ETH zürich

Using PhenoCams for tracking phenology and estimating yields of different cropping systems

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Phenogy has been proved to be a sensitive indicator to global change

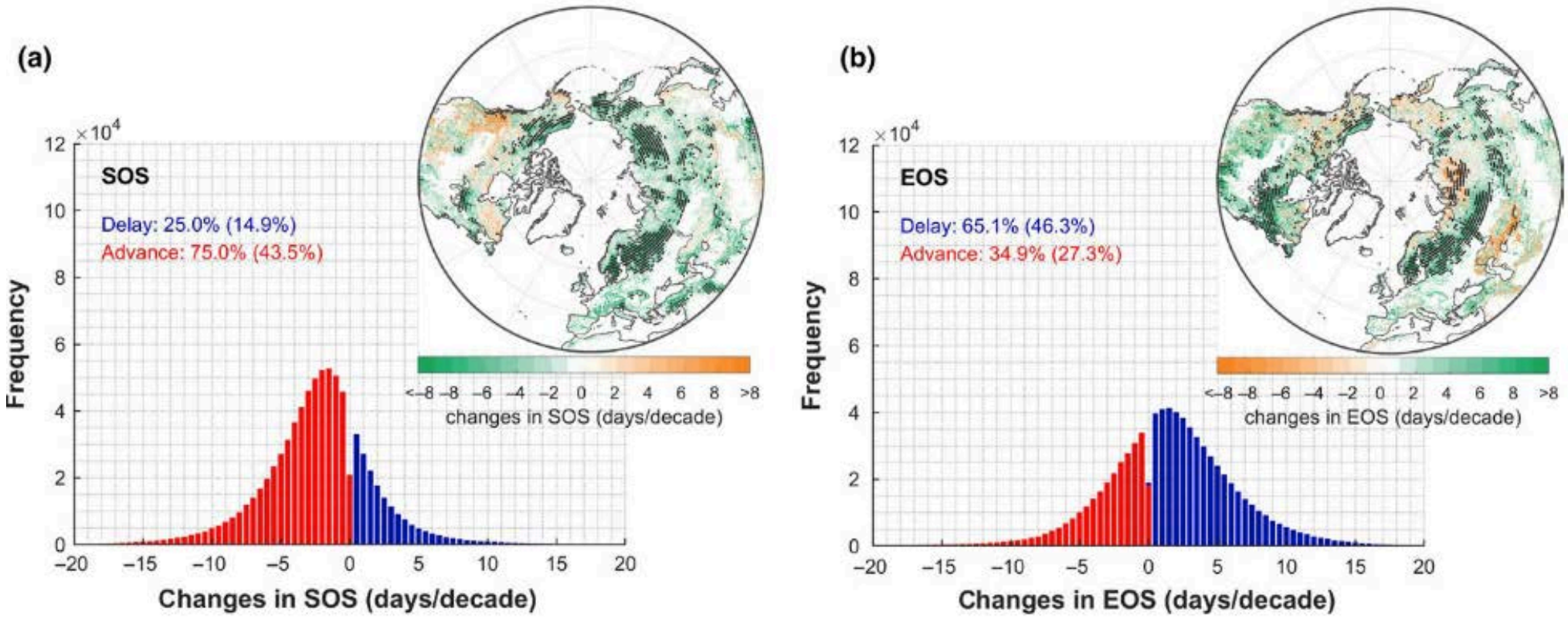
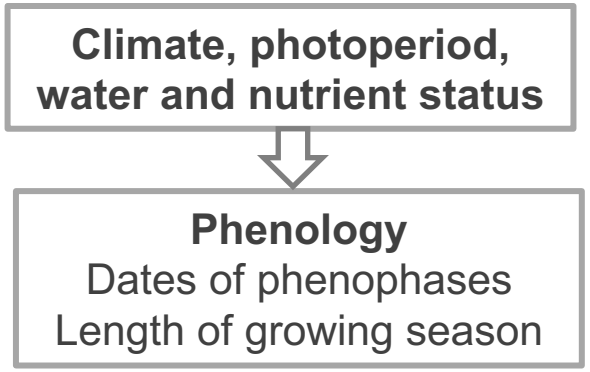


Figure. Changes in satellite-derived start (SOS.a) and end dates of the growing season (EOS, b) over the period 1982-2011. Source: Piao et al. (2019), *Global change biology*

