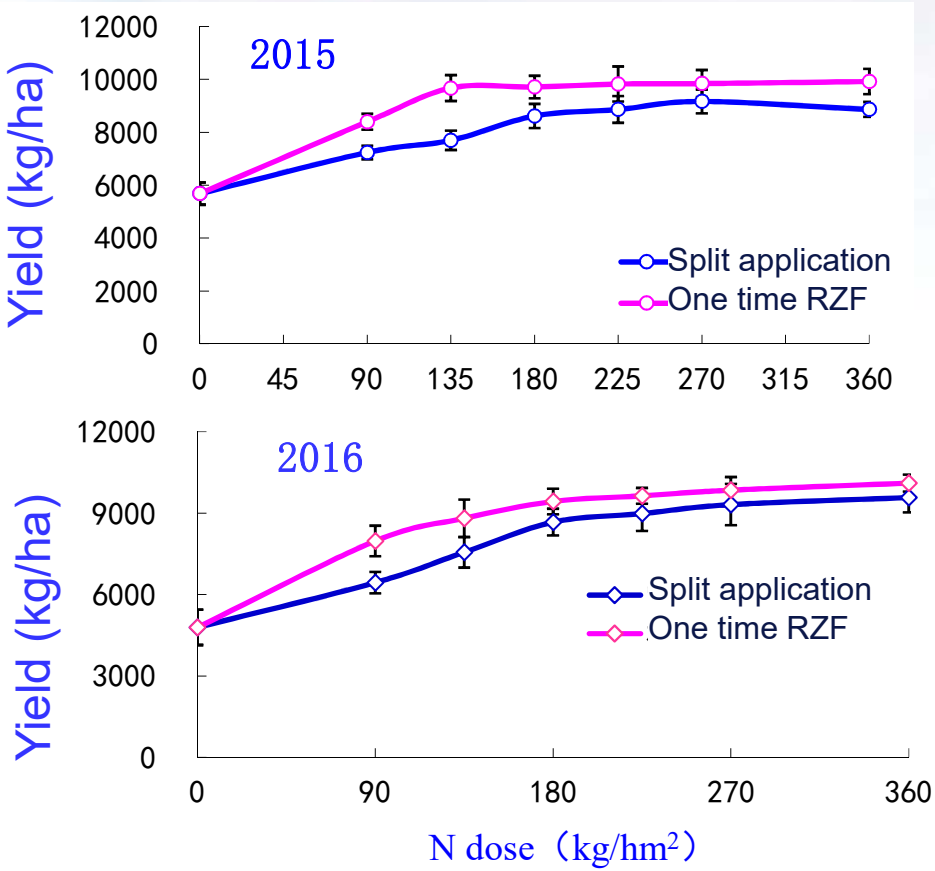
Problems need to be solved for efficient fertilization

Why RZF is a key step for efficient fertilization

Site 1: Taihe



Site 2: Dongzhi



One time RZF of urea increased maize yield 2-6% and 10-25% in two sites of Anhui province as compared with common farmer's practice.

