China-Chile Workshop on Water Resources Management

Deficit irrigation and its approaches for improving water use efficiency in agriculture

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Outline

- Agricultural water use in world and China
- Deficit irrigation for improving WUE
- The approaches for deficit irrigation scheduling

  - Weather based: modeling of SPAC energy balance

  - Soil based: direct measurement of soil moisture

  - Plant based: measurement of plant water status and plant response to available water
- Technologies for deficit irrigation practice
- Future developments and possible collaborations

1. Agricultural water use in world and China

Agricultural water use for global food security

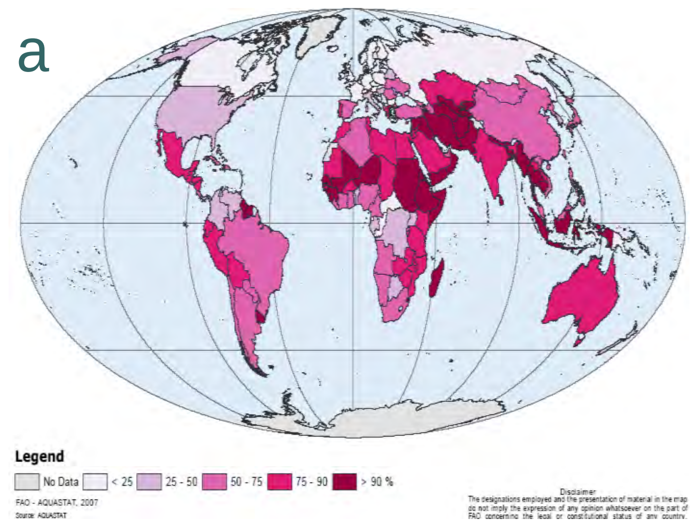
- Water for agriculture accounts for 70%-95%
- 1 kg cereal needs 1-3 tons water
- 2000—5000 L water produces a person’s daily food
- 70% cereal production come from irrigated land
- Drought decreases crop yield mostly

More crop per drop

(FAOWATER, 2008)

1. Agricultural water use in world and China

Water use in agriculture accounts for a large proportion of total water use



Word:

More than 70% total water

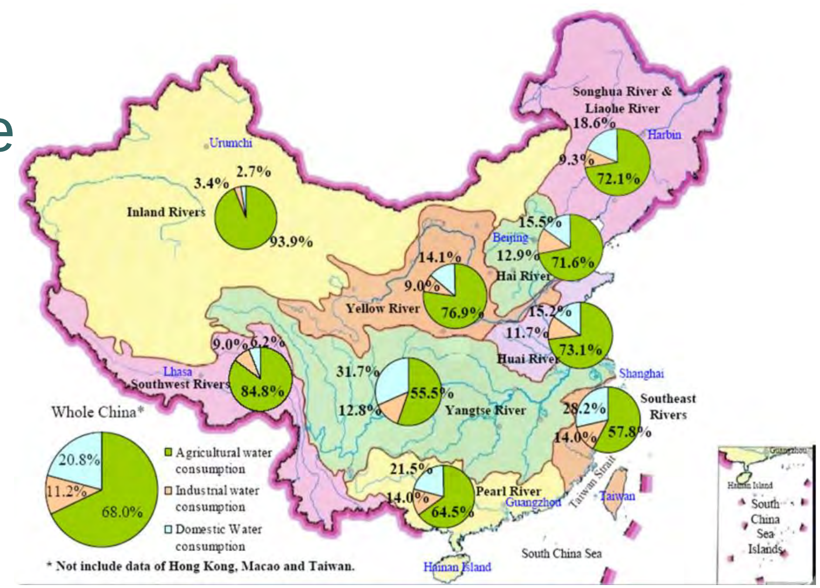
consumption is for Agriculture

China:

63% of total water is for agriculture

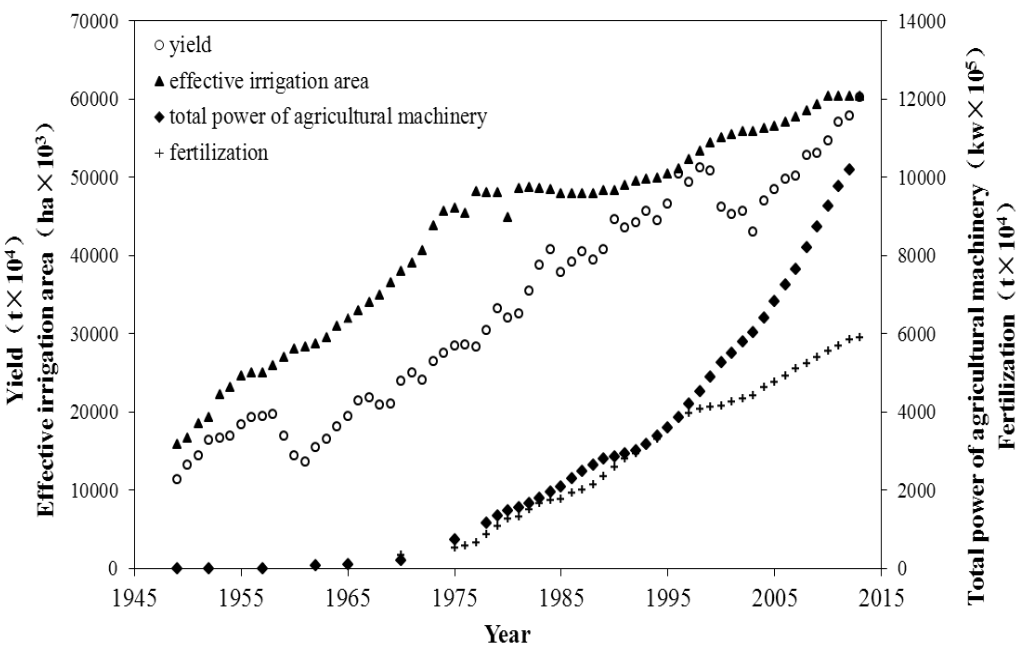
90% in Northwest China

75% in North China

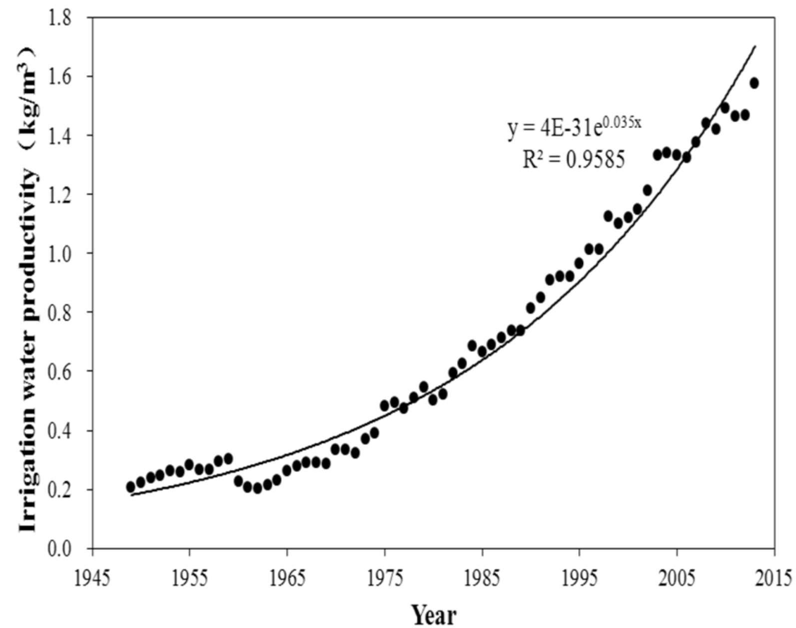


Contribution of irrigation to food security and IWP in China

- **In China, more than 60 million ha cultivated land is irrigated, accounting for 49% of total cultivated area, which produces more than 75% of total grain production and 90% of cash crop production.**
- **Irrigation plays a prominent role in ensuring food security.**

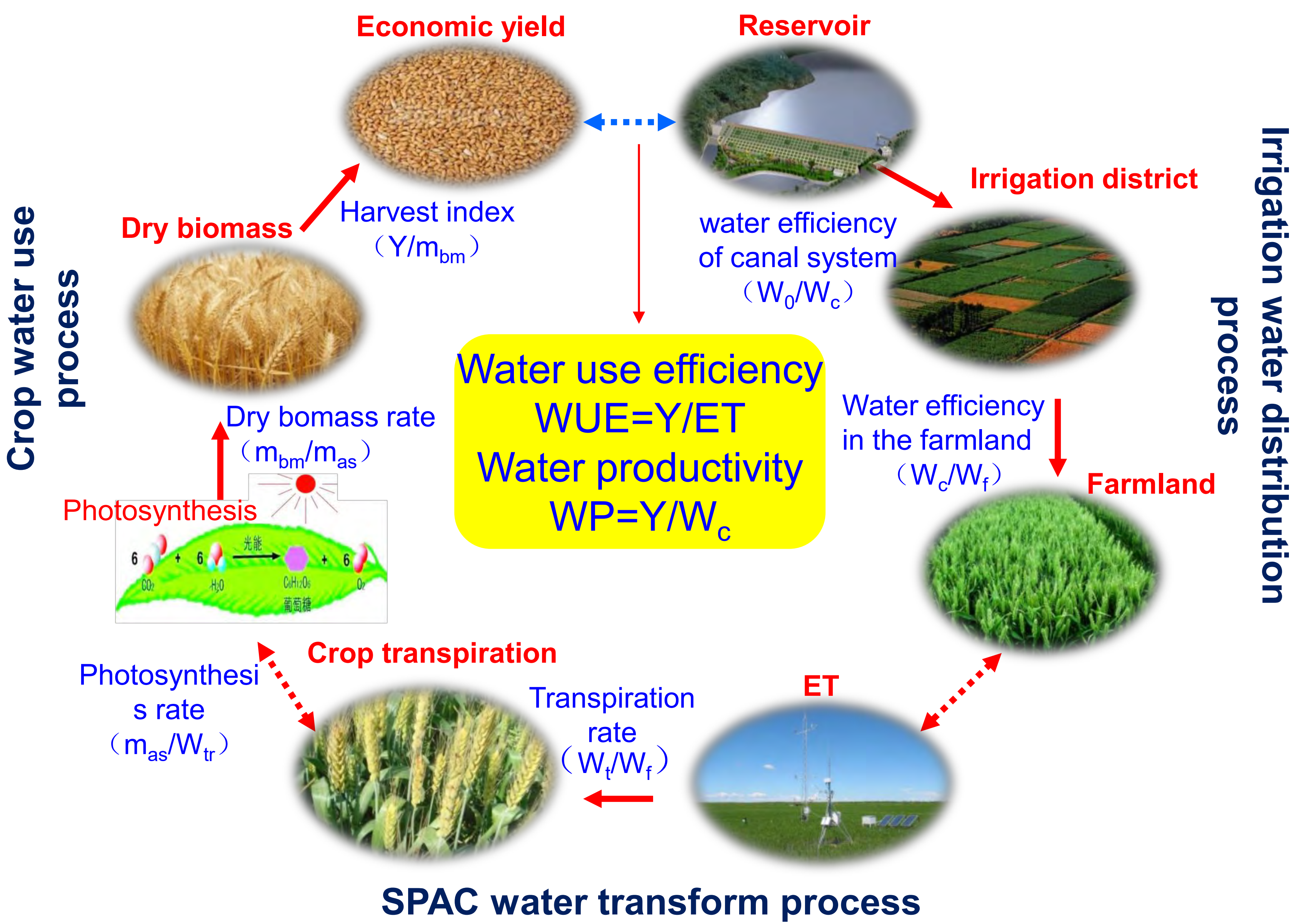


Evolution of total grain crop yield and effective irrigation area, fertilization amount and total power of agricultural machinery in China during the period of 1949–2013. Source: The National Bureau of Statistics of China.



