Role of Climate and Soil in Regulating Water Limitations to Crop Productivity

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CSIRO LAND AND WATER/SUSTAINABLE AGRICULTURE FLAGSHIP

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Presentation outline

- **Agriculture in semiarid regions**
- **Crop yield, water use, Water Use Efficiency (WUE)**
- **Role of climate /climate change (in regulating WUE)**
- **Role of soil and crop managements**
- **Summary**

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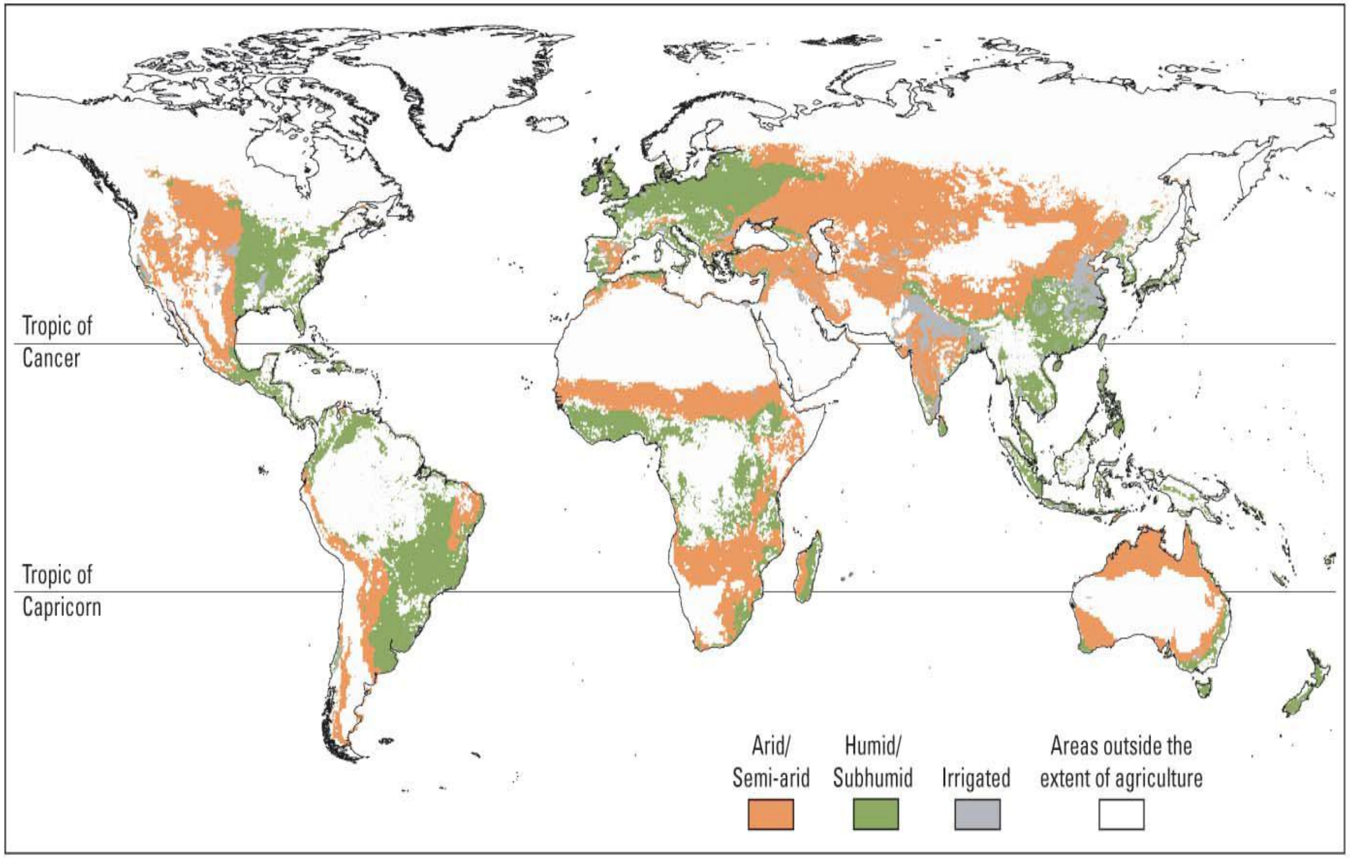
Semiarid Regions

Transition zone between arid and sub-humid regions



- **Low and restricted rainfall**
- **Abundant radiation and heat energy**
- **High potential evapotranspiration** (higher than rainfall)
- **High temperatures (30-40^{o}C) in hottest months**
- **Dry and wet period** – wet period 3-4 months (P>PET)
- **1/3 of the earth's land surface area**

Source: Sebastian 2007, based on GAEZ climate data from FAO/IIASA; GMIA irrigated area data from FAO; and cropping and pastureland data from Ramankutty/SAGE.
Note: Agricultural areas include those with at least 10 percent irrigated, cultivated, or grazing lands.