Problems need to be solved for efficient fertilization

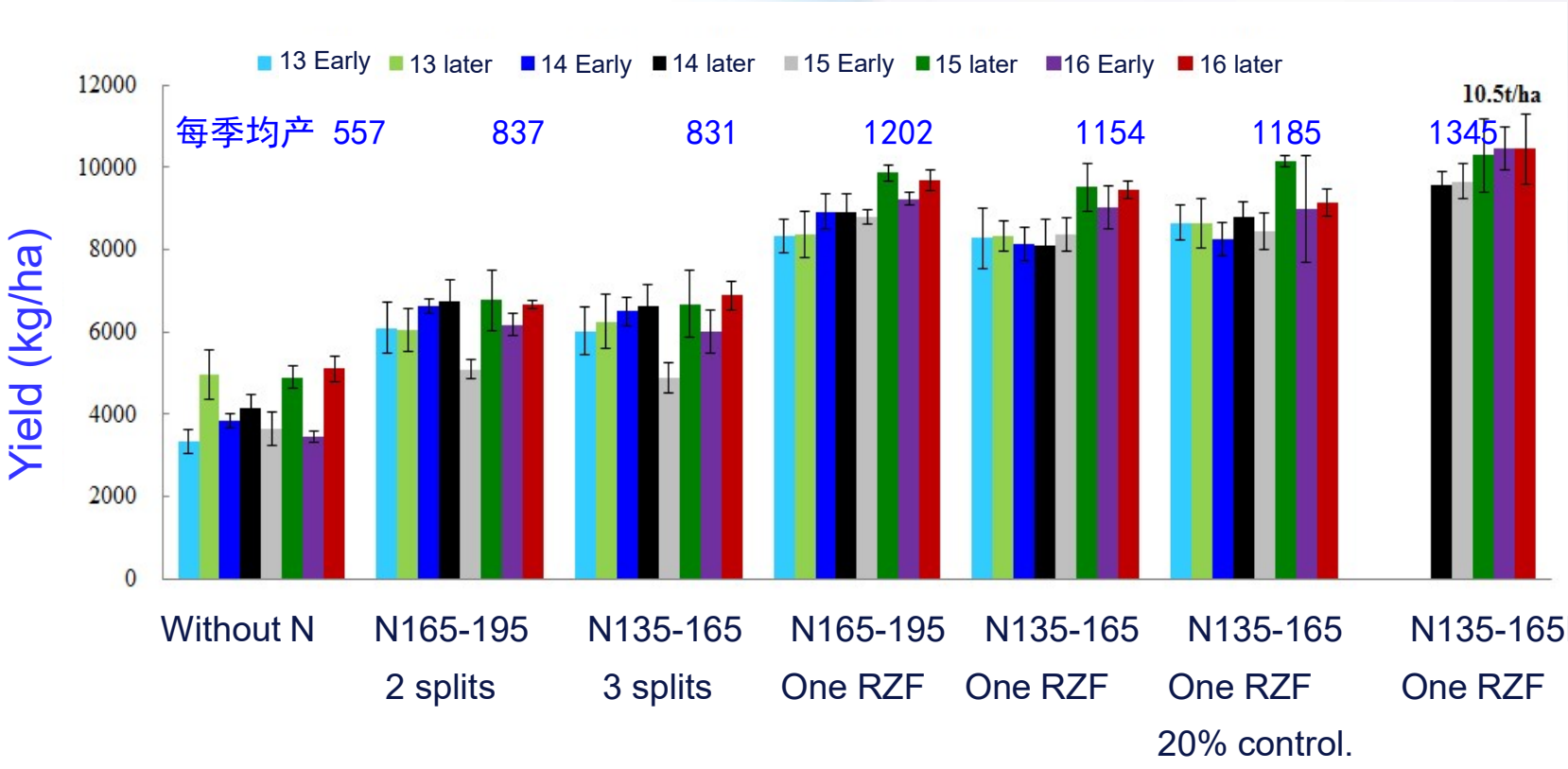
Why RZF is a key step for efficient fertilization

	Fertilization technique	N dose (kg/ha)	Site 1: Taihe		Site 2: Dongzhi	
			ARE (%)	Loss rate (%)	ARE (%)	Loss rate (%)
2015	Split application	135	45 bc	32.2 ab	50 c	39.5 a
		180	41 c	35.7 a	49 c	39.6 a
	One time RZF	135	54 a	24.2 c	68 a	21.6 b
		180	49 ab	26.6 bc	59 b	27.9 b
2016	Split application	135	47 b	27.2 a	47 b	33.9 ab
		180	41 c	27.5 a	47 b	37.1 a
	One time RZF	135	52 a	18.3 b	56 a	25.7 c
		180	50 ab	17.1 b	54 a	29.4 bc

One time RZF of urea could reduce urea loss rate in maize season 8-18 percentage as compared with common farmer's practice in Anhui province.