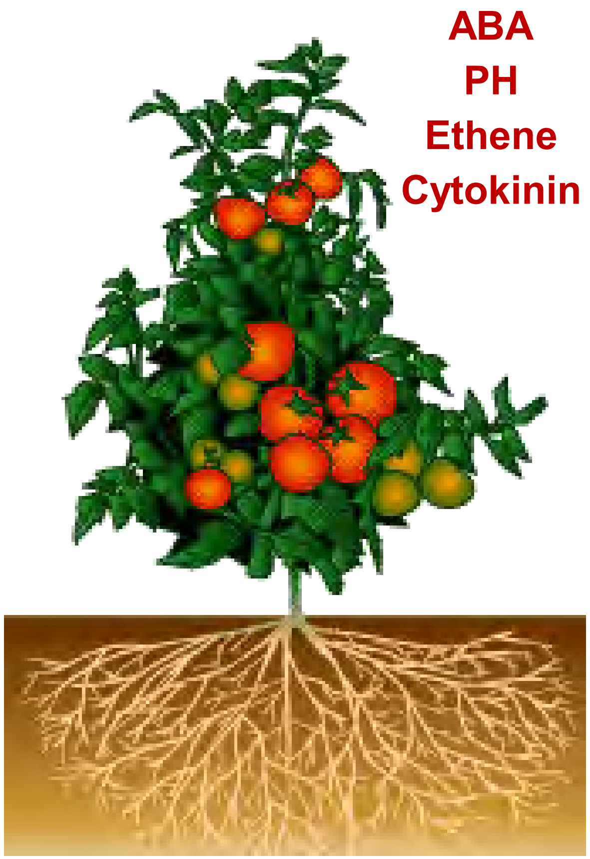
Evolution of irrigation water productivity for grain crops in China during1949–2013. IWP equals to the total grain crop yield divide by the total irrigation water use for grain crops.

Improving WUE in agriculture: from regional to crop scale

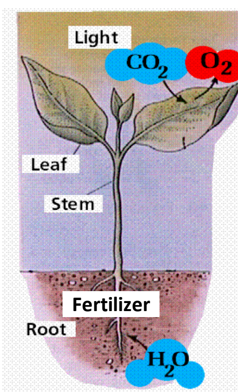


2. Deficit irrigation for improving WUE

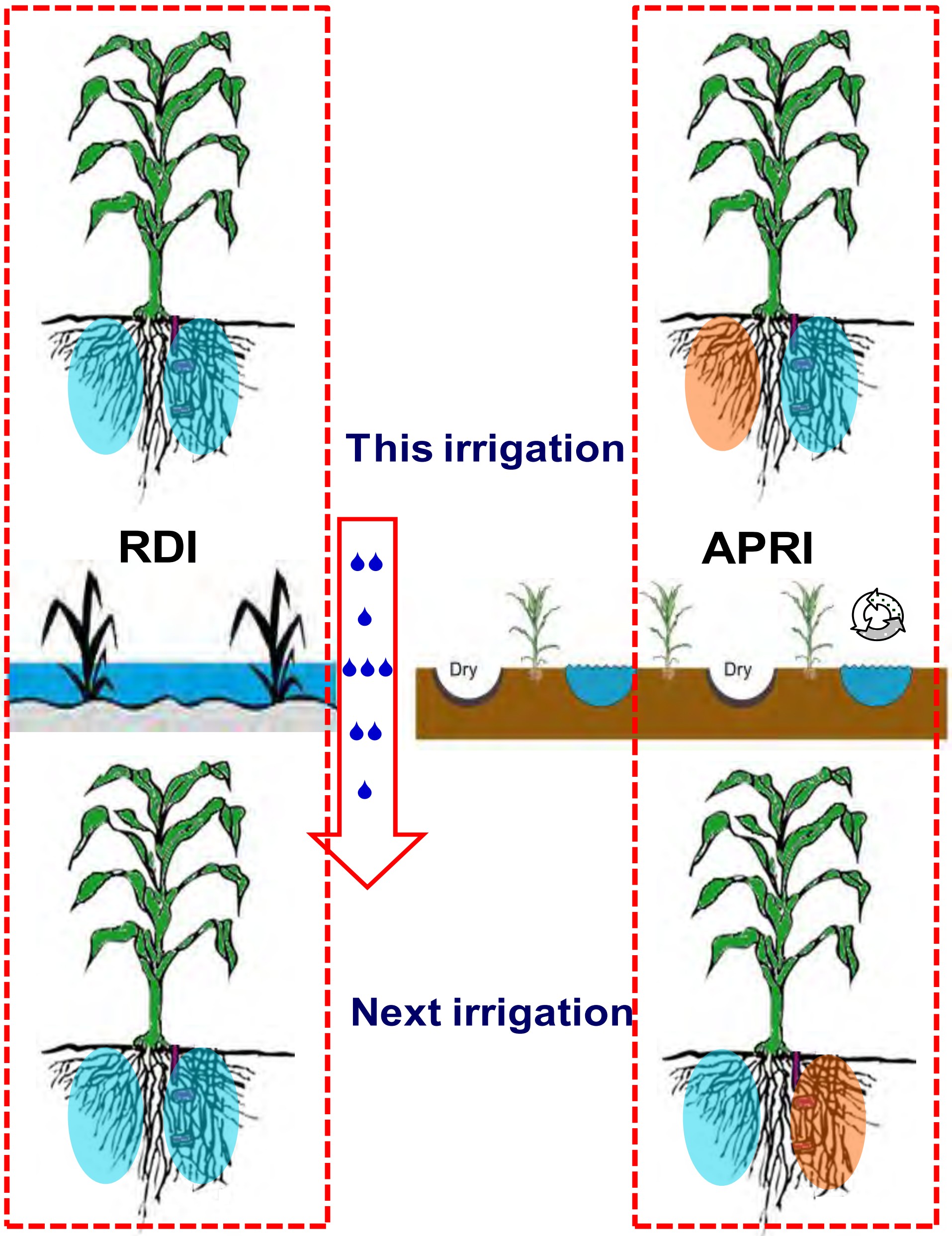
- **Crops have perception to information of water, fertilizer, gas and heat in the environment**
- **Crops have its own regulating and adapting ability**
- **The formation of crop yield and quality is the result of synergistic effect of multi-factors in SPAC**
- **The crops' water use process should be taken into account for 'scientific irrigation'**



If the crops could talk…, what would they say?



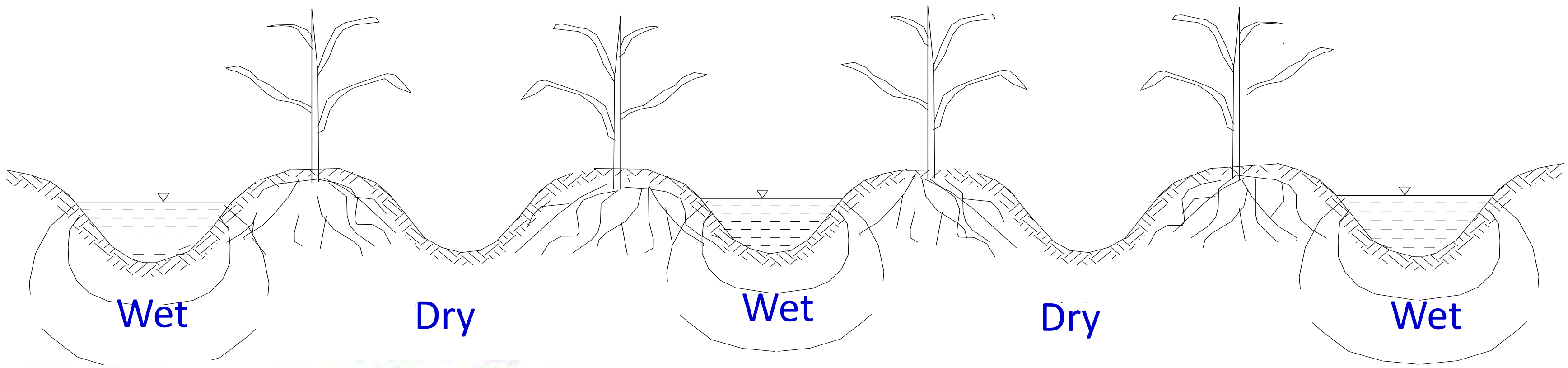
2. Deficit irrigation for improving WUE

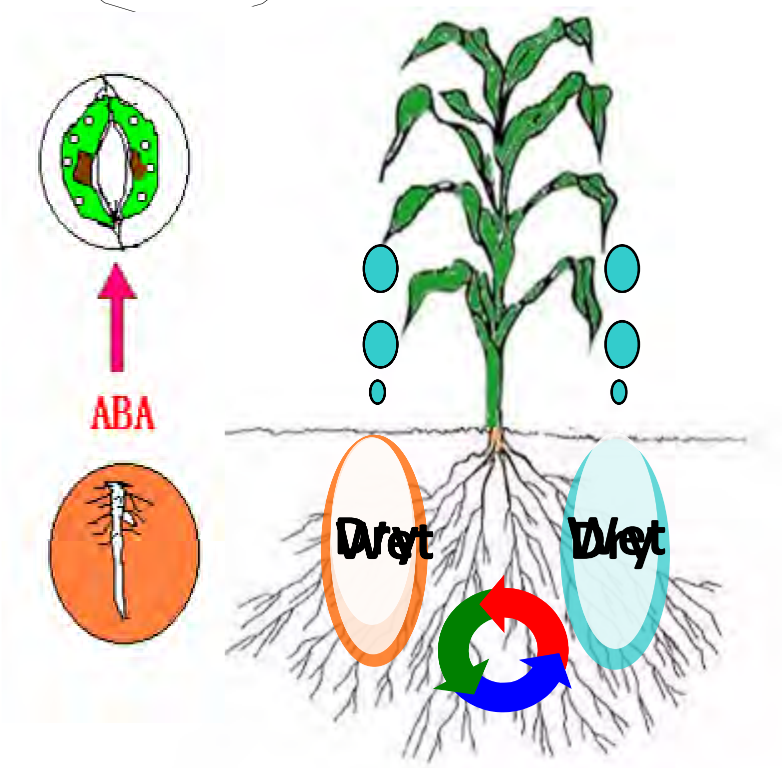


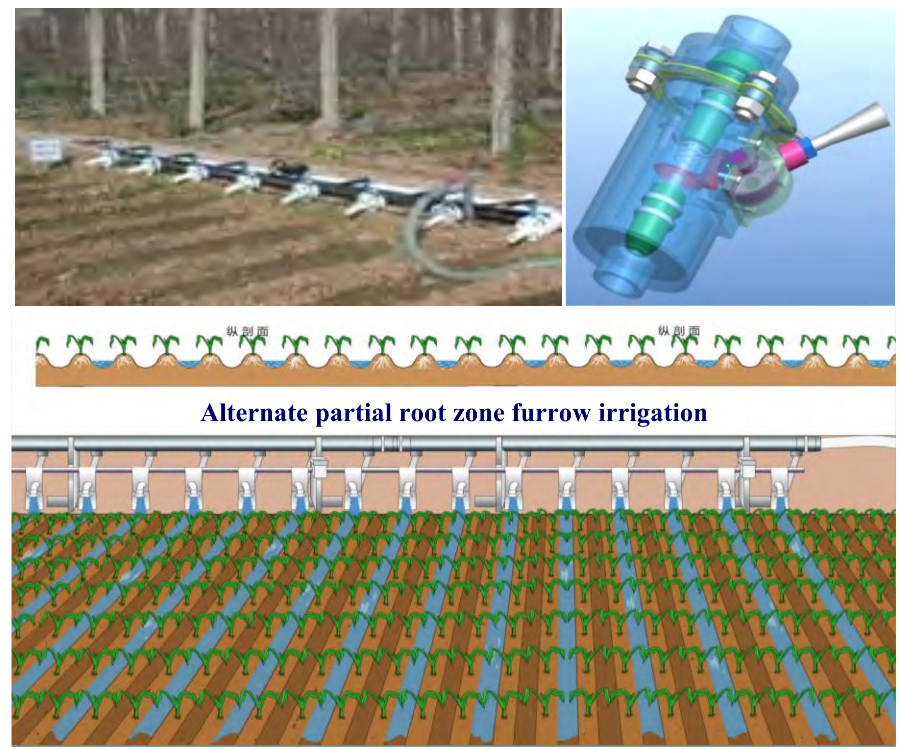
RDI: Water stress on crops is manipulated over different growth stages, but irrigating in the whole root zone to control reproductive and vegetative growth.

