High productivity and resource use efficiency in intercropping

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Structure of this talk

- What is intercropping?
- What are the advantages of intercropping?
- What are the challenges of intercropping?
- Research needs?

Intercropping

- Cultivation of multiple (usually two) crop species in a field at the same time
- Relay intercropping: cultivation of two crop species with partially overlapping growing periods

- Reason: to increase yield and resource use efficiency
- Intercropping can work under different conditions for very different reasons
- Performance depends on genotype * genotype * environment * management interaction

Intercropping and crop/tree mixture along the Yellow River in Gansu, China (photo: Li Long)


There is an incredible diversity of systems
Wheat - maize
Photo: Zhang Fusuo

There is an incredible diversity of systems

There is an incredible diversity of systems





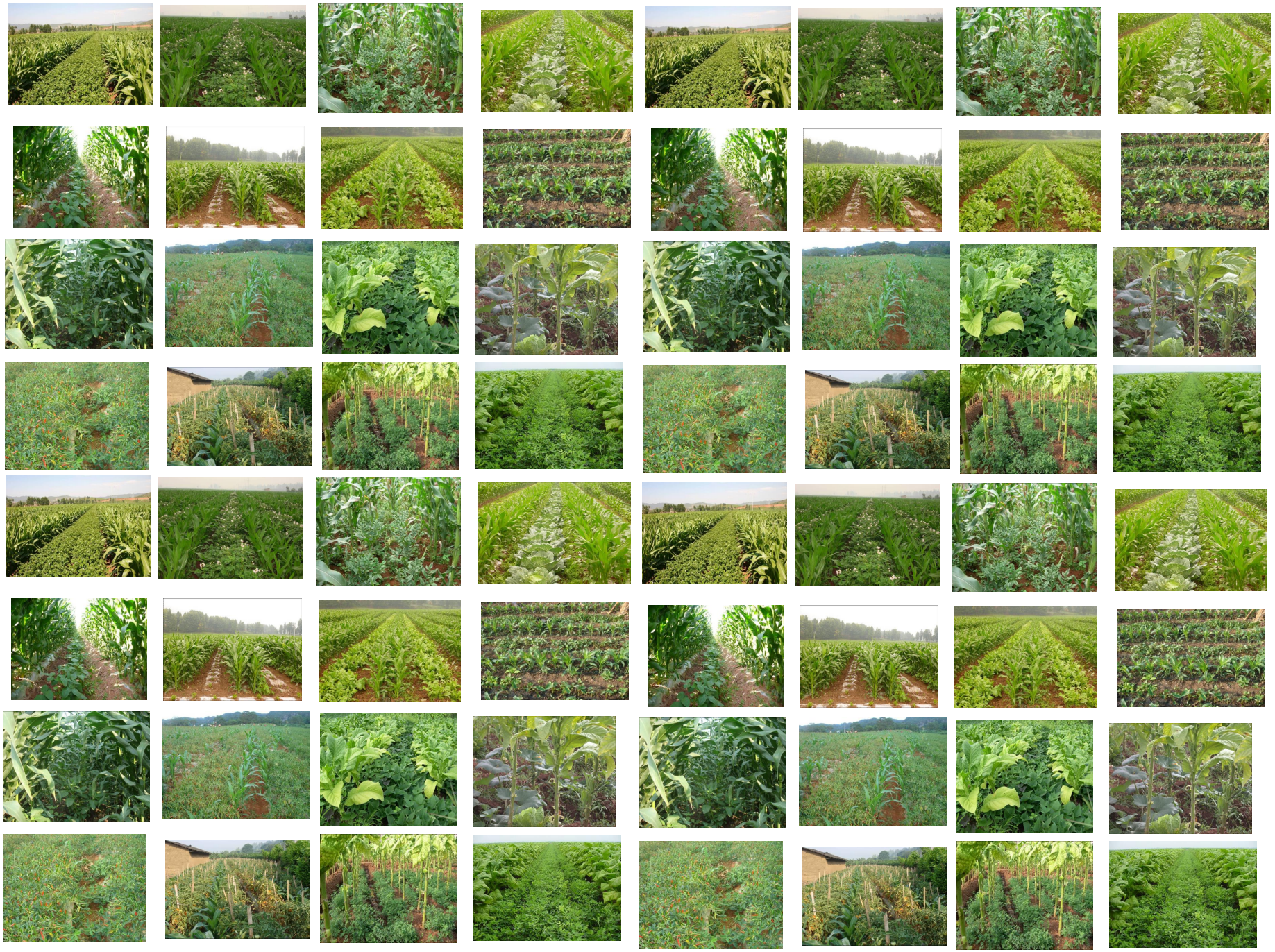










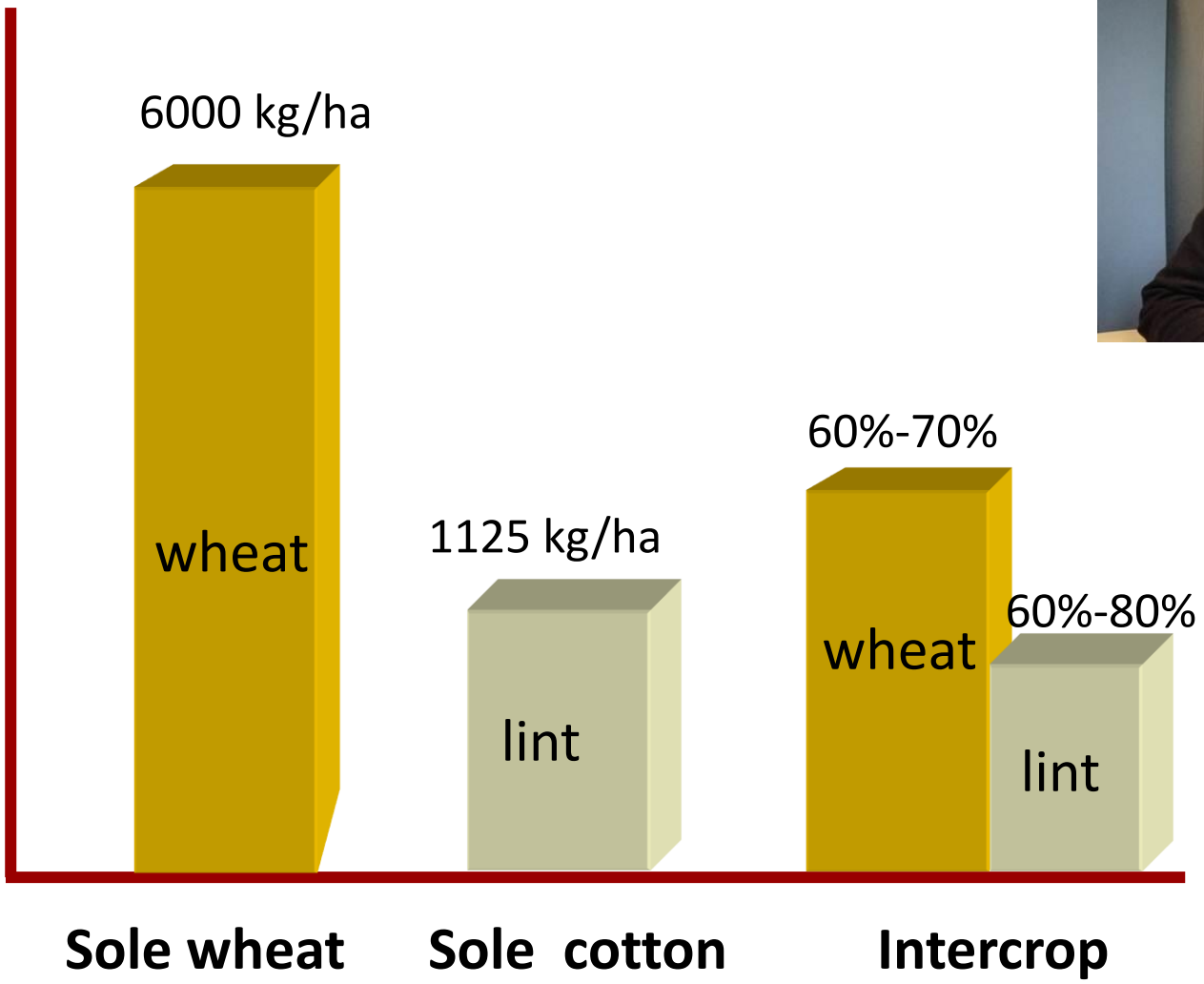
Advantages of intercropping

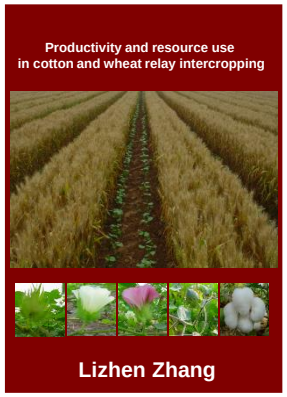
- Uses the land more efficiently
- Uses soil nitrogen and soil phosphorus more efficiently
- Reduces pests and diseases
- Suppresses weeds better than the average of the sole crops (almost as good as the better weed competitor)
- Builds soil organic matter more than sole crops do


