Estimating the global number and distribution of maize and wheat farms

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ABSTRACT

Strategic planning for global agricultural R&D is hampered by a lack of comparable data on target populations. Surprisingly, even the global number of crop-specific farms are unavailable for any given year. We estimate the number of farms growing maize and wheat – the two most important cereals globally – at multiple geographic scales. For 2020, we estimate that a third and a fifth of global farms cultivated maize and wheat respectively. For 2030, we estimate the number of maize farms to increase by 5% (from 216 to 227 million) and wheat farms to decrease by 4% (from 135 to 130 million). Our estimation approach can be extended to other crops, and can contribute to improved agricultural investment programming.

1. Introduction

Agriculture is a primary conduit for achieving many of the Sustainable Development Goals (SDGs) and, as the primary livelihood for the majority of the world’s poor, occupies a central position within the 2030 Agenda (UN, 2015; Omilola and Robele, 2017). Access to agricultural data is key to policy and decision making and “quality, accessible, timely and reliable disaggregated data will be needed to help with the measurement of progress and to ensure that no one is left behind” (UN, 2015: paragraph 48). The number of beneficiary farms and farm households targeted are often central to the framing of agricultural development strategies and objectives (Erenstein et al., 2021). Surprisingly, however, we know relatively little about the number and distribution of the world’s farms (Erenstein et al., 2021), particularly in the developing world where data scarcity is particularly acute (Economist, 2021). Furthermore, we have no reliable statistics on the number of farms producing specific crops. For strategic planning, targeting, and accountability purposes, it is important to develop reasonable estimates of such numbers, and their global distribution.

A recent paper estimates that there are 656 Million (M) farms globally in 2020, with a projected decline to 624 M farms globally by 2030 (Erenstein et al., 2021). Those estimates build on Londer et al. (2016, 2019), but reflect global and regional estimates which are harmonized for a given year, along with projections through 2030, to inform the 2030 Agenda. Most policy and development efforts would benefit from additional farm attributes, e.g. characterizing farms by primary production activities (crops, livestock); production orientation (home consumption, national markets, export markets); technology use (inputs, mechanization); management (family farm, corporate farms); and scale (farm size).

The role of the primary production activities (field crops, livestock, horticulture) in agricultural transformation processes has long been acknowledged (Dixon et al., 2001, 2020; Hazell, 2010; Renkow and Byerlee, 2010; Smale et al., 2013). Fifty years ago, the CGIAR, a global agricultural research partnership, was largely structured around centers focusing on primary production (CGIAR, 2021), including the International Maize and Wheat Improvement Center (CIMMYT, Byerlee, 2016). In part, this reflected the CGIAR’s original mission to globally eliminate hunger. Of late, this has expanded to transforming the world’s food, land, and water systems in a climate crisis (CGIAR-SO, 2021). Still, many agricultural Research-&-Development (R&D) efforts retain primary production activities as the key entry point – most notably for germplasm improvement, but also for improved agronomy and natural resource management in agricultural systems, whereas value chains are often commodity (group) specific. What is more, the funders of the CGIAR increasingly call for more granular data of projected outcomes and beneficiaries and achieved impacts. For crop improvement this implies an increased emphasis on innovation profiles, associated market segments and investment cases for its crop-specific germplasm products. In much the same way for the development and targeting of its agronomic innovations. Unfortunately, given the lack of reliable statistics on the number of farms producing specific crops, much of the big picture implications in terms of beneficiaries often remain guided by expert estimates.

Our primary objective in this article is to describe a process for estimating the number and distribution of farms growing specific crops...
and to illustrate this using the case of maize and wheat. Wheat, followed by maize, are the two most widely grown crops globally (Table 1), and widely grown in both developing and developed economies. Maize is cultivated on 197 Million (M) ha (Table 1), of which 32% is produced in Low and Lower-Middle Income Countries (L/LM-ICs). Wheat is cultivated on 216 M ha, including 29% in L/LM-ICs. Despite their wide cultivation and similar magnitudes, there are substantive variations in terms of extent, use and technology by crop, geographies and economies (Grote et al., 2021). After presenting the underlying data and methods, we summarize our main findings and discuss their implications.

2. Methods and data

The farm is the basic unit of operation in agricultural production. The definition of a farm and associated attributes however vary from one country to another as well as within each country (Lowder et al., 2016, 2021). The World program for the Census of Agriculture (WCA - FAO, 2021) uses a harmonized farm definition across countries and here we use agricultural holdings as reported in these agricultural censuses as the basis of our estimates. Some 100+ countries run such agricultural censuses using comparable methods as part of the WCA (FAO, 2021), which compiles data in roughly 10-year rounds, with the latest being the 2010 round (2006–2015). We estimate here the number of maize and wheat farms in 2020 and 2030 in all 204 countries for which farm number estimates are available (Erenstein et al., 2021). Given we already have the total number of estimated farms from the said source, the additional key metric to do so is the estimated crop-specific farm share for 2020 and 2030. We estimate this share by applying a set of consistent rules.