APRI: The plant growth was modified by keeping part of the root zone dry and the rest of the root zone well watered alternately, which was derived from the split-root research.

● Hot research topic: Practice of APRI







Du TS, Kang SZ, Zhang JH, et al., 2015, Journal of Experimental Botany, 66: 2253-2269.

➢ Mild water deficit at earlier stage is a better choice for grain yield and WUE of summer maize.

No.	Treatments	Soil water content maintained (% θ_f)			
		Seedling-Stem elongation	Stem elongation-Booting	Booting-Milking	Milking-Harvesting
1	NNNN	65	70	75	70
2	MNNN	60	70	75	70
3	SNNN	50	70	75	70
4	NMNN	65	60	75	70
5	NSNN	65	50	75	70
6	NNMN	65	70	60	70
7	NNSN	65	70	50	70
8	NNNM	65	70	75	60
9	NNNS	65	70	75	50
10	MMMM	55	60	60	50

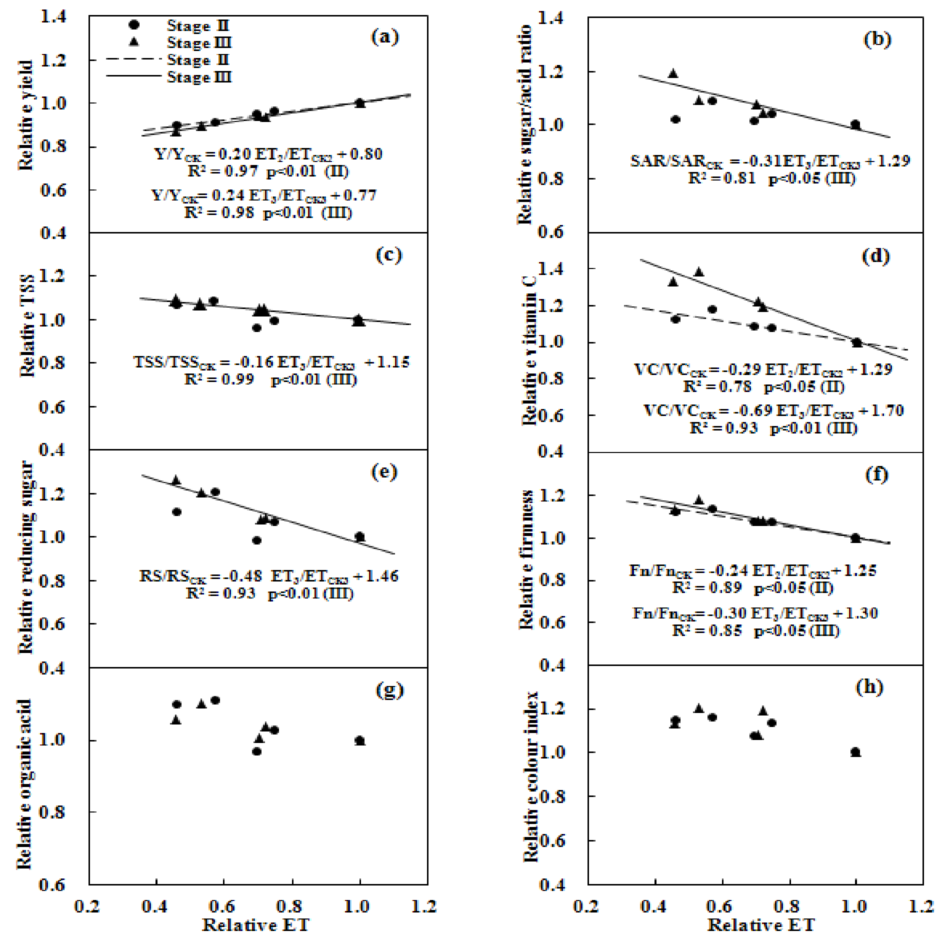
Grain yield and WUE of summer maize under RDI

Treatments	NNNN	MNNN	SNNN	NMNN	NSNN	NNMN	NNSN	NNNM	NNNS	MMMM
Grain yield(t/hm^2)	6.695	6.215	5.750	5.695	5.225	5.965	5.390	5.115	4.247	3.409
ET(mm)	382.4	343.9	347.9	332.4	328.8	362.9	342.3	281.9	227.7	203.6
WUE(kg/m^3)	1.75 ab	1.81 a	1.65 ab	1.71 ab	1.59 b	1.64 ab	1.57 b	1.81 a	1.86 a	1.67 ab
WUE increment(%)	0.00	3.22	-5.61	-2.16	-9.25	-6.12	-10.07	3.64	6.51	-4.37

Du TS, Kang SZ, Sun JS, et al., 2010. Agricultural Water Management, 97(1): 66-74.

➢ RDI at different growth stage on tomato yield and quality

- ✓ Tomato yield was affected by water deficit during flowering (Stage I), fruit development stage (Stage II) and fruit maturation stage (Stage III).
- ✓ However, fruit quality (TSS, Reducing sugar, V_C et al.) was mainly affected by water stress during Stage III.

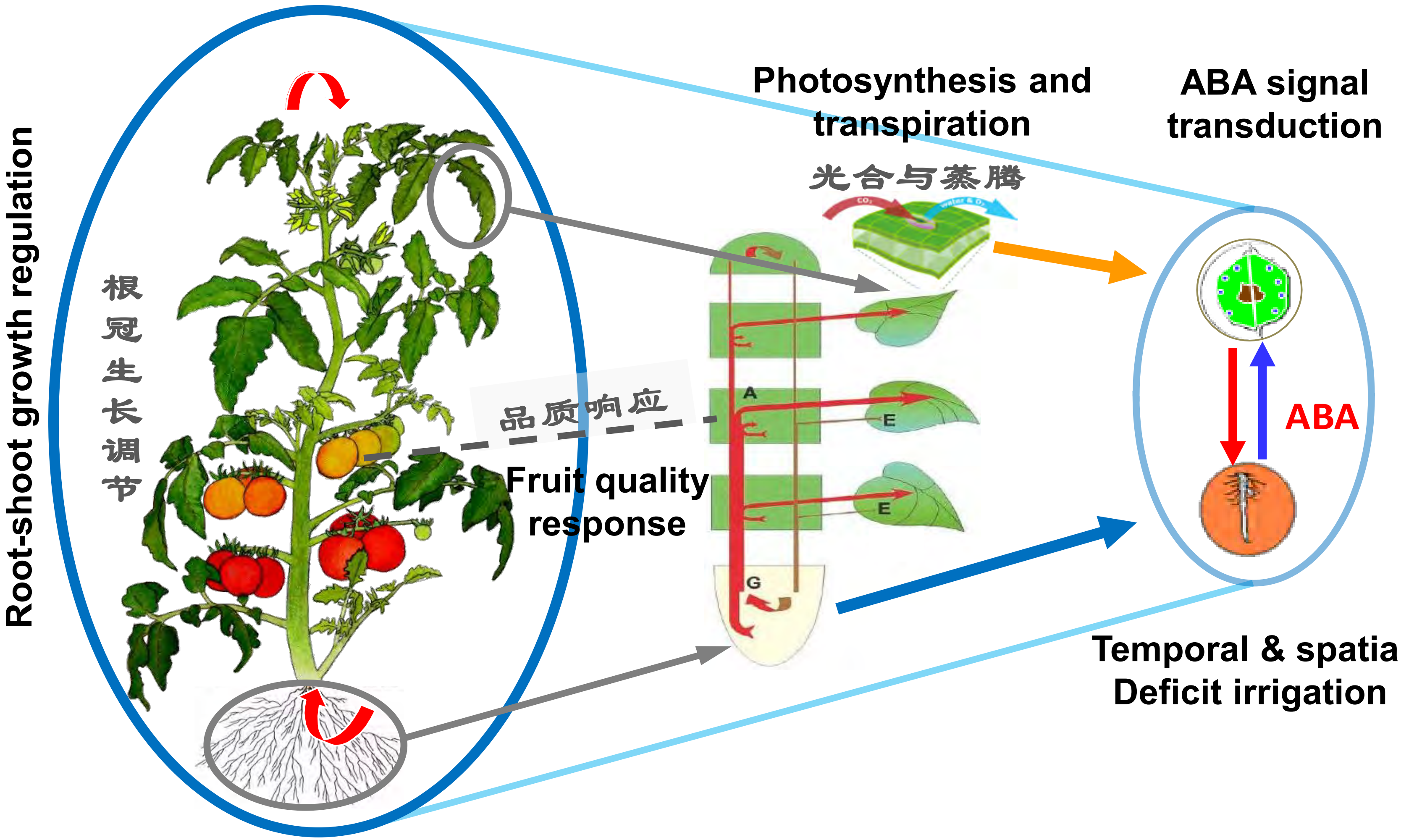


Relationships between relative yield, quality parameters and relative ET at Stage II and Stage III.

Chen JL, Kang SZ, Du TS, et al., 2013. Agricultural Water Management, 129: 152-162.

● Hot research topic: Relationship between yield and fruit quality

Deficit irrigation for improving fruit quality and WUE based on crops water use regulation and water-fruit quality response

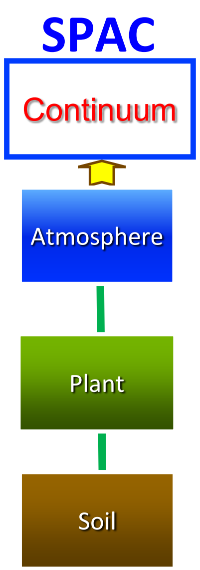


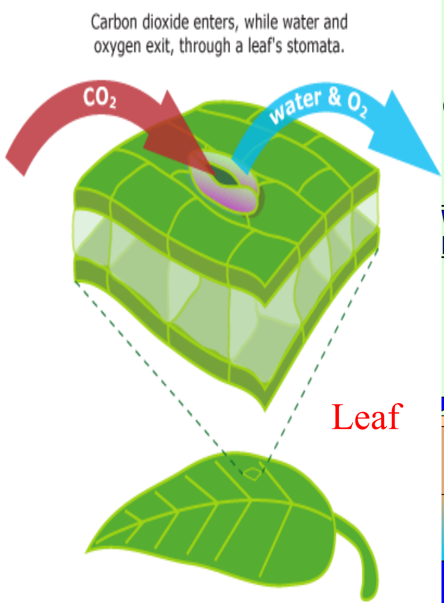
Du TS, Kang SZ, Zhang JH, et al., 2015, Journal of Experimental Botany, 66: 2253-2269.