4LD-2

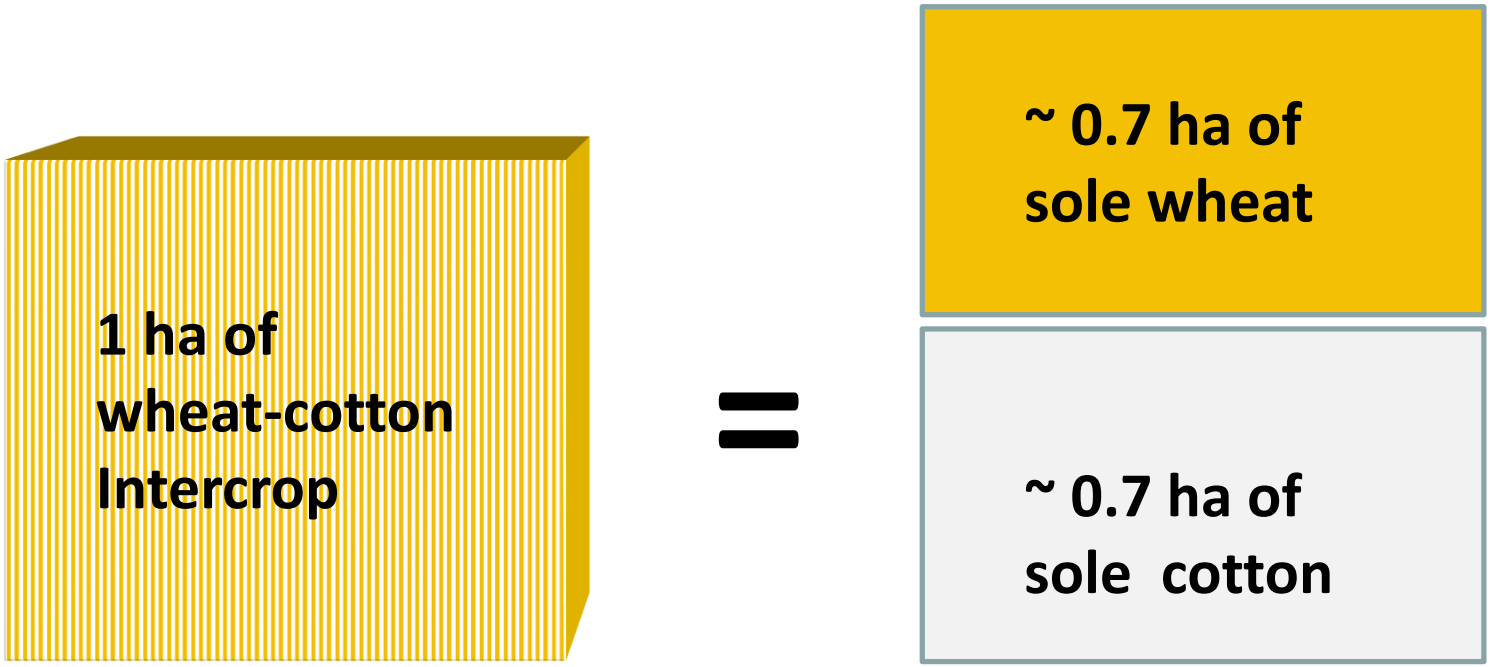
Example of the land equivalent ratio

Lizhen Zhang



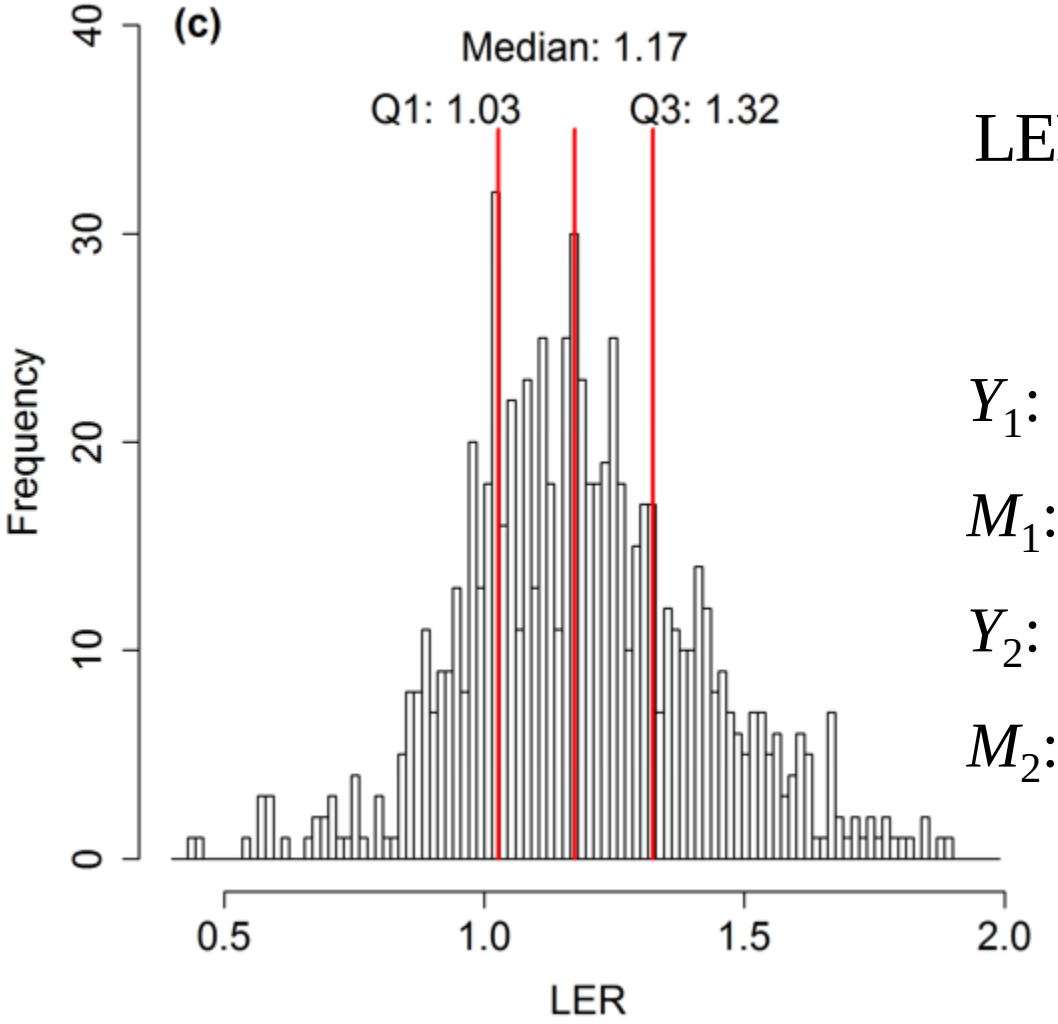


Reduced need for land!



LER is a measure for land use efficiency, for “land sparing”

Average land equivalent ratio (LER) is 1.22



$$\mathrm{LER} = \frac{Y_1}{M_1} + \frac{Y_2}{M_2}$$

Y_1: yield of species 1 in intercrop

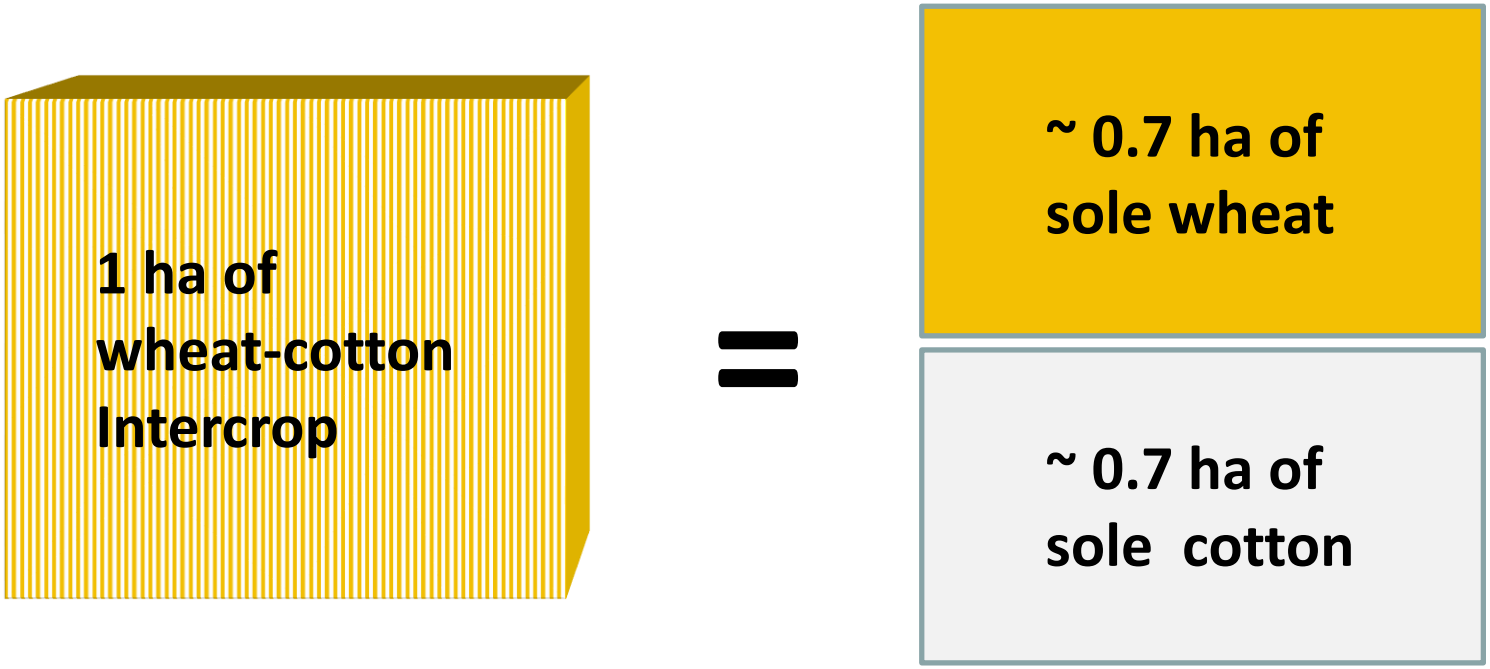
M_1: yield of species 1 in sole crop

Y_2: yield of species 2 in intercrop

