Designing wheat ideotypes for a changing climate

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Food security: global food demand

2.4% yield increase per year required to double food production by 2050

(Ray et al, PLoS ONE, 2013)
Wheat yield stagnation in Europe

Changes in EU agricultural subsidy polices reduced the incentive for intensive cultivation. In addition, environmental policies restricted the use of fertilizers and may have limited yield growth. Climate trends can account for ∼10% of the yield stagnation observed over the last two decades.
Adverse events increased with climate change

Increase in adverse weather by 2060 for CMIP5 climate projections

(Trnka et al, Nature CC 2014)

With increased probability of adverse weather events, the risk of crop failure across Europe will increase under climate change.
Sustainable intensification aims on closing global yield gaps between currently realized and potentially achievable yields. The exploitable yield gap represents the difference between $Y_a$ and 80% of $Y_p$ or $Y_w$.

*(van Ittersum et al, FCR 2013)*

*(Foley et al, Nature 2011)*
Managing food-demand for climate mitigation

Even if yield gaps are closed, the projected demand will drive further agricultural expansion. Demand-side mitigation options (improved diets and decreases in food waste) are essential to deliver emissions reductions from agriculture and to provide global food security in 2050.

(Bajželj et al, NCC 2014)
What the world eats in a week

Peter Menzel’s Hungry Planet

Germany

Chad
Increasing yield potential

- In 1981, the world record yield of 14.0 t/ha at a field scale was achieved in Scotland.
- In 2015, a British farmer had a new record of 16.5 t/ha (cv. Reflection).
- 20:20 Wheat ® aims to achieve yield potential of 20 t/ha.
Adapting wheat for uncertain future

Challenges

• Large uncertainty in predicting future environments and climates
• No clear targets for breeding, future threats are unknown
• Cultivars can be only tested under current, not future conditions

Key

• Modelling is a powerful tool for designing wheat ideotypes and discovering target traits for crop improvement
Modelling framework for ideotype design

Cultivars/Genetics
Management
Weather
Soil

Sirius
crop model

CMIP5 climate projections

LARS-WG
weather generator

Ideotypes optimised for future climates
Sirius 2015: crop simulation model

**INPUT**
- Cultivars
- Weather
- Soil
- Management

**MODEL**
- Canopy
- Phenology
- RUE & Biomass
- Water & N limitation
- Soil
- Grain yield & quality
- Extremes

**EXPLORATION**
- Model parameters
- Optimizing ideotypes
- Inter-model comparison
- Inter-plant competition
- Impacts of climate change
- Calibration & validation
- Evolutionary algorithm
Cultivar parameters: coding wheat ideotypes

**Phenology**
- phyllochron $\text{Ph}$
- daylength response $\text{PP}$
- duration of grain filling $\text{Gf}$

**Canopy**
- max leaf size $\text{A}$
- “stay green” $\text{S}$

**Tolerance to drought**
- response of photosynthesis to water stress $\text{Wsa}$
- leaf senescence $\text{Wss}$

**Roots efficiency**
- water uptake $\text{Ru}$
Optimisation: evolutionary algorithm

Objective:
maximise 100yr mean yield for ideotypes with yield CV < 15% and HI95 < 0.63

Stopping rule:
search stops when Y95 exceeds a target, or no further improvement is possible

We start with 20 “parents” randomly scattered in the parameter space.
Target environment: Europe, CMIP5, 2050

Map of Europe with marked locations:
- Rothamsted, UK
- Seville, Spain

Graphs showing:
- Monthly maximum temperature in degrees Celsius
  - Rothamsted, UK
  - Seville, Spain
- Monthly precipitation in millimeters
Substantial increase in yield in 2050

Modelling predicts yield increase of **56-109 %** for ideotypes optimized for future climates compared with current wheat cultivars.
Trait discovery

Claire, Rothamsted, UK

Cartaya, Seville, Spain

Parameter relative value

Claire
id5
id9
id4
id18
id11

Cartaya
id10
id21
id16
id3
id7
Effect of heat stress on wheat around flowering

(Alghabari et al., J Agr Crop Sci 2013)

High temperature and water stress during booting reduce grain number and grain weight in wheat
Heat tolerance is a key trait in S.Europe

In Seville, HT ideotypes can achieve 111% higher yield potential compared with HS, in Debrecen yield CV increased by 265% for HS ideotypes

(Stratonovitch & Semenov, JXB 2015)
Lack of heat tolerance in European wheats

Effect of high temperature during anthesis on (A) grain yield and (B) grains per spikelet (C) grain weight of S.European (MV Emese, Renesansa) and UK wheat cultivars (Mercia, Savannah)

(Semenov et al., J Cer Sci 2014)
Handling uncertainty in climate projections

(IPCC AR5 WG1)

(RCP4.5, RCP85) x (GISS, HadGM)
Uncertainty in future yields

Mean yields for heat-tolerant (HT) or heat-sensitive (HS) ideotypes optimised for future 2050 climates predicted by HadGEM2 and GISS for RCP4.5 and RCP8.5.

(Semenov & Stratonovitch, Clim Res 2015)
Key messages

• There is no a single solution to resolve global food security. Closing yield gaps, managing food-demand and increasing yield potentials should be explored.

• Wheat yield potential can be substantially increased by 2050.

• Increase in light use efficiency, extended grain filling and optimal phenology are key traits. In water-limited environments increased drought tolerance will be needed.

• To achieve the high yield potential in S.Europe, tolerance to heat stress is needed.

• Identified key traits for wheat improvement are robust and not affected by the uncertainty in CMIP5 climate projections.
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