We first estimate the aggregate and crop-specific cultivated areas for each country in 2020 and 2030. We use the FAO reported annual data for the last decade (2009–2019, FAOStat, 2021) and extrapolate to 2020 and 2030 using an exponential triple smoothing algorithm. The base estimates use the 10 year trend. Where the 2020 estimate deviates with more than ±15% from the last available triennium average, we default to the 5 year trend or the triennium average ±15%, whichever is closer to the triennium average. The same applies to the 2030 estimate, but now capped at a maximum deviation of ±50% from the last triennium average. The relative maize and wheat areas are used as a key metric to adjust farm number estimates over time.

For the countries actually reporting crop-specific farms in any of the last 3 WCA rounds (i.e. 1990, 2000, 2010) we estimate the 2020 and 2030 share of farms reporting the specific crop based on the last available WCA farm share estimate, updated proportionally by the relative crop area share for the specific year relative to the last census year.

Based on the countries reporting we used a regression model to estimate the farm share growing wheat or maize. We estimated different models for each crop – one for only the larger subset of WCA 2000 data and one including all three rounds; and with 1–3 independent variables. The regression model specification is:

\[ \text{sFARM}_i = m_1 \cdot \text{sCROP}_i + m_2 \cdot \text{dLLIC}_i + m_3 \cdot \text{skCAL}_i + b \]  

where:

- \( \text{sFARM}_i \) - farm share growing crop \( i \) in census year (sFARM\(_i\));
- \( \text{area share of crop}_i \) in census year (sCROP\(_i\));
- dummy indicator of a country’s status as either low or low-middle income (dLLIC);  
- share of crop, in human caloric consumption (skCAL\(_i\)).

The model estimates were substantially more robust when using only the WCA 2000 round – likely reflecting enhanced consistency between countries – and is therefore retained here. The models were also more robust using all 3 independent variables. Table 2 provides the descriptive statistics and Table 3 the regression estimates.

For countries not reporting any crop-specific farm estimates in the WCA we estimate the 2020 and 2030 share of farms growing the specific crop based on the regression models. The base model uses all 3 independent variables in equation (1). Where independent variables are missing we used a parsimonious specification. Where the model predicts a negative or otherwise inconsistent farm share (e.g. in some countries with very low wheat area shares) we rely on the crop area share as the predictor of farm share. The same adjustment is applied to countries that are prevailingly lowland tropical in the case of wheat, as wheat is a relatively temperate crop with its cultivation primarily in higher latitudes and in tropical regions in the higher altitudes. Model predictions are capped at 100%.

The regression statistics show the model estimates to be relatively robust (Table 3) and their implications are discussed in more detail in the next section. Triangulation with the limited amount of other available data further suggest our estimates to be relatively robust: e.g., they align well with crop-specific farm estimates across recent representative farm surveys in Ethiopia, Tanzania and Nigeria (EPAR, 2019).

3. Results

3.1. Estimating crop-specific farm shares

The specific crop area share is a major determinant of the number of crop-specific farms. To illustrate the relation it merits revisiting the data from the WCA 2000 round and our regression models. Table 2 provides the descriptive statistics and shows that for the WCA 2000 subset of countries, maize covered 12% (0.4–34%) of the crop area and comprised 32% (1–100%) of the farms; and wheat covered 18% (0.1–50%) of the crop area and comprised 26% (0.4–81%) of the farms (no country being lowland tropical). The 2 key metrics thereby are strongly correlated (0.82 for maize and 0.67 for wheat in WCA 2000). The relation persists across the 3 regression models, even as its magnitude decreases as other independent variables are added to the models (Table 3). Still, the crop area share alone thereby explains the bulk of the crop-specific farm share (i.e. simple regression model with \( R^2 \) of 0.67 for maize and 0.45 for wheat - Table 3). The estimate of \( \hat{m}_1 \) in the simple linear regression is also indicative of the role of the crop in the farms, with values exceeding unity suggesting the crop is widely grown across the farm population whereas values below unity suggest increasing concentration of the crop on a few farms. The \( \hat{m}_2 \) estimates for both maize and wheat surpass unity in the simple linear regression and particularly for maize is high (2.38) suggesting it is widely grown across farms in the sample countries.