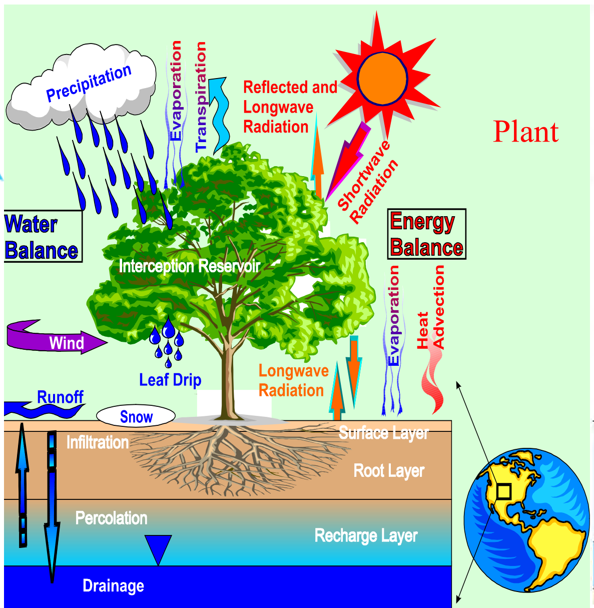
3. The approaches for deficit irrigation scheduling

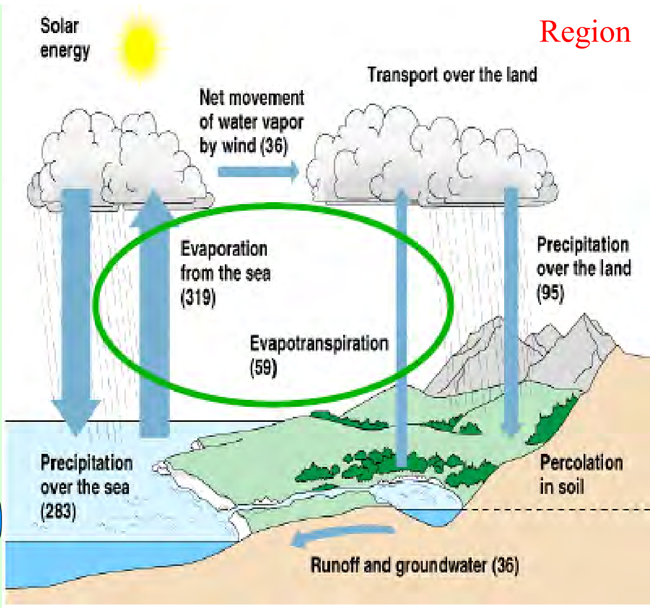
3.1 Weather based: modeling of SPAC energy balance

- **Important system of surface energy exchange**
- **Key issue of water resources allocation in the catchment**
- **Scientific basis for efficient water use in agriculture**
- **Information for farmland water management**
- **Determining factor of irrigation district engineering**







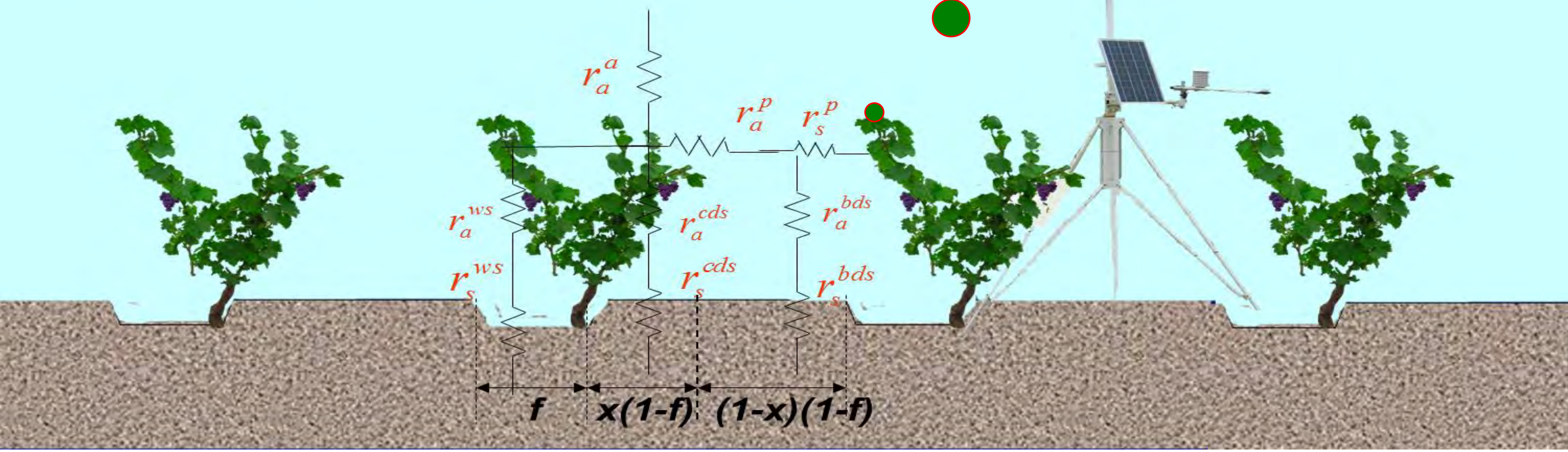


Canopy flux measurements in vineyard

➢ An evapotranspiration (ET) model for sparsely vegetated canopies under partial root-zone irrigation (PRI-ET)

This model considered differences in soil water content between furrow-irrigation ditch and ridge under the PRI scheme and variable canopy shading over the surface.

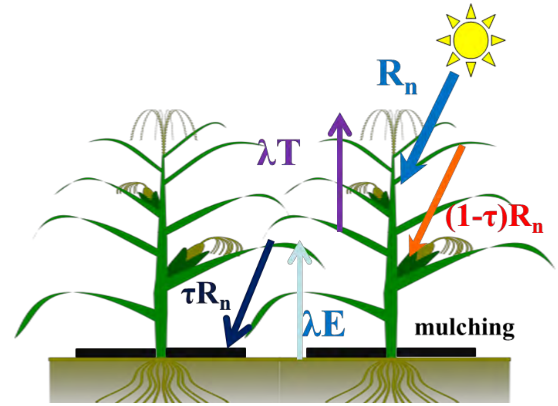
$$\lambda ET = x(1-f)C^{p}PM^{p} + fC^{ws}PM^{ws} + x(1-f)C^{cds}PM^{cds} + (1-x)(1-f)C^{bds}PM^{bds}$$



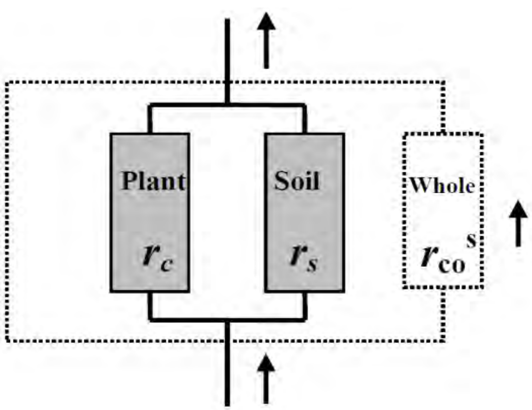
Zhang BZ, Kang SZ, Li FS, et al., 2008. Agricultural and Forest Meteorology, 148: 1629-1640.

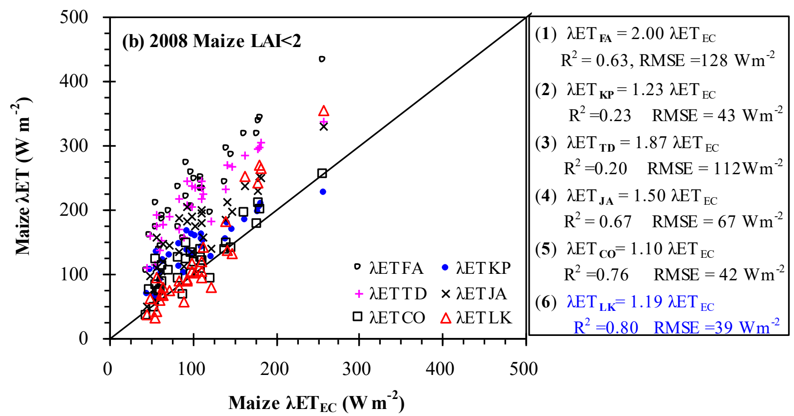
✦ Dynamic coefficient PT model

- **Improving from a constant coefficient in original Priestley–Taylor (PT) model, a dynamic coefficient PT model, incorporating the effect of leaf area, soil moisture, mulching fraction and leaf senescence on ET, was developed.**



- **By combining the Jarvis canopy resistance model and the soil resistance model, a coupled surface resistance model to calculate surface resistance in Penman-Monteith equation, was developed.**

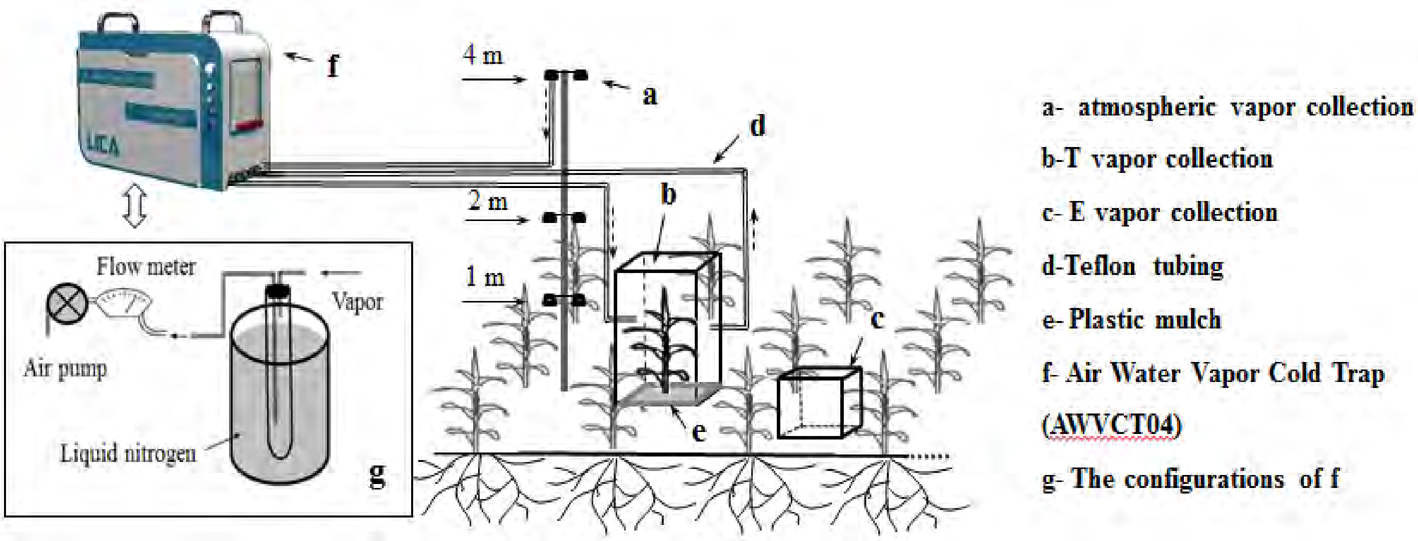




Ding RS, Kang SZ, Li FS, et al., 2013. Agricultural and Forest Meteorology, 168: 140-148.

Li SE, Kang SZ, Du TS, et al., 2013. Journal of Hydrology, 489: 124–134.