Agriculture in semiarid regions

- **High radiation & temperature** - high potential yield under **irrigation**
- **High evapotranspiration** – low groundwater recharge
- **Fragile ecosystems** - vulnerable to climate change

- **Water scarcity is the top limitation to crop production**
- **Poor soils also play an essential role**

Yield increase through:

- **Effective use of limited rainfall – increasing water use efficiency**
- **Soil improvement & fertiliser application – water limited potential**

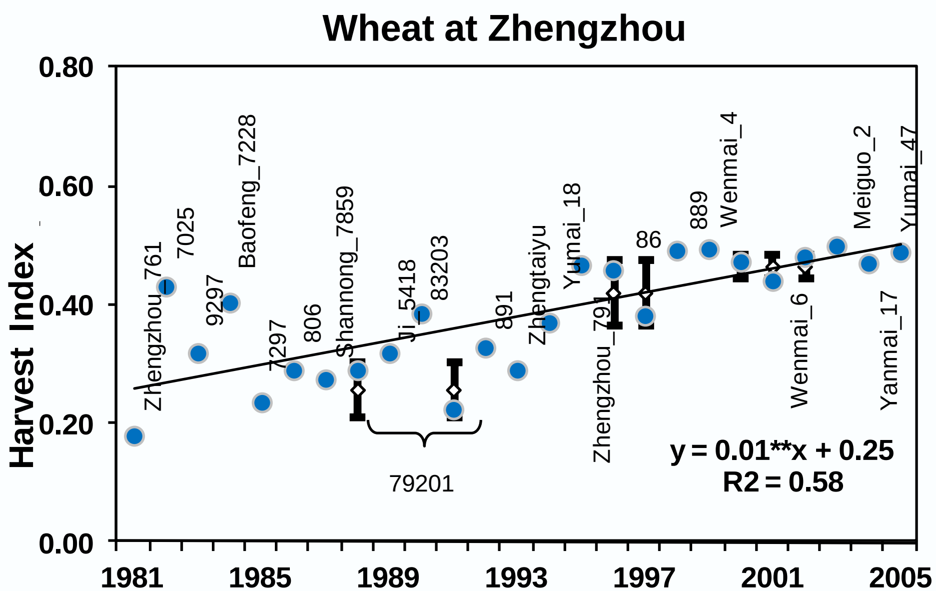
Water use efficiency

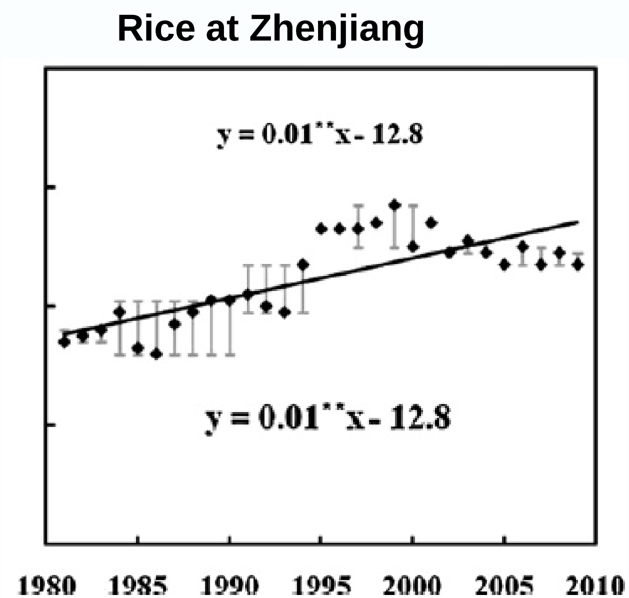
Water Use Efficiency	ET Use Efficiency	Transpiration Efficiency
$WUE_P = \frac{Y}{P+I}$	$WUE_{ET} = \frac{Y}{E+T}$	$WUE_T = \frac{Y}{T}$

Y – Yield, P – precipitation, I – Irrigation, T – Transpiration, E – Evaporation from soil

***Y = BM * Hi** (harvest index)*

Variety improvement led to significant increase in Hi thus WUE





Climate and soil impact on WUE

Water Use Efficiency	ET Use Efficiency	Transpiration Efficiency
$WUE_P = \frac{Y}{P+I}$	$WUE_{ET} = \frac{Y}{E+T}$	$WUE_T = \frac{Y}{T}$

Y – Yield, P – precipitation, I – Irrigation, T – Transpiration, E – Evaporation from soil

Increase Water Use Efficiency (WUE) means:

$$P+I \rightarrow E+T \rightarrow T \rightarrow BM$$

$P+I \rightarrow E+T$	$E+T \rightarrow T$	$T \rightarrow BM$
Climate (rainfall) pattern Soil water holding capacity Crop cover/rooting	Soil surface cover Soil nutrient levels Crop canopy cover	Climate condition (regulation) Crop physiology (limitation)

Climate regulation and crop water demand

$$WUE_T = \frac{Y}{T} = Hi\frac{BM}{T} = Hi\left(\beta\frac{\Delta C}{D}\right)$$

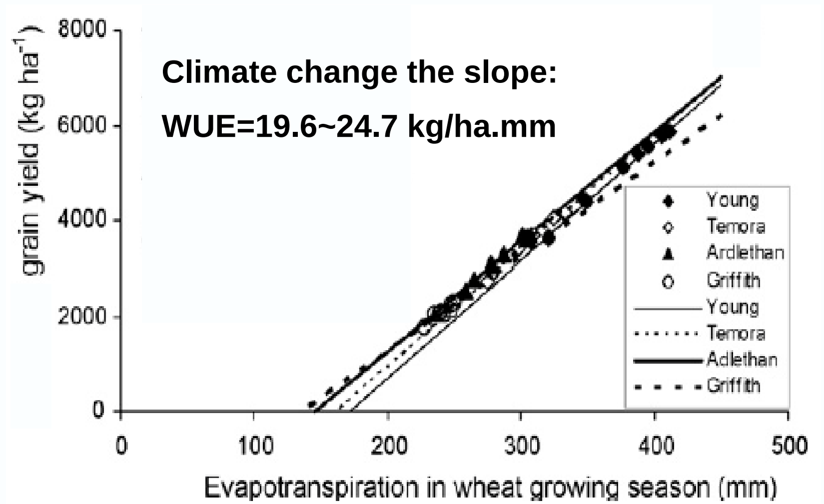
For a given crop genotype:

- ***Hi*** increase has a limit
- β is conservative, crop related
- Higher ***BM*** require more water
- Plants with higher ***WUE$_T$*** tend to use less water, but also produce less biomass

Wang et al (2004) Aust J Agr Res 55:1227-40

Climate /change impact - demand:

1. **Air wetness (D) variation and change**
   - **Drier climate - lower WUE**
   - **Wetter climate - higher WUE**
2. **CO_2 concentration (C)**
   - **Rising CO_2 increases WUE**
   - **But limited by photosynthesis capacity**

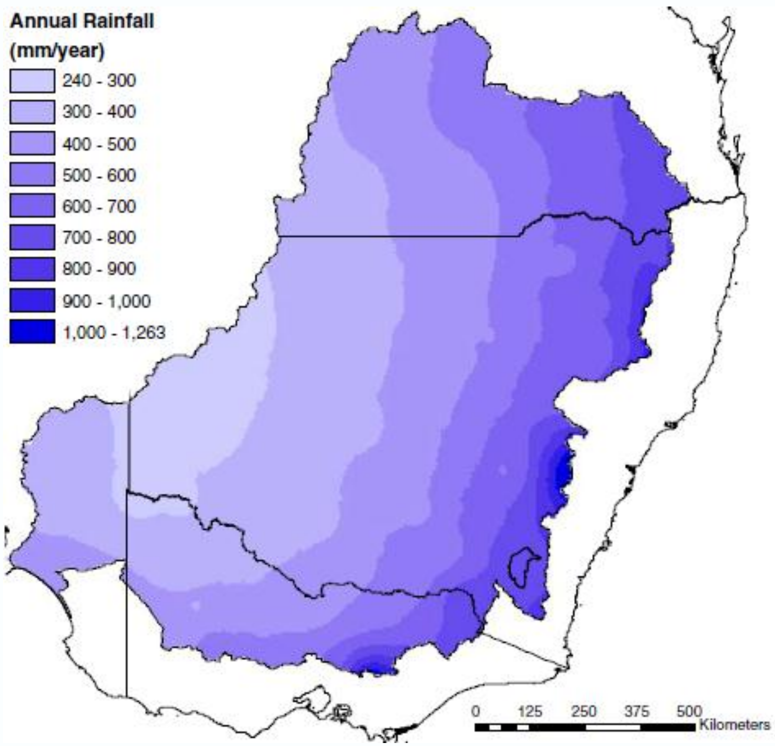