### Table 1
Global cereal area and production (average 2017–19).

| Cereal Type | Area (Million ha) | Share of cereal area (%) | Production (Million mt) | Share of cereal production (%) |
|-------------|-------------------|--------------------------|------------------------|-------------------------------|
| Wheat       | 216               | 30                       | 757                    | 26                            |
| Maize       | 197               | 27                       | 1137                   | 39                            |
| Rice, paddy | 164               | 23                       | 757                    | 26                            |
| Other cereals | 149              | 21                       | 301                    | 10                            |
| Cereals, Total | 727              | 100                      | 2952                   | 100                           |

Source: FAOStat, 2021.
Estimated crop area indicators for regions.

| Sub-Region            | Estimated crop area (Million ha) | Estimated maize area (M ha, % crop area) | Estimated wheat area (M ha, % crop area) |
|-----------------------|----------------------------------|-----------------------------------------|-----------------------------------------|
|                       | 2020                             | 2030                                     | 2020                                    | 2030                                      |
| Sub-Saharan Africa (SSA) | 255.6                            | 278.1                                   | 41.3                                    | 16.2%                                     | 50.9                                    | 18.3%                                     | 3.0                                      | 1.2%                                     | 3.3                                       | 1.2%                                     |
| South Asia (SA)        | 222.9                            | 224.6                                   | 12.7                                    | 5.7%                                      | 13.9                                    | 6.2%                                      | 41.1                                    | 18.5%                                     | 41.7                                     | 18.6%                                     |
| East Asia & Pacific (EAP) | 305.4                            | 322.8                                   | 57.1                                    | 18.7%                                     | 71.8                                    | 22.2%                                     | 35.1                                    | 11.5%                                     | 31.2                                     | 9.7%                                      |
| Middle East & North Africa (MENA) | 62.8                            | 64.8                                   | 1.3                                     | 2.1%                                      | 1.4                                    | 2.1%                                      | 17.6                                    | 28.0%                                     | 18.4                                     | 28.4%                                     |
| Europe & Central Asia (ECA) | 353.4                            | 351.1                                   | 19.5                                    | 5.5%                                      | 22.1                                    | 6.3%                                      | 84.0                                    | 23.8%                                     | 87.7                                     | 25.0%                                     |
| Latin America & Caribbean (LAC) | 179.6                            | 189.8                                   | 38.3                                    | 21.3%                                     | 47.6                                    | 25.1%                                     | 9.8                                      | 5.5%                                      | 12.0                                     | 6.3%                                      |
| North America (NA)     | 199.5                            | 200.4                                   | 34.4                                    | 17.2%                                     | 33.5                                    | 16.7%                                     | 24.7                                    | 12.4%                                     | 20.8                                     | 10.4%                                     |
| Global                | 1579.1                           | 1631.8                                  | 204.7                                   | 13.0%                                     | 241.2                                   | 14.8%                                     | 215.4                                   | 13.6%                                     | 215.1                                    | 13.2%                                     |

Source: FAOStat, 2021; FAOBright (new food balance).

Table 4

| Sub-Region                | Estimated crop area (Million ha) | Estimated maize area (M ha, % crop area) | Estimated wheat area (M ha, % crop area) |
|---------------------------|----------------------------------|-----------------------------------------|-----------------------------------------|
| Sub-Saharan Africa (SSA)  | 255.6                            | 278.1                                   | 41.3                                    | 16.2%                                     | 50.9                                    | 18.3%                                     | 3.0                                      | 1.2%                                     | 3.3                                       | 1.2%                                     |
| South Asia (SA)           | 222.9                            | 224.6                                   | 12.7                                    | 5.7%                                      | 13.9                                    | 6.2%                                      | 41.1                                    | 18.5%                                     | 41.7                                     | 18.6%                                     |
| East Asia & Pacific (EAP) | 305.4                            | 322.8                                   | 57.1                                    | 18.7%                                     | 71.8                                    | 22.2%                                     | 35.1                                    | 11.5%                                     | 31.2                                     | 9.7%                                      |
| Middle East & North Africa (MENA) | 62.8                            | 64.8                                   | 1.3                                     | 2.1%                                      | 1.4                                    | 2.1%                                      | 17.6                                    | 28.0%                                     | 18.4                                     | 28.4%                                     |
| Europe & Central Asia (ECA) | 353.4                            | 351.1                                   | 19.5                                    | 5.5%                                      | 22.1                                    | 6.3%                                      | 84.0                                    | 23.8%                                     | 87.7                                     | 25.0%                                     |
| Latin America & Caribbean (LAC) | 179.6                            | 189.8                                   | 38.3                                    | 21.3%                                     | 47.6                                    | 25.1%                                     | 9.8                                      | 5.5%                                      | 12.0                                     | 6.3%                                      |
| North America (NA)       | 199.5                            | 200.4                                   | 34.4                                    | 17.2%                                     | 33.5                                    | 16.7%                                     | 24.7                                    | 12.4%                                     | 20.8                                     | 10.4%                                     |
| Global                   | 1579.1                           | 1631.8                                  | 204.7                                   | 13.0%                                     | 241.2                                   | 14.8%                                     | 215.4                                   | 13.6%                                     | 215.1                                    | 13.2%                                     |