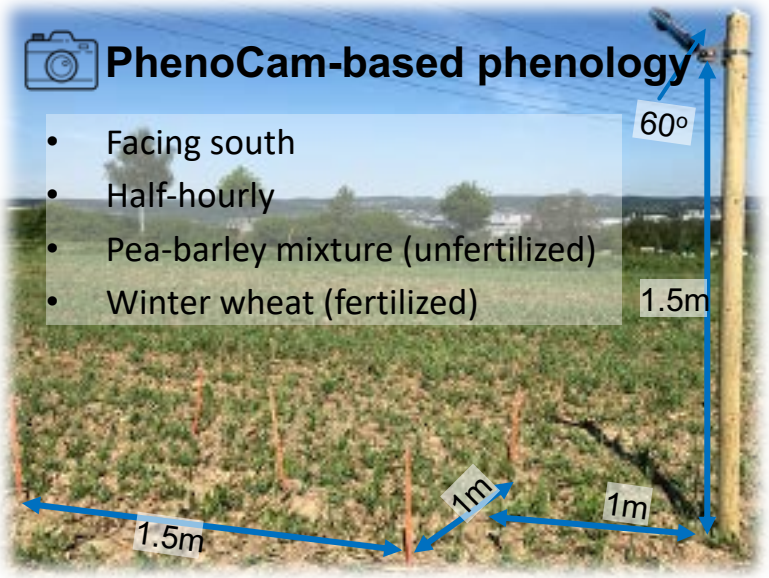
Background: phenology, cropping systems and yields



- The timing of plant life-cycle events, such as leaf bud burst, flowering and fruiting
- Phenogy has been proved to be a sensitive indicator to global change
- Most of the studies focus on large scale or natural systems, such as forest or grassland

Background: phenology, cropping systems and yields

Digital repeat photography



Cameras were pointed to north to minimize shadows and lens flare

Climate, photoperiod, water and nutrient status

⇩

Phenology
Dates of phenophases
Length of growing season

affect?

⇩

Responses of cropland
- Carbon uptake & cycling
- Physiology
- Yields

Cropping systems

C_IT
Conventional Intensive Tillage

C_NT
Conventional No Tillage

O_IT
Organic Intensive Tillage

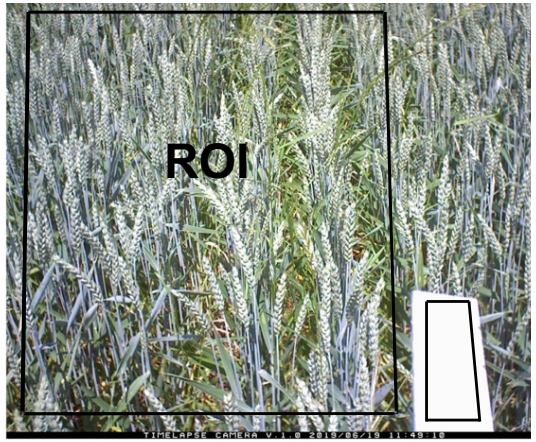
O_RT
Organic Reduced Tillage

Hypothesis

- **H1**: PhenoCams can be used to record and extract different phenological patterns of **different arable crop species**;
- **H2: Different cropping systems affect crop phenology**, including specific metrics such as the start of season (SOS), end of season (EOS), and length of growing season (LOS);
- **H3**: Phenological metrics extracted from PhenoCam images can **explain and predict differences in yields** across different cropping systems.

Method: image processing R package "Phenopix" (Filippa et al., 2016)

Region of interest (ROI) → Extract RGB Compute GCC → Filter GCC → Regress daily GCC



Greenness: Green chromatic coordinate G_{CC}

$$G_{CC} = \frac{G_{DN}}{R_{DN} + G_{DN} + B_{DN}}$$

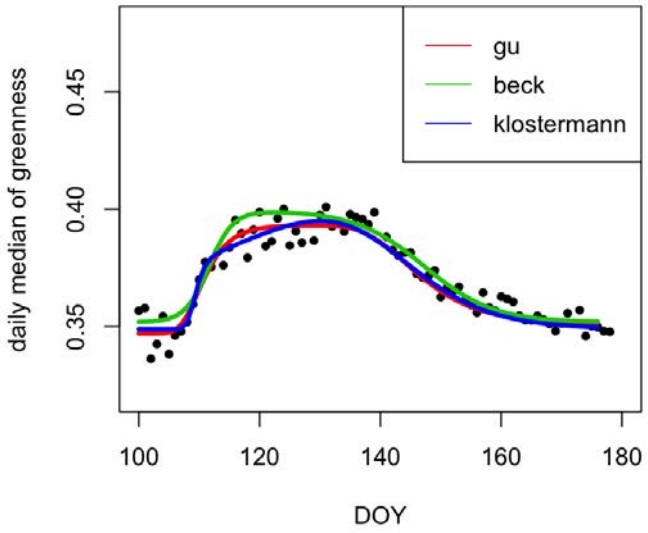
G_{DN}, R_{DN}, B_{DN} are green, red and blue digital numbers

To suppress the effects of changes in scene illumination

night, mad, blue, spline
- Low illumination
- Bad weather conditions
- Dirty lense

