Prospects for Achieving Higher Nutrient Use Efficiency as Yields Increase in Cereal Production Systems

提高谷物生产系统产量和资源利用效率的展望

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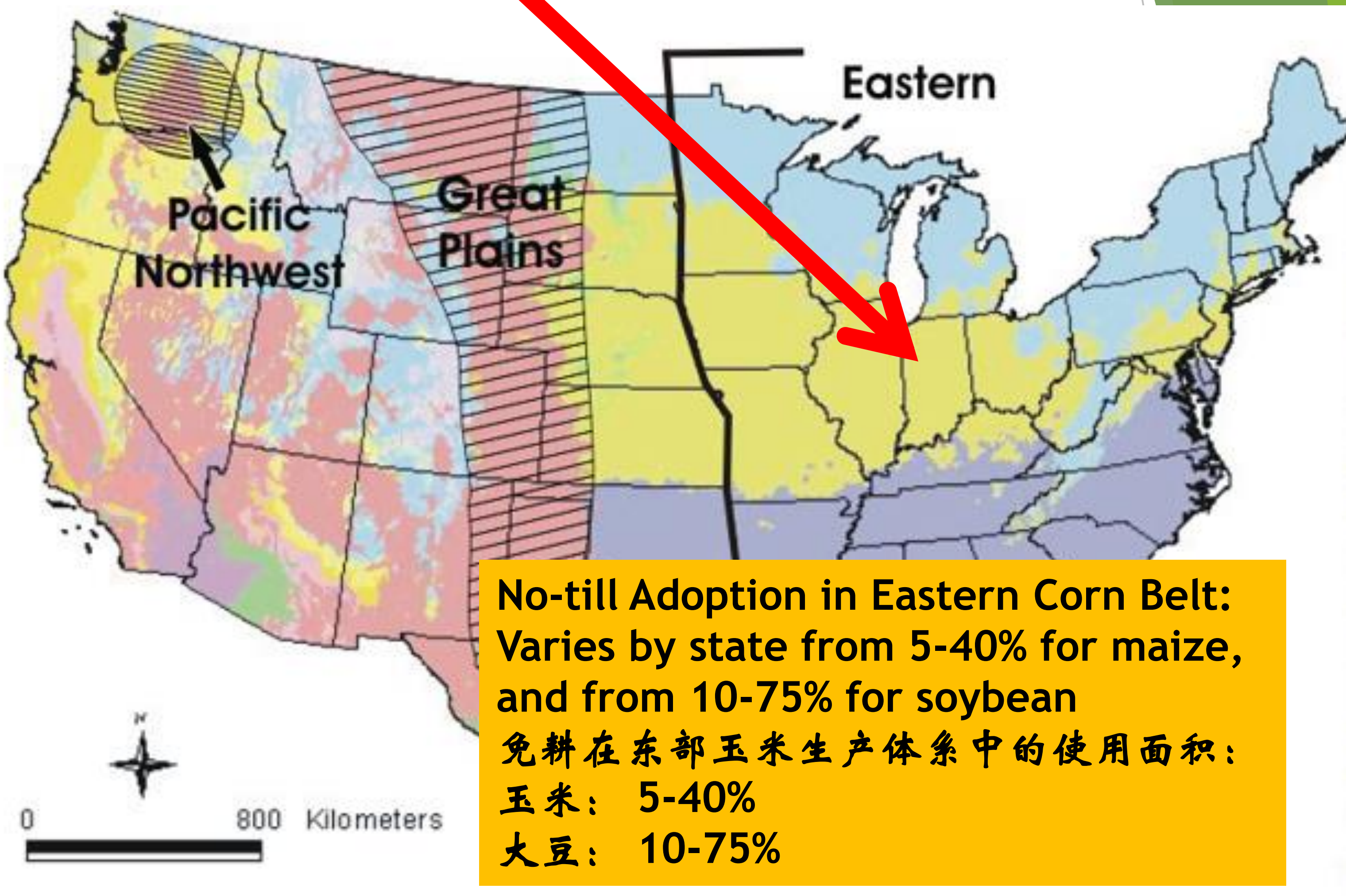
Purdue University



No-till Adoption in Eastern Corn Belt: Varies by state from 5-40% for maize, and from 10-75% for soybean

免耕在东部玉米生产体系中的使用面积：

玉米： 5-40%

大豆： 10-75%

Research Context（研究内容）:

On-going Experiments with Strip-Till and No-till Maize and Associated Management Options:

正在进行的实验：条耕和免耕玉米和相关的管理技术

1. Nutrient Placement, Rate, Timing, and Source

养分的放置，量的调控，施肥时间，和养分种类

2. Maize Management (hybrid, plant density, rotation)

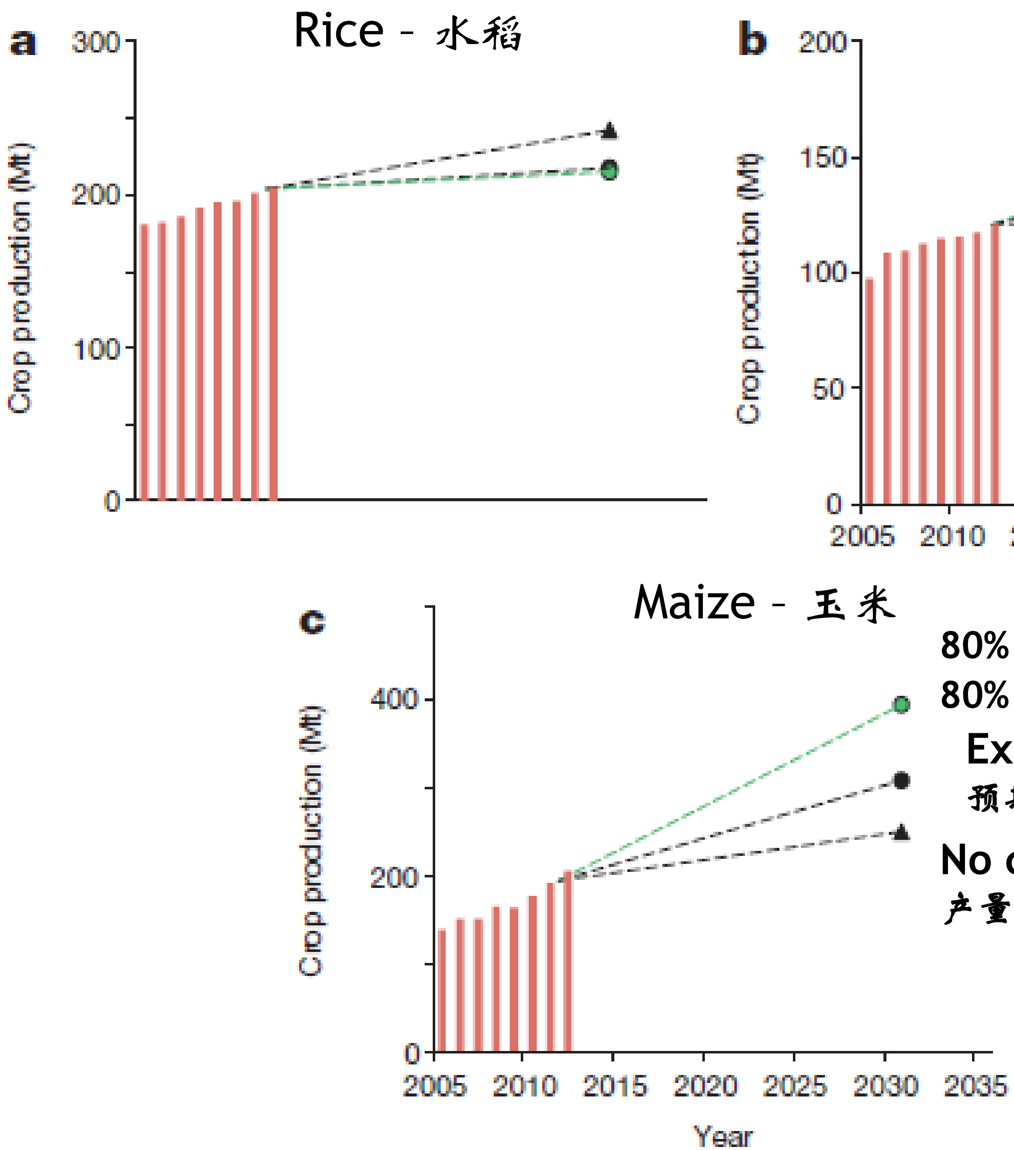
玉米管理（品种，密度，轮作）

Introduction and Pertinent Questions
引言和相关的问题

1. **Are higher cereal yields only possible with ever higher nutrient application rates per unit area?**
   （高产是只能在增加施肥量的前提下实现吗？）
2. **What is the evidence for past gains in nutrient use efficiency with cereal yield gains?**
   （谷物生产体系中养分资源利用效率提高的历史？）
3. **What technology advances are needed to achieve the goal of simultaneous productivity and nutrient efficiency gains?**
   （产量和养分利用效率提高需要的科技？）

These aren't new questions! Note the title of Chen et al. (2014) paper in Nature
"Producing More Grain With Lower Environmental Costs":
在降低环境风险的情况下提高产量

Realization of Cereal Output in China by 2030 with 3 Production Scenarios
2030年中国三大谷物生产量



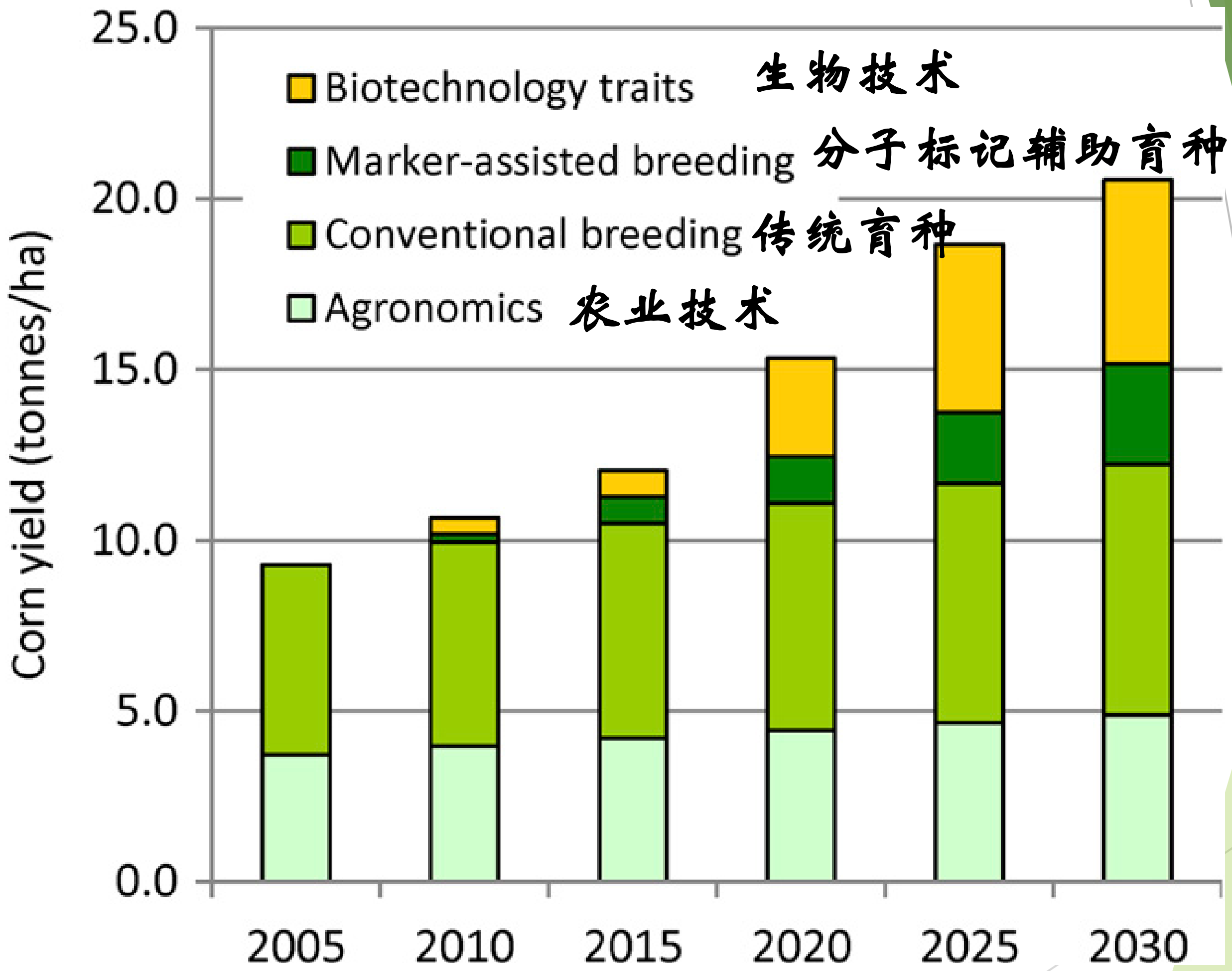
80% of Integrated soil-crop system management
80% 土壤-作物综合管理体系 (ISSMM)

Expected demand
预期的需求

No change in yield trend from 2005-2012
产量趋势在2005-2012年间无变化

Source: Chen et al., 2014, Nature

Projected Basis for U.S. Maize Yield Predictions?
美国未来玉米产量的四个基础



Source: M.D. Edgerton, 2009, Plant Physiology 149: 7-13.

Defining Nutrient Use Efficiency
养分利用效率的定义

1. NUE = delta yield gain/delta nutrient applied relative to control

   养分利用率 = （施肥区产量－不施肥区的产量）／施肥量

2. NIE = Cereal grain yield/total N uptake

   养分内部利用率 = 产量 ／ 总吸氮量

   Note: NIE is influenced by both grain HI and NCE (whole-plant biomass/whole-plant nutrient uptake)