Murray Darling Basin (Australia) and North China Plain

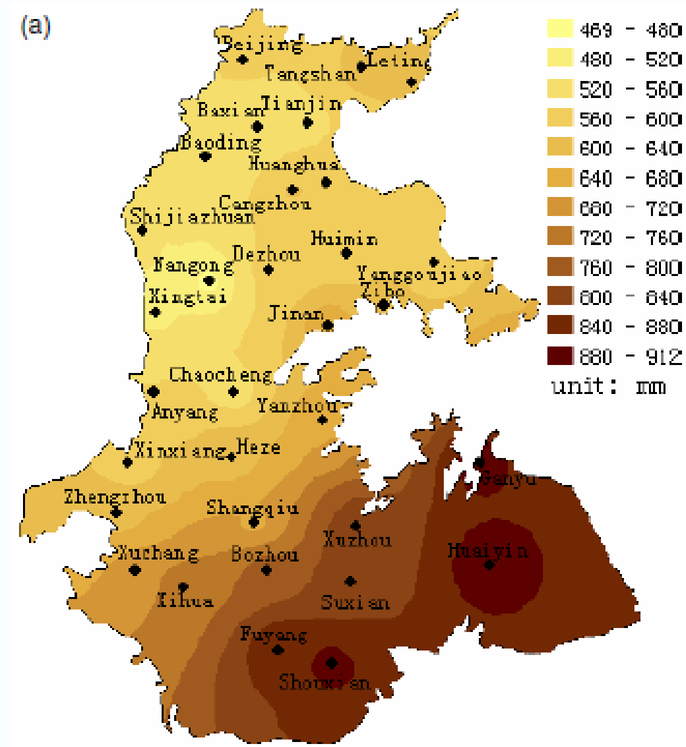
Annual rainfall spatial distribution

Murray Darling Basin

North China Plain



Wang et al (2009) Theor Appl Climatol 95: 311-330

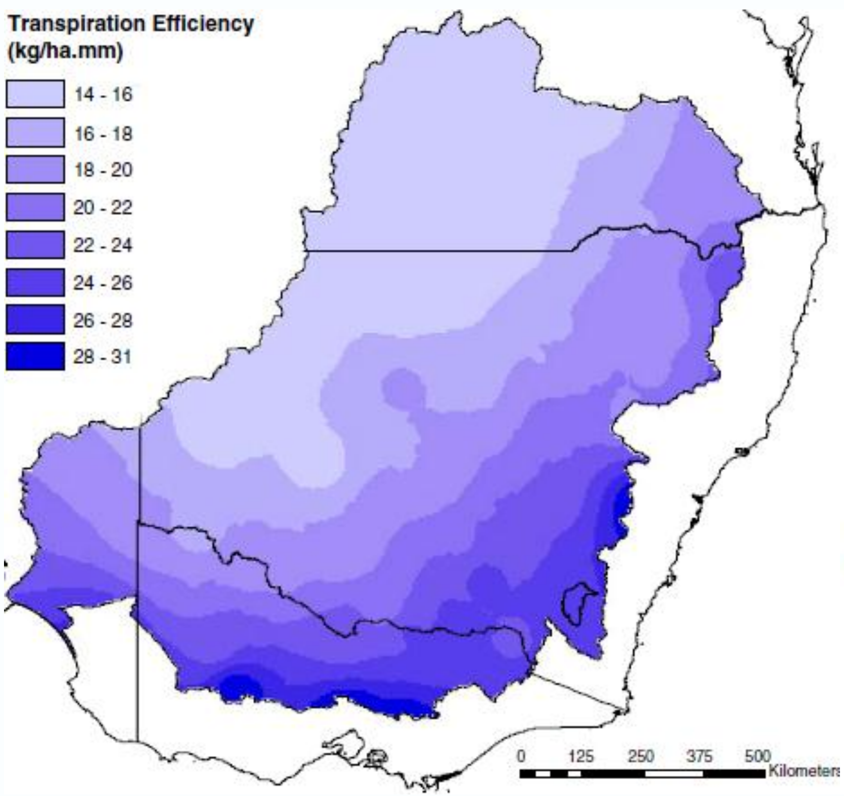


Wang et al (2008) Int J Climtol 28: 1957-70

Murray Darling Basin (Australia) and North China Plain

Transpiration efficiency of wheat crop

Murray Darling Basin



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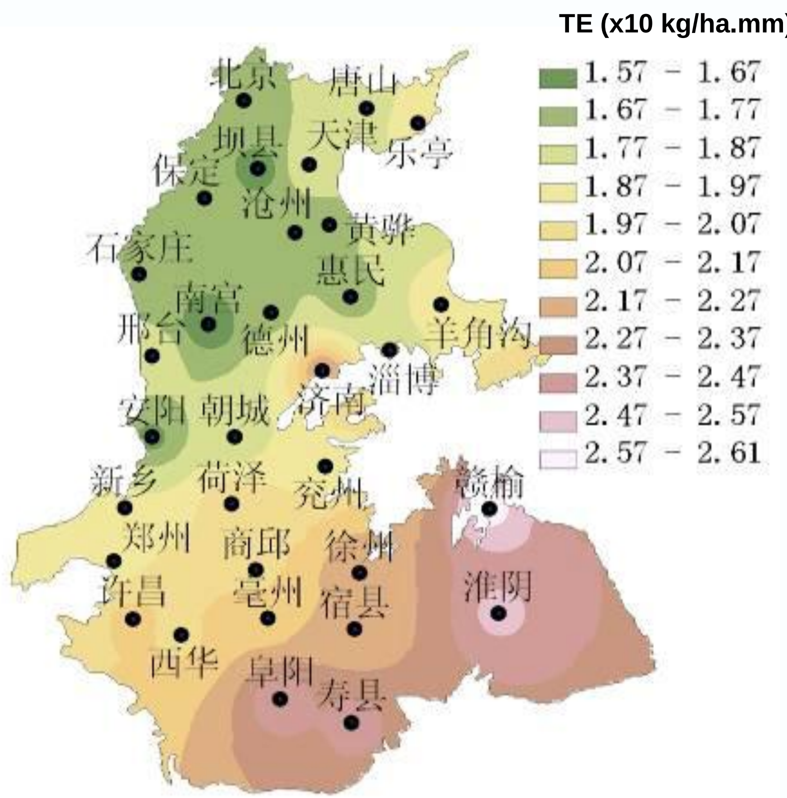
North China Plain