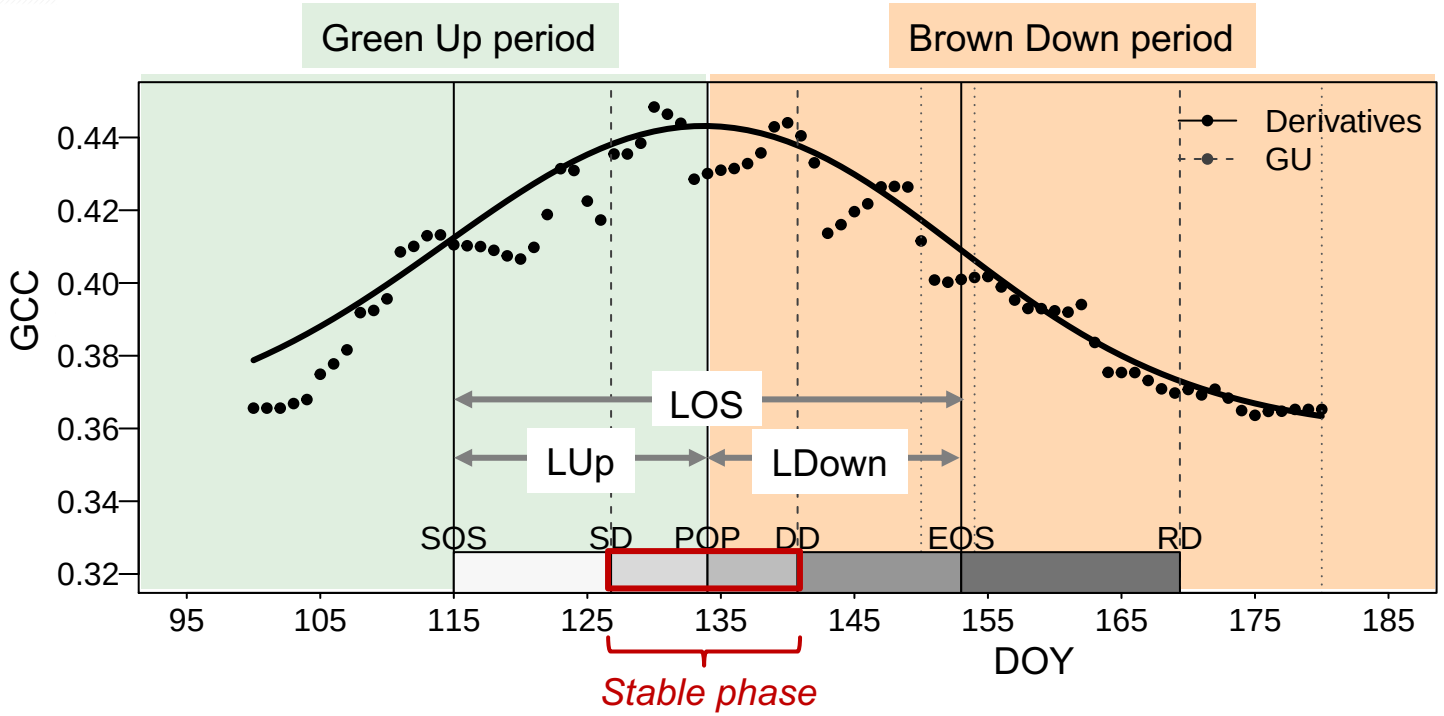
A three-day moving window, 90th percentile

Double logistic functions



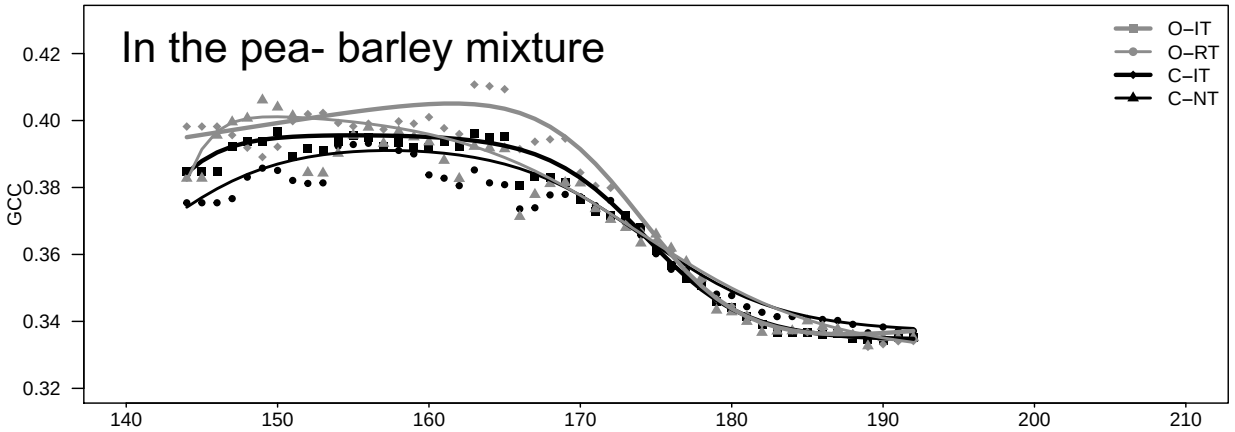
Compute phenological metrics

Phenological metrics



- **Green Up period, before or at peak greenness (3):** SOS: start of growing season; SD: stabilization date; POP: position of peak GCC;
- **Brown Down period, after peak greenness (3)**: DD: downturn date; EOS: end of growing season; RD: recession date;
- **Duration of phenophase (4)**: LOS: length of growing season; LUp: length of increasing greenness; LDown: length of decreasing greenness, *stable phase*