   注：养分内部利用率受到收获指数和养分转化效率的影响

3. NRE = delta nutrient uptake/delta nutrient applied relative to control.

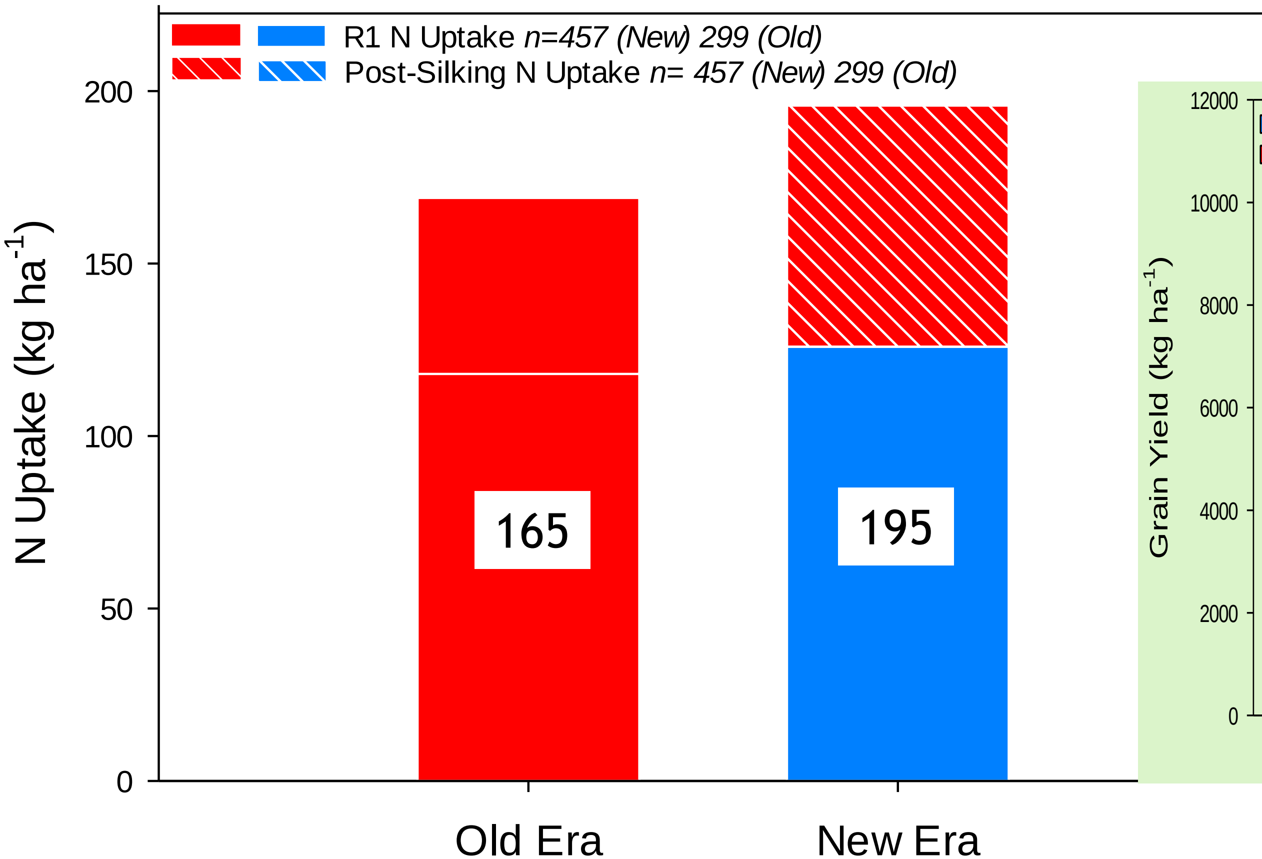
   养分回收率 = （施肥区养分吸收量－不施肥区养分吸收量）／施肥量

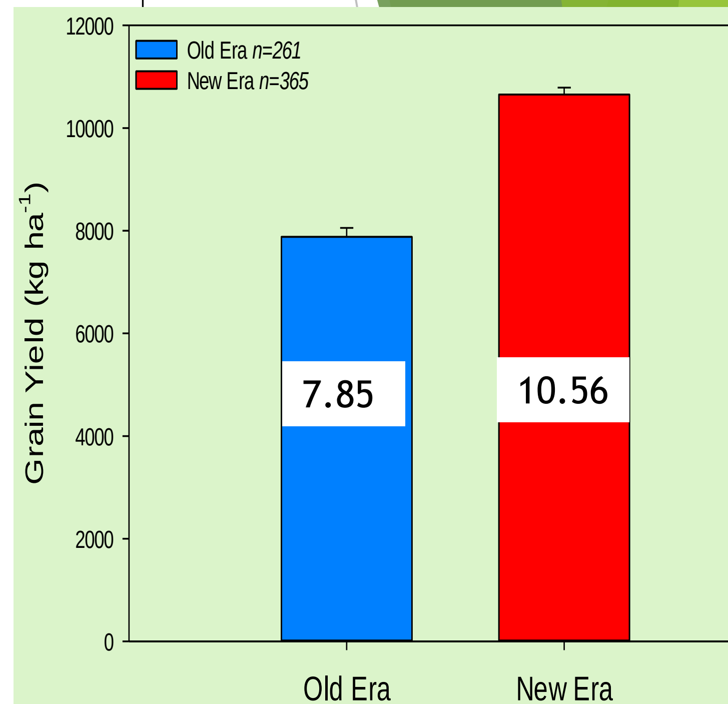
Summary of Maize Genetic Changes Over Time
玉米中变量随时间的变化

Variable （变量）		Old Era（老品种）	New Era（新品种）
Mean N Rate (kg/ha)	（氮肥使用量均值）	139	138
Plant Density/ha	（种植密度）	54,000	71,000
Yield (Mg/ha)	（产量）	7.2	9.1
N Use Efficiency (PFP)	（偏生产力）	58	66
N Internal Efficiency (NIE)	（氮肥内部利用率）	49.7	56.0
Grain Harvest Index (HI)	（收获指数）	47.6	49.8
N Harvest Index (NHI)	（氮素收获指数）	63.1	63.8
Grain N %	（种子中的氮浓度）	1.33	1.20
Stover N%	（茎干中的氮浓度）	0.77	0.69
% of Total Plant N coming from new N uptake after R1	（花后期吸氮总量）	31%	36%
% of Grain N that came from new N uptake after R1	（花后期籽粒中氮素含量）	52%	56%

Ciampitti and Vyn (2012, Review Paper, Field Crops Research 133: 48-67)