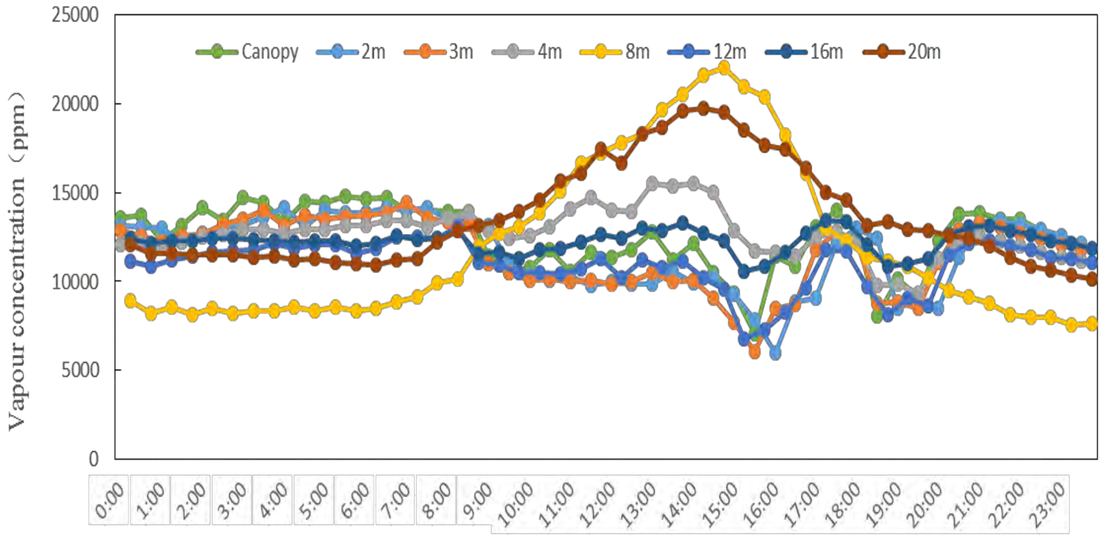
ET Model based on stable isotopes

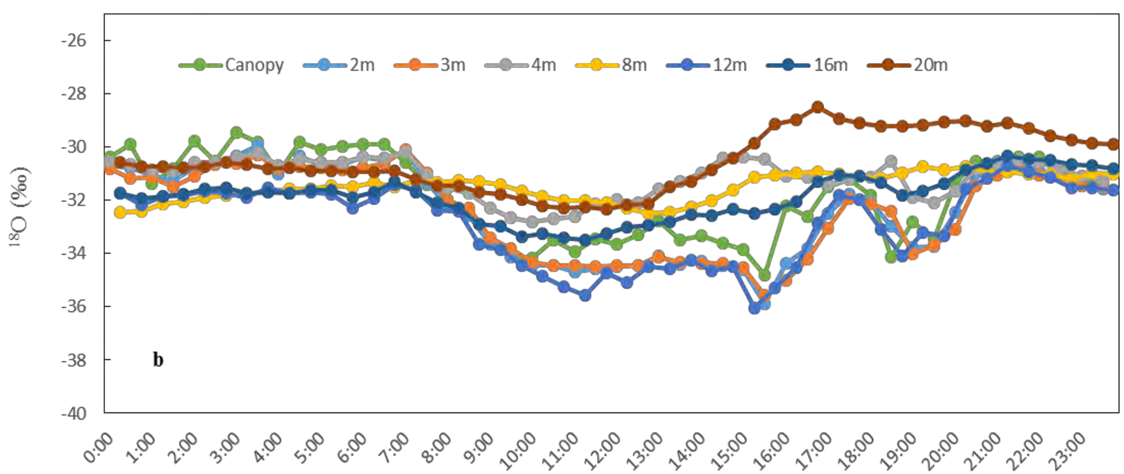


Field experiment configurations for water vapor samples collection
(Using our dynamic chamber measurements system)

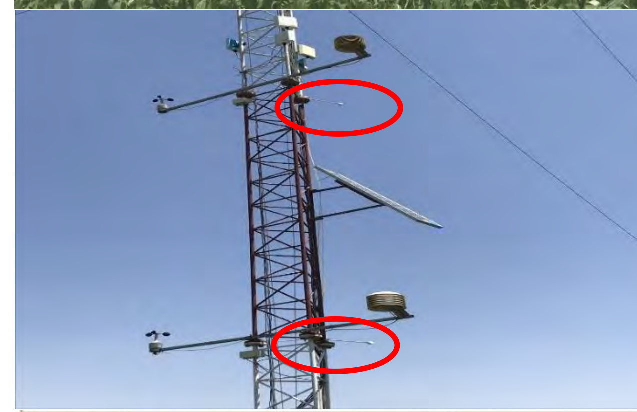
Wu YJ, Du TS, Ding RS et al., 2017. Journal of Hydrometeorology, 18: 139-149.*

✦ **The continuous isotope flux system combine with vapor inlet, heat retaining tube, and vapour isotope analysis model.**





Yuan YS, Du TS, Lin WQ et al., unpublished data.*



3. The approaches for deficit irrigation scheduling

3.2 Soil based: direct measurement of soil moisture

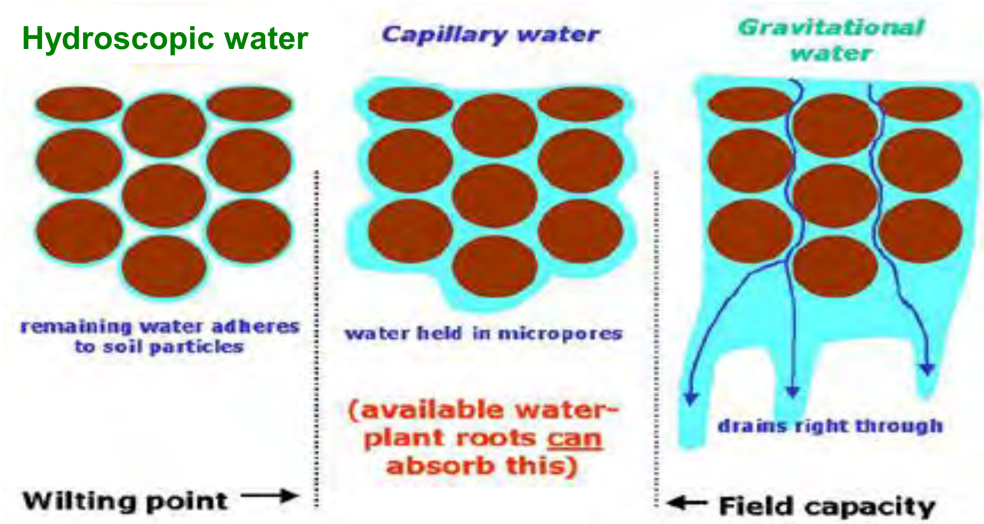
$$ET_a = P + I + \Delta W - R - D$$

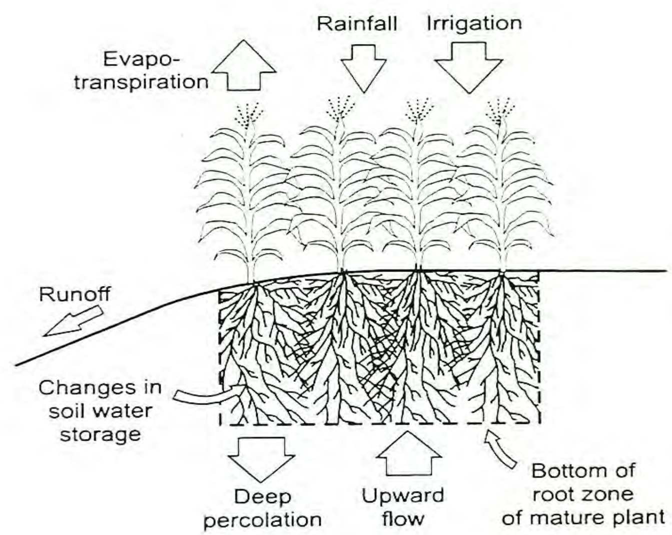
Subscripts:

ET_a is actual crop evapotranspiration (mm); P is precipitation (mm);

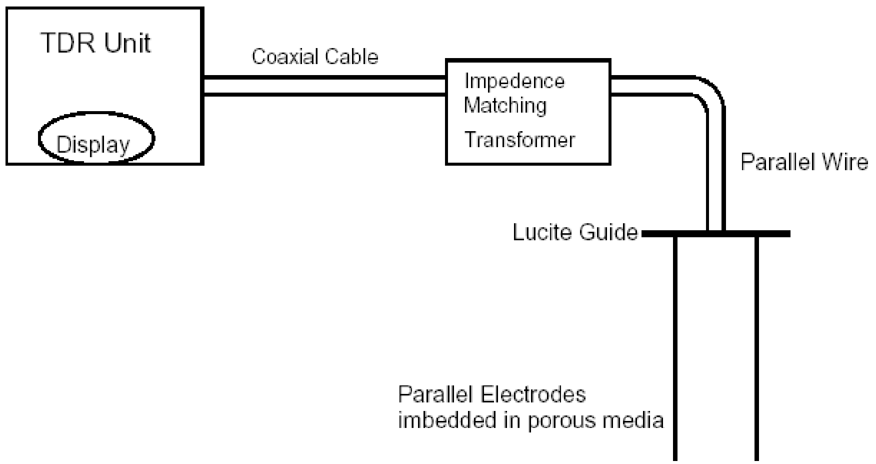
I is irrigation water amount (mm), ΔW is the change in soil water storage (mm);

R is the surface runoff (mm) and D is deep drainage (mm).



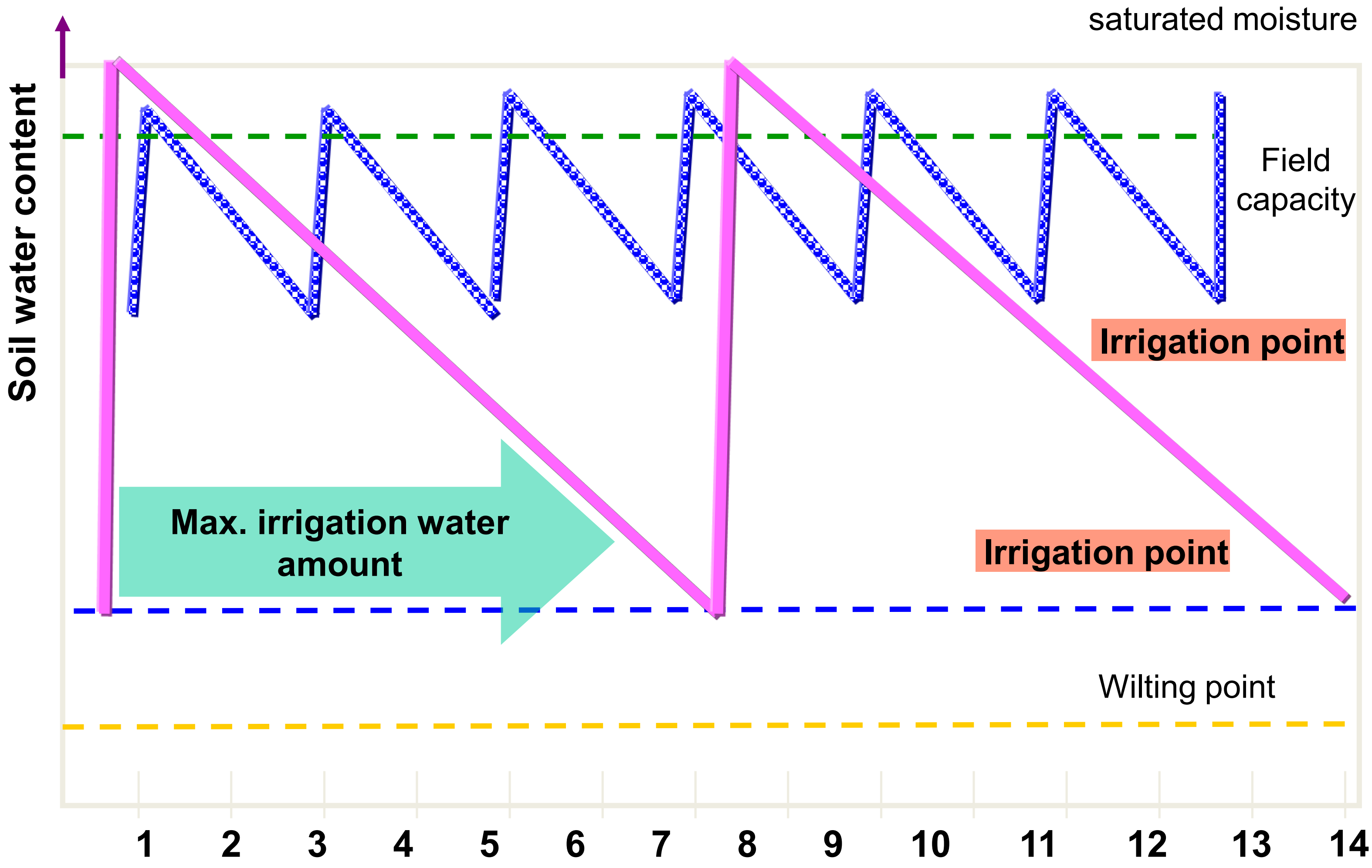


Time domain reflectometry (TDR)