Trajectories of GCC seasonal course in different crops and cropping systems



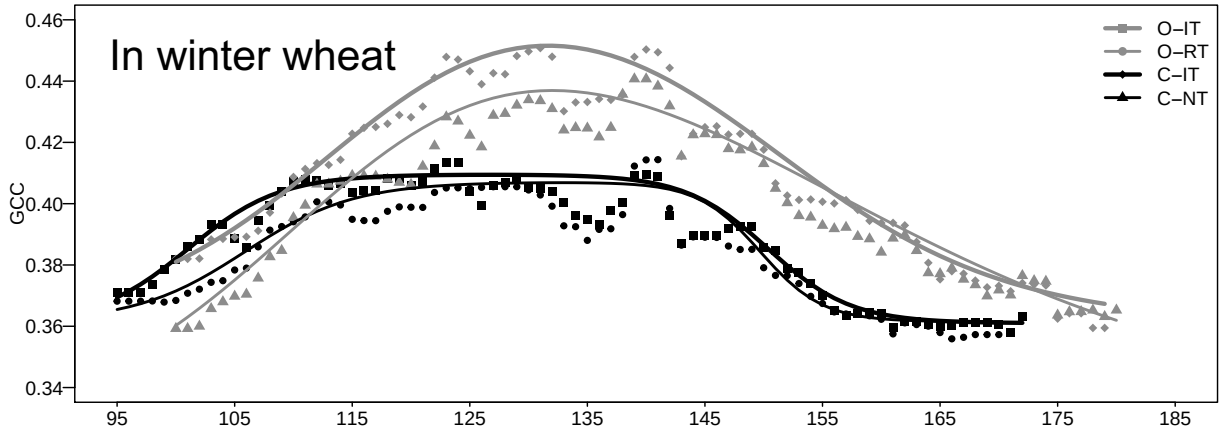


Figure. Comparison of daily median green chromatic coordinate (GCC) seasonal course of the pea-barley mixture and winter wheat among cropping systems.

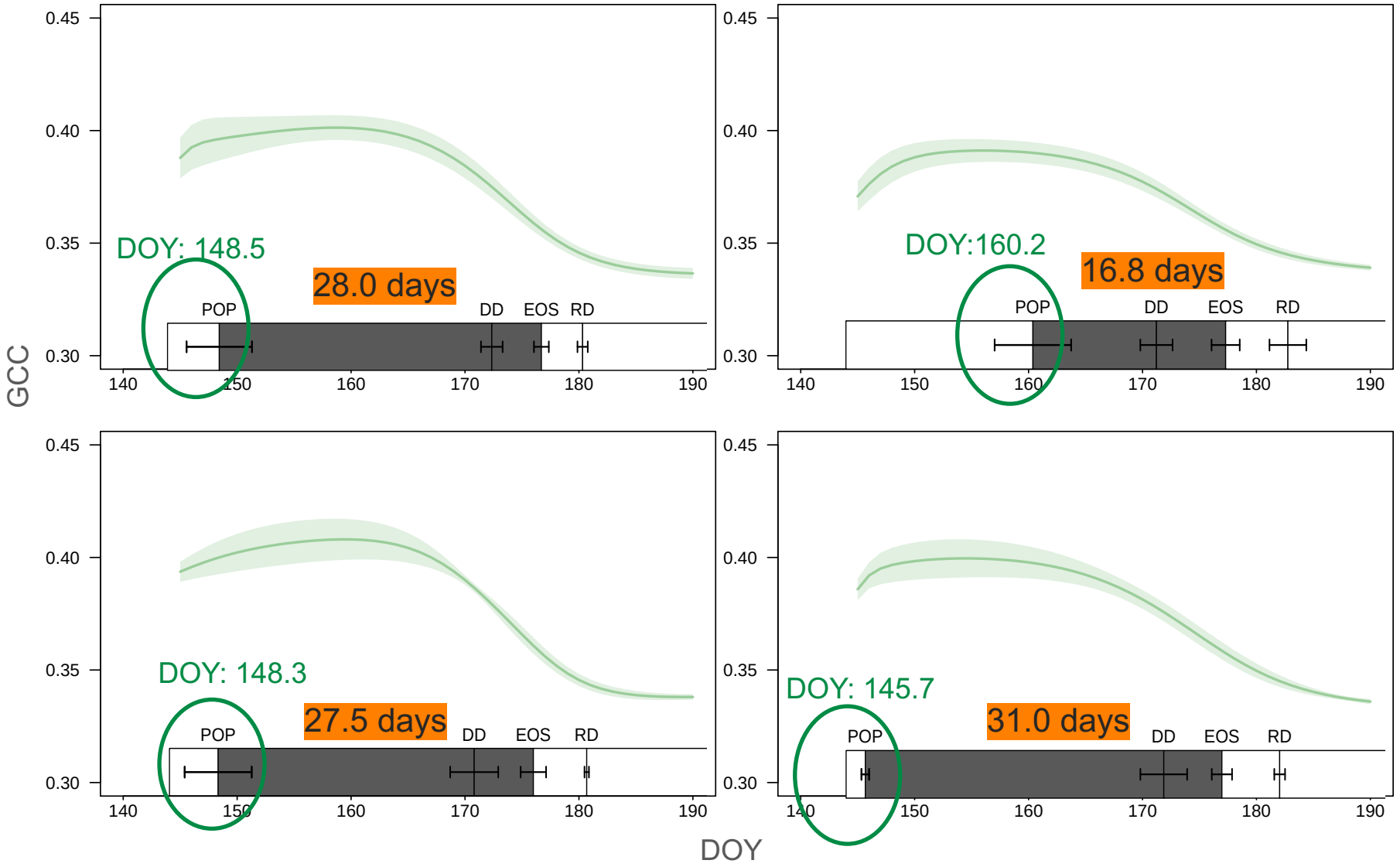
- no obvious response to the cropping system