Higher and Later N uptake in Modern Maize Hybrids
玉米花前期和花后期吸氮在新、老品种间的差异



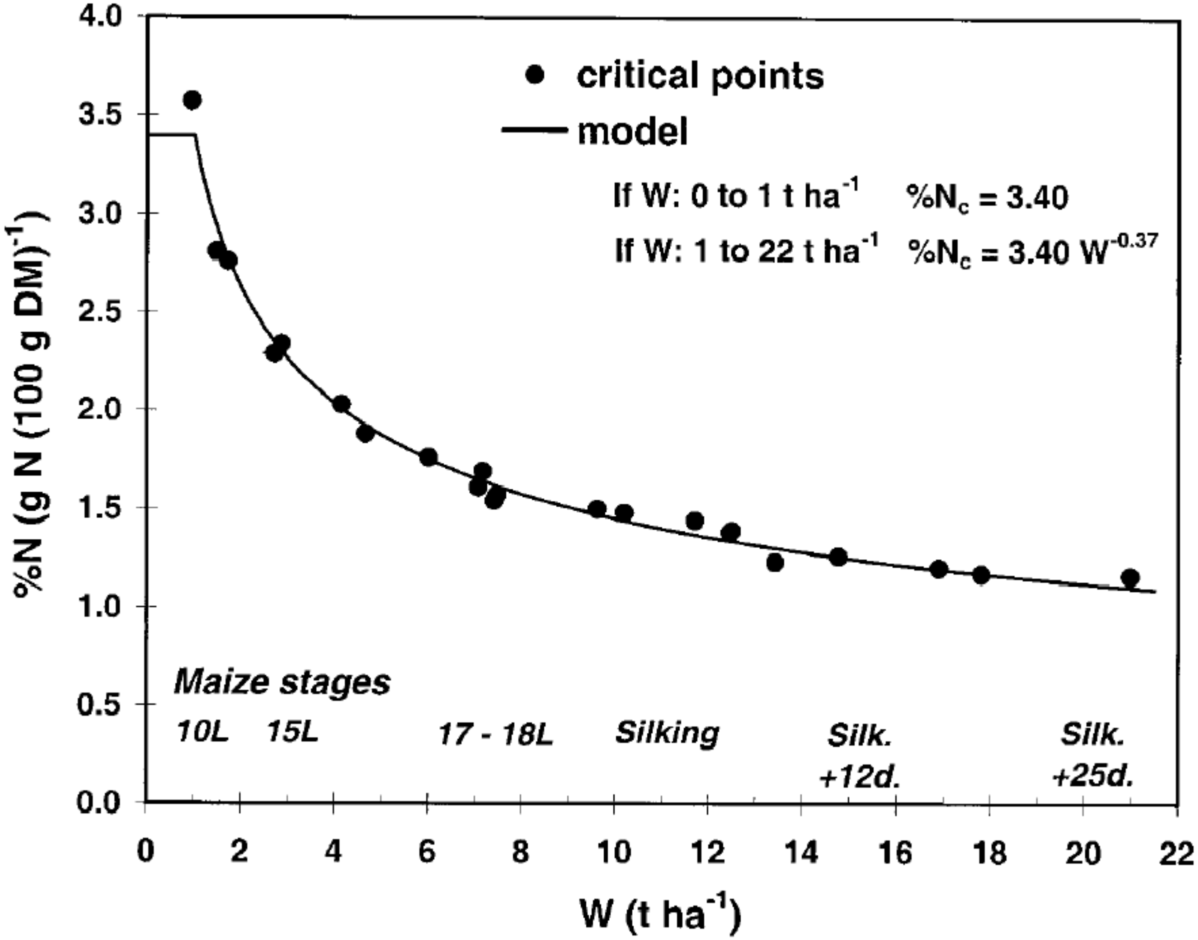


Mean N rates in kg N ha^{-1}:

173.3 173.7

Source: S. M. Mueller and T.J. Vyn 2016 (Frontiers in Plant Science)

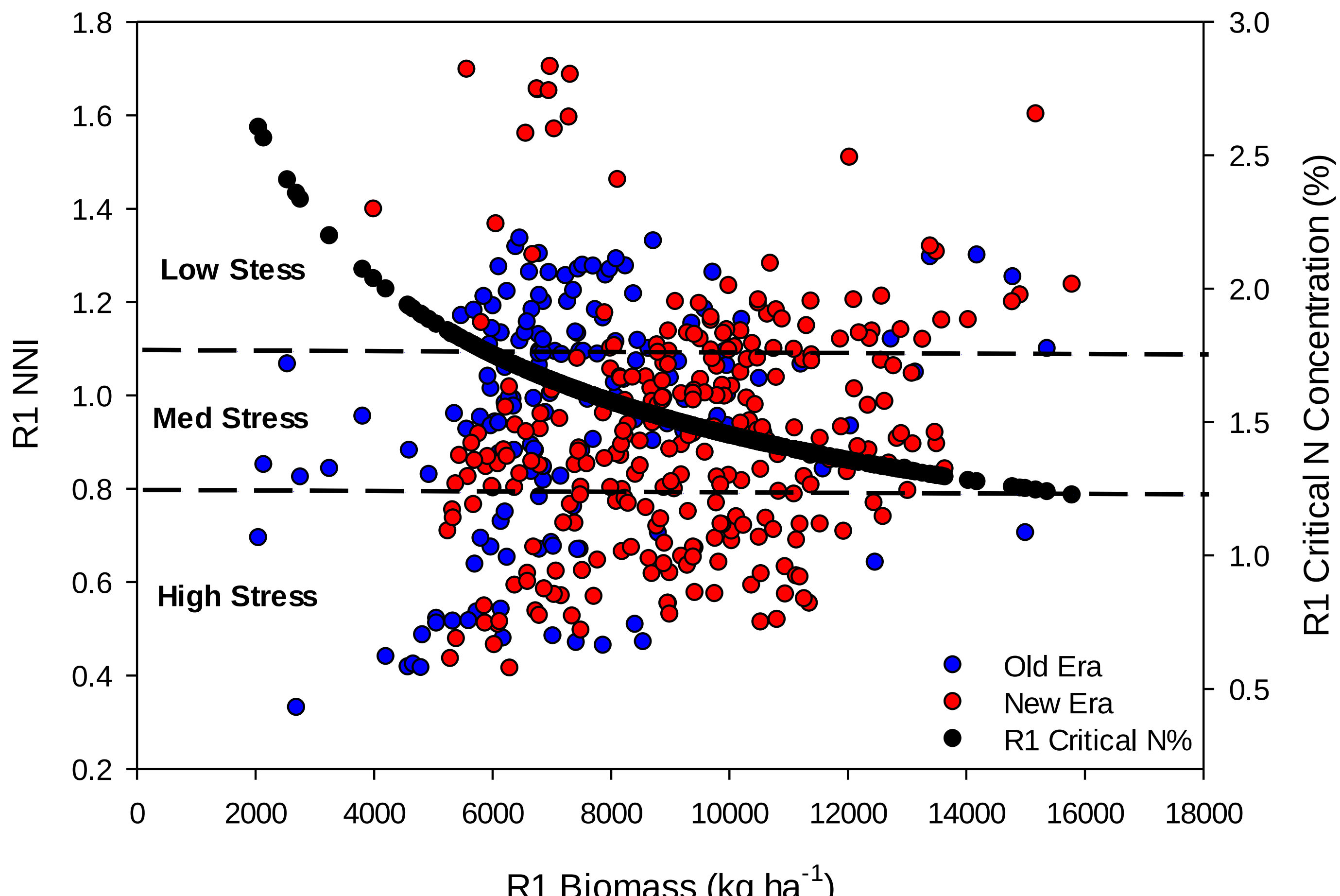
Critical N Dilution Curve for Maize and Nitrogen Nutrition Index (NNI)
氮素稀释曲线和NNI