Problems need to be solved for efficient fertilization

Why RZF is a key step for efficient fertilization

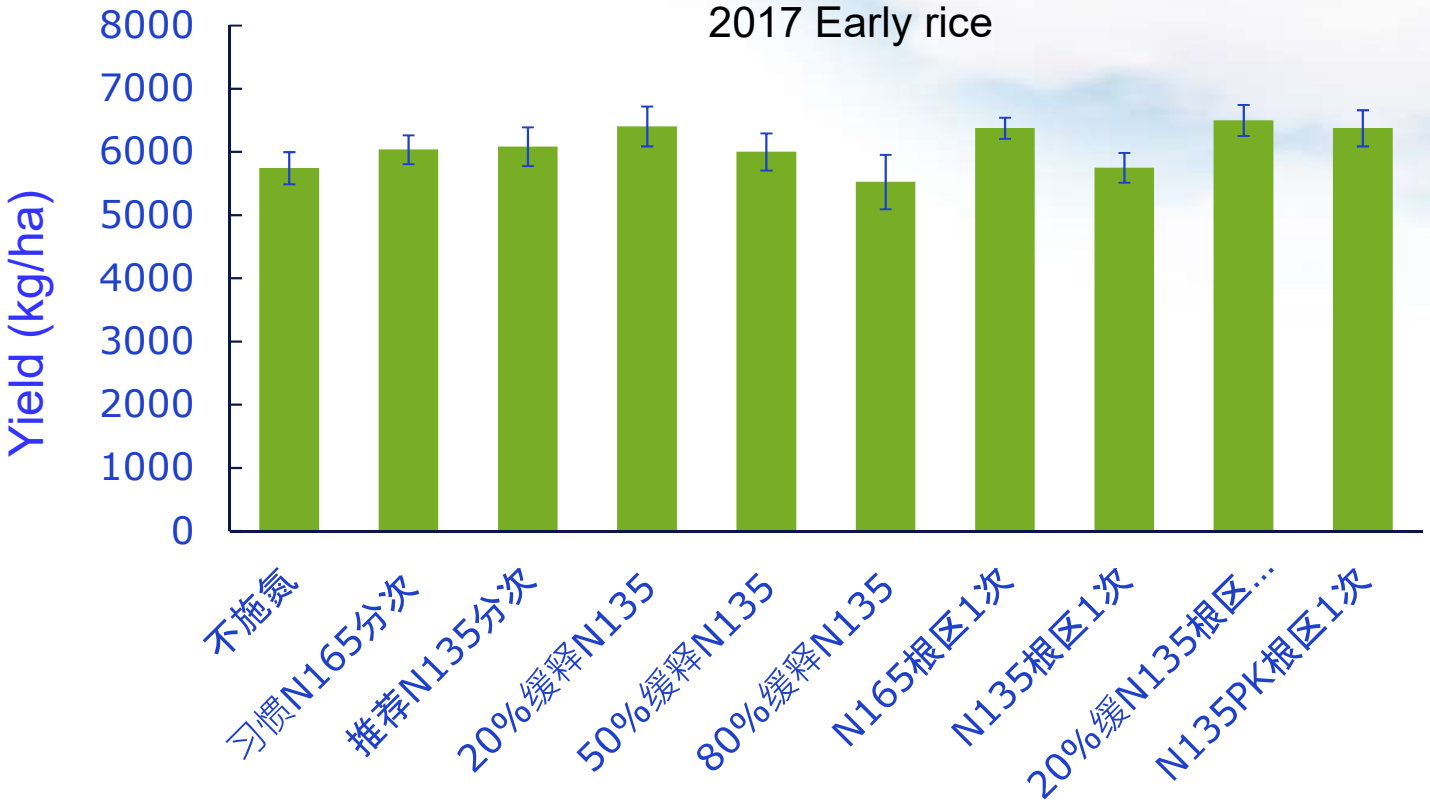


Averaged ARE of N (%)：	15.1	22.4	56.9	60.1	61.6	76.6

One time RZF of urea or NPK could hugely increase rice yield and N ARE during 8 seasons double rice in Jiangxi Province (data from Zhongpei Li).