Table 3

| Model          | Crop | \(m_i\) | \(m_2\) | \(m_3\) | \(b\) | \(R^2\) |
|----------------|------|---------|---------|---------|------|--------|
| Full (3)       | Maize| 1.67    | –3.97   | 1.194   | 2.27 | 0.802  |
|                | (0.26)| (5.05)  | (0.244) | (3.29)  |      |        |
|                | Wheat| 1.02    | 16.95   | 0.785   | –12.79 | 0.615  |
|                | (0.22)| (5.36)  | (0.287) | (6.14)  |      |        |
| Parsimonious (2)| Maize| 2.32    | 3.86    | –       | 3.52 | 0.674  |
|                | (0.28)| (6.07)  |        | (4.15)  |      |        |
|                | Wheat| 1.32    | 16.68   | –       | 0.33 | 0.543  |
|                | (0.20)| (5.77)  |        | (4.43)  |      |        |
| Simple (1)     | Maize| 2.38    | –       | 3.98    | 0.670 |        |
|                | (0.27)|        | (4.06)  |        |      |        |
|                | Wheat| 1.29    | –       | 3.26    | 0.449 |        |
|                | (0.22)|        | (6.61)  |        |      |        |

3.2. Maize and wheat area shares

Given the importance of the crop-specific area share in determining the number of crop-specific farms we estimate first the corresponding maize and wheat area shares by country in 2020 and 2030. Crop areas are relatively dynamic and most of the crop-specific farm estimates date back to the WCA 2000 round (1996–2005). We estimate wheat and maize area to have surpassed 200 million (M) ha globally each in 2020. Wheat still had the largest estimated area at 215 M ha – 13.6% of global cropped area in 2020. Wheat is a dominant crop in Middle East & North Africa (MENA, 28% of regional crop area), Europe & Central Asia (ECA, 24%) and South Asia (SA, 19% - Table 4). Wheat is less prominent in Sub-Saharan Africa (SSA, 1% of crop area) and the Low-Income Countries (LICs, 4% of crop area - Table 5). Maize area was estimated at 205 M ha in 2020 – 13% of global cropped area. Maize is a dominant crop in Latin America & Caribbean (LAC, 21% of crop area), East Asia & Pacific (EAP, 19%), North America (NA, 17%) and SSA (16% - Table 4). Maize thereby is more evenly spread across the country income groups, with the largest share in Upper-Middle Income Countries (UMICs, 16% of crop area) and similar shares of 11–12% elsewhere (Table 5).

We estimate the global crop area at 1,580 M ha in 2020, and to increase by 3% to a total of 1,630 M ha in 2030. The associated crop area dynamics show a marked regional disparity; the increase largely confined to SSA (+9% over 2020) and EAP (+6%) and LAC (+6%), with areas remaining constant in NA and declining marginally in ECA (−1%, Table 4). We thereby estimate crop area to remain constant in the High Income Countries (HICs), with the most substantive increase in Low Income Countries (LICs, +11%), and more modest increases in Lower-Middle Income Countries (LMICs, +3%) and Upper-Middle Income Countries (UMICs, +4% - Table 5). Global wheat area is estimated to remain more or less constant through 2030, albeit with regional disparities, including substantive area increases in LAC (+22% over 2020) and SSA (+10%, albeit from a low base); and decreases in NA (−16%) and EAP (−11%, Table 4). Wheat area is set to increase in UMICs (+7% over 2020), and decrease in LICs and HICs (−13%, Table 5). In contrast to wheat, global maize area is estimated to continue to increase, to 241

### Table 2

| Crop (n = 41) | sFARMMa | area share of maize in census year (%) | dLLIC dummy indicator of a country’s status as either low or low-middle income (yes = 1, n = 0) | skCAL share of maize in calorific consumption (%) |
|---------------|---------|--------------------------------------|-----------------------------------------------------------------------------------|----------------------------------|
| Maize         | 31.7    | 28.6                                 | 20.2                                                                              | 1.0                             |
| Wheat         | 11.6    | 9.8                                  | 8.4                                                                               | 0.4                             |

Source: regression estimates (standard error) based on data in Table 2. Model specifications: (3) sFARMMa = m1 * sCRoPy + m2 * dLLIC + m3 * skCAL + b; (2) sFARMMa = m1 * sCRoPy + m2 * dLLIC + b; and (1) sFARMMa = m1 * sCRoPy + b.
M ha in 2030 (+18% over 2020), overtaking wheat as the most widely grown crop in the world. Maize area dynamics also show marked regional disparities, with marked increases in EAP (+26% over 2020), LAC (+24%) and SSA (+23% - Table 4). This corresponds with above average increases in UMICs (+26% over 2020) and LICs (+25% - Table 5); with marginal decreases in NA (−3%) and HICs (−4%).