Plénet and Lemaire, 2000, Plant and Soil 216:65-82

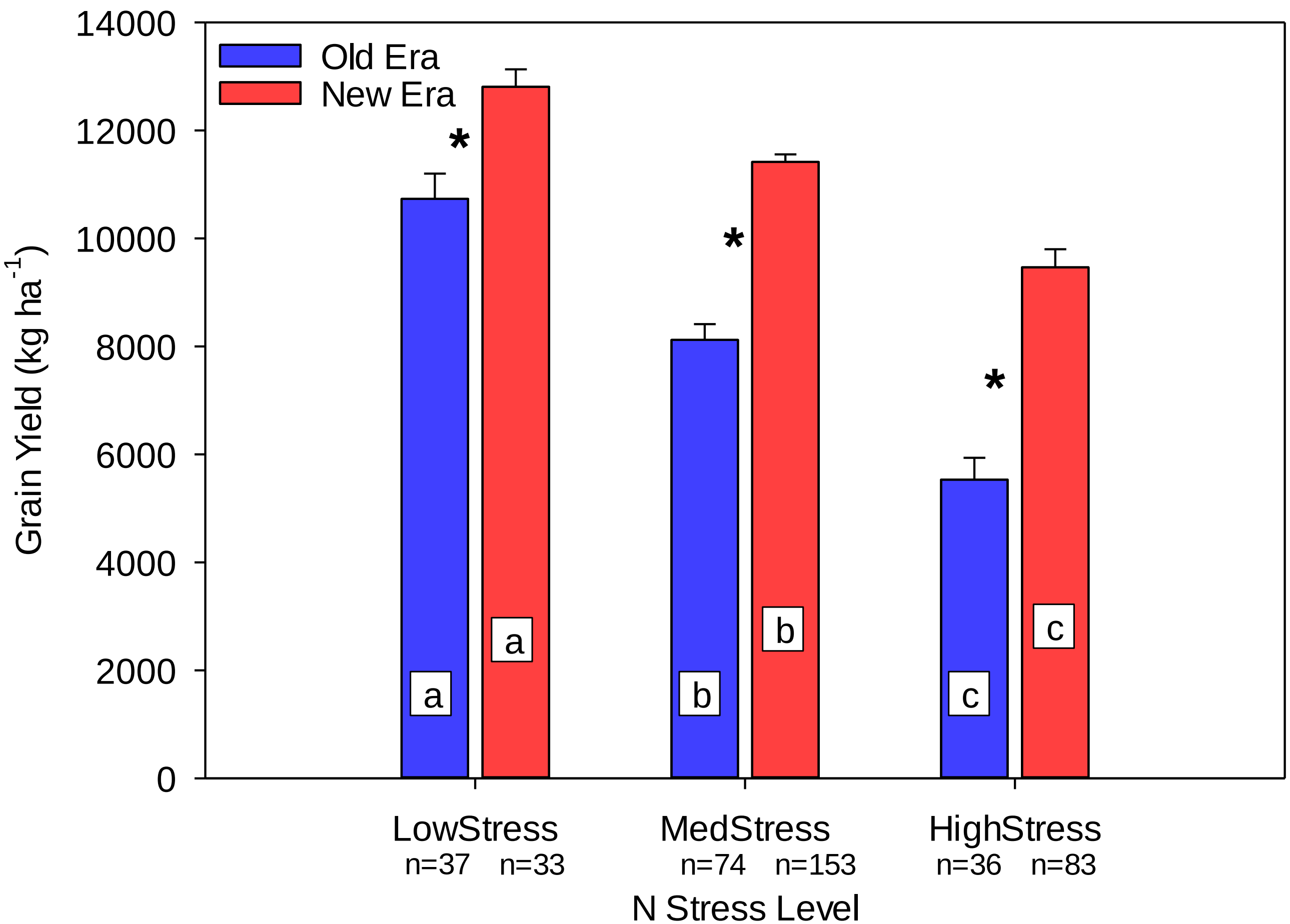
Division of R1 stage biomass and N content data from Old Era versus New Era Maize into Low, Medium and High Stress relative to NNI

新、老品种在抽雄期生物量和含氮量分化到不同的氮胁迫水平（NNI）



Mid-season N stress level impacts on grain yields in Old Era versus New Era Hybrids
抽雄期氮胁迫水平对产量在新、老品种中的影响

Grain Yield (kg/ha)



Source: S. M. Mueller and T.J. Vyn 2016 (Frontiers in Plant Science)

Genetic Improvements in NUE
玉米品种改良对氮素利用效率的贡献

1. Considerable gains in NUE in last 50 years.

   氮素利用效率在过去50年里的提高是可观的

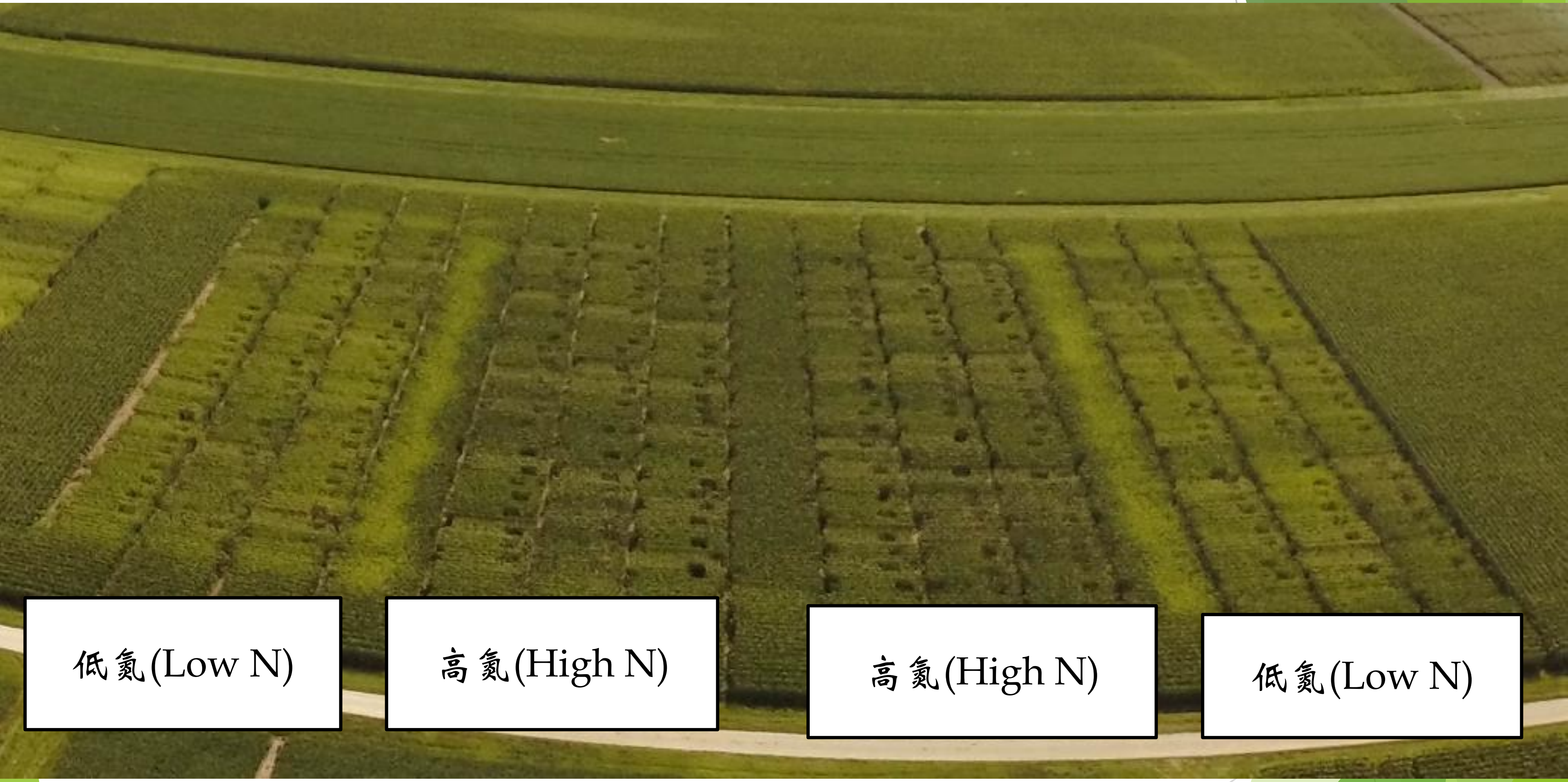
2. Considerable variation in NUE among current commercial genotypes for the same region and environment.

   在现代玉米品种里，氮素利用率的差异在同一地区和环境是相当大的

3. Considerable effort in both public and private breeding companies in trying to increase NUE via traditional or transgenic approaches.