Problems need to be solved for efficient fertilization

Why RZF is a key step for efficient fertilization



The early rice yield of 2017 of all treatments came back to normal levels as the fertilizer was applied with common practice. (data from Zhongpei Li).

Problems need to be solved for efficient fertilization

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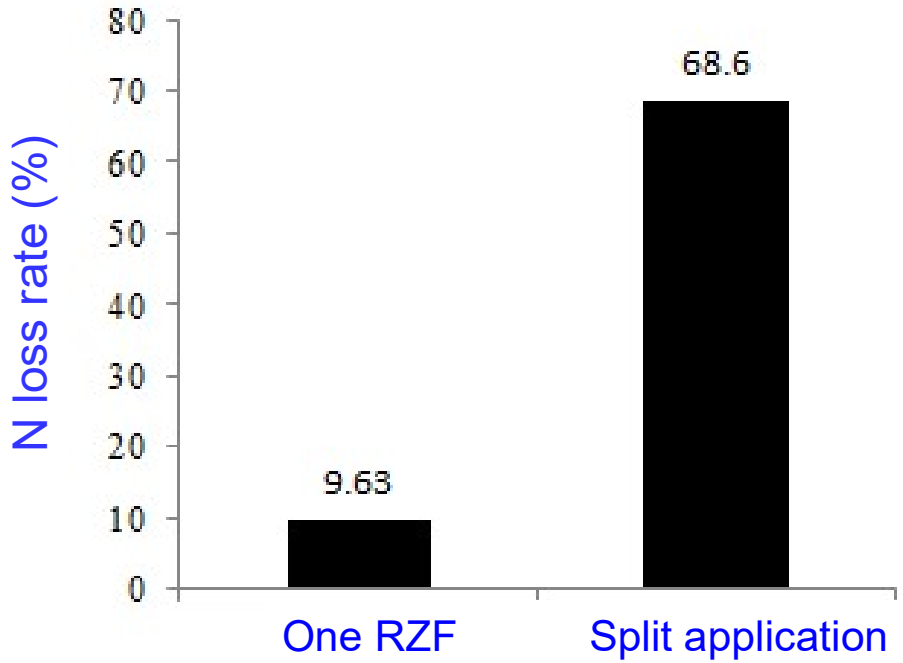

The N loss rate of 2015 later rice calculated by N15 isotope method

The N loss rate could be greatly reduced from about 70% to 10%. (data from Zhongpei Li).