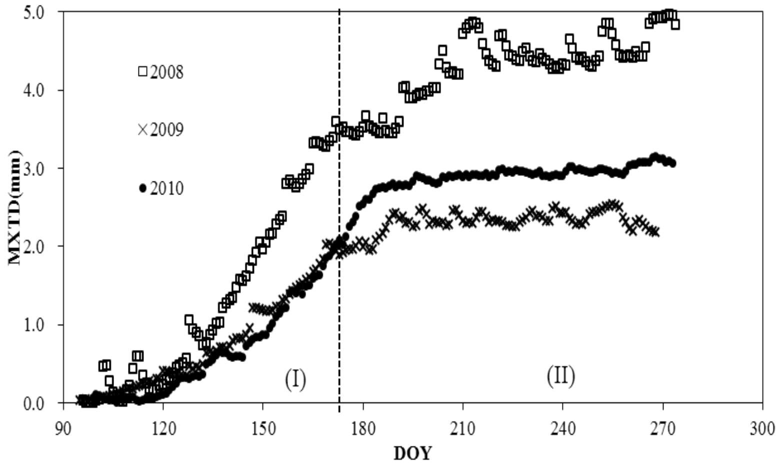
● **Large weighing lysimeters: standard method for water balance**

e.g., Irrigation scheduling under drip and border irrigation

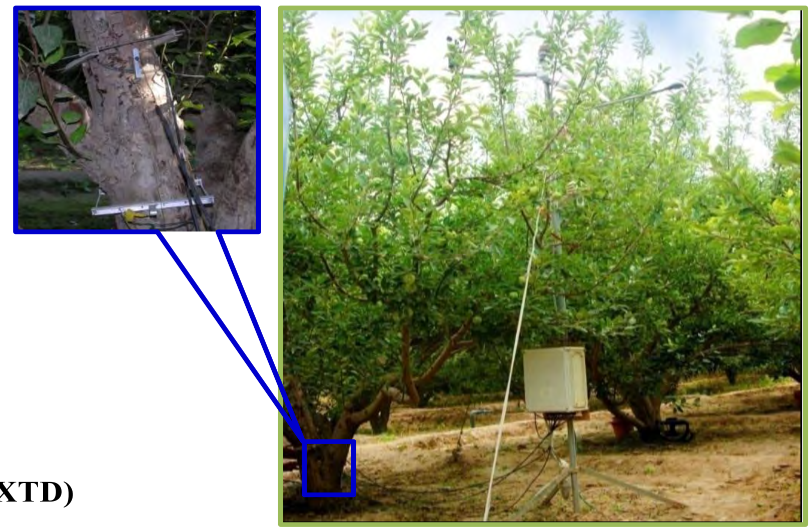


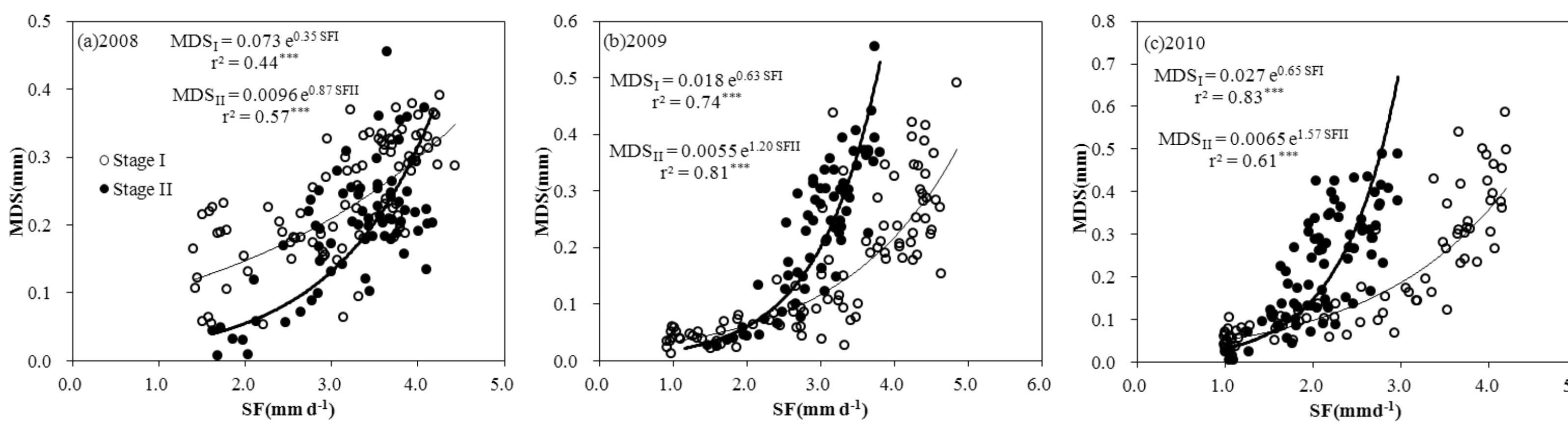
3. The approaches for deficit irrigation scheduling

3.3 Plant based: measurement of plant water status and plant response to available water



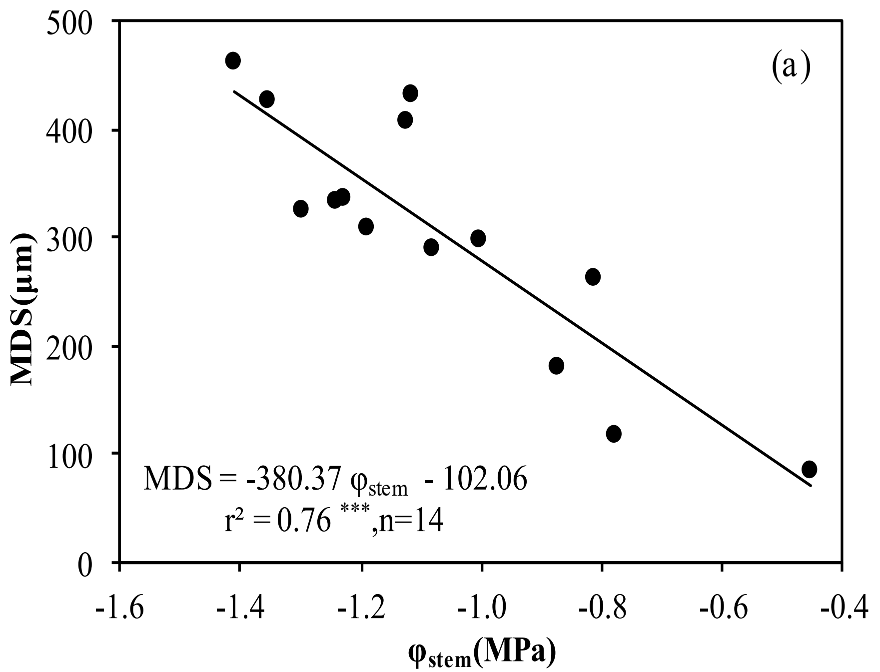
Seasonal variation of maximum daily trunk diameter (MXTD)



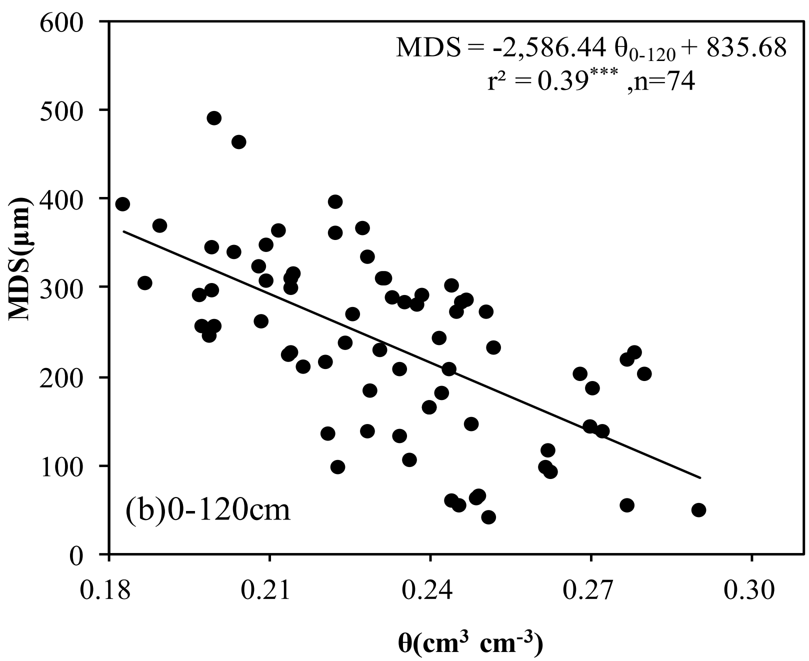


Liu CW, Du TS, Li FS et al., 2012. Agricultural Water Management, 104(2): 194-202.

- **Maximum daily stem shrinkage(MDS) had remarkably exponential relationship with sapflow (SF), and MDS has close relationships with stem water potential and soil water content.**



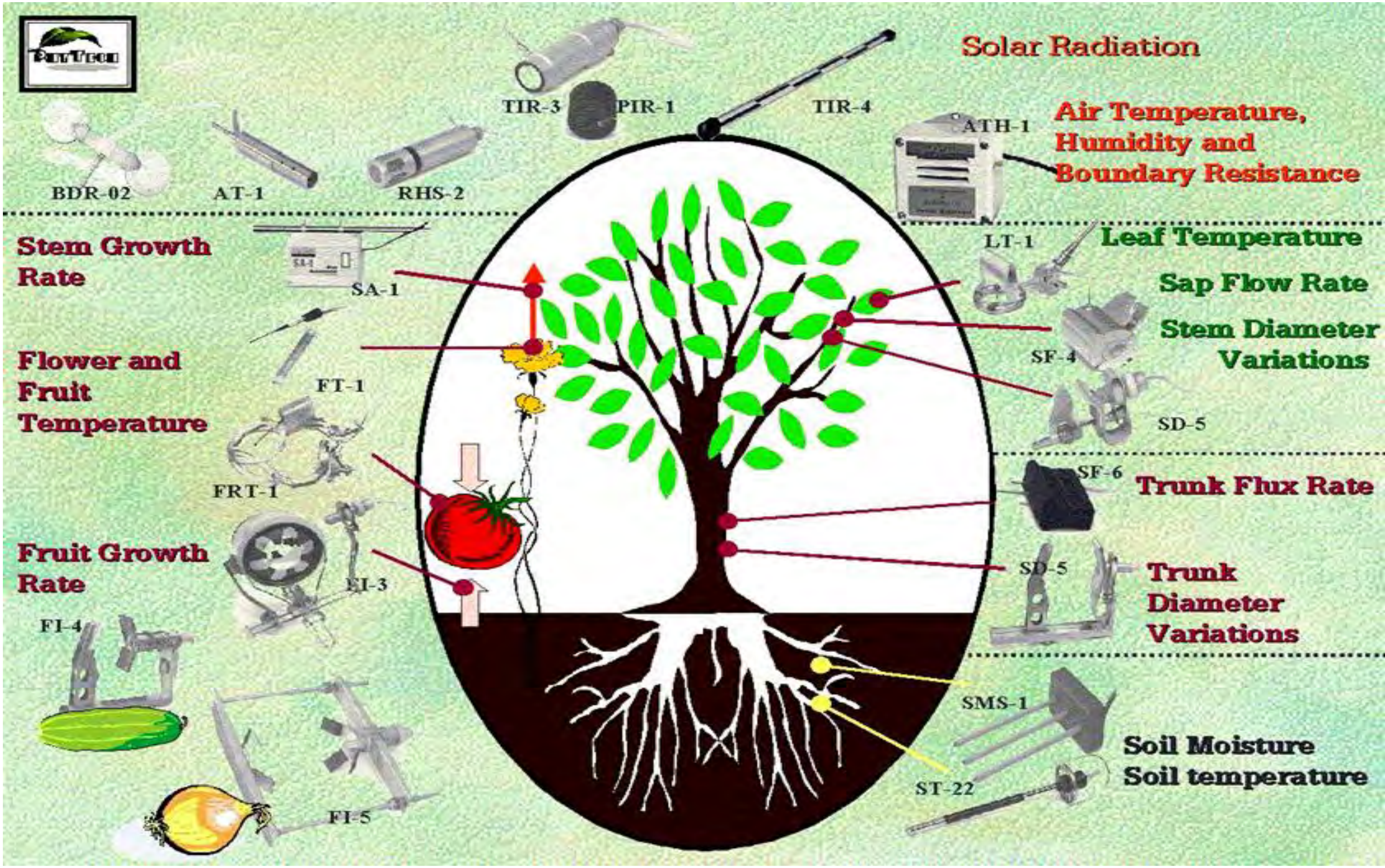
Relationship between maximum daily stem shrinkage (MDS) and stem water potential.*** for P<0.001.



