Global data on fertilizer use by crop and by country

Cameron I. Ludemann1✉, Armelle Gruere2, Patrick Heffer2 & Achim Dobermann2

Understanding how much inorganic fertilizer (referred to as fertilizer) is applied to different crops at national, regional and global levels is an essential component of fertilizer consumption analysis and demand projection. Good information on fertilizer use by crop (FUBC) is rarely available because it is difficult to collect and time-consuming to process and validate. To fill this gap, a first global FUBC report was published in 1992 for the 1990/1991 period, based on an expert survey conducted jointly by the Food and Agriculture Organization (FAO) of the UN, the International Fertilizer Development Center (IFDC) and the International Fertilizer Association (IFA). Since then, similar expert surveys have been carried out and published every two to four years in the main fertilizer-consuming countries. Since 2008 IFA has led these efforts and, to our knowledge, remains the only globally available data set on FUBC. This dataset includes data (in CSV format) from a survey carried out by IFA to represent the 2017–18 period as well as a collation of all historic FUBC data.

Background & Summary
Fertilizer often constitutes the major source of nutrients in a crop system1–3. Therefore the input of nutrients in the form of fertilizer is often an important component of crop nutrient balances and assessments or monitoring of nutrient use efficiency at different scales4. Crop nutrient balances highlight regions of the world where crop production could be limited by nutrients and/or where there are an excessive quantity being applied. The former situation may result in poor crop or livestock production with detrimental effects on food security, while the latter situation may lead to a loss of nutrients with potentially detrimental effects on the environment.

Collection of FUBC data is difficult and time-consuming at a global scale. While statistics for grain production in a country can be relatively easily estimated given you can attribute the quantity of grain back to a certain crop, this is not the case for FUBC data. Firstly, good information on country level FUBC is rarely available or monitored by statistical bureaus. Secondly, attributing fertilizer back to one certain crop can be made more difficult in countries where there is integration of grassland with crop production. In these cases fertilization of arable land can be part of a crop rotation that aids productivity of the subsequent grassland crops, or vice versa. Thirdly, multiple crops per year, or multiple crops in the same area of land can make a binary distribution of FUBC back to a single crop more difficult.

The first country level FUBC data were published in 1992 to fill the gap in data availability5 with (up until the present study) the latest results published in 20177. The first data were based on a survey of experts conducted by FAO, IFDC and IFA. Similar surveys were undertaken and published every two to four years for the main fertilizer-consuming countries (Table 1). IFA has led these survey efforts since 2008. To our knowledge these are the only globally available dataset for FUBC.

The current dataset includes data from the latest FUBC survey conducted by IFA as well as a collation of all available FUBC data shown in Table 1. The current survey benefited from the agronomic expertise of numerous experts to provide and validate estimates. This is the best effort that IFA can achieve with its current resources. It provides a general overview of how fertilizers are being used worldwide for the three main nutrients: nitrogen (N), phosphorus (P, reported here as P2O5) and potassium (K, reported here as K2O). We caution, however, that for many countries the estimates provided here are associated with substantial uncertainties. Likewise, comparisons with previous reports must be made with caution because methodologies and sources of information have changed over time. Nevertheless, this dataset constitutes the best estimates of FUBC at a country level with a global coverage to date.

1Wageningen University & Research, Plant Production Systems, Wageningen, Netherlands. 2International Fertilizer Association, Paris, France. ✉e-mail: cameron.ludemann@wur.nl
In particular, the areas of crop suggested by the survey respondents were compared with FAOSTAT values. In some cases, the application of N, P\textsubscript{2}O\textsubscript{5} and K\textsubscript{2}O for each crop for their country of expertise. The exact methodology used by respondents and statistical agencies to develop estimates of fertilizer use by crop is not known to the authors. The questionnaire itself was composed of an Excel (version 2102, Microsoft Corporation, Redmond Washington, USA) spreadsheet (Supplementary Table 3). Rows were included in the spreadsheet for the correspondent to add estimates of the area of crop, percentage of total crop area that had been fertilized, and total application of N, P\textsubscript{2}O\textsubscript{5} and K\textsubscript{2}O for each crop for their country of expertise. The exact methodology used by respondents and statistical agencies to develop estimates of fertilizer use by crop is not known to the authors. Methodologies therefore may differ across countries and may range from including actual farm survey data to simply estimating representative application rates based on their knowledge of the country. Survey participants were asked to report planted area for each crop, however in some cases harvested area was provided. If these data were not available, the FAOSTAT\textsuperscript{5} harvested areas for each crop were used. Planted areas were used for 51 countries, harvested areas were used for 11 countries and ‘fertilized area’ was used for one country (Ukraine).