- GCC values: comparatively higher in organic plots than in conventional plots;
- GCC seasonal course: in conventional farming, a longer plateau stage

Phenological metrics affected by cropping system

In the pea-barley mixture

- Crops in C-NT reached peak greenness **POP** significantly later, delayed in no-till system
- DD, EOS, RD, ns
- Crops in O-RT had the longest days of **LDown** and crops in C-NT had the shortest days of LDown



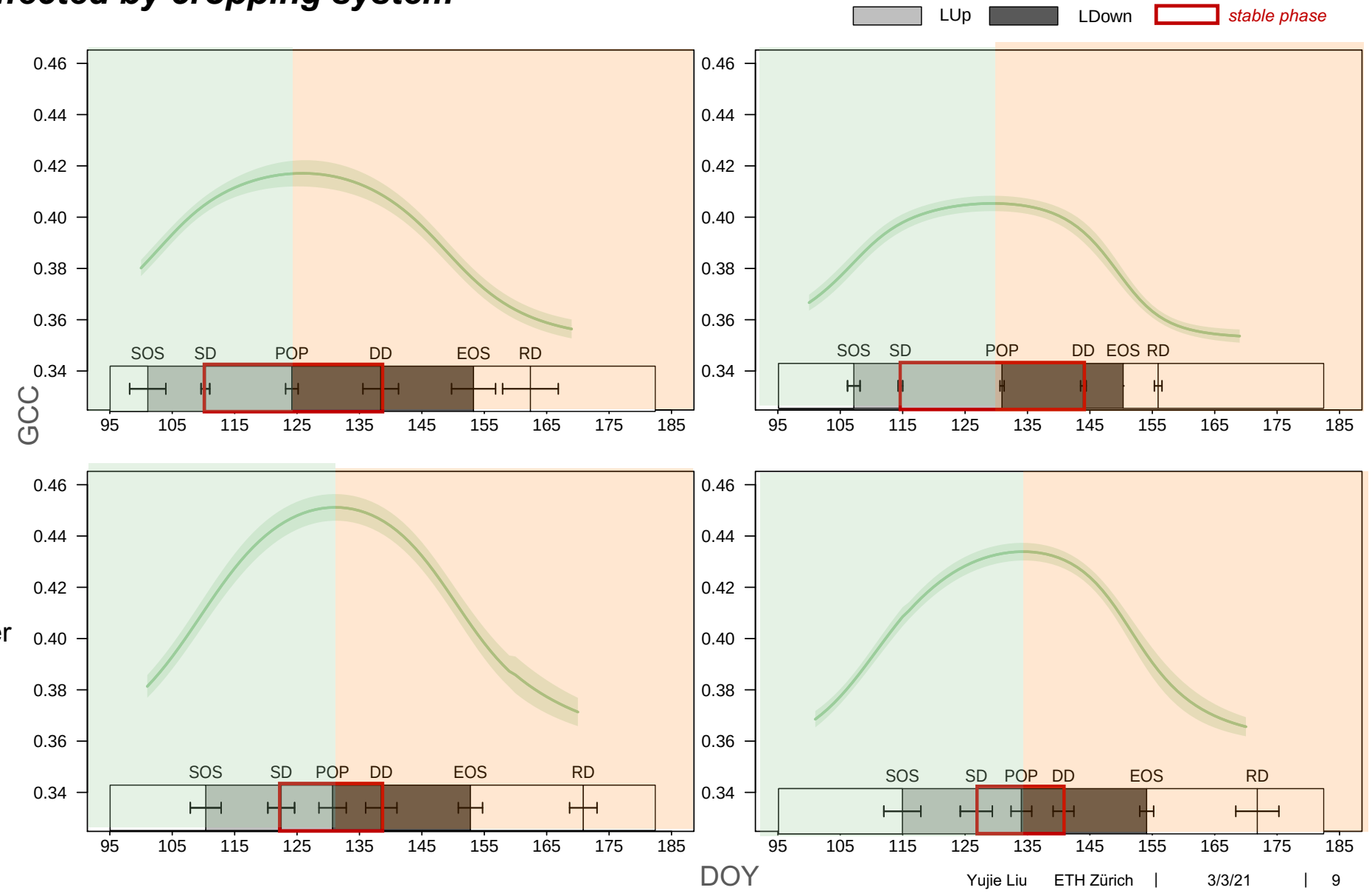
Phenological metrics affected by cropping system