   育种公司利用传统育种技术和转基因技术来提高氮肥利用效率的努力是巨大的

博士课题 Ph. D. Topic of Chen Keru



博士课题 Ph. D. Topic of Chen Keru

主区设计 (Main effect)：

N水平 - 低氮 (High N)：55 kg/ha；高氮 (Low N)：220 kg/ha

裂区设计 (Sub effect):

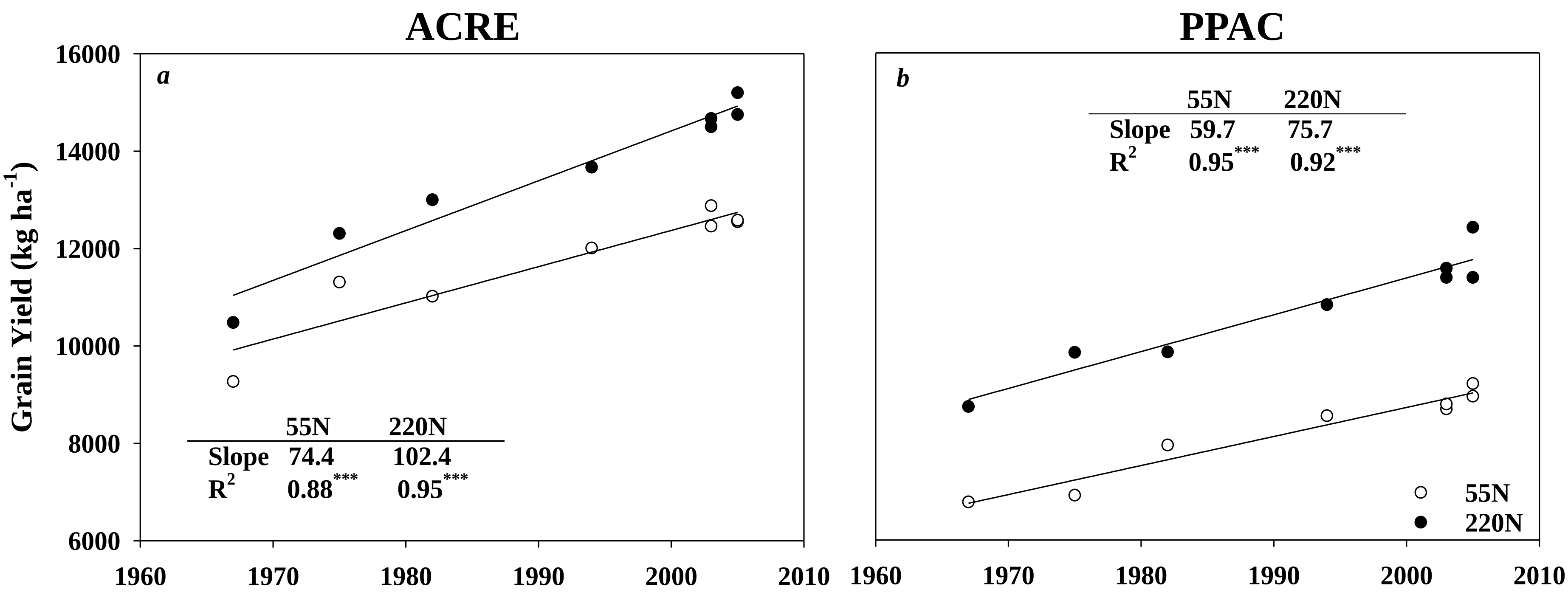
密度 (Density) – 低密度 (Low)：54,000 株/公顷；中密度 (Medium)：79,000 株/公顷；高密度 (High)：104,000 株/公顷

再裂区设计 (Sub-sub effect)：品种 (Era of hybrids)

1. DKC61-69[VT3]: 2005 (RM
2. DKC61-72[RR2]: 2005 (RM
3. RX752[VT3]: 2003 (RM
4. RX752RR2[RR2]: 2003 (RM
5. RX730[Conv.]:1994 (RM
6. DK636[Conv.]:1982 (RM
7. XL72AA: 1975 (RM
8. XL45: 1967 (RM

MONSANTO

Grain yield increase in past 40 years in a series of DeKalb hybrids (2013-2014)
40年间玉米产量的增加 – 基于对DeKalb玉米品种的研究



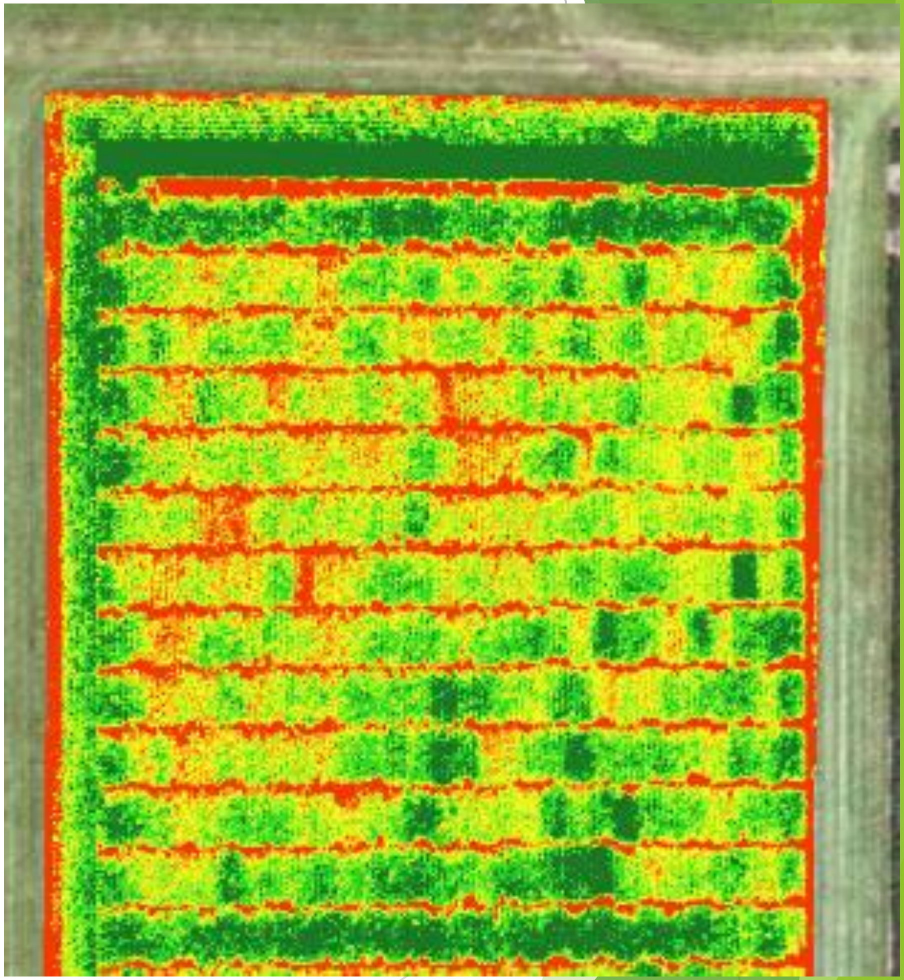
Source: Keru Chen and Tony Vyn, 2016

Newer hybrids took up more N during post-silking period
新品种较老品种在花后期吸收更多的N素

年份		Post-silking N uptake (PostN)	
		2012	2013
		(kg ha^{-1})	(kg ha^{-1})
	N rate (kg ha^{-1})		
	55N	28 b	45 b
	220N	65 a	62 a
	Density (pls ha^{-1})		
	54,000	46	65 a
	79,000	43	49 b
	104,000	51	46 b
年份	**Hybrid**		
2005	**DKC61-69**	53	58 a
2005	**DKC61-72**	47	62 a
1975	**XL72AA**	40	47 b
1967	**XL45 (only in 2013)**		46 b