M_2: yield of species 2 in sole crop

http://dx.doi.org/10.1016/j.fcr.2015.09.010

Reduced need for land for the same product output



Reduced need for water

Reduced need for N

Reduced need for P

LER and FNER: Land equivalent ratio and Fertilizer N equivalent ratio

Land equivalent ratio: relative area of land required when using sole crops to obtain the yield that is obtained in a unit area that is intercropped

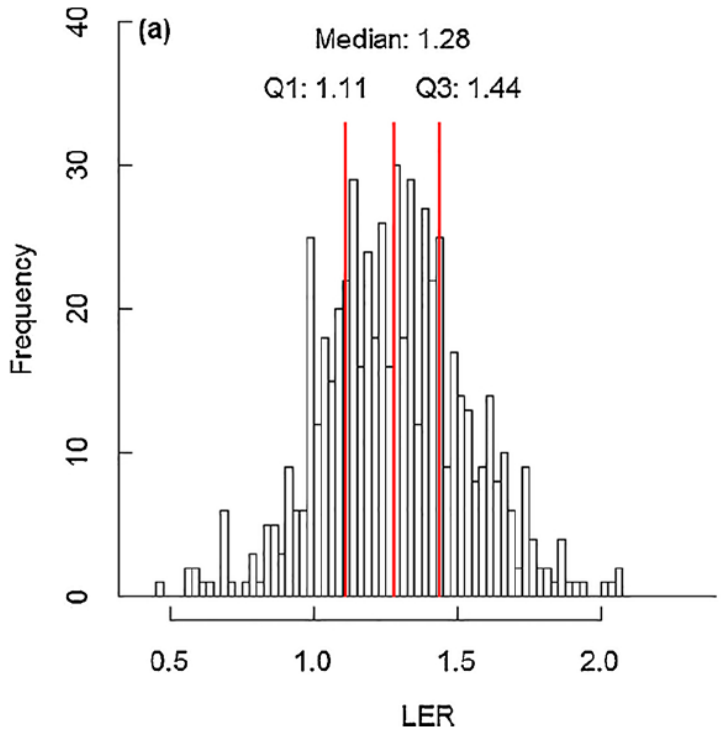
$$LER = pLER_1 + pLER_2 = \frac{Y_1}{M_1} + \frac{Y_2}{M_2}$$