Processing of latest survey data. In contrast to the historic data included in the combined dataset, (where we kept the same crop names as were used in the published reports), data from the latest survey were aggregated, where possible, into a limited set of aggregate crop names (see Table 4). This was performed to align to the crop categories reported by Heffer, et al.\textsuperscript{35} However, this resulted in some of the information from the original survey being lost. Therefore, in addition to the combined dataset, we also include a separate raw datafile of the latest survey results that include information for the original crop names. The R code required to convert the raw data file being lost. Therefore, in addition to the combined dataset, we also include a separate raw datafile of the latest survey.
for the latest survey results and merge it into the combined csv file is available at: https://github.com/ludemannnc/FUBC_1_to_9_2022.git.

In relation to the latest survey data that had been aggregated by crop names (in the combined data file), in some cases it was not possible to categorize the crop names received from the survey respondents into the categories listed in Table 4. For instance, for most countries in the European Union, the data followed Fertilizers Europe’s own method of categorisation whereby rice was grouped with rye, triticale and oats, and soybeans were grouped with sunflower and linseed. For countries in the European Union, rice therefore had to be categorized as an ‘other cereal’, while soybeans had to be categorized as an ‘other oilcrop’. Respondents from New Zealand grouped wheat, oats and barley into an aggregated cereal grains category. In this case the cereal grains category had to be included in the ‘other cereal’ crop category. The total nutrients applied to each (aggregate) crop category in each country were divided by the total area of each (aggregate) crop category in each country to estimate the mean application rates for each nutrient per hectare.

Estimates for the most recent survey could not be obtained for ten important fertilizer consuming countries: Australia, Bangladesh, Egypt, Indonesia, Iran, Malaysia, Mexico, Morocco, Russia and Vietnam. For these countries, the previous average application rates (calculated based on nutrient quantities and FAO 2014 crop area) were multiplied by 2018 FAO (harvested) crop area. The resulting nutrient quantities were adjusted so that total fertilizer use in the country matched the consumption of nutrients estimated by country from IFASTAT. For example, if the 2014 application rates were multiplied by the 2018 FAO crop areas and this resulted in a total nutrient consumption for a certain country that needed 10% more to be equivalent to the value from IFASTAT then the 2014 application rates were multiplied by 1.1 to get alignment in total nutrient consumption between the two surveys.

Data Records
Combined dataset (FUBC_1_to_9.csv). This dataset can be downloaded from DRYAD7 (https://doi.org/10.5061/dryad.2rbnzs7q) and is available in CSV file format. Tables 2, 3 provide an overview of the data records in the combined data file.

| Parameter                                | Description                                                                 | Format     | Units                                                                 |
|------------------------------------------|-----------------------------------------------------------------------------|------------|-----------------------------------------------------------------------|
| Original_country_name_in_FUBC_report     | Original name of country used in FUBC report                               | Character  | Character                                                             |
| Country                                  | Country name based on official United Nations English name, with the exception that references to Belgium-Luxembourg were converted to ‘Belgium’, and referrals to Taiwan were converted to China, Taiwan | Character  | Character                                                             |
| ISO3_code                                | The 3-letter ISO3 United Nations code to signify country or region. Note that China, Taiwan was given the TWN 3-letter code | Character  | Character                                                             |
| Region_IFA                               | Region, based on the International Fertilizer Association (IFA) list of aggregate countries and regions | Character  | Character                                                             |
| Year                                     | Year in which the data relates to. Year is in character format because in some reports the data relate to non-calendar years e.g. 1991/92, 1997–98. These therefore include a mixture of calendar and ‘fertilizer’ years | Character  | Character                                                             |
| FUBC_report_number                       | The fertilizer use by crop (FUBC) report number. This is a sequential number assigned to each report since they were first published | Numeric    | Integer                                                              |
| Year_FUBC_publication                    | The fertilizer use by crop (FUBC) report, year of publication               | Numeric    | Integer                                                              |
| Crop                                     | Crop type, based on those originally reported in the fertilizer use by crop (FUBC) reports | Character  | Character                                                             |
| Crop_area_k_ha                           | The total crop area which may include planted or harvested areas depending on what data the survey respondents had available | Numeric    | Kilo hectares (1000 ha/year)                                         |
| N_k_t                                    | Total nitrogen applied to total crop area                                  | Numeric    | Kilo (*1000) metric tonnes of elemental nitrogen/year                |
| P2O5_k_t                                 | Total P2O5, applied to total crop area                                      | Numeric    | Kilo (*1000) metric tonnes of P2O5/year                              |
| K2O_k_t                                  | Total K2O applied to total crop area                                       | Numeric    | Kilo (*1000) metric tonnes of K2O/year                               |