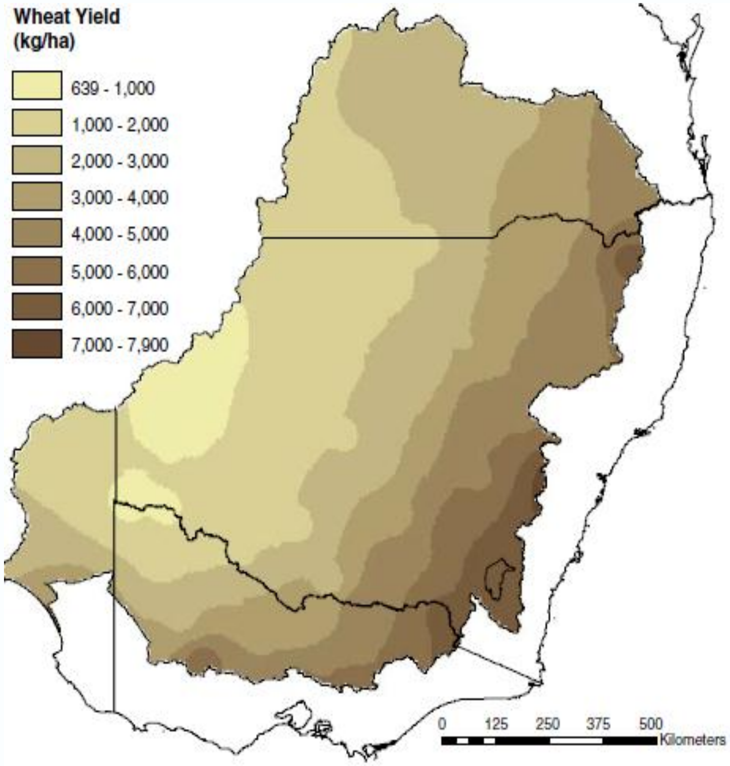


Chen(2009) PhD Thesis, CAAS, Beijing

Murray Darling Basin (Australia) and North China Plain

Wheat grain yield – water-limited potential

Murray Darling Basin



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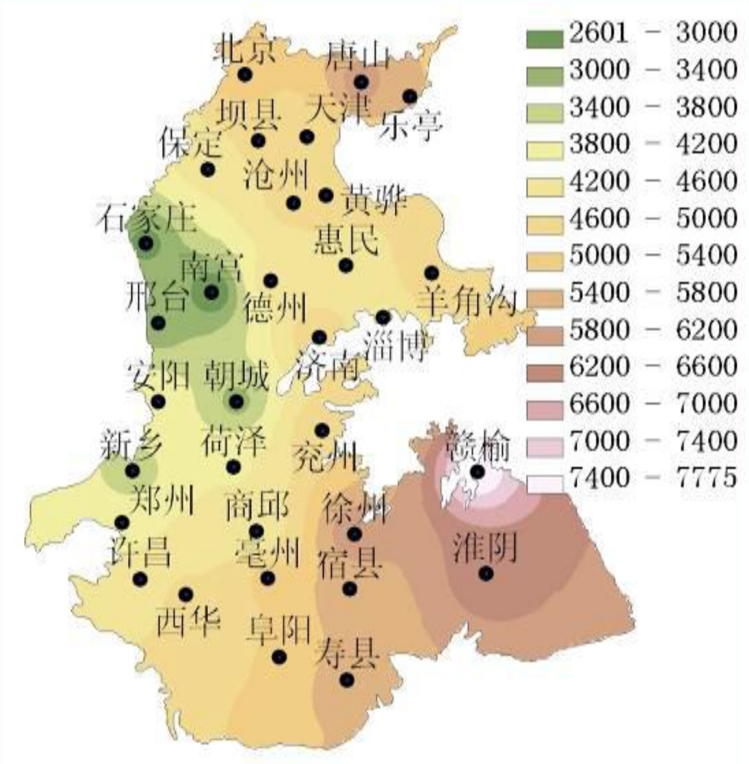
North China Plain

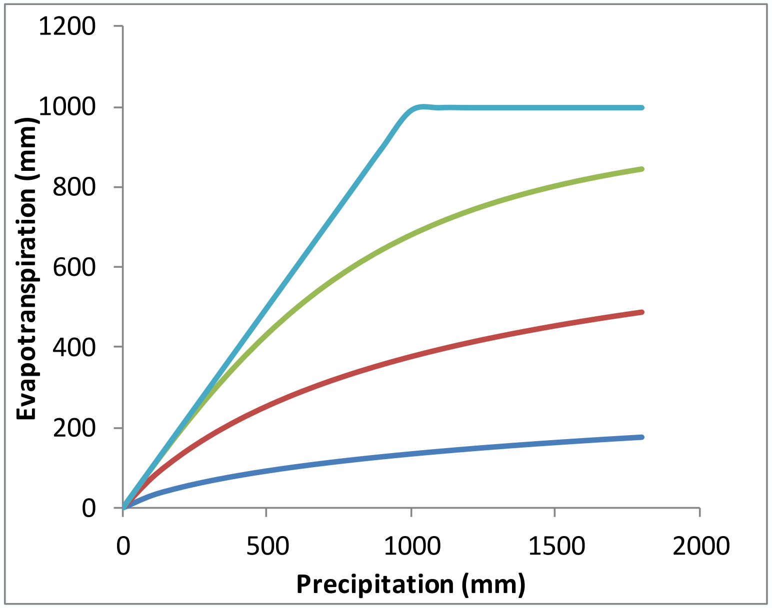
Wheat yield (kg/ha)

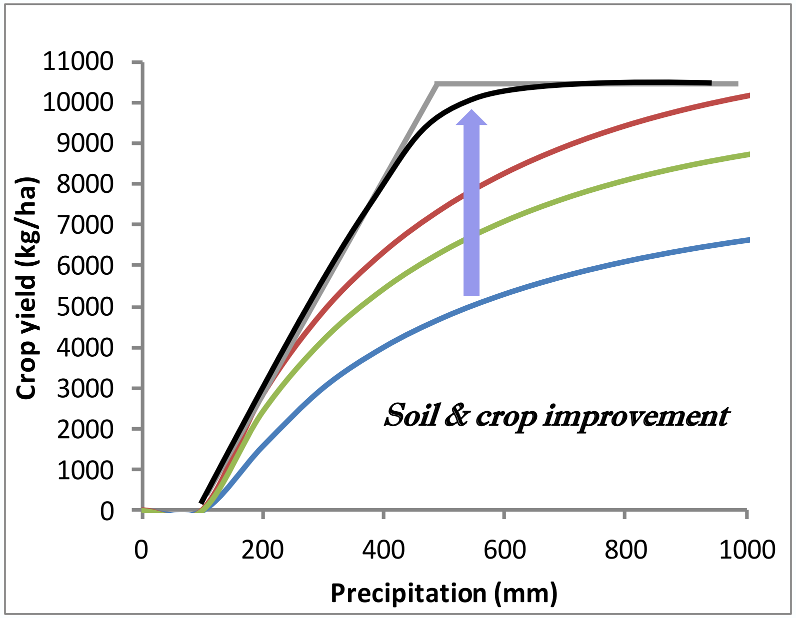


Chen(2009) PhD Thesis, CAAS, Beijing

Soil and crop managements - supply

1. Soil water holding capacity (PAWC) - (vegetation type)
2. Soil nutrient (N,P,K…) supply levels
3. Biotic stress (acidity, salinity, pests & diseases)
4. Runoff & drainage reduction
5. Out-seasonal water harvesting
6. Evaporation reduction