In winter wheat

Before peak greenness
- SOS, SD, POP*
- C-IT< C-NT<- O-IT<- O-RT
- Delayed in organic systems
- Delayed in conservation tillage systems

After peak greenness
- DD, EOS, ns, consistent
- RD*, delayed in organic systems

Duration of phenphases
- LUp, ns, 21.2 days
- LDown, significantly longer in intensive tillage systems
- *Stable phase*, significantly longer in conventional systems than organic systems



Grain yields

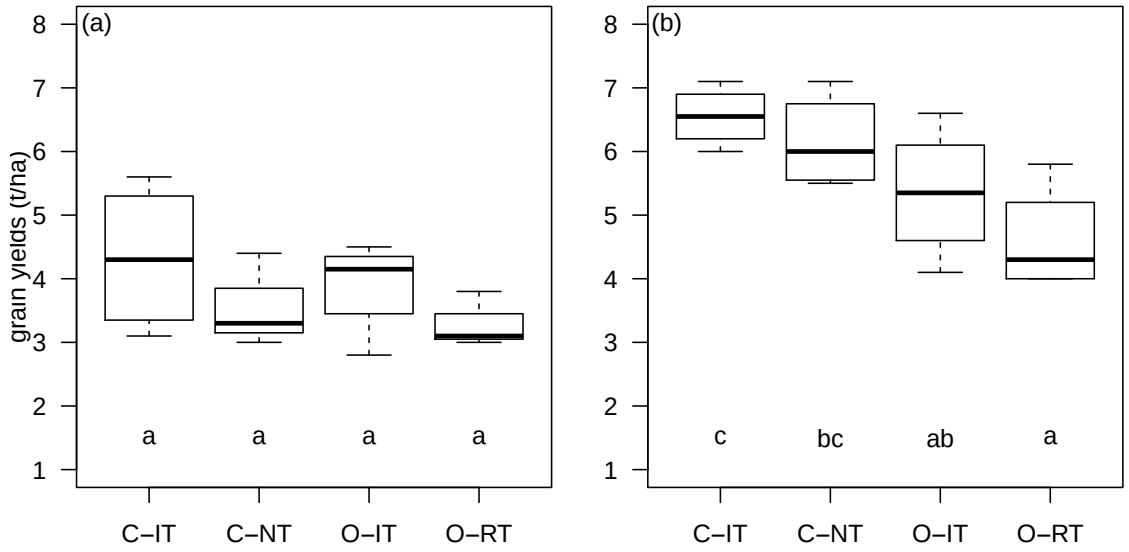


Figure. Grain yields of (a) the pea-barley mixture and (b) winter wheat from different cropping systems.

- H3: Phenological metrics extracted from PhenoCam images can **explain and predict differences in yields** across different cropping systems?

The total grain yields of pea and barley were not significantly affected by cropping systems. Yields of winter wheat differed with highest yields in the C-IT (6.55 ± 0.23 t/ha), intermediate in the C-NT (6.15 ± 0.38 t/ha) and O-IT (5.35 ± 0.52 t/ha), and lowest in the organic system with reduced tillage (O-RT) (4.60 ± 0.42 t/ha).