Table 2. List of parameters, formats and units for the fertilizer use by crop (FUBC) data in the combined dataset (which included all available FUBC surveys, and had the latest survey results where values had been aggregated to crop categories that aligned to the last published FUBC report)³. 

---

1Scientific

---

2Scientific

---

3Scientific
### Table 3. List of parameters, formats and units for the fertilizer use by crop (FUBC) data in the combined dataset (which included all available FUBC surveys, and had the latest survey results where values had been aggregated to crop categories that aligned to the last published FUBC report) (continued).

| Parameter               | Description                                                                 | Format                      | Units                                      |
|-------------------------|-----------------------------------------------------------------------------|-----------------------------|--------------------------------------------|
| N_P2O5_K2O_k_t          | Total nitrogen + P₂O₅ + K₂O applied to total crop area                      | Numeric                     | Kilogram (+ 1000) metric tonnes of N + P₂O₅ + K₂O/year |
| N_rate_kg_ha            | Mean application rate of nitrogen to area of crop that actually received fertilizer (see N_pc_fert for percentage of crop area where N was applied) | Numeric                     | Kilograms of nitrogen per hectare (kg N/ha/year) |
| P2O5_rate_kg_ha         | Mean application rate of P₂O₅ to area of crop that actually received fertilizer (see P₂O₅_pc_fert for percentage of crop area where P₂O₅ was applied) | Numeric                     | Kilograms of P₂O₅ per hectare (kg P₂O₅/ha/year) |
| K2O_rate_kg_ha          | Mean application rate of K₂O to area of crop that actually received fertilizer (see K₂O_pc_fert for percentage of crop area where K₂O was applied) | Numeric                     | Kilograms of K₂O per hectare (kg K₂O/ha/year) |
| N_pc_fert               | Percentage of total crop area that received any nitrogen fertilizer          | Numeric                     | Percent (%)                                |
| P2O5_pc_fert            | Percentage of total crop area that received any P₂O₅ fertilizer             | Numeric                     | Percent (%)                                |
| K2O_pc_fert             | Percentage of total crop area that received any K₂O fertilizer              | Numeric                     | Percent (%)                                |
| Aver_N_rate_kg_ha       | Mean application rate of nitrogen across total crop area                     | Numeric                     | Kilograms of nitrogen per hectare (kg N/ha/year) |
| Aver_P2O5_rate_kg_ha    | Mean application rate of P₂O₅ across total crop area                        | Numeric                     | Kilograms of P₂O₅ per hectare (kg P₂O₅/ha/year) |
| Aver_K2O_rate_kg_ha     | Mean application rate of K₂O across total crop area                         | Numeric                     | Kilograms of K₂O per hectare (kg K₂O/ha/year) |
| Aver_N_P2O5_K2O_rate_kg_ha | Mean application rate of nitrogen + P₂O₅ + K₂O across total crop area. | Numeric                     | Kilograms of N + P₂O₅ + K₂O per hectare (kg N + P₂O₅ + K₂O /ha/year) |