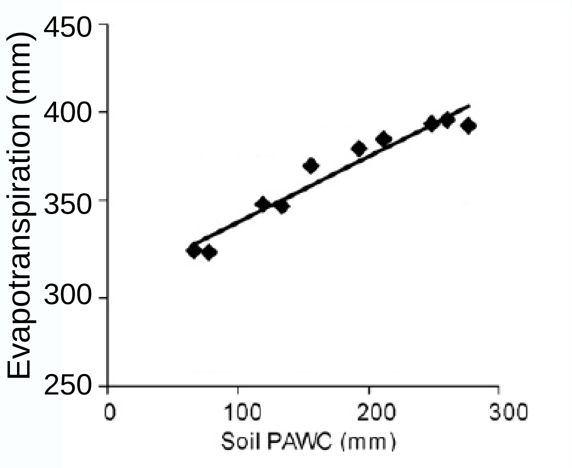


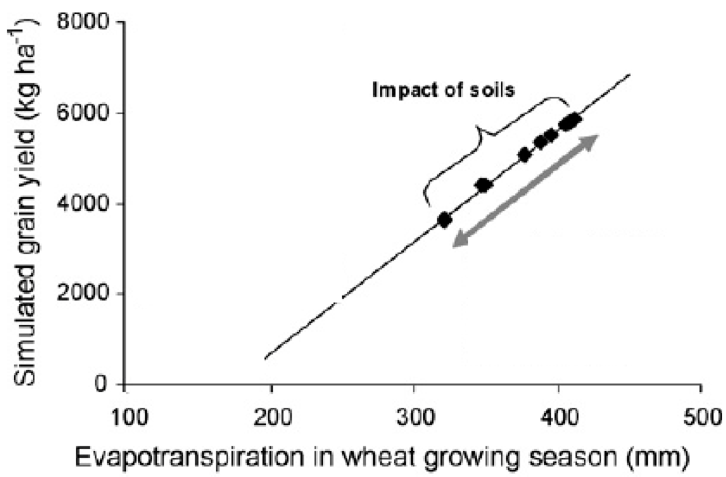


Murray Darling Basin (Australia) – dryland agriculture

Soil PAWC (Plant Available Water holding Capacity):

1. Higher soil PAWC increases evapotranspiration, thus crop yield, and WUE
2. Higher soil PAWC stores more water from fallow – water harvesting
3. Soil PAWC does not increase transpiration use efficiency, but reduces leakage
4. Soil PAWC is also linked to deeper plant rooting
5. Soil PAWC can be increased by mitigating sub-soil constraints



