quantities are comparable if farmers are able to fully exploit the effects of CO_2 fertilization (Fig. 1).

As long as food commodities are priced by weight or volume and only rough categories are used to distinguish quality (for example, the use of protein content to determine baking quality in wheat), a decrease in essential minerals will go largely unnoticed by consumers and effectively increase the prices of nutrients essential to human nutrition. Hidden hunger, that is, the insufficient supply of vitamins and minerals like zinc or iron in diets with sufficient calorie content, currently affects about two billion people and the problem is amplified by food price volatility[9]. Both CO_2 fertilization and climate change — which is expected to increase food prices and volatility[8] — will presumably exacerbate hidden hunger and jeopardize one of the central millennium development goals, even in the long term. Myers *et al.*[3] present evidence that crop breeding could alleviate some of the negative effects of increased atmospheric CO_2, especially for rice, which shows relatively high variation in the CO_2–nutrient response among the different cultivars evaluated. Much work is already underway, through breeding or transgenic methods, to produce variants of staple crops with increased nutrient concentrations[10], but much more work is still needed to understand how these cultivars would perform under the very different conditions induced by high atmospheric CO_2 concentrations.

To improve our understanding of risks to food quality, two central challenges need to be tackled. First, CO_2 fertilization and its multiple, ambivalent effects on food security need to be better understood and represented in crop models. Myers *et al.*[3] provide evidence that reduced mineral contents are not only caused by dilution through increased carbohydrate production, thus highlighting the deficiency in our current understanding of the processes of plant response to enhanced CO_2. To improve this situation, crop modellers, breeders, physiologists and human health and nutrition researchers will need to work together to understand future climate-driven challenges in food security. The Agricultural Model Intercomparison and Improvement Project (www.AgMIP.org) and ISI-MIP could and should serve as platforms to facilitate this interaction. Second, we need to broaden the scope of modelling to elucidate hidden hunger. This requires moving from a quantities-only perspective to one that includes impacts on nutritional quality, which will involve a new look at non-staple crops — for which models have often never been developed — that may become increasingly important in a world of high-calorie, low-quality grains and legumes. ❐

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AGRICULTURAL IMPACTS

Europe's diminishing bread basket

Global demand for wheat is projected to increase significantly with continuing population growth. Currently, Europe reliably produces about 29% of global wheat supply. However, this might be under threat from climate change if adaptive measures are not taken now.

Holger Meinke

By the middle of the twenty-first century, it is probable that climate change will result in more frequent wheat crop failures accross Europe[1]. There are many reasons why the frequency and severity of crop failures might increase in the future, albeit with large regional differences. Some adaptive measures to minimize yield losses show more promise than others, yet none of them seem to be sufficient to fully avoid the problem.

Assessments of the potential impact of climate change on agriculture have flooded the scientific literature over the past decade. They range from detailed laboratory or field experiments[2,3] to global impact studies[4]. In the majority of cases, these analyses account for probable crop physiological responses to either temperature, rainfall or CO_2. These factors are generally evaluated progressively, rarely considering changes in the extremes of climatic variables (such as intensive rainfall events or heatwaves) or the combined effect of extreme events on crop physiology and crop management practice. Thus, most studies examine climate change impacts from a monocausal, crop physiological perspective. Yet, as every farmer knows, producing an economically viable yield requires the effective management of a multitude of potential perils, combined with a fair amount of skill and luck.

As they report in *Nature Climate Change*, Trnka and colleagues[1] take a refreshingly different approach to this problem. Not only do they avoid the common monocausal trap, they also resist the temptation to 'over-quantify' climate change impacts on wheat yields by, for instance, using highly parameterized production models. Instead, the authors only simulate the bare essentials — the probable changes in crop development (phenology) over the next 50 years from the present period (1981–2010) to the middle of the twenty-first century (2051–2070) — for 14 locations across Europe. These simulations provide the necessary input dates (sowing, anthesis and maturity) for a carefully designed, multi-peril risk assessment.

Trnka *et al.*[1] selected 14 case study locations across 13 countries covering the major wheat-producing regions of the

European Union (including some possible future production sites), ranging from Seville in Spain to Jyvaskyla in Finland and from Rothamsted in the UK to Athens in Greece. For each site they evaluated the changing frequencies in the occurrence of 11 separate risk factors, considering each factor individually as well as combinations of factors. These risk factors include direct climate impacts on crop growth such as frost, heat stress, water logging and drought, but also climatic impacts on crop management such as adverse conditions during either sowing or harvesting.

While several previous studies suggested a possible northern shift of European wheat production due to changes in thermal suitability, the study by Trnka *et al.* strikes a more nuanced note by considering the probability of multiple risk factors, either in isolation or by considering their combined probabilities. The study found that overall, and in spite of the uncertainties associated with climate change projections, the 'adverse event frequency' is more likely to increase than decrease across all 14 European sites. This raises a cautionary flag for policy makers as it indicates that the problem a changing climate poses is complex and cannot be solved by simply moving production north, in accordance with the changing temperature gradients.

However, the increase in adverse event frequency is by no means uniform: some central and northwestern European locations exhibit small increases in risk compared with their counterparts in the south and the east, suggesting possible geographic shifts in European wheat production. Yet, with only one exception, the risk of extreme events exceeding a damage threshold increased for all of the sites and wheat varieties considered. Furthermore, the study found that the frequency of adverse event occurrence increased by 30% or more for all sites, while at five of the sites the frequency doubled.

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Although the authors used a simple analysis to extracted useful insights from a complex dataset, this 'elegance of simplicity' has a price. The findings of this study will be useful in guiding regionally specific adaptation strategies for policy, crop management and breeding, but the analysis is contingent, among other factors, on a correct estimate of phenology under current and future climates. The difficulty of predicting phenology across environments and sowing dates is well known. In rice, for example, prediction error has been shown to increase with temperature[5], leading to concerns about the use of model-based estimates of flowering and maturity dates for climate change impact studies. Although there is no easy fix to this problem, the precautionary principle applies: this study might be a useful guide for screening possible adaptation options, but it is not a surrogate for real-world empirical evidence.

Moreover, the study is limited to wheat grown on free-draining soils with high water-holding capacity. Soil type differences are likely to impact on risk profiles such as frequency and severity of water stress or water logging. This is a major limitation and is acknowledged by the authors. Although the basic assessment principles and the climatic characteristics have a degree of generality and transferability, some site-specific characteristics will always prevail and need to be understood when basing decisions on such analyses.

In conclusion, the study by Trnka *et al.* is refreshing and constitutes a way forward for multi-peril, agricultural impact assessments. The quantification of multiple adverse event frequencies is methodologically sound and may assist in the development and selection of regionally based adaptation options. Nevertheless, these options will require a more rigorous empirical validation. ❐

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Correction

In the News & Views 'Nutrients trigger carbon storage' (*Nature Climate Change* **4,** 425–426; 2014), the name of the author of the associated Letter was incorrectly stated and it should have read Marcos Fernández-Martínez. This has now been corrected in the online versions after print 29 May 2014.