Source: Keru Chen and Tony Vyn, Field Crops Research, 2015

2015 Field Evaluations of 300 Hybrids for NIE
2015年对300个玉米品种进行氮素内部利用率的测定



N rate = 66 kg N ha^{-1}

Fertilizer Technology Improvements to Help Achieve Higher NUE
施肥技术的增加提高氮肥利用效率

1. Enhanced Efficiency Fertilizers
2. Fertilizer placement technologies
3. Variable rate technologies
4. Fertilizer timing options have expanded

1. 增加高效率肥料的使用
2. 更精准的施肥放置技术
3. 更精准的施肥量
4. 施肥的时间有更多的选择

UAN和硝化抑制剂

On-farm Studies with Intentional Late-Season N Applications of 30 to 50 kg N ha^{-1}

后期施肥—30 ~ 50 磅氮肥

Photo from 360 Yield Center

Crop Management Improvements to NUE
管理技术对于提高氮肥利用率的贡献

1. Tillage and crop rotation practices
2. Water management and water use efficiency gains
3. Plant density impacts
4. Planting date and pest management impacts
5. Management guided by an "Ecological Intensification" approach versus "Traditional Farmer Practice" as in the current IPNI studies on Global Maize

1. 耕作和轮作的实践
2. 水分管理和水资源利用率的增加
3. 种植密度的影响
4. 播种时间和病虫害管理的影响
5. 生态集约化和传统农业的对比

Hongguang Cai (CAAS, Jilin Province) Crop Systems Research in 2014

- Higher yield cultivation by using integrated agronomic techniques
- Plant nutrition (N, P and K management)
- Soil fertility (including return of straw and other organic materials)
- Conservation tillage (Alternating wide -90cm- and narrow rows -40cm)
- Water saving techniques (Drought tolerance)








Conclusions

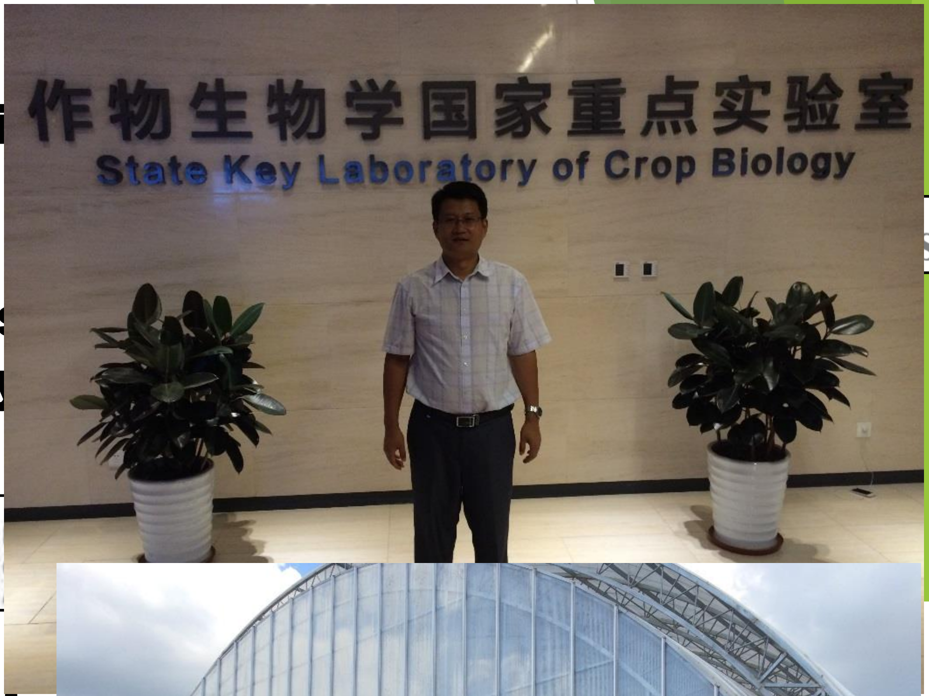
- **There has already been considerable gains in NUE over time in cereal grain production systems.**
  在谷物生产系统中，氮素利用率已经有了可观的增加

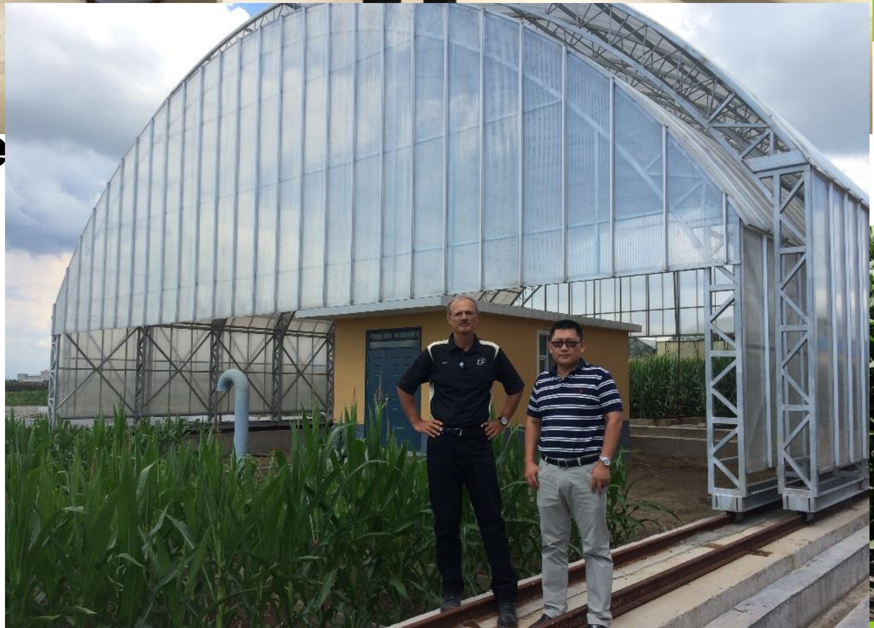
- **Those gains have come about because of the combination of genetic, fertilizer practice, and crop management improvements over time.**
  氮素利用率的增加来源于品种的提升，肥料和作物管理的提升

- **There are significant challenges ahead in achieving continued NUE improvements but those are best addressed in more coordinated (multi-lateral) and systems-level research.**
  氮素利用率的继续提升面临巨大挑战，但是多方面和系统的研究能帮助更好的找到增加氮素利用率的方法

- **Research partnerships with other scientific disciplines and with fertilizer industry and grower organizations need to be expanded.**
  科学研究与化肥生产厂和其他组织的合作应该增加