Grain yields as explained by phenological phases

	Pea - barley				Winter wheat		
Phenological metrics	***F***	***p***	***Multiple R2***		***F***	***p***	***Multiple R2***
SOS	*NA*	*NA*	*NA*	↓	**17.779**	**0.001**	**0.60**
SD	*NA*	*NA*	*NA*	↓	**29.387**	**<0.001**	**0.71**
POP	0.192	0.669	-0.066	↓	**18.385**	**0.001**	**0.61**
DD	0.234	0.637	-0.063		1.669	0.221	-
EOS	0.472	0.505	-0.042		1.769	0.208	-
RD	0.915	0.358	-0.007		3.149	0.101	-
Stable phase	*NA*	*NA*	*NA*	↑	**8.541**	**0.013**	**0.42**
LOS	*NA*	*NA*	*NA*	↑	**4.171**	**0.064**	**0.26**
Lup	*NA*	*NA*	*NA*	↑	4.521	0.055	-
Ldown	0.746	0.405	-0.020	↑	2.454	0.143	-

Green Up period before peak greenenss

Brown Down period after peak greenness

Duration of phenophase

Table. Effects of phenological metrics on grain yields derived from linear models. F values and p values were derived from ANOVA Type III outputs. Significant factors and interactions are given in bold. ($p < 0.05$, n=15 for pea and barley and n=14 for winter wheat in 4 blocks). Arrows (↓↑) indicate a significantly increasing or decreasing effect according to estimates derived from summary() function of the model with R. Abbreviations for phenological metrics: see Table 1. NA = not available.

- 65% of variations in grain yields were explained by SOS, SD and POP in winter wheat.

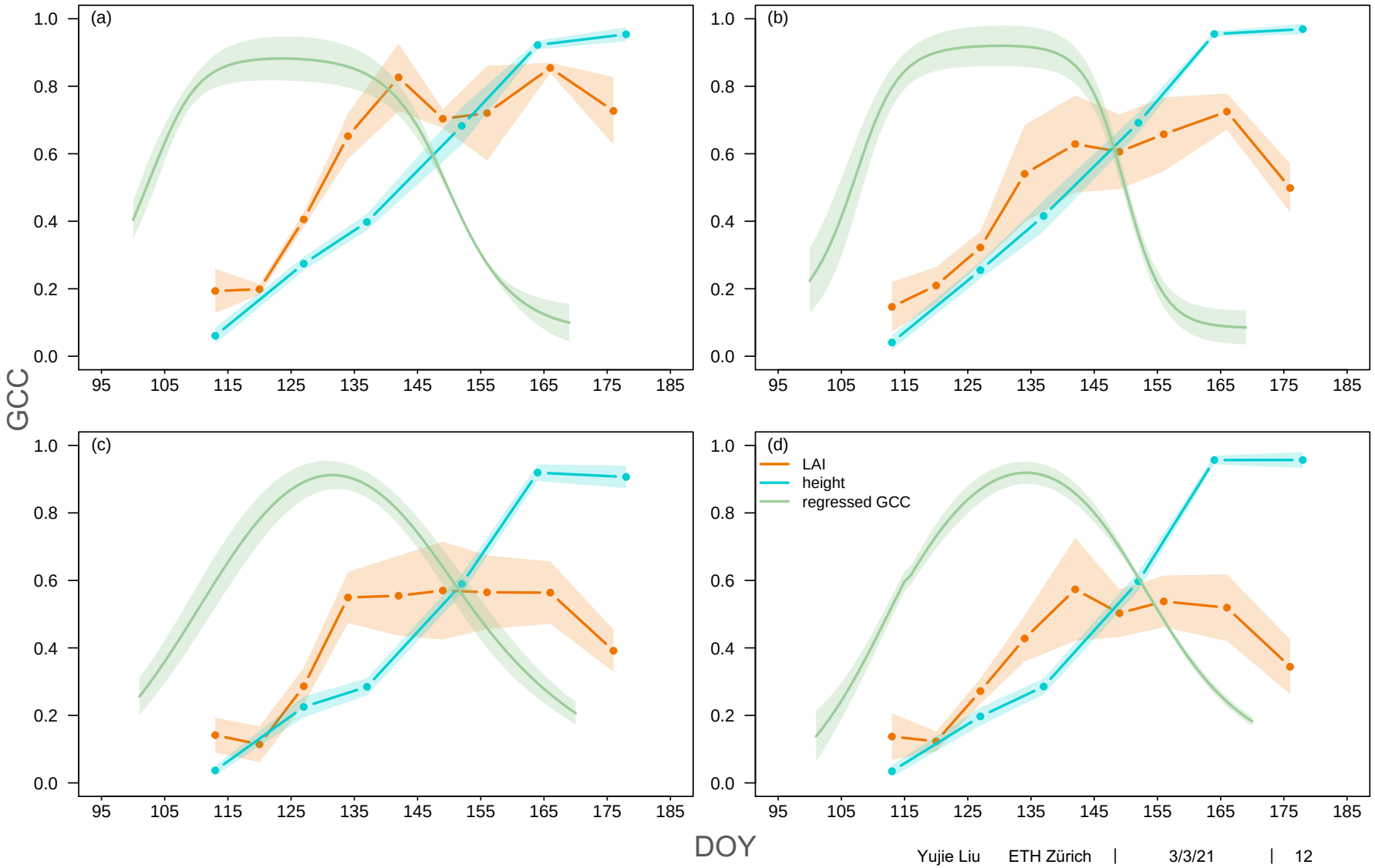
Stand characteristics in relation to GCC