Problems need to be solved for efficient fertilization

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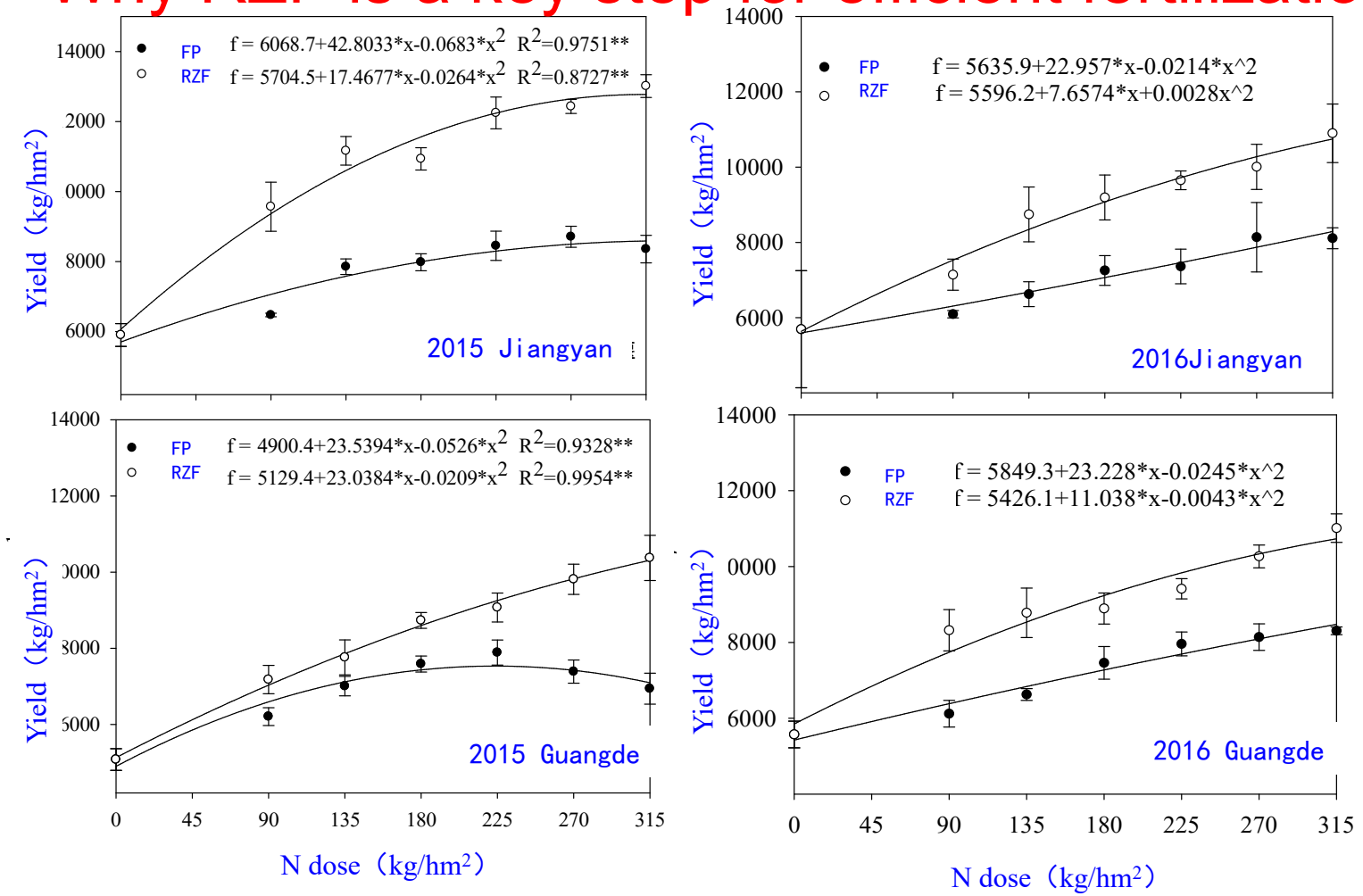

RZF of urea hugely increased rice yield potential (22%-56%) as N dose increased *(Liu et al., Paddy Water Envirion. 2017)*