Nₖ_t, P₂O₅ₖ_t and K₂Oₖₜ reflected the total quantities of nitrogen, P₂O₅ and K₂O respectively in thousands of metric tonnes per year. In some cases the total quantities of nutrients do not equal the total crop areas multiplied by the percentage of total crop area that received fertilizer and the kilograms of nutrient rate per hectare. This is because, firstly the latest FUBC data did not include percentages of total crop area that had been fertilized. The values for nutrient application rates were means for across total crop area in the latest FUBC data. Secondly, the references for the historic FUBC data (see Table 1) warned that in some cases values did not add up due to rounding errors. Numeric values from the historic FUBC data were kept the same as those reported in the original publications. N_P2O5_K2O_k_t is the sum of the N_k_t, P2O5_K_t and K2O_k_t numeric values.

N_rate_kg_ha, P2O5_rate_kg_ha and K2O_rate_kg_ha are the mean application rates of nitrogen, P₂O₅ and K₂O respectively in kilograms of nutrient per hectare per year. These are the mean application rates of each respective nutrient to the areas of crop that actually received any fertilizer. N_pc_fert, P₂O5_pc_fert, K2O_pc_fert denote in numeric terms the percentage of total crop area that has had any nitrogen, P₂O₅ or K₂O fertilizer applied to it respectively. Aver_N_rate_kg_ha, Aver_P2O5_rate_kg_ha, Aver_K2O_rate_kg_ha, and Aver_N_P2O5_K2O_rate_kg_ha, are the average application rates of nitrogen, P₂O₅, K₂O and N + P₂O₅ + K₂O respectively (in kg per hectare per year of the respective nutrients) across the total crop areas. They are a function of the total nutrients applied divided by the total crop area. Note that in the original sources of historic FUBC data there was variation between countries, crops and years as to whether the average application rates across total crop area, and/or average application rates across fertilized areas of crops were used. These numeric data were included in the dataset as they were reported in the original publication, and no attempt was made to interpolate data to fill in missing values.

A meta data file accompanies the combined data file and is named Meta_data_FUBC_1_to_9.csv.

**Latest FUBC survey raw data file (FUBC_9_raw_data.csv).** This dataset can be downloaded from DRYAD (https://doi.org/10.5061/dryad.2rbyn7z7qy) and is available in CSV file format. Details of each parameter in this file are listed in Table 5.

Original_country_name_in_FUBC_report and Original_crop_name_in_FUBC_report provide information on the original country and crop name from the survey respectively as names in text format. Year data are not represented as integers, but are instead represented as text to align to the format of Year in the combined (FUBC_1_to_9.csv) dataset. Year_for_FAO_area indicates the most appropriate FAO ‘year’ for aligning FUBC survey data with FAO crop areas and are represented as integer values. The FAO_area_ha and IFA_area_ha represent the numeric areas of crop per year based on the FAO data and the latest FUBC survey respectively.

FAO_area_used_Yes_No indicates whether the FAO or latest FUBC survey estimates of crop are were used in the meta data file. Original_country_name_in_FUBC_report and Original_crop_name_in_FUBC_report provide miscellaneous information (in character format) related to data that came from the survey as well as information on whose information was used in the estimate, respectively.
Table 4. Categorisation of crop names for the latest* fertilizer use by crop survey data. *Crop information for the historic fertilizer use by crop data were not changed from that reported in the original source.

