

Assessment of the Global Warming effect on a wheat crop by using an Ecotron showed that not all the paradigms used to outline crop behaviour remain valid under future meteorological conditions

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Introduction

Wheat is the third most worldwide cultivated cereal and the first one in Europe which represent 24% of the global production^{1,2}. Global warming is predicted to significantly impact its production, slightly enhancing the yield in northern Europe but vastly increasing its variability^{3,4}.

These predictions are based on models fitted on the actual meteorological conditions. In this study, by using an Ecotron, a common wheat crop was submitted to two meteorological conditions, respectively representative of the present and of the future climate around the end of 21th century of western Europe under RCP 8.5. The aim of this experiment was to test the validity of validity of those claims.

Approach

The Terra-Ecotron, being a fully closed facility, are able to materialise present and future meteorological conditions. The experiment aimed to compare the behaviour of an agro-ecosystem including a wheat crop, under two meteorological conditions, one representative of the present climate and the other representative of the late 21st century under RCP 8.5. The technical path, in particular the sowing dates and the fertilisation, was based on the actual practice. It was cultivated in a lysimetre having a soil area of 2 m² and a volume of 3 m³. The external border was marginally used only to assess the phenology stages. The inner circle, 0.8 m² was used for the evaluation of the final yield and plant and soil composition. The intermediate area was sampled during winter, at end tillering and at anthesis to evaluate the crop development. Air and soil sensors measured the environmental drivers.

Main results and interpretation

Some of the results from this experiment have been surprising and diverged from literature and model forecasts on several points. Yet, when analysing the phenomena causing the divergences, they were in adequacy with plant physiology references. The reason of these discrepancies were mostly found in the paradigms, the mental models, used by phytotechnicians which were losing some of their relevance. Here are some of the main intriguing observations.

Global Warming (GW) would favour yield under temperate European climate

When happening during the growth period, the temperature rise is cited to hasten the crop development and increase yield^{5, 6, 7, 8, 9, 10, 11, 12} but it can have devastating effect during grain filling^{13, 14, 9}. Overall, regional climate models over Belgium showed that GW would increase mean yield in Winter Wheat production³.

Under future meteorological conditions (FMC), a yield drop down to 74% was observed. Phytotechnicians often analyse the wheat yield based on its three components, the ears (tillers) numbers, the amount of grain per ear and the grain weight.

A priori, the low number of ears was surprising since one tiller is supposed to develop each 100 °C.d¹⁵ and since the FMC enjoyed 350 °C.d more than present meteorological conditions (PMC), 3.5 extra tillers could be expected. And yet, 1.2 less were counted. Three causes are cited for a tiller reduction¹⁵, the lack of water, the lack of nitrogen and the competition for light between plants when there is a high density of shoots. The first two can be dismissed for this experiment : the FMC winter rain amount was 24% higher while the nitrogen up taken by the crop under FMC was also about 57% higher. On the other hand, the high germination rate, close to 100% against around 75-80% in field, explained the lower number of tillers per plant but the higher tiller per unit area than usual (for both meteorological conditions - MCs). The crop under FMC presenting a higher LAI (+83%) might have suffered more of the competition for light (25% less tillers for FMC). So it was the higher winter growth that, paradoxically, reduced the first yield component.

At anthesis, apart from the ear numbers (-12%), the other variables were quite similar, especially the amount of grain.

During the reproductive period, in summer, the crop under FMC suffered from a water deficit stress. This was assessed by chlorophyll fluorescence measurements and by the estimation of the evapo-transpiration that dropped during the stress. This was surprising since the vapour pressure deficit during that period was not really higher for the FMC and not in the stressing range while the soil water content was marginally higher comparing to PMC. So it must have been the plant that was less able to extract soil solution.

Phenological hastening would reduce the time to accumulate biomass and yield would drop

Previous researches have found that reducing the time between anthesis and ripening could reduce the grain filling time^{9, 16} and so the yield.

The phenological hastening did happen, but it was the juvenile period that was shorter. The transition from juvenile period to the vegetative one requires a vernalisation¹⁵, which was easily satisfied and was an issue for neither MCs. It also requires accumulating a given amount of degree-days, but they are weighted (reduced) for short days. All this resulted in a juvenile period that was three weeks shorter for FMC. Accordingly, the vegetative period was in advance, during a season when the temperature is growing and thus colder. This compensated the increase of the temperatures linked to the GW and resulted in a period where temperature was similar for both MCs.

During the juvenile period the limiting factor is the temperature and the GW had a positive effect on the plant growth. During the vegetative period, earlier in spring, day length was shorter which reduce global photosynthesis on the period, but the reallocation of the biomass produced to

aboveground organs during winter compensated. So at anthesis the crops under both MCs were quite similar.

C:N ration would rise

Elevated CO₂ air concentration have been observed to facilitate the CO₂ absorption and the photosynthesis, driving to a C:N ratio and yield rise^{17, 3, 18, 19}.

The CO₂ fertilisation may have helped during the vegetative period. On the contrary, during the water deficit stress, the stomata close to reduce the transpiration and reduce the photosynthesis. This latter process had clearly the upper hand in this experiment.

Water clogging an anoxia risks would be higher

During the autumnal and winter period the soil water profile is replenished and is usually at field capacity at the end of winter. Waterlogging in spring is cited as a higher risk³.

The crop under FMC received 24% more rain during the juvenile period and yet, at the end of winter, the soil was drier, particularly in the upper layers. This may be explained by the higher plant development, resulting in higher leaf surface, under milder temperatures and a higher vapour pressure deficit that favoured the transpiration. During the vegetative period, the rain was 44% higher under FMC. In link with the phenological advance, the vapour pressure deficit and the irradiance were lower and as a result the evapotranspiration was lower too. As a consequence, the soil humidity profile at the end of the period were different, while the whole profile had been taken up in the upper layers under PMC, under FMC the water content increased with depth and as a whole contained more water.

Overall, the risk of anoxia seems limited by the higher plant transpiration.

Effect on roots is uncertain

Different author described different effect and no clear conclusion can be defined²⁰.

During the first weeks after sowing, the root growth was similar under MCs but after a few weeks it changed and the final root density was lower for FMC compared to PMC, particularly in the row, but not between the row. The root density profile presented differences between the profile more obvious near the root crown than deeper. The soil water profiles confirmed that the root development in depth seemed less important under FMC.

The lower FMC root amount may be partly linked to the lower number of tillers. But the root development is also known to be linked to the water and nitrogen availability. When these are easily available, the plant favours the epigeal growth to the detriment of hypogeal one. The large amount of nitrogen in the plants at the end of tillering was available by reallocation during the vegetative period when winter leaves became senescent.

Conclusions

Discrepancies between observations during this experiment and results presented in literature are linked to the multifactorial and bidirectional relations between the drivers and the phenology.

It was arguably during winter that most changes were observed, and these changes had a lasting effect. This is probably what is most overlooked in the literature.

Learning objectives

This experiment was about “everything” in the sense that it did not try to evaluate the effect of one particular short set of variables on the agro-ecosystem. It was about submitting two agro-ecosystems to two complete sets of different variables representative of two climates. This of course made the interpretation difficult. It required a team of experts in several field of expertise. Yet this is maybe the closest we could get to our real future. While some results were in accordance with predictions, quite some were disturbing. Ultimately, this was because our paradigms, the mental models we are using to somehow summarise the agro-ecosystem behaviour, were built under the present climate. Some of these seems to become obsolete under the future climate or at least need to be amended, in particular during the juvenile, winter period.

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