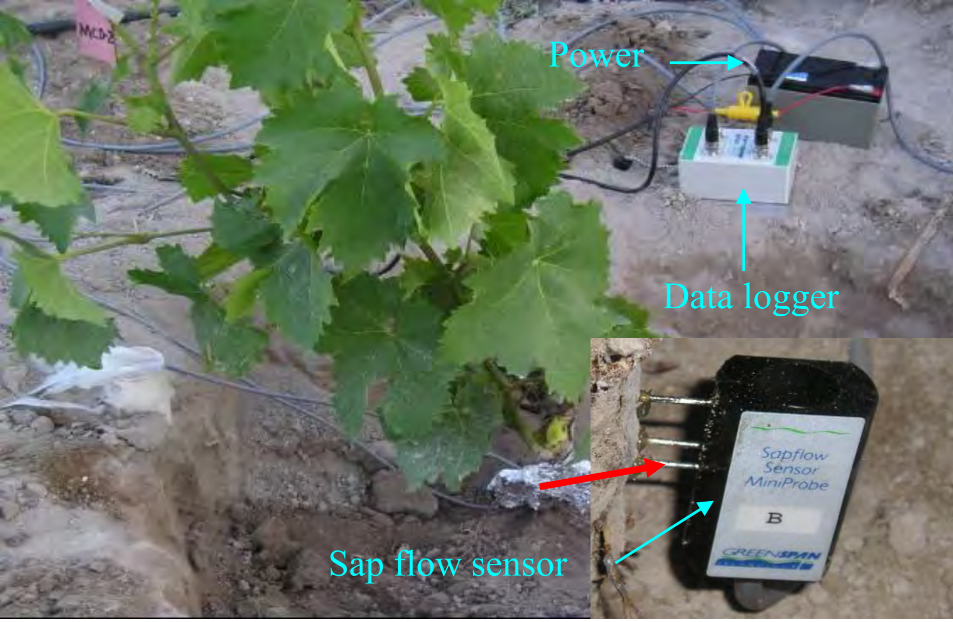
Relationship between maximum daily stem shrinkage (MDS) and soil water content .*** for P<0.001.

Liu CW, Du TS, Li FS et al., 2012. Agricultural Water Management, 104(2): 194-202.

Hot research topic: What are the signals？




Plant physiological monitoring system



Sap flow sensor

Root ecosystem monitoring system

Root water conductivity meter

Plant canopy analysis system

4. Technologies for deficit irrigation practice

Canal lining
Canal lining in Shaanxi

Furrow irrigation
Furrow irrigation in Shaanxi

Drip irrigation under mulch
Drip irrigation under mulch in Xinjiang

Drip irrigation
Drip irrigation in Gansu

Sprinkler irrigation
Sprinkler irrigation in Gansu

Level border irrigation
Level border irrigation in Shaanxi

Remarkable Highlights

All facilities for micro-irrigation system can be manufactured in China.

Driplines with labyrinth emitters

Driplines with inline emitters

Pressure compensating emitters

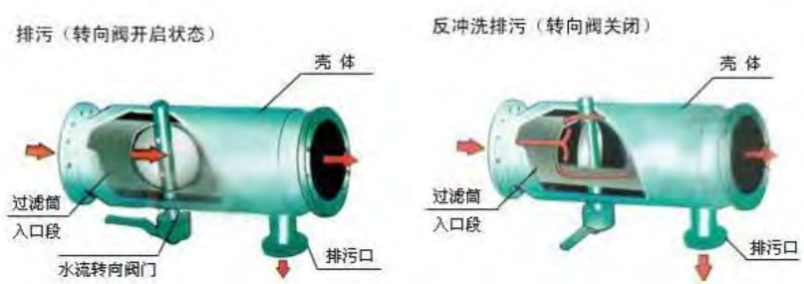
Filters

Cyclonic filter

Screen filter

Disk filter

Sand media filter



Automatic backflush system

Fertilizer injectors

Pressure differential tank

Venturi injector

Water-driven proportional pump

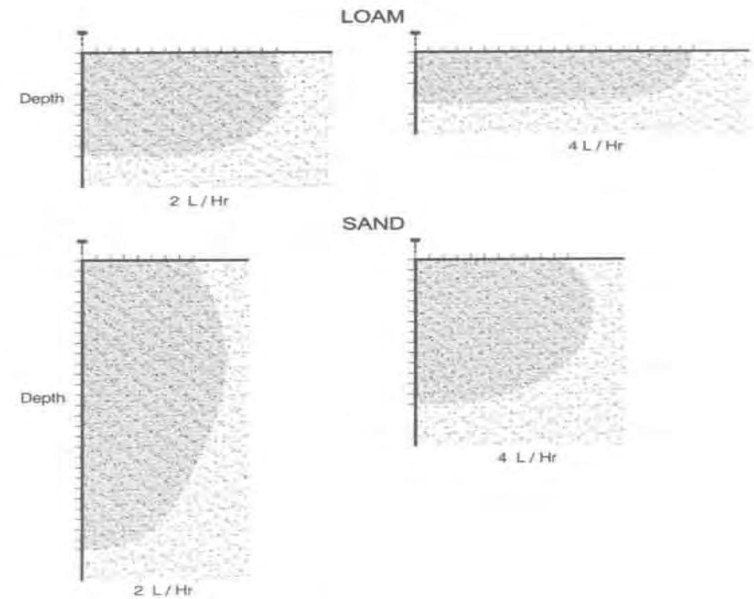

Greenhouse vegetable crops

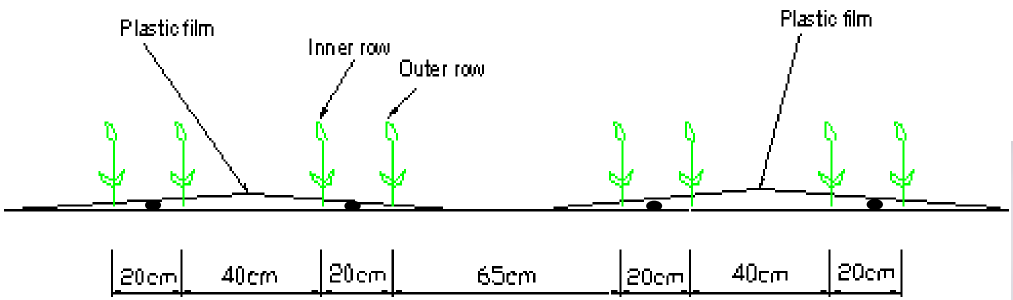

Cotton

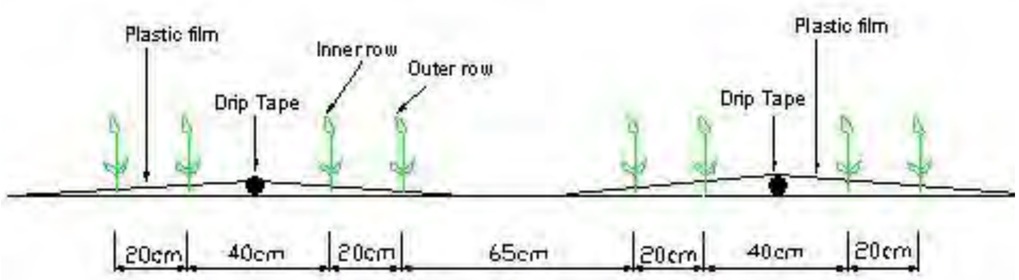

Maize

Drip line layout, crop planting, soil texture coordination

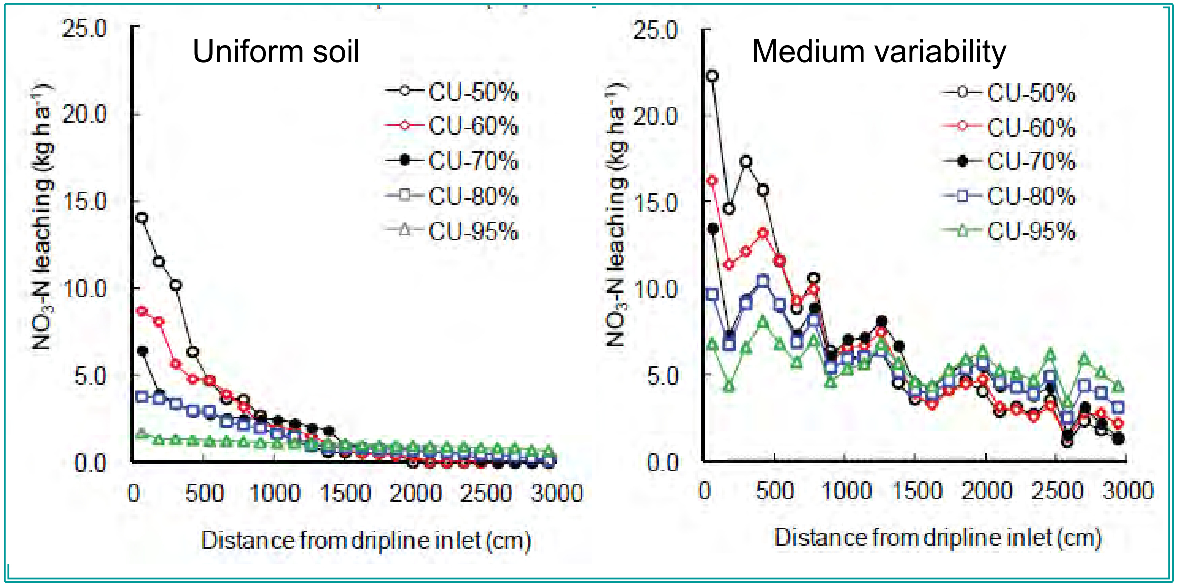
- Planting density
- Soil texture
- Wetted percentage
- Emitter discharge

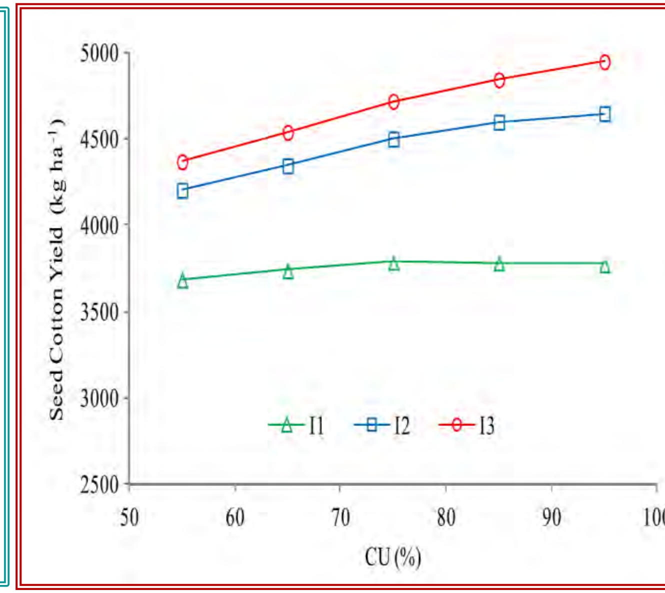






➢ Hot scientific topic: Drip irrigation uniformity improved by considering soil variability and nitrate leaching