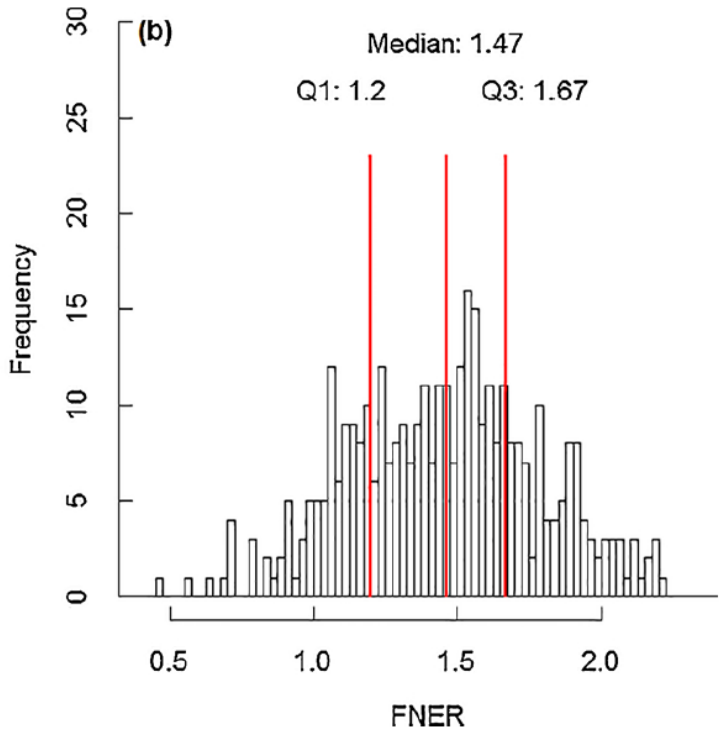
Fertilizer N equivalent ratio: relative quantity of N fertilizer required when using sole crops to obtain the yield that is obtained in a unit area that is intercropped with a reference quantity of N fertilizer

$$FNER = pFNER_1 + pFNER_2 = pLER_1 * \frac{F_1}{F_{IC}} + pLER_2 * \frac{F_2}{F_{IC}}$$

https://doi.org/10.1016/j.fcr.2019.107661

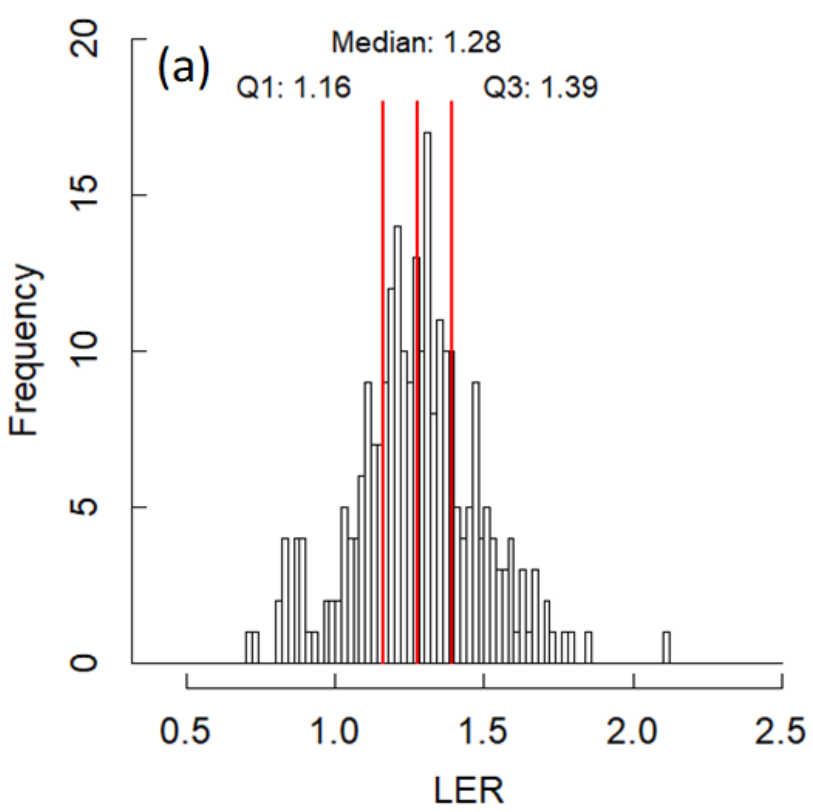
Intercropping maize and soybean increases efficiency of land and fertilizer nitrogen use

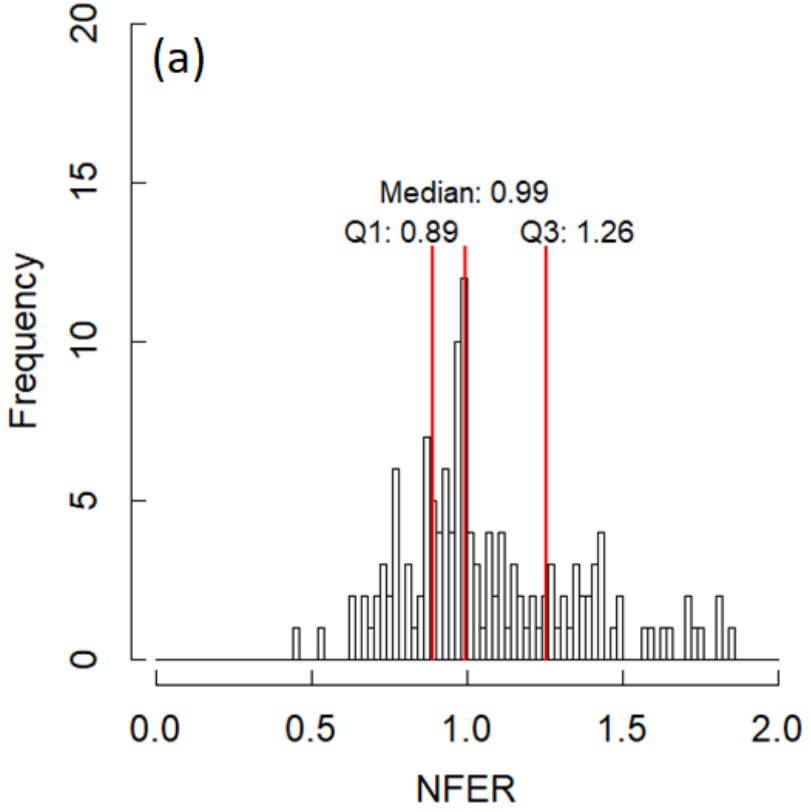




https://doi.org/10.1016/j.fcr.2019.107661

Intercropping maize and peanut increases land use efficiency **but not** nitrogen use efficiency because researchers applied too much N in the intercrop