| Final crop name in datafile | Variations of crop names (from survey respondents) included in final crop name category. |
|-----------------------------|------------------------------------------------------------------------------------------------|
| Wheat                       | Wheat                                                                                       |
| Rice                        | Rice                                                                                       |
| Maize (grain)               | Crop names that either stated maize only, or mentioned maize and grain                       |
| Maize green                 | Crop names that mentioned maize and the fact it was not used for grain (e.g. Maize green, maize silage and maize bioenergy) |
| Other cereals               | Cereal, irrigated field crop, other cereals, grain mixed sheep & beef                         |
| Soybeans                    | Soybeans                                                                                   |
| Pulses                      | Pulses, beans, peas, black-eyed peas (niébé)                                               |
| Oil palm                    | Oil palm, oil palm fruit                                                                    |
| Rapeseed                    | Canola, rapeseed, oilseed rape                                                              |
| Other oil crops             | Coconut, sunflower, other oil crops, other oil seeds, linseed, sesame, groundnut, peanut, olive |
| Cottonseed                  | Cotton                                                                                     |
| Sugar beet                  | Sugar beet                                                                                 |
| Sugar cane                  | Sugar cane                                                                                 |
| Tea                         | Tea                                                                                        |
| Coffee green                | Coffee, green                                                                              |
| Roots/tubers                | Roots and tubers, potato, taro, cocoyam, cassava, yam                                       |
| Fruits and treenuts         | Fruits, melon, citrus, treenuts                                                            |
| Vegetables                  | Vegetables, tomato, onion, sweet corn, garlic                                               |
| Grassland                   | Grass, pasture, hay, rangeland, lucerne, perennial crops, fodder, forages                   |
| Residual (Other crops)      | Forest, rubber, flowers, cocoa, fresh herbs, orchards, amenity horticulture, ginger, horticulture, tobacco, other industrial crops, other crops, short rotation coppice, perennial herbaceous crops (Miscanthus, etc.), residual |

A meta data file accompanies the latest FUBC survey dataset raw data file and is named Meta_data_FUBC_9_raw_data.csv.

**IFA regions data file (IFA_Regions.csv).** This dataset can be downloaded from DRYAD7 (https://doi.org/10.5061/dryad.2rbnzs7qh) and is available in CSV file format. This file indicates how countries were assigned to 'IFA Regions'. It includes columns of information (all in character format) for Country, ISO3_Code, and Region_IFA. Country indicates the country name based on the official United Nations English name, ISO3_Code indicates the 3-letter ISO3 United Nations code to signify country or region, and Region_IFA indicates categories of regions based on the International Fertilizer Association (IFA) list of aggregate countries and regions.

*Crop information for the historic fertilizer use by crop data were not changed from that reported in the original source.*

A meta data file accompanies the IFA_Regions data file and is named Meta_data_IFA_Regions.csv.

**Country tables data file (Country_tables.xlsx).** This dataset can be downloaded from DRYAD7 (https://doi.org/10.5061/dryad.2rbnzs7qh) and is available in xlsx (Excel) file format. Country_tables.xlsx contains the planted areas (in hectares), total nutrients applied, nutrients applied per hectare and the percentage share of nutrient use for nitrogen, P2O5, and K2O for the different categories of crops, for all countries where data were available. The categories of crops in this file are the same as those reported by respondents in the survey.

**Technical Validation**
This is the only known world-wide survey of fertilizer use by crop at a country level, which makes validation of the nutrient application rate data within this dataset difficult. As mentioned in the Method section, respondents of the survey used different methodologies for making their estimates and the crop categories also varied somewhat by country. Where possible, estimates from the respondents were compared with official statistics from the respective country and/or from FAOSTAT5. In some cases where there were major discrepancies, respondents from the survey were contacted to clarify their estimates. The main forms of clarification included correcting obvious mistakes in either quantities of fertilizer or areas of crop, clarifying the types of crops or grassland considered, clarification of production practices that helped explain higher than expected fertilizer application rates (for example, application rates of irrigated area are greater than those on rainfed areas). If the respondent could not provide an explanation, estimates from other sources were used. If better estimates were not available the following three options were utilised: (1) if the crop area was small relative to the country's total crop area, the crop was attributed to the residual category; (2) if the crop area accounted for a significant share of the country's total, and the country was a small fertilizer consumer, we decided not to publish the country data, and (3) if the crop area accounted for a significant share of the country's total, and the country was a significant consumer of fertilizers, then an estimate was made based on an extrapolation of the data from the previous survey as previously described in the 'Processing of latest survey data' section.

