Supplementary Information

Measuring extremes-driven direct biophysical impacts in agricultural drought damages

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Figure S1 shows the area under drought (SMI<0.2) in the vegetative active period (April-Oct) for 2016-2022. A district under drought in Germany had an average affected area of 78%, with notable differences between years and locations. The map also illustrates variations in the number of districts impacted by agricultural drought. For instance, in 2021, only 36 districts were affected, located primarily in southwest Germany, with an average district area under drought of 62%. Conversely, in 2018, all German districts experienced agricultural drought with the range of areas under drought varying from 50% to 100%. Furthermore, spatial variability across different years is evident- in 2018 and 2022, nearly all of Germany was affected by droughts, while in 2016, it mainly affected districts in Mecklenburg-Vorpommern, Sachsen-Anhalt and the surrounding districts in central Germany. In 2017, Nordrhein-Westfalen and Rheinland-Pfalz were mostly impacted by drought. These results show temporal and spatial variability in drought occurrence in Germany.

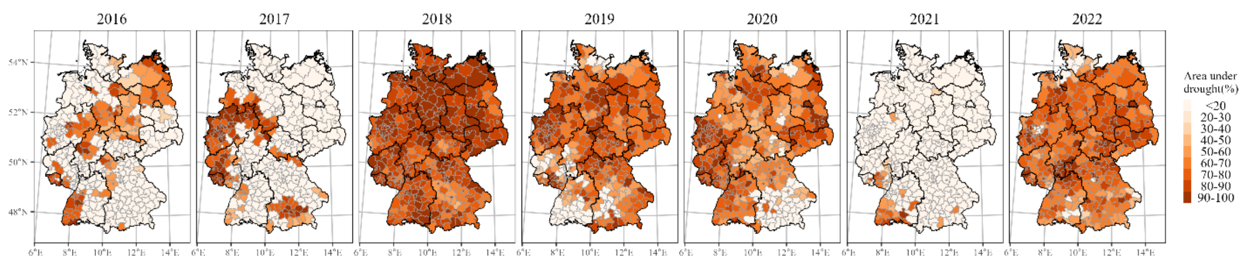

Figure S1 Spatial and temporal variation in area under drought (%) during the vegetative active period (April-Oct) in German district-level administrative units. The values are calculated based on monthly SMI (<0.2) data obtained from mHM.

We use the yields simulated by the statistical yield modeling approach to evaluate biophysical yield losses during droughts from 2016-2022 in Germany. This is done by comparing the simulated yield of a drought year with the average simulated yield of 5 preceding non-drought years. The non-drought years (as described in the methods section) are categorized at the district level. The district-level biophysical yields are simulated for eight major field crops in Germany: winter wheat, winter barley, rapeseed, maize, spring barley, spring oats, sugar beets, and potatoes. The distribution of yield losses for these crops over the studied period across drought-affected districts of Germany is presented in Figure S2. Sugar beets suffered the highest yield losses under droughts across almost all studied years. Winter crops (winter wheat and winter barley) experienced amongst the lowest losses during this period. While there was limited spatial occurrence of drought in the years 2016, 2017, and 2021 (Figure S2); all crops suffered moderate yield losses. In both 2018 and 2022, maize and potatoes suffered the highest yield losses followed by sugar beets. In contrast, in 2019, the yield losses of spring oats and rapeseed were more pronounced than those of other crops. Notably in 2020, the yield losses were lower than in 2018 and 2019, despite being the third consecutive drought year for most of the country. It is also interesting to note the outliers in Figure S2 which display significant yield losses due to droughts in Germany.

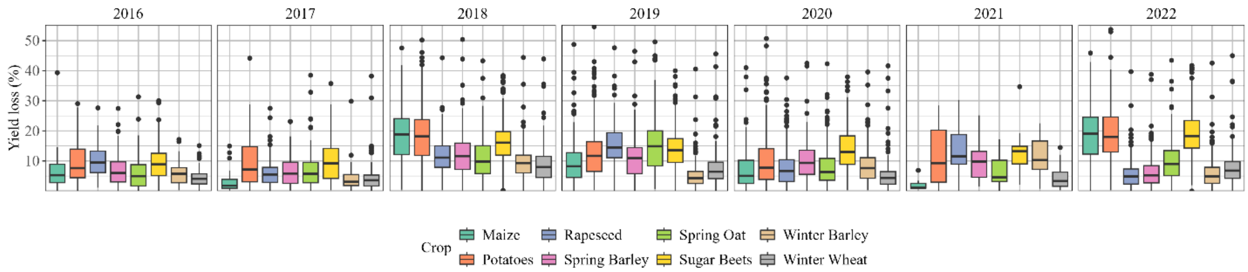

Figure S2 Simulated yield losses under droughts in 2016-2022, compared to yields in the preceding five non-drought years based on the yields simulated by the statistical yield modeling approach.

Next, in Figure S3, we present the annual average yield loss for all crops during droughts across Germany, weighted by the district-level acreage of each crop. These findings are valuable for understanding the spatial distribution of yield losses in droughts across the country. The results show significant yield losses across Germany in 2018 (12.7%), 2019 (8.7%) and 2022 (9.9%). While nearly all districts experienced yield loss during these years, higher losses were observed in northern Germany compared to southern regions.

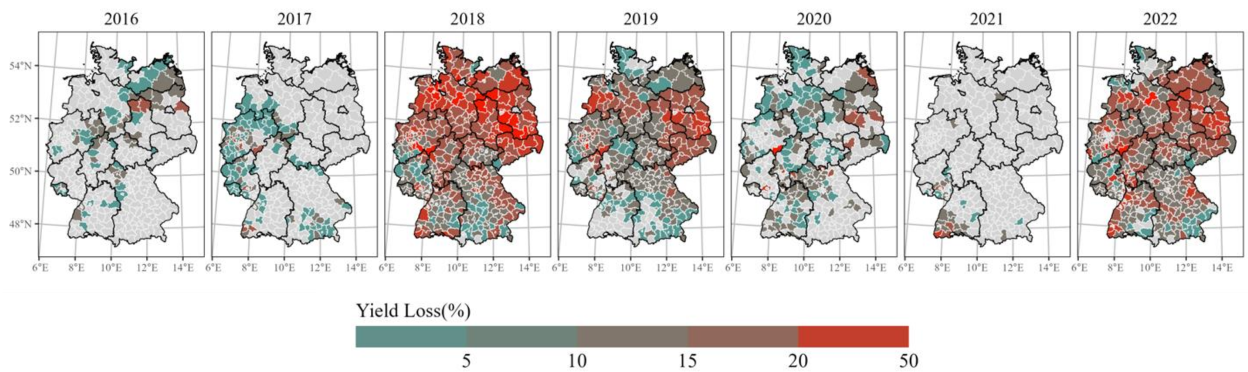

Figure S3 Average simulated yield losses (%) in German district-level administrative units. The values show area-weighted average yield anomaly for eight field crops included in the analysis. The different colors show the average yield loss in the districts.