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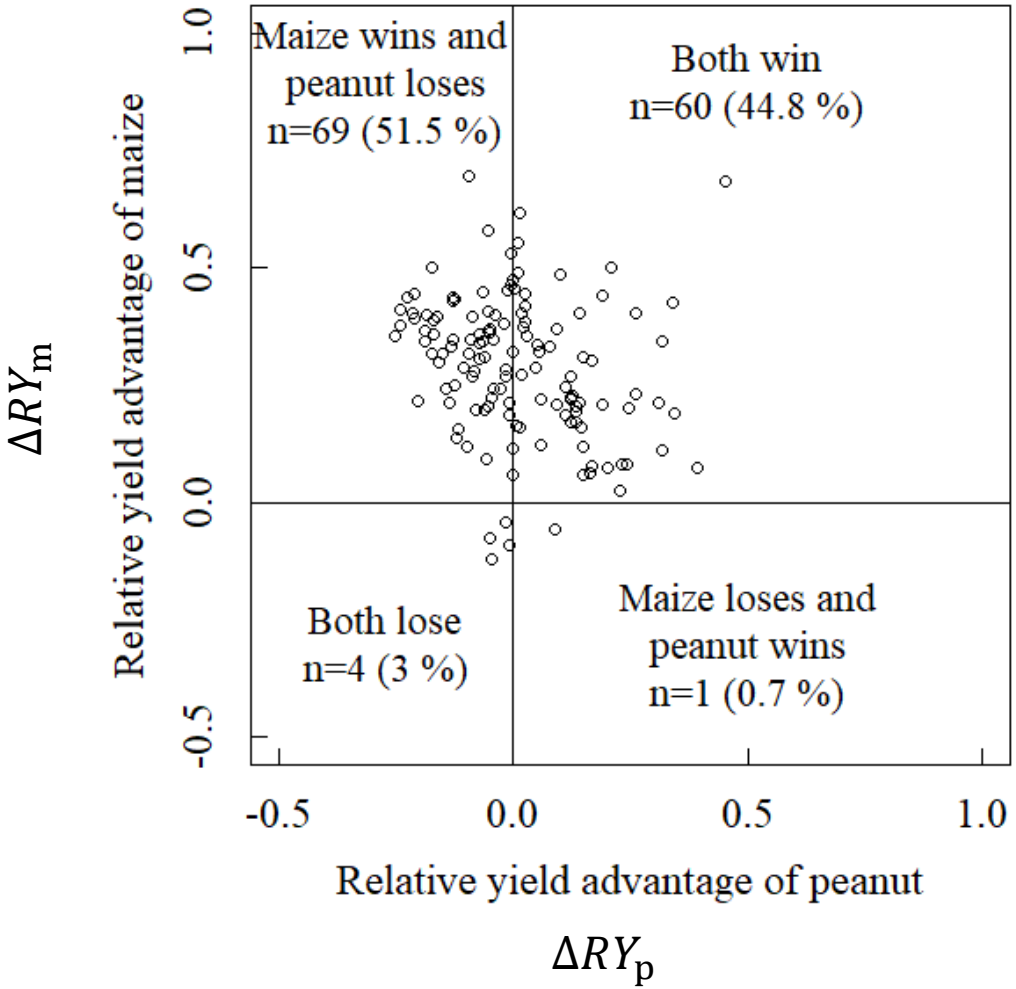
http://dx.doi.org/10.1016/j.fcr.2021.108208

High land use efficiency in maize/peanut intercropping is due to higher than expected maize yield and same as expected peanut yield



$$\Delta RY_{\mathrm{m}} = pLER_{\mathrm{m}} - p_{\mathrm{m}}$$

$$\Delta RY_{\mathrm{p}} = pLER_{\mathrm{p}} - p_{\mathrm{p}}$$

Where p_m and p_p are the land shares of maize and peanut

$$p_{\mathrm{m}} + p_{\mathrm{p}} = 1$$

http://dx.doi.org/10.1016/j.fcr.2021.108208

Metrics for intercropping performance

- **Land equivalent ratio**: sum of relative yields
  Interpretation: the relative land area required in sole crops to achieve the same production as the intercrop

$$LER = pLER_1 + pLER_2 = RY_1 + RY_2 = \frac{Y_1}{M_1} + \frac{Y_2}{M_2}$$

- **Net effect**: the difference between the **realized total** yield (e.g. grain yield) and the **expected total** yield

$$NE = NE_1 + NE_2 = Y_1 - \frac{RD_1}{RD_1 + RD_2} M_1 + Y_2 - \frac{RD_2}{RD_1 + RD_2} M_2$$

Advantages and disadvantages of LER and NE

- LER is scale independent (both an advantage and a disadvantage)
- Not about yield but about land areas!
- Units are elusive: ha sole crop per ha intercrop for the same production
- People tend to misunderstand and misinterpret the LER as it is a sum of ratios (hard to understand)
- LER > 1 does **not** mean that the intercropped field has a greater yield than sole crops
- LER > 1 means that the **farm** may get a higher production (and a higher land use efficiency) by using intercropping
- You can have a high LER at terrible yield levels; agronomically irrelevant

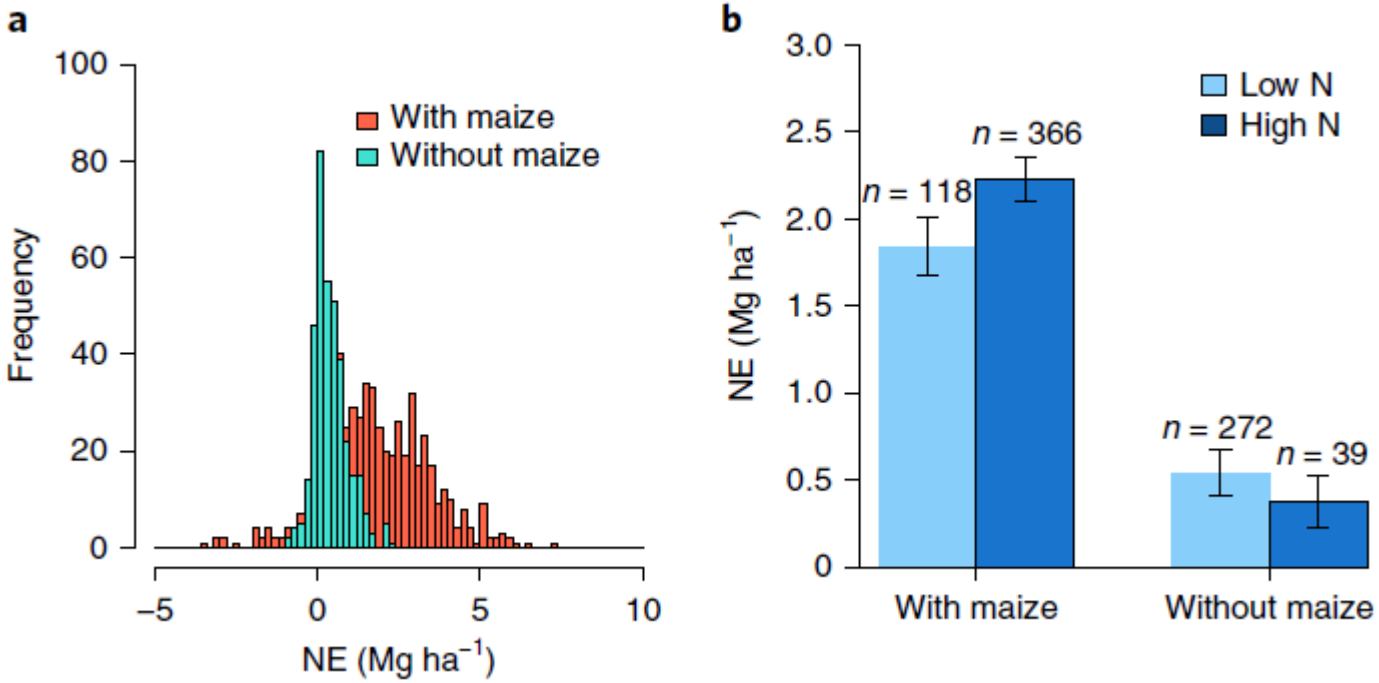
Net Effect (NE)

- NE has units of yield (kg/ha) this is both an advantage and a disadvantage
- NE compares the achieved total yield to a weighted average (expected yield) of the sole crop yields. Is that relevant?
- Would it not be more appropriate to compare the intercrop yield to the yield of the highest yielding crop (transgressive overyielding)?