Disaggregated projections of maize and wheat through 2030 reflect diverging uses of these two major staple cereals (Grote et al., 2021). Wheat is traditionally a food crop – with two-thirds of global production used as food and a fifth as feed. The use of wheat as feed is primarily concentrated in the UM/H-ICs, with L/LM-ICs emphasizing food use. In developed economies with a role as energy crop in some. With eco

Table 5
Estimated crop area indicators for countries by income groups.

| Income group          | Estimated crop area (M ha) | Estimated maize area (M ha, % crop area) | Estimated wheat area (M ha, % crop area) |
|-----------------------|----------------------------|-----------------------------------------|-----------------------------------------|
|                       | 2020 | 2030 | 2020  | 2030 | 2020  | 2030 | 2020  | 2030 | 2020  | 2030 | 2020  | 2030 |
| Low Income Country (LIC) | 152.4 | 169.1 | 17.0 | 11.1% | 21.2 | 12.5% | 5.6 | 3.7% | 4.9 | 2.9% |
| Lower-Middle Income Country (LMIC) | 445.6 | 457.8 | 48.3 | 10.8% | 57.3 | 12.5% | 55.1 | 12.4% | 56.3 | 12.3% |
| Upper-Middle Income Country (UMIC) | 619.5 | 642.1 | 96.5 | 15.6% | 121.7 | 19.0% | 93.9 | 15.2% | 100.8 | 15.7% |
| High Income Country (HIC) | 361.7 | 362.7 | 42.9 | 11.9% | 41.0 | 11.3% | 60.8 | 16.8% | 53.1 | 14.6% |
| Global                | 1579.1 | 1631.8 | 204.7 | 13.0% | 241.2 | 14.8% | 215.4 | 13.6% | 215.1 | 13.2% |

3.3 Maize and wheat farms

For 2020, we estimate 216 million (M) farms to have cultivated maize globally, with wheat farms totaling 135 M (Table 6). We estimate that a third of global farms cultivated maize in 2020. The share of maize farms varies substantially by region, with nearly half the EAP farms growing maize in 2020, 44% in LAC and 43% in SSA (Table 6). Over half (56.5%) the global maize farms are located in EAP, primarily driven by China (110 M). Nearly a quarter (22%) of global maize farms are located in SSA, and 12% in SA. Overall, 28 countries are estimated to have over 1 M maize farms in 2020, the top 5 including after China, India (19 M), Ethiopia (7.5 M), Indonesia (7 M) and Congo DR (5 M - Table S1). China’s contribution implies 60% of global maize farms are located in UMICs (Table 7), with a quarter in LMICs. On average, a maize farm is estimated to have cultivated 0.95 ha of maize in 2020 – but this masks regional disparities from 0.5 ha of maize per maize farm in SA and EAP, to about average in SSA and increasingly higher averages from ECA, to LAC and NA (Table 6). HICs estimated average maize area amounted to 11.4 ha per maize farm, with the average area not surpassing 1 ha per maize farm in the other country income categories (Table 7).

We estimate that a fifth of global farms cultivated wheat in 2020. The share of wheat farms again varies substantially by region, with over half (53%) the MENA farms estimated to have grown wheat in 2020, 38% in ECA and 29% in SA (Table 6). Some 40% of global wheat farms are located in SA, 27.5% in EAP and 17% in ECA. Overall, 14 countries are estimated to have over 1 M wheat farms in 2020, the top 5 including after India (37 M) and China (36.5 M), the Russian Federation (8 M), Pakistan (7 M) and Ethiopia (5 M – Table S2). India and China’s contribution implies half of global wheat farms are located in LMICs and 38% in UMICs (Table 7), with 10.5% in LICs and only 2% in HICs. On average, a wheat farm is estimated to have cultivated 1.6 ha of wheat in 2020 – but this masks regional disparities from 0.8 to 1 ha of wheat per wheat farm in SA and EAP, about average in MENA and increasingly higher averages from ECA, to LAC and NA (Table 6). HICs estimated average wheat area amounted to 22 ha per wheat farm, with about average in UMICs and the average area not surpassing 1 ha per wheat farm in LMICs and LICs (Table 7).