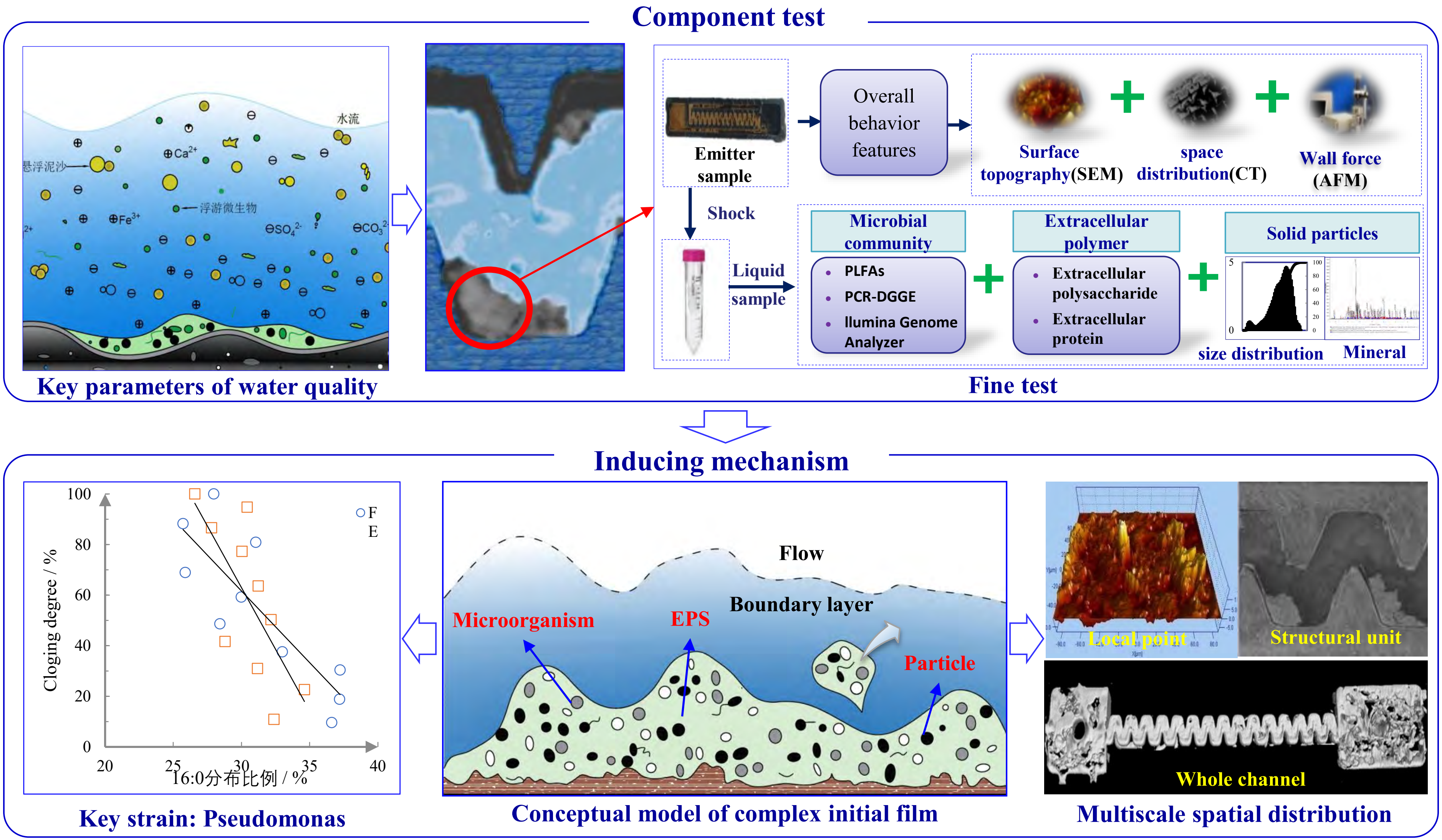




- **Nitrate leaching decreased slightly with increasing CU, while it increased considerably with increasing spatial variability of soil properties.**
- **Microirrigation system uniformities (CUs) as low as 60% in a semi-humid or wetter region may be acceptable in terms of crop yield and quality and nitrate leaching. A higher target CU (e.g. a CU = 75–80%) in the arid region is recommended.**

Li JS. 2018. Irrigation and Drainage, 67(1): 97-112.

➢ Hot scientific topic: method of anti-clogging irrigation emitter

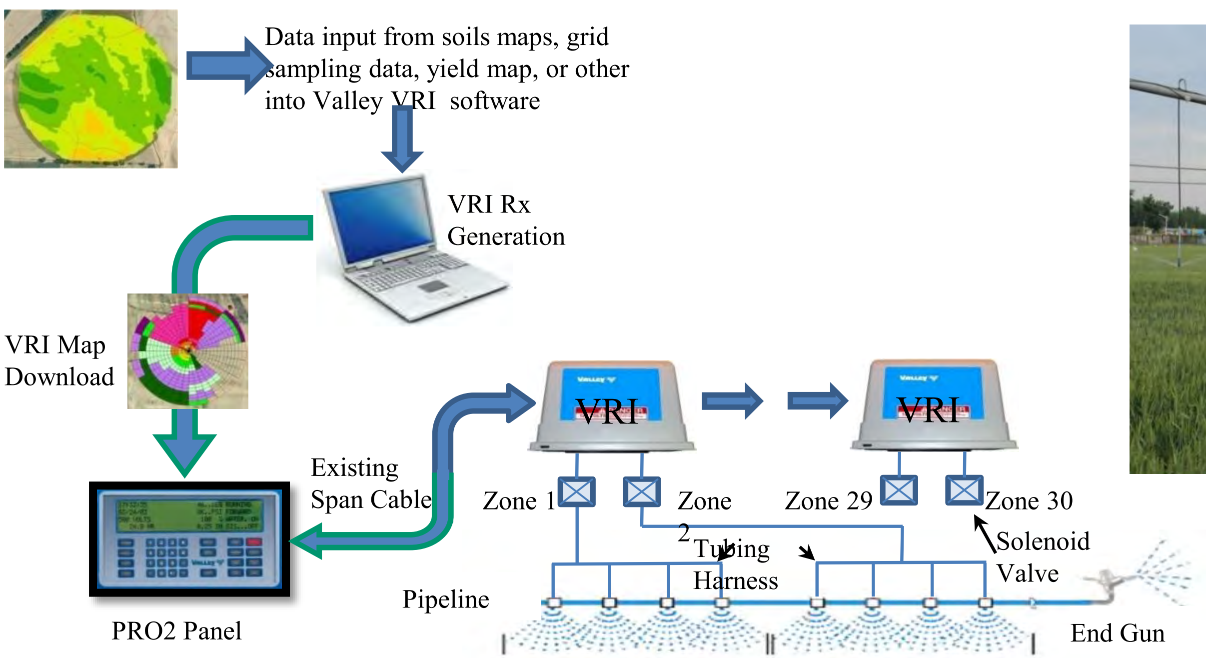


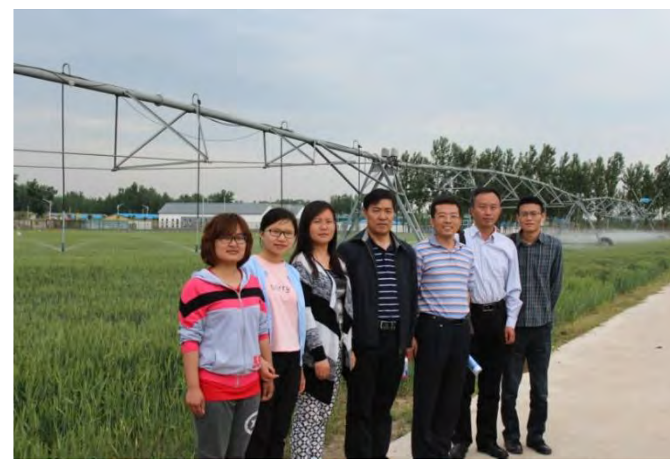
Li YK et al., Irrigation Science. 2008, 26: 427-438;

Li YK et al., Agricultural Water Management, 2016, 168: 23-34

➢ Hot scientific topic: Variable Rate Irrigation

- Variable rate irrigation（VRI）can be defined as the ability to spatially vary water application depths across a field to address specific soil, crop, and/or other conditions.
- Our studies showed that VRI has the potential to saving 10-15% of irrigation water and reducing deep percolation while maintaining a yield similar to the traditional uniform rate irrigation.



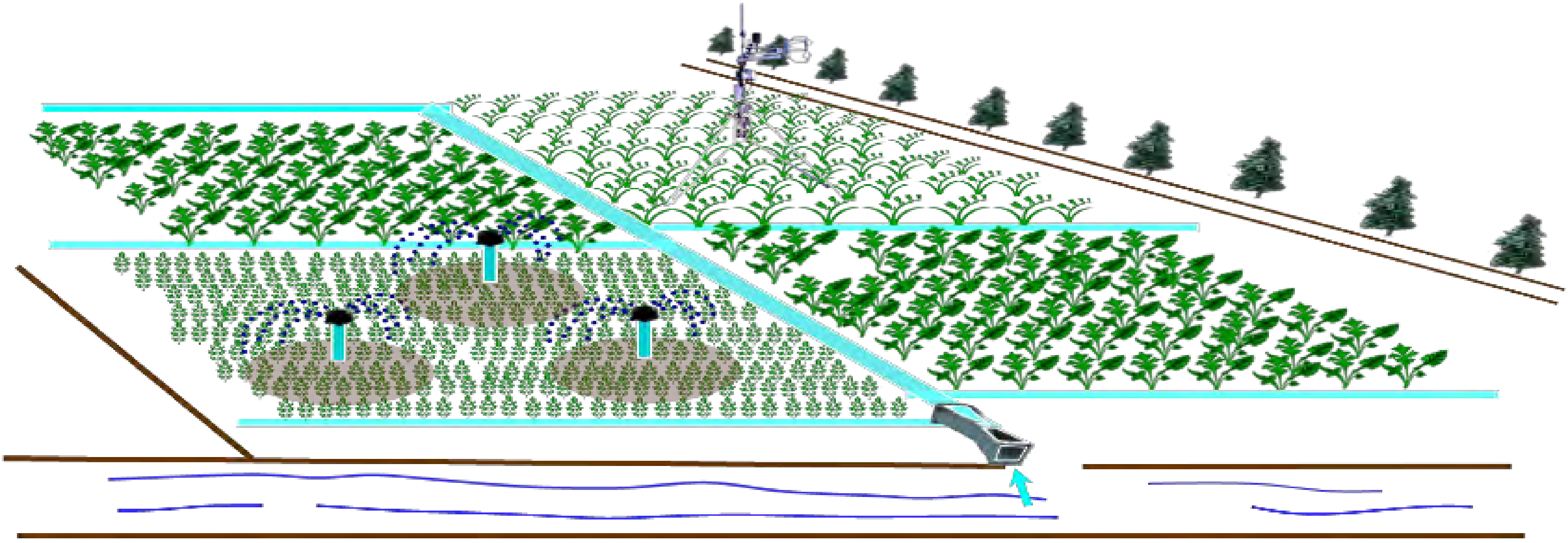


A VRI system that provide individual sprinkler control system (VRI iS)

Li JS. 2018. Irrigation and Drainage, 67(1): 97-112.

5. Future developments and possible collaborations

- **Measurement and modeling of water, heat, carbon, nitrogen and trace gas fluxes in field and regional scales**
- **Hydrological/crop model development and validation in field and regional scale under changing environments**
- **Improving WUE by integrated measures**
- **Water management for catchment sustainability**
- **Irrigation equipment and precision control**




Thanks for your attention !