Furthermore, total nutrient use for each country was estimated through multiplication of the application rate per hectare by the area of each crop. This allowed estimates of total nutrient use for each country to be compared with estimates of total nutrient consumption by country from IFASTAT. As shown in Supplementary Table 4,
there was general agreement in the total quantities of nitrogen, P$_2$O$_5$, and K$_2$O (applied as fertilizer) for each country depending on whether it was based on the IFASTAT data or data from the latest FUBC survey. This is indicated by the relatively low percentage differences in total values. There were some countries where the estimates, the resulting 2018 fertilizer consumption for the country exceeded the IFASTAT total national consumption estimate by 42%, and that of the National Bureau of Statistics by 15%. The gap would be even larger if significant effect on estimates of nutrient consumption at the global aggregate level. Nevertheless, these sources of variation represent considerable uncertainty for the estimates of those countries. Given that we did not receive information on how each survey respondent made their estimates, we were not able to interrogate any further why this variation may have occurred and should be an area of focus in any subsequent surveys. We can only speculate that errors in the methods by which the estimates were made for the IFASTAT and/or latest survey results (for example, if some crops are missing) contributed to this variation. The R code used for the aforementioned comparison in estimates using results from IFASTAT and the latest survey results is available at: https://github.com/ludemannc/FUBC_1_to_9_2022.

Estimates for some countries are therefore associated with substantial uncertainties. Therefore analysis of these data across years and between countries should be made with caution. Likewise, comparisons with previous reports must be made with caution because methodologies, crop categories and sources of information have changed over time. This is especially the case for China. China did not have the greatest difference in final estimates of fertilizer consumption between IFASTAT and the latest FUBC survey compared with other countries (it had 35% variation). However, China is a major consumer of fertilizer, with 32% of the world’s use of fertilizer (as nitrogen + P$_2$O$_5$ + K$_2$O) coming from this country. Any variation in consumption by China will have a significant effect on estimates of total world consumption of fertilizer. Unfortunately, the data for China are difficult to reconcile with the FAOSTAT published crop harvest area statistics and IFASTAT consumption estimates. Average 2018 fertilizer application rates were collected for the major crops of China based on county-level statistics published by the National Development and Reform Commission of the People’s Republic of China (NDRC), but also farm survey data collected by research groups at China Agricultural University (CAU) and the Chinese Academy of Agricultural Sciences (CAAS). However, when multiplied with 2018 FAO crop area estimates, the resulting 2018 fertilizer consumption for the country exceeded the IFASTAT total national consumption estimate by 42%, and that of the National Bureau of Statistics by 15%. The gap would be even larger if average fertilizer application rates could also be obtained for minor crops. The IFASTAT estimate of total fertilizer consumption in China is lower than actual fertilizer consumption but it is not expected that the actual fertilizer consumption would be 42% greater than the IFASTAT estimates.

| Parameter                                    | Description                                                                                   | Format | Units     |
|----------------------------------------------|----------------------------------------------------------------------------------------------|--------|-----------|
| Original_country_name_in_FUBC_report         | Original name of country used in FUBC report                                                 | Character | Character |
| Original_crop_name_in_FUBC_report           | Crop type, based on those originally reported in the fertilizer use by crop (FUBC) reports    | Character | Character |
| Year                                         | Year the fertilizer application information relates to (this is in character format as it includes some crops that grow across multiple years, such as 2017/18 which denotes a fertilizer year starting in mid 2017 and ending in mid 2018) | Character | Character |
| Year_for_FAO_area                            | Food and Agriculture (FAO) Year that is most applicable to the year in which the fertilizer application information estimation was made for | Numeric | Integer to denote Gregorian calendar years |
| FAO_area_ha                                  | International Fertilizer Association (IFA) area for each crop based on Fertilizer Use By Crop (FUBC) survey information | Numeric | Hectares per year |
| IFA_area_ha                                  | Provides an indication of whether it was decided the FAO or the IFA estimate of crop area is to be used, whereby Yes = FAO crop are used, and No = IFA crop area is used | Character | Character |
| FAO_N_t                                      | Total nitrogen applied to total crop area per year                                           | Numeric | Metric tonnes |
| FAO_P2O5_t                                   | Total P$_2$O$_5$ applied to total crop area per year                                          | Numeric | Metric tonnes |
| FAO_K2O_t                                    | Total K$_2$O applied to total crop area per year                                              | Numeric | Metric tonnes |
| Comment                                      | Comments made about each data point                                                         | Character | Character |
| Survey_respondent                            | Information on whose information (from the survey) was used in the estimate                   | Character | Character |