We estimate maize farms to increase to 227 M globally in 2030 (Table 6), an overall increase of 5% from 2020. By 2030, we estimate that 35% of global farms will cultivate maize (up from 33% in 2020). Given the regional disparities in the importance of the crop and associated dynamics, the regional maize farm numbers will evolve
The most marked increases for 2030 are set for SSA (+20% over 2020) and SA (+10%), with the most marked decrease in NA (−13%). The maize farm dynamics in the other regions are more modest (from −4% in LAC to +4% in ECA, Table 6). This growth is concentrated in LICs (+21% over 2020) followed by LMICs (+13%), with a modest decline in UMICs (−2%), and a more substantial decline in HICs (−10%; Table 7).

We estimate wheat farms to decrease by 4% from 2020 levels, to 130 M globally in 2030 (Table 6). Still, the share of global farms cultivating wheat is estimated to remain at a fifth, given the estimated similar decline in global farms over the period. The regional wheat farm numbers evolve differently, with the most marked increase for 2030 for SSA (+17% over 2020, albeit over a low base) and with modest increases for MENA (+5%) and SA (+4%); with the most marked decrease in EAP (−23%) and NA (−29%, Table 6). This translates in the most marked increase in 2030 for LICs (+13% over 2020) and the most marked decreases in HICs (−11%) and UMICs (−17%); whereas LMICs show a modest increase (+3%, Table 7).

4. Discussion

Wheat and maize are the two most widely grown crops globally with

| Crop          | Income category                      | Estimated number of crop-specific farms (Million) | Share of crop-specific farms in group total farms (%) | Share of income group in global crop-specific farms (%) | Av. crop area per crop-specific farm (ha) |
|---------------|--------------------------------------|--------------------------------------------------|----------------------------------------------------|------------------------------------------------------|------------------------------------------|
|               | 2020  | 2030  | 2020  | 2030  | 2020  | 2030  | 2020  | 2030  | 2020  | 2030  |
| Maize         |       |       |       |       |       |       |       |       |       |       |
| Low Income Country (LIC) | 26.4  | 31.9  | 34.6  | 41.7  | 12.2  | 14.0  | 0.64  | 0.66  |       |       |
| Lower-Middle Income Country (LMIC) | 56.2  | 63.7  | 20.0  | 22.7  | 26.0  | 28.1  | 0.86  | 0.90  |       |       |
| Upper-Middle Income Country (UMIC) | 130.1 | 128.1 | 46.1  | 45.4  | 60.1  | 56.4  | 0.74  | 0.95  |       |       |
| High Income Country (HIC) | 3.8   | 3.4   | 22.7  | 20.4  | 1.7   | 1.5   | 11.41 | 12.13 |       |       |
| Global        | 216.4 | 227.1 | 33.0  | 34.6  | 100.0 | 100.0 | 0.95  | 1.06  |       |       |
| Wheat         |       |       |       |       |       |       |       |       |       |       |
| Low Income Country (LIC) | 14.1  | 16.0  | 18.5  | 17.7  | 10.5  | 12.3  | 0.40  | 0.31  |       |       |
| Lower-Middle Income Country (LMIC) | 66.7  | 68.7  | 23.7  | 23.8  | 49.6  | 53.1  | 0.83  | 0.82  |       |       |
| Upper-Middle Income Country (UMIC) | 50.9  | 42.3  | 18.1  | 18.3  | 37.9  | 32.7  | 1.84  | 2.38  |       |       |
| High Income Country (HIC) | 2.8   | 2.5   | 16.7  | 17.0  | 2.1   | 1.9   | 21.94 | 21.59 |       |       |
| Global        | 134.5 | 129.5 | 20.5  | 20.7  | 100.0 | 100.0 | 1.60  | 1.66  |       |       |

Fig. 1. Map of estimated maize (A.) and wheat (B.) farms in 2030 (Million of crop specific farms per country).
areas estimated to exceed 200 M ha each in 2020. Whereas global wheat area is projected to remain relatively constant at 215 M ha in 2030, global maize is estimated to continue to increase to 241 M ha in 2030. Maize is thereby overtaking wheat as the most widely grown crop in the world in the coming decade. Beneath the aggregate numbers there are marked disparities in the underlying area dynamics for each crop by region and country income with important implications for agricultural transformation processes and prospective outcomes. We estimate that a third and a fifth of global farms cultivated maize and wheat respectively in 2020. The estimated 216 M maize farms globally in 2020, is estimated to increase with 5% to 227 M by 2030, whereas the estimated 135 M wheat farms globally in 2020, is estimated to decrease with 4% to 130 M by 2030. China and India remain the countries with the most maize and wheat farms (Fig. 1).

