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Cereal yield gaps across Europe

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A R T I C L E I N F O

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A B S T R A C T

Europe accounts for around 20% of the global cereal production and is a net exporter of ca. 15% of that production. Increasing global demand for cereals justifies questions as to where and by how much Europe's

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production can be increased to meet future global market demands, and how much additional nitrogen (N) crops would require. The latter is important as environmental concern and legislation are equally important as production aims in Europe. Here, we used a country-by-country, bottom-up approach to establish statistical estimates of actual grain yield, and compare these to modelled estimates of potential yields for either irrigated or rainfed conditions. In this way, we identified the yield gaps and the opportunities for increased cereal production for wheat, barley and maize, which represent 90% of the cereals grown in Europe. The combined mean annual yield gap of wheat, barley, maize was 239 Mt, or 42% of the yield potential. The national yield gaps ranged between 10 and 70%, with small gaps in many north-western European countries, and large gaps in eastern and south-western Europe. Yield gaps for rainfed and irrigated maize were consistently lower than those of wheat and barley. If the yield gaps of maize, wheat and barley would be reduced from 42% to 20% of potential yields, this would increase annual cereal production by 128 Mt (39%). Potential for higher cereal production exists predominantly in Eastern Europe, and half of Europe's potential increase is located in Ukraine, Romania and Poland. Unlocking the identified potential for production growth requires a substantial increase of the crop N uptake of 4.8 Mt. Across Europe, the average N uptake gaps, to achieve 80% of the yield potential, were 87, 77 and 43 kg N ha^{-1} for wheat, barley and maize, respectively. Emphasis on increasing the N use efficiency is necessary to minimize the need for additional N inputs. Whether yield gap reduction is desirable and feasible is a matter of balancing Europe's role in global food security, farm economic objectives and environmental targets.

1. Introduction

Cereals are grown on half of the European Union's (EU) farms, occupying a third of EUs agricultural area and accounting for a quarter of its crop production value (EU, 2014). On a global scale, Europe accounts for 20% of the total cereal production, of which about 63% is produced in the countries of the EU28 (FAO, 2016). Cereals in the EU28 are mainly used for animal feed (61%) and human consumption (24%), while smaller other purposes include alcoholic beverages (5%), bio-energy (4%) and seeds (3%) (EU, 2016). Wheat and rye are used almost equally for animal feed and human consumption, while barley, maize, sorghum, oats and triticale are predominantly used for animal feed. In recent years, Europe has been a net exporter of around 15% of its cereal production (FAO Food Outlook, 2016). The exported cereals are mainly wheat and barley, while the imports consist mainly of maize.

Over the coming decades the global demand for agricultural products, including cereals, is expected to rise, driven by population and income growth (Alexandratos and Bruinsma, 2012; Godfray and Garnett, 2014). The rising role of crop products in the transition towards low-fossil-carbon economies (Gabrielle et al., 2014) will put further pressure on agricultural production. As suitable agricultural land for expansion of agricultural production is becoming scarce (Lambin and Meyfroidt, 2011) and expanding the agricultural area comes with substantial environmental trade-offs, sustainable production increases from intensifying the use of existing agricultural land will be the main avenue to satisfy the increasing demand. Sustainable intensification, i.e. realising high yields on existing croplands with efficient resource use is important to meet global crop demand with minimal environmental impacts (Tilman et al., 2011). Avoiding food loss and waste, and reducing consumption of livestock products (Garnett et al., 2013) are also important, but are not further considered in this paper.

Projections by the Food and Agricultural Organization (Alexandratos and Bruinsma, 2012) show that the global annual demand for cereals, including both food and non-food use, will increase from 2.1 Gt in the base years around 2006 to 3.0 Gt by 2050. Almost all the increases in the consumption of cereals will come from developing countries, particularly after 2020 when the use of cereals for biofuels is assumed to peak at 180 Mt. Developing countries are projected to continue increasing their net imports of cereals from the rest of the world. Moreover, if intensification is not successful in developing countries, these regions will increasingly depend on imports of cereals (Van Ittersum et al., 2016b), and traditional exporters such as Europe may sustain or even increase their share in the growing global grain trade. Consequently, the question "where and by how much can Europe's production be enhanced to meet future cereal demand?" is justified. Gain in cereal yields will at least partly rely on increased nitrogen (N) and other inputs (Dobermann and Cassman, 2005). Given the importance of reactive N as a driver for many of today's local and global environmental concerns (Sutton et al., 2011; De Vries et al., 2013), it is relevant to complement the estimates of potential production increases with estimates of the associated additional N requirements.

When considering sustainable intensification in the context of European cereal production, it is essential to consider the large heterogeneity of Europe's agricultural landscape. Europe has a wide geographic extent comprising a variety of farm structures and intensities combined with pronounced differences in environmental conditions, rendering substantial variation in inputs (nutrients, pesticides, irrigation) and outputs (crop yields), as well as future yield potential. We use the concept of yield gaps (Van Ittersum et al., 2013) to identify the regions with unlocked yield potential. A yield gap is the difference between potential and actual yield. Potential yields can be calculated for irrigated (yield potential) and rainfed (water-limited yield potential) conditions. Yield potential assumes unconstrained crop growth and perfect management that avoids yield limitations from nutrient deficiencies and water stress, and yield reductions from weeds, pests and diseases. Yield potential is therefore location and year specific and depends on the crop genotype along with solar radiation and air temperature during the crop growing season. In addition, water-limited yield potential depends on water supply as dictated by precipitation and soil available water. Full yield gap closure is generally not economically feasible nor environmentally desirable (Cassman, 1999; Van Ittersum et al., 2013). We thus take 80% of the yield potential as the reference for increases that can be achieved in farming practice.

The objective of the present study is to quantify actual and potential yields for wheat, barley and maize in Europe. Together these three crops represent 90% of the European cereal production. We use a country-by-country, bottom-up approach to establish statistical estimates of actual grain yield, and compare these to modelled estimates of potential yields. In this manner, we identify the yield gaps and the associated opportunities for increased cereal production. Furthermore, we aim to quantify the additional N required to increase yields and reduce yield gaps. These results provide essential information for strategic decisions by policy makers, NGO's, agro-industry and commodity traders on topics related to market development and EU and national policies for agriculture, food security and sustainable development.

2. Material and methods

The yield gap analysis of cereals in Europe applies the approach developed and described by the Global Yield Gap Atlas (GYGA; www.yieldgap.org) project. In brief, the approach distinguishes the following main steps: (1) selection of representative climate zones (CZ) based on dominant crop areas, (2) selection of reference weather stations (RWS)