Table 5. List of parameters, formats and units for the latest fertilizer use by crop raw data file (FUBC_9_raw_data.csv) where original crop information was retained.
The 42% difference could be explained by a combination of reasons: overestimated crop area, overestimated average fertilizer application rates (if less than 100% of crop area is fertilized), and/or underestimated apparent consumption. At this stage, we are not able to resolve these differences. However, considering the huge importance of the major cereal crops and the generally known uncertainties about crop harvested area statistics in China, we replaced the 2018 FAO crop area estimates for rice, wheat and maize with more accurate estimates based on integrating multi-data sources, including remote sensing from Luo et al. This adjustment reduced the consumption estimate difference to about 35% compared to IFASTAT (see Supplementary Table 4).

Usage Notes
The following files are available at the DRYAD repository (https://doi.org/10.5061/dryad.2rbnzs7qh):

- README_FUBC_DATA_2022.txt
  - Provides a summary of all the datafiles in the DRYAD repository.

- FUBC_1_to_9.csv
  - Includes fertilizer use by crop data from the 8 previously published reports (FUBC 1 to 8), as well as the fertilizer use data from the latest (9th) survey (FUBC 9) carried out by the International Fertilizer Association. It is important to note that the FUBC 9 data have been aggregated by crop categories that align to those used in the previous survey (FUBC 8).
  - In total the combined dataset included 516 unique crop names, many of which have only slight variations in spelling based on how they were written in the previously published FUBC reports.

- Meta_data_FUBC_1_to_9.csv
  - Includes meta-data associated with the FUBC_1_to_9.csv file.

- FUBC_9_raw_data.csv
  - Includes fertilizer use by crop data from the latest fertilizer use by crop survey.
  - This file includes data where the crop names remained the same as those originally received by survey respondents. This file can be used to access the original crop information (for FUBC 9) that is otherwise lost from the FUBC_1_to_9.csv file due to crop aggregation.
  - In total this file contains 159 unique crop names.

- Meta_data_FUBC_9_raw_data.csv
  - Includes meta-data associated with the FUBC_9_raw_data.csv file.

- IFA_Regions.csv
  - Includes information shown in Supplementary Table 1 as a csv file for programmatic ease of use.

- Meta_data_IFA_Regions.csv
  - Includes meta-data associated with the IFA_Regions.csv file.

- Country_tables.xlsx
  - Includes original fertilizer use by crop data from the latest survey with separate excel worksheets for each country. This file includes more information (as ‘Notes’) on how estimates were made for each crop and country.

Code availability
The R project associated with aggregating the raw datafile (FUBC_9_raw_data.csv) into crop categories for inclusion in the combined data file (FUBC_1_to_9.csv), and creation of results in Supplementary Table 4 are available at https://github.com/ludemannnc/FUBC_1_to_9_2022.