- Net effect: the difference between the **realized total** yield (e.g. grain yield) and the **expected total** yield

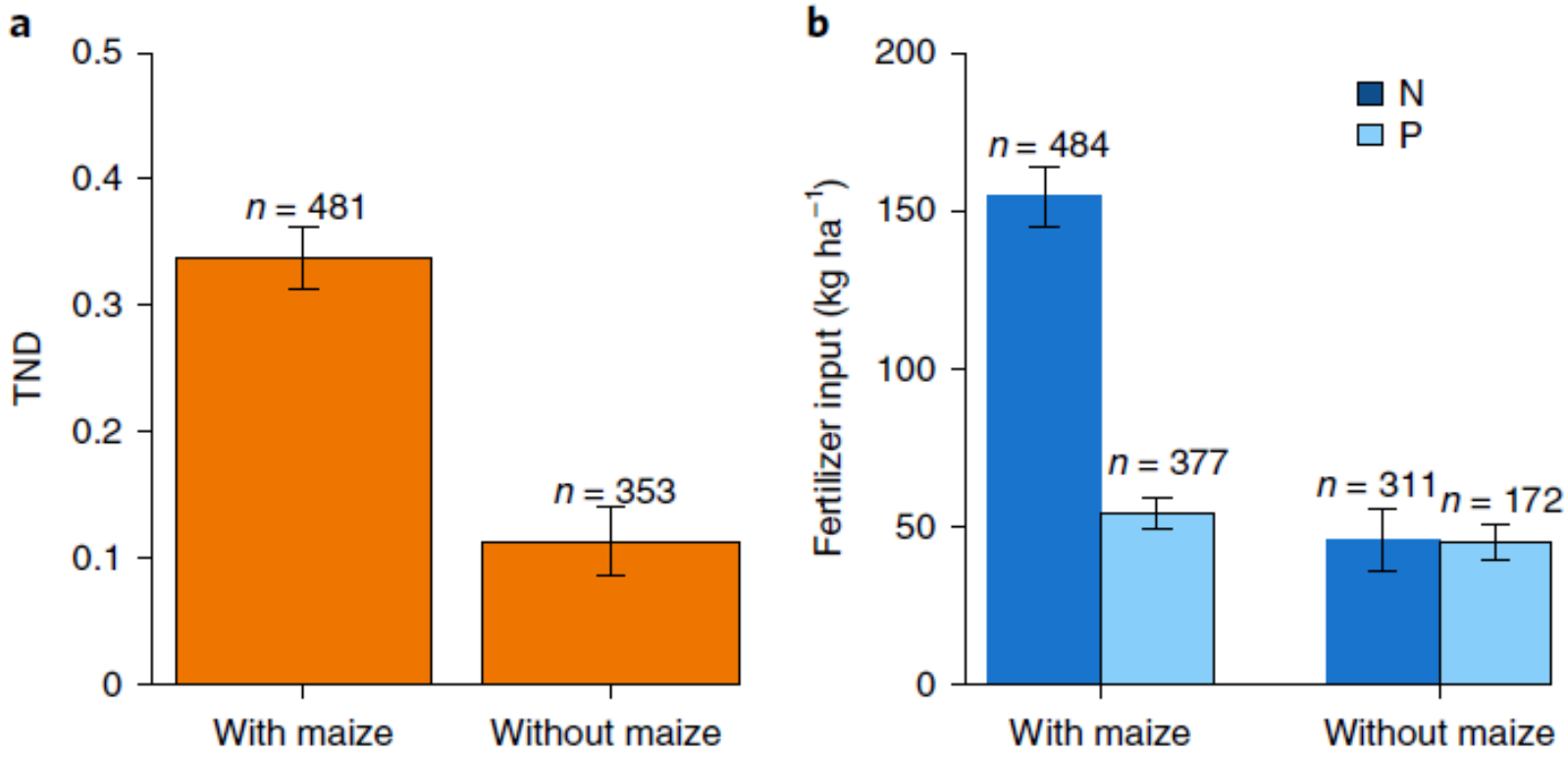
$$NE = NE_1 + NE_2 = Y_1 - \frac{RD_1}{RD_1 + RD_2} M_1 + Y_2 - \frac{RD_2}{RD_1 + RD_2} M_2$$

The effect of maize on yield gain in intercropping



Systems with maize had much greater yield gains than systems without maize
Higher N input increased NE in systems with maize but decreased it in systems without maize

https://doi.org/10.1038/s41477-020-0680-9



Systems with maize had much greater TND and much greater N input than systems without maize -> syndromes of production

https://doi.org/10.1038/s41477-020-0680-9

Syndromes of production in intercropping

With maize

- High yield, high NE
- High N input
- Relay (high TND)
- High input – high output syndrome

Without maize

- Lower yield, lower NE
- Lower N input
- Simultaneous
- Low input – low output syndrome

https://doi.org/10.1038/s41477-020-0680-9

More metrics

- Transgressive overyielding index:

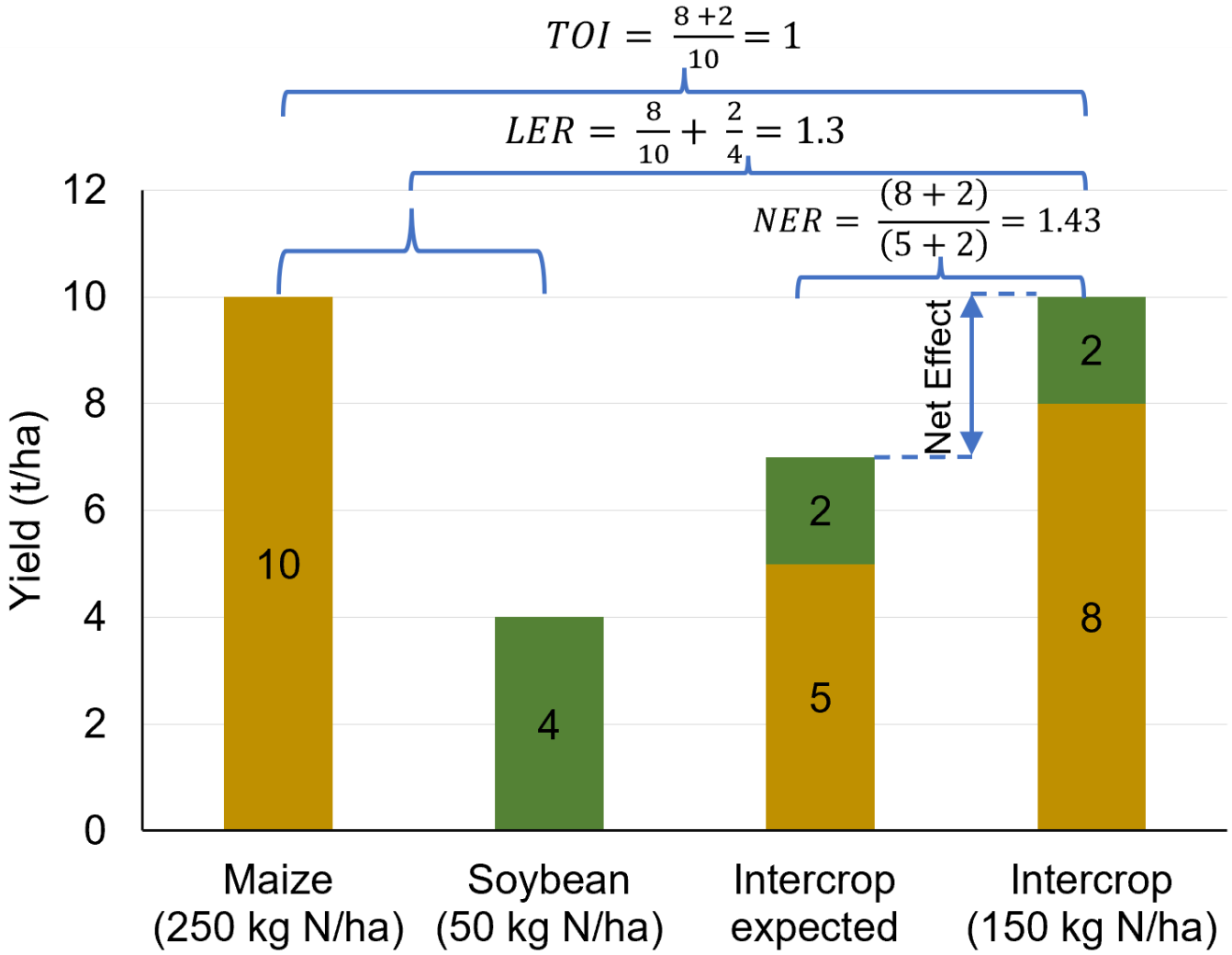
$$TOI = \frac{\text{Observed total intercrop yield}}{\text{Observed yield of the highest yielding sole crop}}$$