In winter wheat

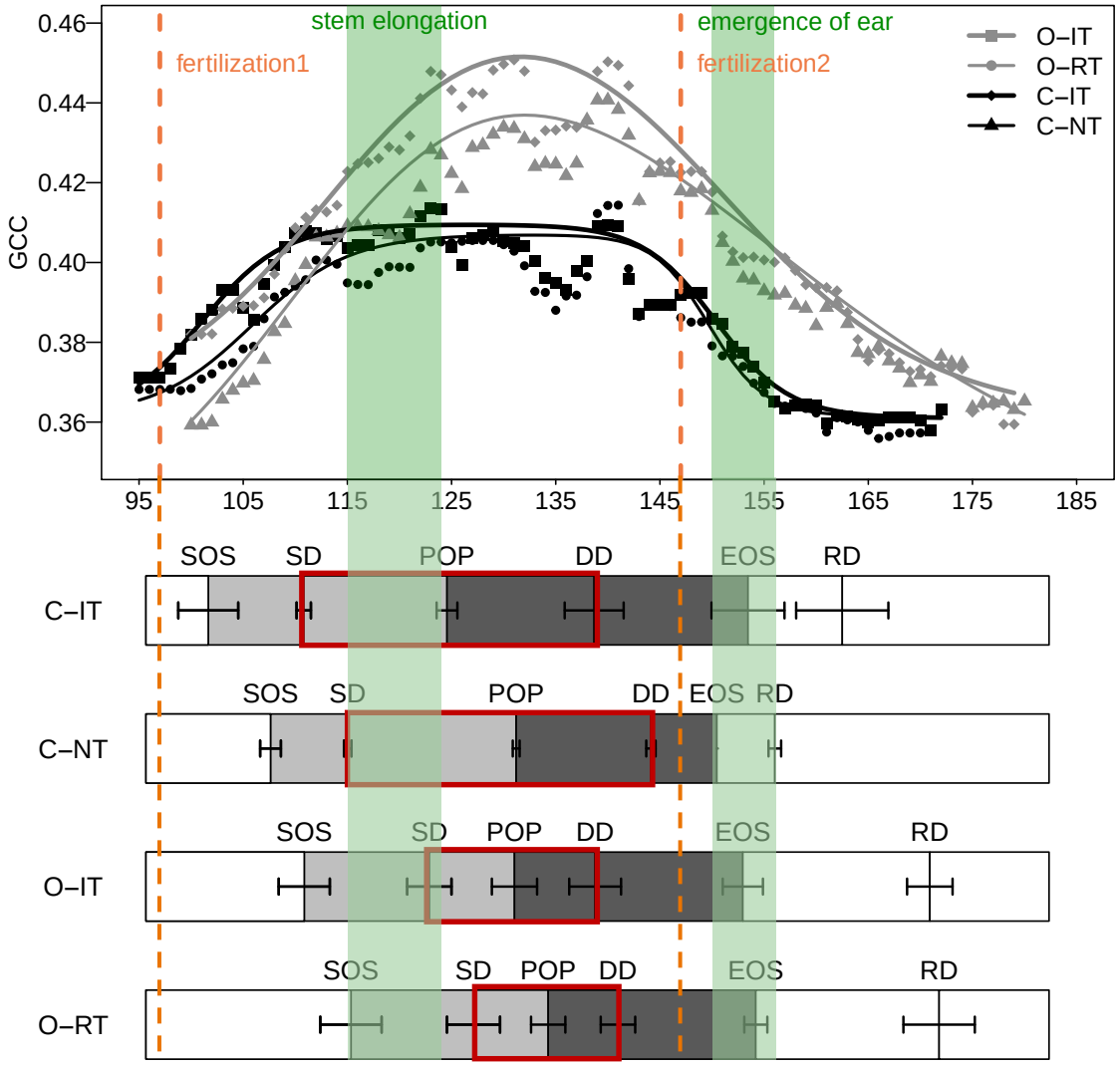
- Peak of height and peak of LAI lagged POP in all cropping systems

- The delayed days between the peak of LAI and POP were significantly different among the cropping systems,

- C-IT 18 days;
- C-NT 11.4 days
- O-IT 8.2 days
- O-RT 3.5 days.



(a) C-IT: conventional intensive tillage, (b) C-NT: conventional no tillage, (c) O-IT: organic intensive tillage, (d) O-RT organic reduced tillage.



- In winter wheat
- SD is rouly ralated to the stem elongation
- EOS is related to the emergence of ear

LUp LDown *stable phase*

Take home message

- Crops in conventional systems had significantly earlier start of growing and longer growing season compared to organic systems in winter wheat.
- Crops in conservation tillage systems had delayed phenophase compared intensive tillage systems in both pea-barley mixture and winter wheat.
- 65% of variations in grain yields were explained by SOS, SD and POP in winter wheat.