Received: 12 May 2022; Accepted: 25 July 2022; Published online: 17 August 2022

References
1. Vitousek, P. M. et al. Nutrient Imbalances in Agricultural Development. *Science* **324**, 1519–1520, https://doi.org/10.1126/science.1170261 (2009).
2. West, P. C. et al. Leverage points for improving global food security and the environment. *Science* **345**, 325–328, https://doi.org/10.1126/science.1246067 (2014).
3. FAO, IFA & IFDC. Fertilizer use by crop at the global level. 19 (International Fertilizer Association, International Plant Nutrition Institute, Paris, France, 1992).
4. Heffer, P., Gruere, A. & Roberts, T. Assessment of fertiliser use by crop at the global level. 19 (International Fertilizer Association, International Plant Nutrition Institute, Paris, France, 2017).
5. FAOSTAT. FAOSTAT, http://www.fao.org/faostat/en/#country (2022).
6. IFA. Fertilizer use by crop and country for the 2017–2018 period. 45 (2022).
7. Ludemann, CI., Gruere, A., Heffer, P. & Dobermann, A. Global data on fertilizer use by crop and by country, DRYAD, https://doi.org/10.5061/dryad.2rbnzs7qh (2022).
8. Luo, Y. C., Zhang, Z., Chen, Y., Li, Z. Y. & Tao, F. L. ChinaCropPhen1km: a high-resolution crop phenological dataset for three staple crops in China during 2000–2015 based on leaf area index (LAI) products. *Earth Syst. Sci. Data* **12**, 197–214, https://doi.org/10.5194/essd-12-197-2020 (2020).
9. FAO, IFA & IFDC. Fertilizer use by crop 2. 64 (Food and Agriculture Organization of the United Nations, International Fertilizer Association, International Fertilizer Development Center, Rome, Italy, 1994).
10. FAO, IFA & IFDC. Fertilizer use by crop 3. 74 (Food and Agriculture Organization of the United Nations, International Fertilizer Association, International Fertilizer Development Center, Rome, Italy, 1996).
11. FAO, IFA & IFDC. Fertilizer use by crop 4. 78 (Food and Agriculture Organization of the United Nations, International Fertilizer Association, International Fertilizer Development Center, Rome, Italy, 1999).
12. FAO, IFA, IFDC, IPI & PPI. Fertilizer use by crop 5. 67 (Food and Agriculture Organization of the United Nations, International Fertilizer Association, International Fertilizer Development Center, International Potash Institute, Phosphate and Potash Institute, Rome, Italy, 2002).
13. Heffer, P Assessment of Fertilizer Use by Crop at the Global Level 2006/07 – 2007/08. 11 (International Fertilizer Association, Paris, France, 2009).
14. Heffer, P Assessment of Fertilizer Use by Crop at the Global Level. 10 (International Fertilizer Association, Paris, France, 2013).

Acknowledgements
The authors wish to thank the following people and organizations for sharing information on their respective country or region: Maria Fernanda Gonzalez, Fertilizar A.C. (Argentina); Konstantin Golombek and Jacob Hansen, Fertilizers Europe (European countries); Gennadi Peskovski, Belarusian Potash Company (Belarus); Cleber Vieira, Agroconsult (Brazil); Fred Gyasi and Sebastian Nduva, International Fertilizer Development Center (Burkina Faso, Mali, Nigeria, Senegal, Tanzania); Tom Bruulsema and McKenzie Smith, Fertilizer Canada (Canada); Mauricio Abarca, SQM (Chile); Weifeng Zhang, China Agricultural University, and Ping He, China Academy of Agricultural Sciences (China); Sophie Agasse, UNIFA (France); Thorsten Scheile, Industrieverband Agrar (Germany); Kuldeep Sati, Fertilizer Association of India (India); Asami Yutani, Japan Fertilizer & Ammonia Producers Association (Japan); Hillel Magen and Gershon Kalyan, ICL (Israel); Su Su Win, Ministry of Agriculture, Livestock and Irrigation Myanmar (Myanmar); Vera Power and Greg Sneath, Fertilizer Association of New Zealand (New Zealand); Kassim Motiwalla, Amir Iqbal and Muhammad Asif Ali, ENGRO (Pakistan); Enrique Hahn and Ramiro Samaniego (Paraguay); Federico Ramirez Dominguez (Peru); Raymond P. Ilustre, Atlas Fertilizer (Philippines); Mariusz Matyka and Jerzy Kopiński, State Research Institute Pulawy (Poland); Pieter Haumann, FERTASA (South Africa); Supuk Laudee, Thai Central Chemical Public Company (Thailand); Ismail Cakmak, Sabanci University (Turkey); Chris Dawson (United Kingdom); Harry Vroomen, TFI (United States); Martin Torres Duggan and Fernando García (Bolivia, Paraguay, Uruguay); Kazuki Saito, AfricaRice (rice in Africa). We also acknowledge the efforts made by Mary Layman and Sylvie Marcel in this project as well as others who tried to help us or sent us data which were not ultimately used in this dataset.

Author contributions
P.H. conceived the overarching project. A.G., A.D. and P.H. designed the study. A.G. sent out and collated the survey data. A.G. and C.L. performed analysis of the data. C.L. drafted the manuscript with the assistance of A.G., A.D. and P.H.

Competing interests
This work was funded by the International Fertilizer Association.

Additional information
Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41597-022-01592-z.
Correspondence and requests for materials should be addressed to C.I.L.
Reprints and permissions information is available at www.nature.com/reprints.
Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit http://creativecommons.org/licenses/by/4.0/.

© The Author(s) 2022