$$TOI = \frac{\mathrm{Y}_1 + \mathrm{Y}_2}{\max(\mathrm{M}_1, \mathrm{M}_2)}$$

- Net effect ratio:

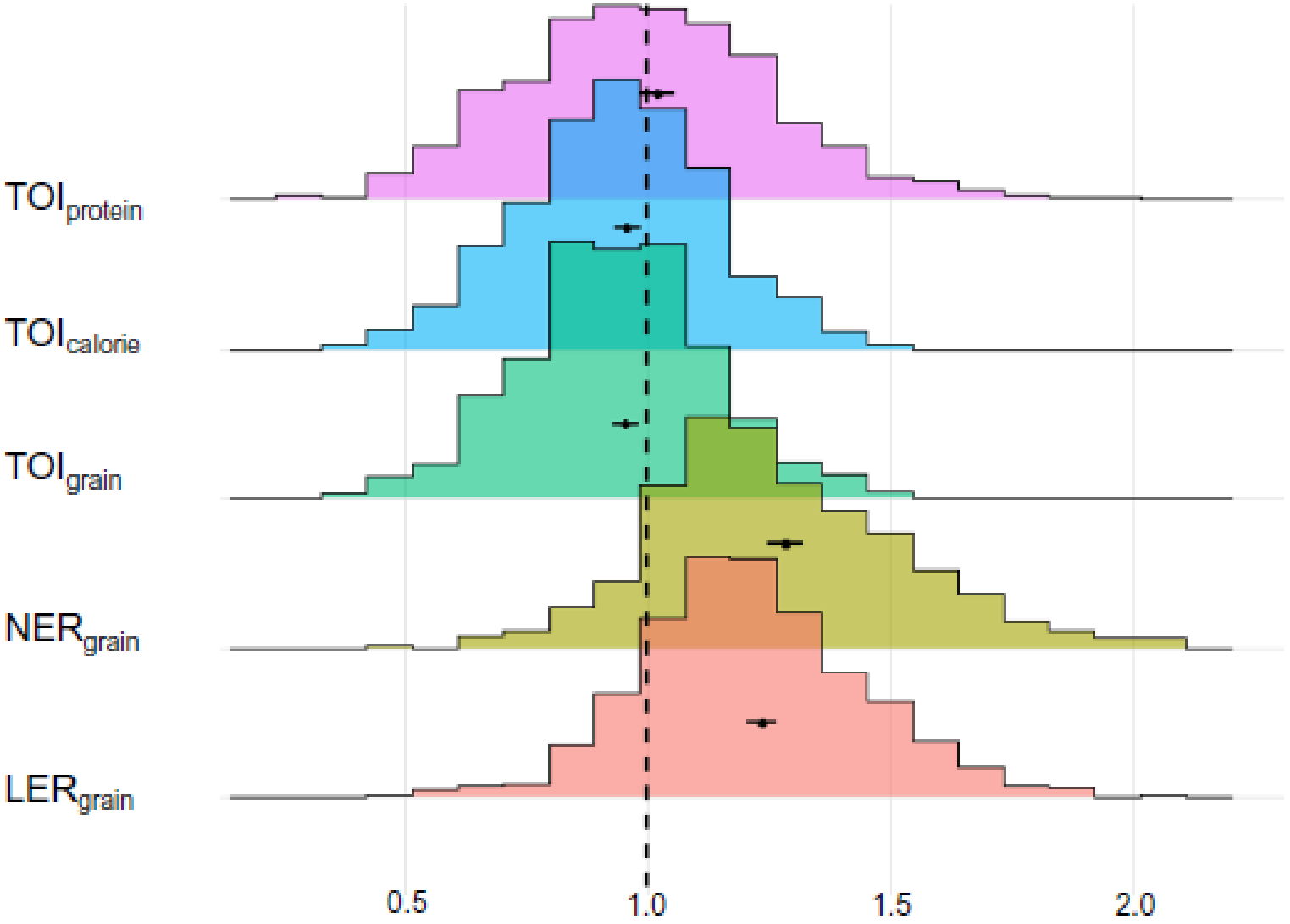
$$NER = \frac{\text{Observed total intercrop yield}}{\text{Expected total intercrop yield}}$$

$$= \frac{Y_1 + Y_2}{\frac{RD_1}{RD_1 + RD_2} M_1 + \frac{RD_2}{RD_1 + RD_2} M_2}$$



Graphical illustration of the calculation of the land equivalent ratio (LER), net effect ratio (NER) and transgressive overyielding index (TOI) from the yields per ha of maize (yellow) and soybean (green) in an intercrop and the sole crops.