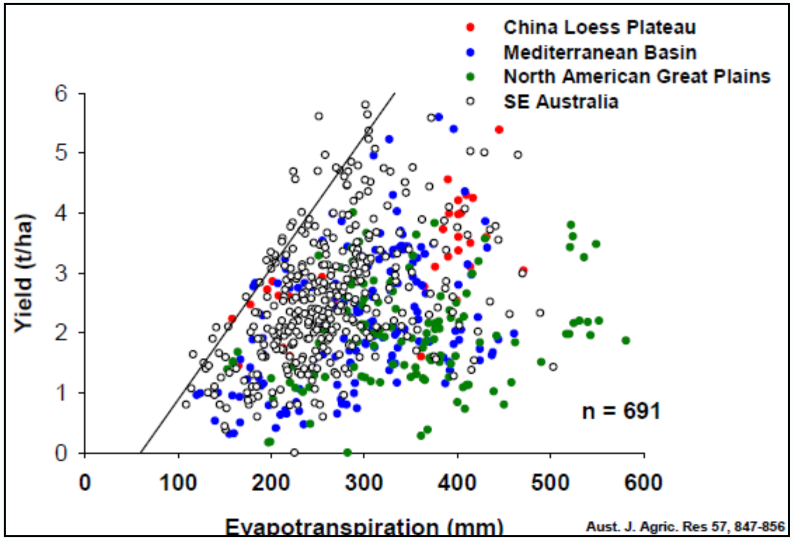


Wang et al (2009) Agr Forest Meteor 149: 38-50

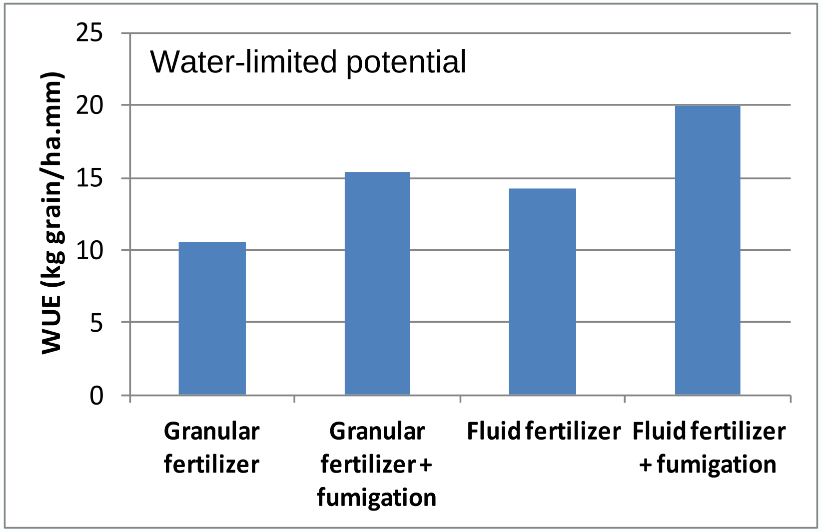
Murray Darling Basin (Australia) – dryland agriculture

Yield is blew the water-limited potential – big role of soil & crop managements

1. Fertilizer application optimized to achieve water limited yield
2. Fungicide, herbicide, and pesticide application to limit biotic stresses
3. Crops with early vigor can develop quickly to reduce evaporation from soil



Sadras & Anugs (2007)

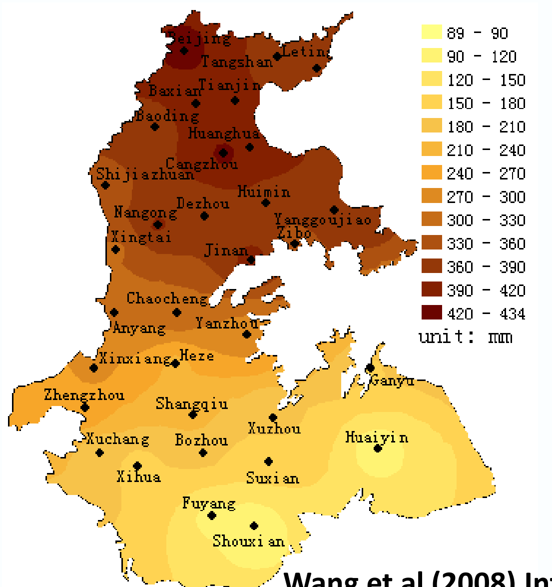


North China Plain – Wheat-Maize double cropping system

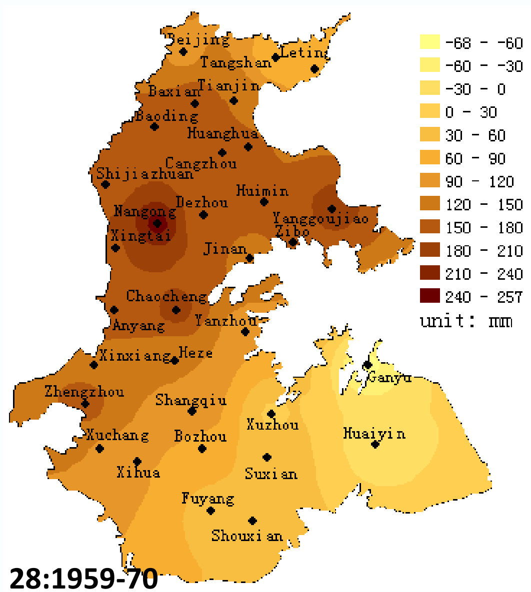
Crop water deficit to meet potential growth:

1. Water deficits exceed 300mm and 200mm for wheat and maize in northern NCP
2. Minimum runoff, reduced summer drainage, role of evaporation reduction
3. Even evaporation reduced to 0, still 200mm deficit for wheat, and 100mm for maize
4. Future projections indicates even drier climate in northern NCP

Wheat water deficit (mm/year)



Maize water deficit (mm/year)

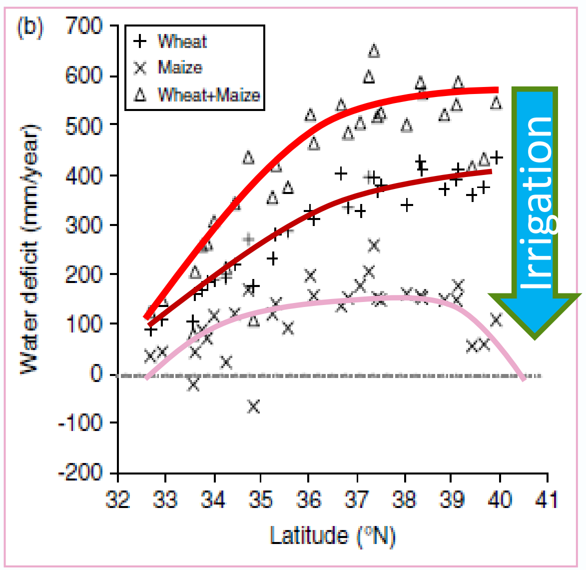


Wang et al (2008) Int J Climatol 28:1959-70

North China Plain – irrigation agriculture

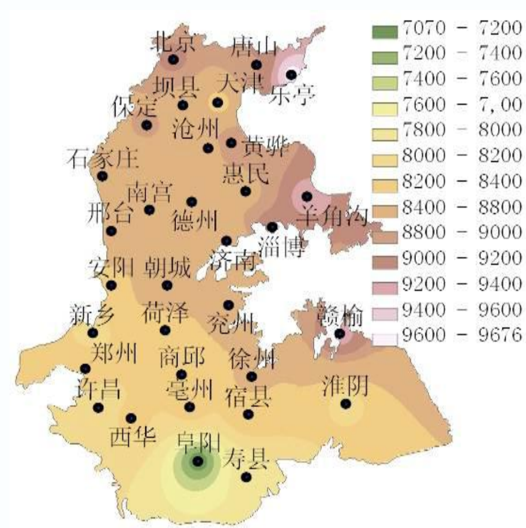
High water and nutrient inputs:

1. Irrigation reduced water stress for wheat and maize crops
2. Yield of both crops reaching 8~10t/ha
3. Groundwater table drops rapidly (>1m/year at Luancheng)
4. Significant hydrological and nutrient imbalances



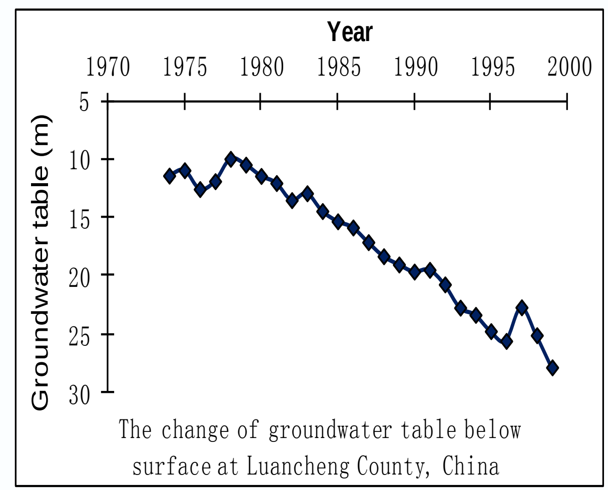
Wang et al (2008) Int J Climatol 28:1959-70

Irrigated wheat yield (kg/ha)



Chen(2009) PhD Thesis, CAS, Beijing

Groundwater depletion

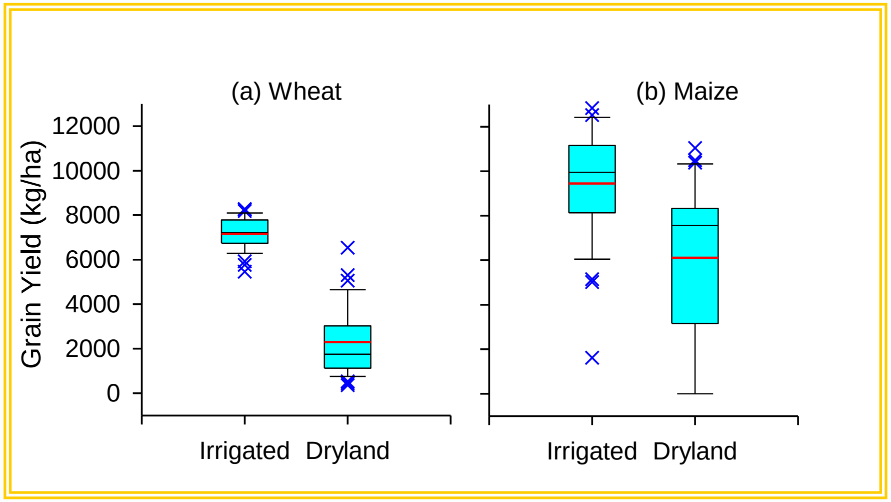


North China Plain – Sustainable yield target

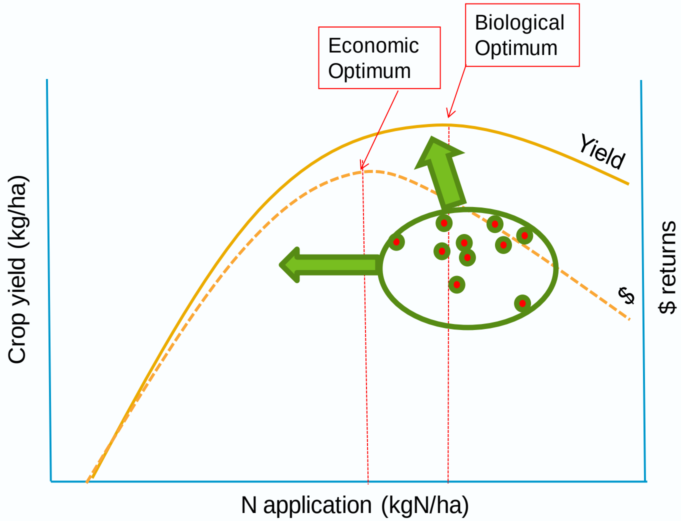
Water, Soil & Crop managements:

1. Current irrigated yield targets not sustainable due to depletion of groundwater
2. Reduction in irrigation inevitably reduce yield & increase yield variability
3. Many areas with crop yield below water-limited potential
4. Soil nutrient management - large rooms to increase yield & nutrient use efficiency

Reduction in Crop Grain Yield:
Wheat: 68%, Maize: 35%



Better nutrient management



Summary

- **In many areas, crop yields are still below water-limited potential defined by genotype and climate**
- **Crop transpiration efficiency (TE) is conservative, but can be regulated by climate and future climate change**
- **Soil management can play a key role in increasing water use efficiency & crop yield, through minimizing water losses**
- **Sustainable agricultural development needs to match crop yield target to regional climate, soil and water resources**
- **Further research to quantify transpiration and evaporation from evapotranspiration may help define what is achievable**

Thank you

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