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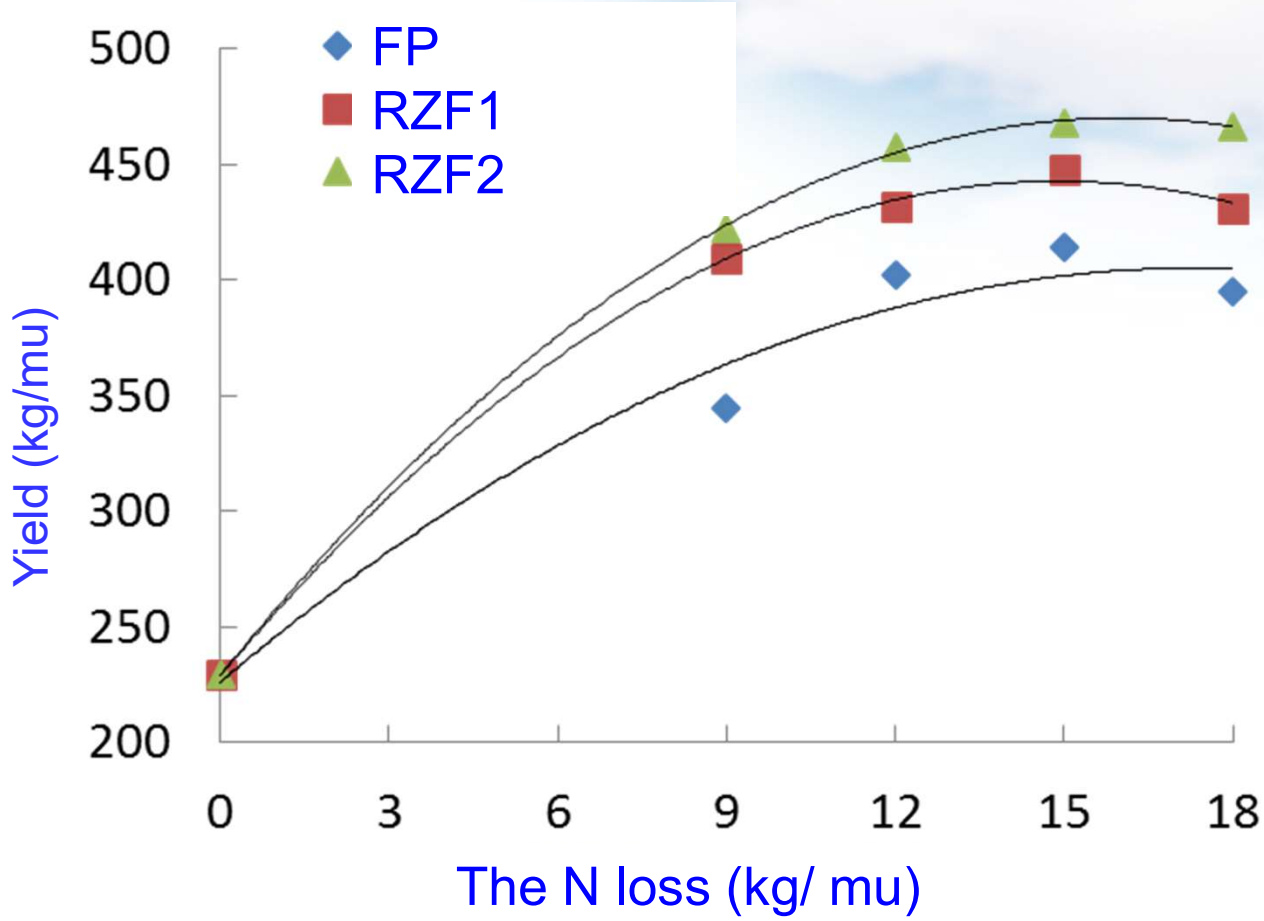

One time RZF increased wheat yield 11%-17% as compared with common 3 time split application of fertilizer treatment

Prospects and suggestions

Chemical fertilizer is very important for sustainable agriculture. The negative effect of fertilizer on environment could be controlled and the positive effect of fertilizer on crop yield could be extend as the RZF technique well developed in future.

How much fertilizer we will use will mainly depend on how higher the crop yield we want to achieve and how much of the nutrients could be recycled and could be saved from the loss.

The loss rate but not ARE is the key index for fertilizer use efficiency. All the fertilizer field experiment or research should focus on measuring and reducing nutrients loss rate in future.

Prospects and suggestions

The other functions of fertilizer additives, soil conditioners, biochar, stimulators or even organic fertilizers should be distinguished from the nutrients supply function, and the mechanism and conditions for other functions of these materials need to be well and clearly evaluated in future.

Fertilizer will aim to provide all the nutrients that plant need, but not provide any cations and anions that plant can not use up.

The effect of fertilizer should test in field continually for several seasons but not only for one or two seasons.

Prospects and suggestions

Fertilizer to right place is the key step for efficient fertilization. RZF technique is the key technique we need to develop in future. The proper form and proper dose of fertilizer need to be reinvestigated for RZF technique. Special fertilizer and fertilization machines for RZF for various crops need to be developed in future.

For the main field crops such as rice, wheat, maize and other crops with growth period of several months, the water soluble fertilizer and control released fertilizer may be not the target crops. One time RZF with proper formula of common fertilizers may work well for these crops in future.

Prospects and suggestions

Let’s start the fertilizer technique revolution!

One time root-zone fertilization for main food crops!

Labor saved, higher yield, less pollution, even without control released fertilizer !


Thank you for your attention!