https://doi.org/10.1073/pnas.2201886120



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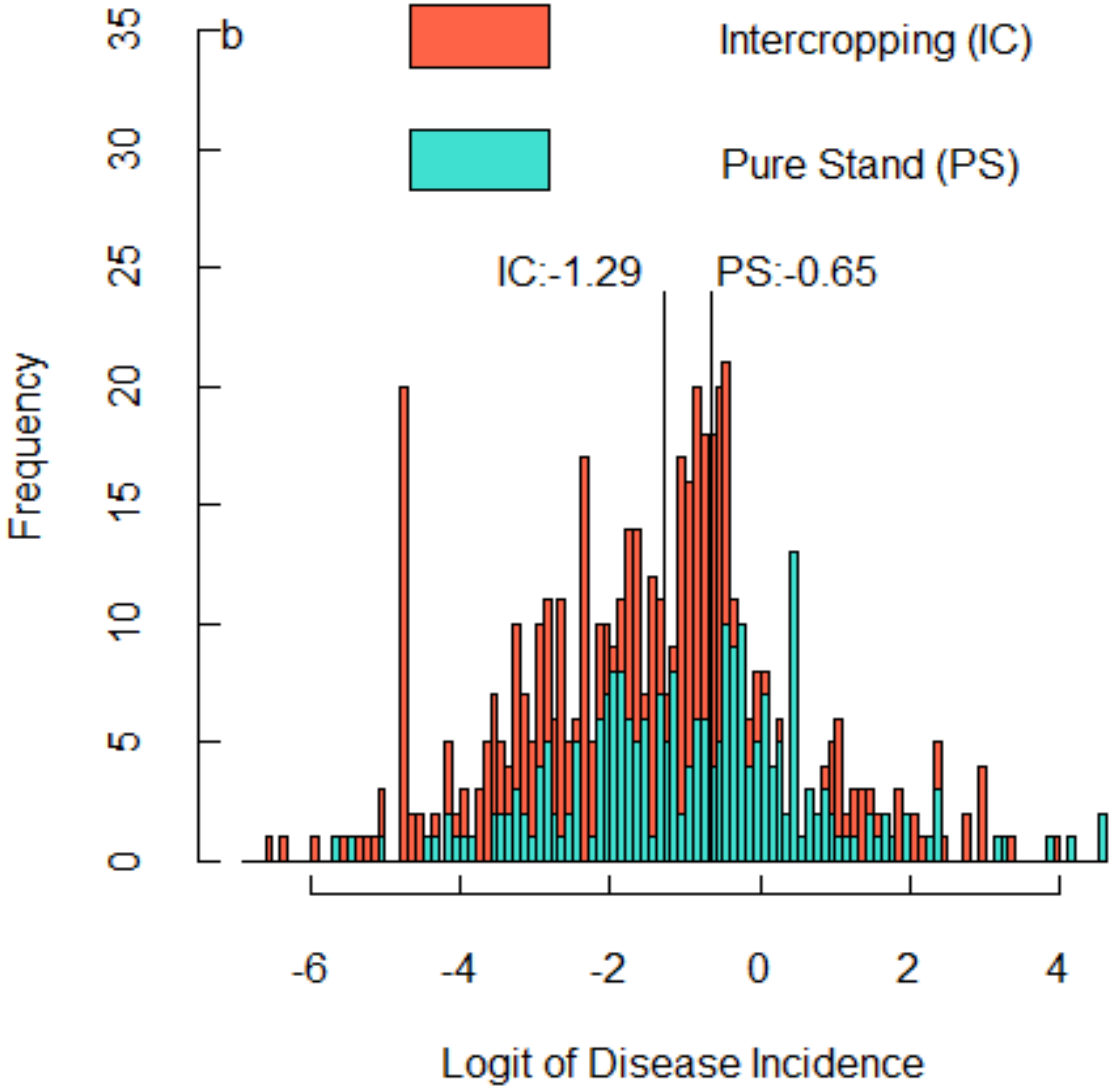
https://doi.org/10.1073/pnas.2201886120

Findings in our 2023 PNAS paper

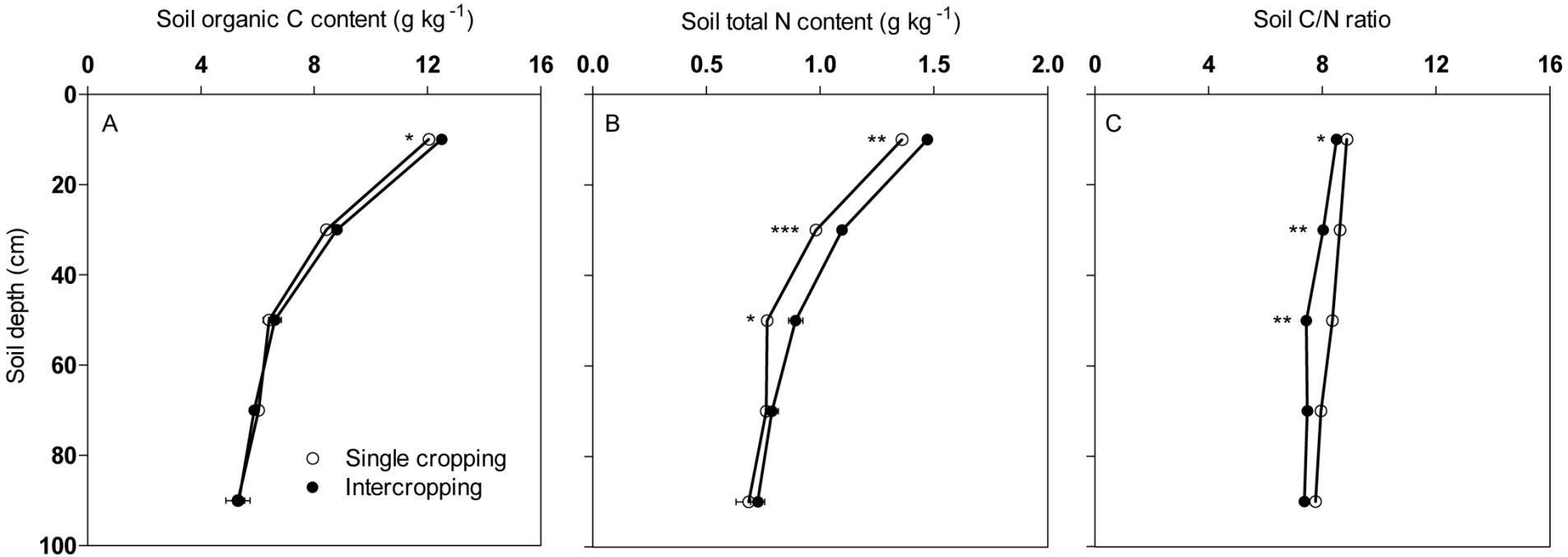
- Intercrops give on average 4% lower yield than the highest yielding sole crop.
- So, if you want to have the highest production, don’t do intercropping. Grow maize.
- However, if you want to have a diversity of food products, intercropping allows you to grow it on a smaller area, with lower input, with better nutrient capture, reduced pests and diseases, and improved soil carbon.
- Moreover, cereal/legume intercrops are marginally superior to both sole crops in producing protein.

https://doi.org/10.1073/pnas.2201886120



1) Disease incidence is lower in intercrops (21%) than in pure stands (34%)
2) Large variability

Long term increases in soil organic C and N associated with intercropping



http://dx.doi.org/10.1111/gcb.12738

Benefits of intercropping

- Better resource capture and more efficient use of land
- Almost as good as the most productive and most efficient sole crop (TOI almost one)
- Thus: increases yield at the farm level, even if the yield at the crop level is diversified but not necessarily increased
- Allows reducing inputs if desired
- Provides other ecosystem services: disease and pest control, soil formation (organic matter)

Principles for productive and resource use efficient intercropping (speculation)

- Complementarity between species
- A difference in growing period (temporal complementarity) allows more light and nutrient capture
    - Works well in high input conditions
- A difference in nitrogen capture mechanism
    - Works well in cereal/legume intercropping at limited N availability
- A difference in water capture mechanism
    - Works well if one species can access water that another species cannot or does not, or not at the same time (perennial/annual mixtures)

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https://doi.org/10.1016/bs.agron.2019.10.002

Challenges

- Need to learn what intercropping system is good for each place and production situation. Need to optimize species combination and management: G*G*E*M.
- For strip intercropping: mechanization for narrow strips. Consider the labour use efficiency (not high)
- For full mixtures: consider the separation of grains or the use of mixed product
- Varieties that are suitable for intercropping, e.g. more shade tolerant soybean

Strip cropping in the Netherlands

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What are the benefits of growing multiple crop species together? - Science Journal for Kids and Teens

Lecture videos from online PhD school: https://www.youtube.com/channel/UCRxVldHWHJAoU8xHNZ0efCQ/videos

Intercropping and crop/tree mixture along the Yellow River in Gansu, China (photo: Li Long)