Acknowledgments





John Deere Cropping Syste

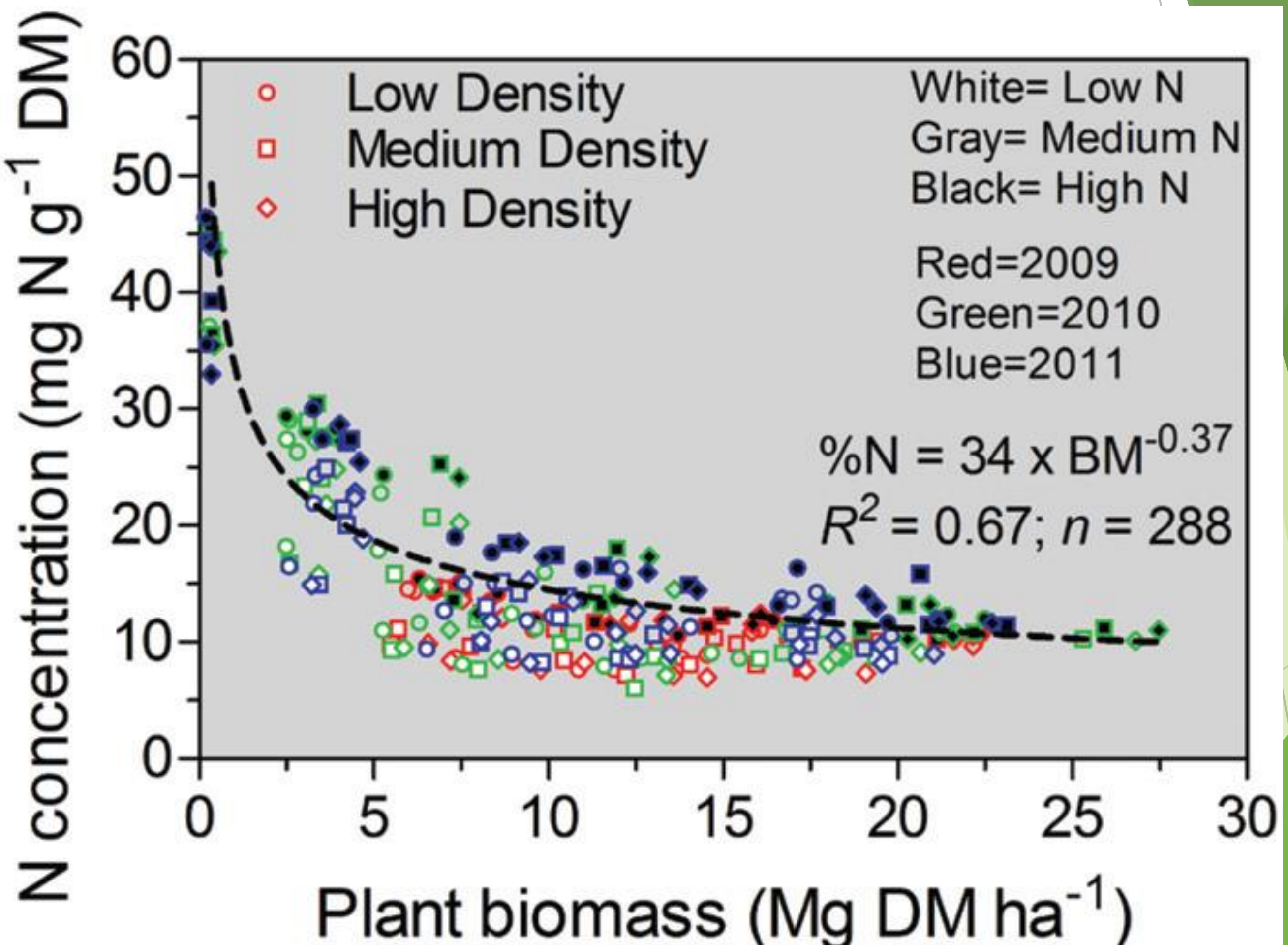
Seed:

Pioneer Hi-Bred, Int'l.
Monsanto
Dow AgroSciences


Questions?

Plant density versus N rate impacts on whole-plant N concentrations over time relative to “critical” N concentrations (2009-2011, 2 sites and 2 hybrids/site)

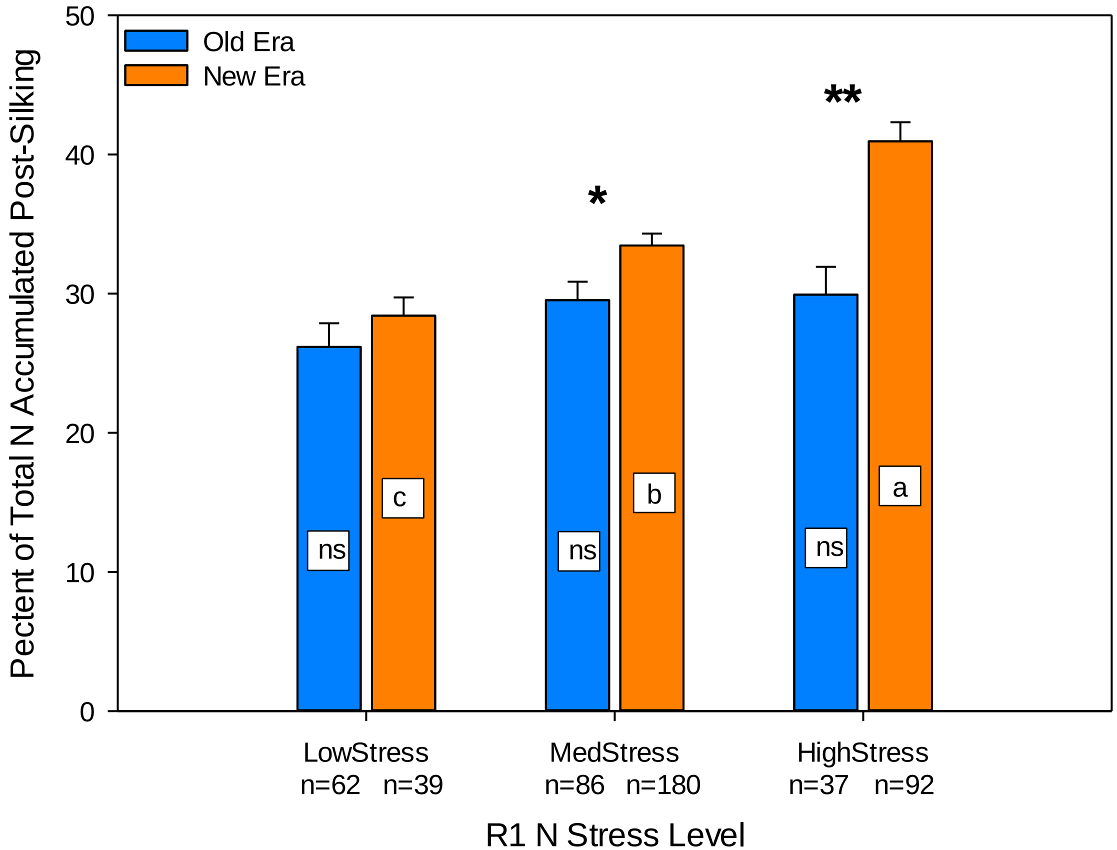
密度和氮水平对整株植物氮素稀释曲线的影响



Ciampitti et al., 2013, Crop Sci. 52:2728

Mid-season N stress level impacts on post-silking N uptake (%) in Old Era versus New Era Maize Hybrids
抽雄期氮胁迫水平对花后期植物氮素含量在新、老品种中的对比

Post-silk N uptake (%)



Differnt letters signify LSMeans within Eras (Old or New) are significantly different across N stres
An * denotes a significant difference between the Old and New LSMeans within a given N stress
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level

Source: S. M. Mueller and T.J. Vyn 2016 (Frontiers in Plant Science)