4.1. Estimation and data issues

While our estimates do address global data gaps, they remain dependent on the availability of robust base data in at least some countries to estimate numbers for all countries. Building on available crop-specific farm census reports and farm number estimates, our crop-specific farm estimates are based on a relatively parsimonious model using crop area shares, country income status and crop-specific shares in human consumption. Additional independent variables could potentially enhance the precision of estimates. However, our choice of regressors was dictated by current data limitations. Adding regressors will necessarily imply fewer observations to work with. For instance, including calorie share improved our estimates, but the indicator was not available in several countries.

Crop area share is a key indicator and we used the area dynamics as the key driver for 2030 projections, based on the extrapolation of the last 5–10 years per country. There is potential for more sophisticated area projections, for instance by better modeling demand and supply dynamics and to take account of farm households’ production and consumption increasingly becoming separable with economic development. This especially would apply when projecting to further out time horizons and when commodities have multiple uses with diverging relative uses over time (e.g. when associated with diverging income elasticities and/or urbanization).

Our estimates could clearly be further improved with better data. Although WCA is a laudable effort to produce harmonized data with global coverage, geographic and thematic coverage remains far from complete. Crop-specific data are particularly in need of updating – our estimates are primarily based on the WCA 2000, given the lack of crop-specific data in later WCA years. Indeed, the two most widely grown crops globally already show varying dynamics. Adding to the dynamic context are the shocks and increasing stresses on global agri-food systems since WCA 2000, including the 2007-08 world food crisis, ongoing climate change and the current Covid-19 pandemic – and the varied responses to all of these. The varied response thereby merits particular attention, as these shocks have generally increased interest in food security for the main staples across the Global South.

Given the data constraints in the Global South, there have been laudable efforts to generate robust household data, including the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA, Carletto and Gourlay, 2019). The LSMS-ISA have run representative surveys and open access data that complement WCA, and e.g. allowed the aforementioned triangulation of our estimates (EPAR, 2019). More recently, the 50x2030 initiative (FAO et al., 2021) will improve data availability in many L/LM-ICs over the coming decade. While these efforts will help to address important data gaps, they will not address all gaps, and there is still a need for additional investments in accurate and globally comparable data.

Our estimates show not only large numbers of maize and wheat farmers globally, but also substantial regional disparities in their spread and dynamics. It is particularly important to develop better data resources for countries with the most farms, such as China and India (Fig. 1). China is particularly dynamic, with rapid economic transformation, urbanization and farm consolidation likely driving China’s contribution to the expected global decline in farm numbers (Erenstein et al., 2021). Questions abound about how best to feed China, also as it exemplifies the dietary transition with marked increases in meat consumption (including pork and the associated maize demand for feed - Erenstein, 2010). India is also experiencing economic transformation, with increased poultry demand fueling expanded maize production (Hellin et al., 2015). Both China and India provide agricultural transformation lessons for other developing nations as well as each other (Gulati and Pan, 2007). There clearly is great value in our ability to monitor such changes in more detail over coming years.

4.2. A research agenda for improved farm distribution estimates

Future farm number estimates could usefully focus on generating more granular, sub-national distributions of crop-specific farm numbers. Considerable efforts have been made to map other aspects of global agricultural production. This includes efforts to broadly map farming systems globally (Dixon et al., 2001) and by region (e.g. SSA - Dixon et al., 2020) and its intersection with poverty and food security. Another body of analysis relies on the Spatial Production Allocation Model (SPAM) which downscales crop production data covering 42 crops into a global set of gridded estimates at roughly 10 km² (You and Wood, 2006; You et al., 2014; Lu et al., 2020; Yu et al., 2020). Another global spatial analysis effort included 175 crops at similar resolution, and indicators such as area, yield and geographical distribution in 18 global agro-ecozones (Monfreda et al., 2008, 2009; Ramankutty et al., 2008). The resulting global spatially explicit estimates of crops have become a critical input to many large-scale targeting, prioritization and other initiatives (Yu et al., 2020). Remote sensing increasingly allows for timely global crop monitoring at field scale and has spurred the ambition to create local to global annual cropland maps at 10 m resolution for maize and wheat (WorldCereal, 2021). All of these efforts, however, remain silent on the associated number and distribution of crop-specific farms. Further research may want to continue to explore how best to establish such links and spatialize the distribution of crop-specific farms and associated implications for poverty and food security.

The evolving prospects of spatializing key attributes and increased data availability has fed an increased interest and demand for their use. In the case of developing germplasm products there is an increased interest to develop product profiles and investment cases. These call for the delineation of market segments for each product profile and associated attributes, including crop area, number of crop-specific farms and associated socio-economic parameters. The development and targeting of improved agronomy and natural resource management in agricultural systems also calls for disaggregated and spatialized data including crop-specific farm numbers, their location, and attributes. For one, to better comprehend the current state of play for smallholders in terms of crop management and agro-ecology; the extent of the associated challenges and opportunities; and to prioritize and guide targeting of innovations. The spatialized data would allow to better assess crop production risks (e.g. related to weather variability and other stresses), the prevailing yield gaps and their agricultural meaning. It would also allow, together with more spatial data becoming available, to improve farmer typologies and the ability to target interventions to specific groups.

Spatialized data would allow to better assess crop-specific climate change implications, like which production areas are likely to get warmer/colder, to have more/less volatile rain seasons, or to have longer/shorter growing seasons. There is a rapidly increasing body of work around the spatial modeling of climate change implications, including for wheat (e.g. Yue et al., 2019; Xiong et al., 2020; Pequeno et al., 2021; Tesfaye, 2021) and maize (e.g. Ramirez-Cabral et al., 2017; Tesfaye et al., 2017; Falconnier et al., 2020; Gao et al., 2021), albeit often at higher regional and global levels and oriented to the
bio-physical implications. Although the frequency of climate extremes is set to increase, most climate change is gradual. Our study thereby limits itself to 2030 projections, based on the extrapolation of the last 5–10 years per country. These projections thereby also consider current farmer and market preferences for maize and wheat, even if other crops may be deemed more ‘climate smart’. Spatialized data also potentially allow for a better understanding of market access and cost implications, including input costs, farm output value, relative prices, and the profitability of innovations (e.g. Cedrez et al., 2020a; 2020b).

Context specificity further complicates matters both within and across countries. For instance, many indicators are not categorical (such as large vs small farms), but continuous: e.g. crop market integration typically presents a gradient of home consumption (“subsistence”) to market oriented, further compounded by seasonality, year-to-year variation and crop-specificity. In eastern Africa, neighboring Kenya and Ethiopia both cultivate maize and wheat, but whereas both crops are grown by smallholders in Ethiopia, in Kenya the situation is distinct, with maize grown by smallholders and wheat grown primarily by larger farms. Farm structures are also evolving and in relatively land-abundant countries in SSA medium-scale farms are playing an increasing role (Jayne et al., 2019a). Urbanization and the urban-rural gradient also has implications for transformation prospects, including competition for land but also increased commercialization opportunities compared to the hinterland (Masters et al., 2013). The spatial distribution of farms within countries therefore needs consideration, also as in some countries smallholders are clustered in marginal less favorable agricultural areas whereas larger farms are agro-ecologically better endowed. The context thereby has implications for the food security and poverty alleviation potential and associated R&D implications.

Attributes of crop-specific farms thereby have important implications for societal goals. Location and crop management are two that merit particular attention as agriculture generates environmental externalities with long-term development implications. Staple food crops present an intensification gradient associated with potential natural resource management pressure points – ranging from extensive systems mining soil fertility to intensive systems with excess inputs (e.g. with resulting run-off, leaching, declining water tables). The intensive-margin tends to coincide with population density and may have externalities for the urban populace (e.g. through air and water quality). The extensive-margin may imply in situ land degradation (such as fallow reduction rather than input intensification, exacerbating soil organic carbon losses), expansion of the agricultural frontier and encroachment onto fragile ecosystems. The location of and technology use on maize-wheat farms and associated dynamics thereby can have significant implications for their environmental footprint and resource use (e.g. deforestation or land sparing - Stevenson et al., 2013). Further research could look into the associated spatial dynamics. For instance, research could spatially model responses to changing domestic demand and rural population density in environmentally or otherwise sensitive areas. Research could also model where intensification and extensification are likely to occur, and the potential implications of climate change adaptation and mitigation. A factor endowment approach could characterize the intensification pathways most feasible in different areas based on relative resource scarcity (Erenstein, 2012; Jayne et al., 2019b).

The location and number of maize and wheat farms therefore has important implications for understanding the development challenges associated with the on-going evolution of global agri-food systems and deriving appropriate policy responses. Further efforts are needed to extend this to other crops and add value by further disaggregating the estimates and enhancing the characterization. Spatialization offers particular prospects, and potentially ranges from revisiting relatively simple overlay analysis to more sophisticated spatial modeling. Modeling the distribution of farm size and other farm characteristics is also of high policy relevance (Hazzell et al., 2010; van Vliet et al., 2015; Graeub et al., 2016; Lowder et al., 2016, 2021). One approach could explore the use of plot size distribution data to predict associated farm size distributions (Meyfroidt, 2017; Lesiv et al., 2019). One challenge for this is that current remote sensing-based plot size distribution maps are very categorically coarse, offering only a predominant farm size category, and with little sub-national variations. But prospects continue to improve following technological and data advances, albeit at all times we need to clearly recognize what are actual data and what are estimates. The current paper hopefully contributes to further ignite such interest and serves as a steppingstone to the emerging research agenda to further guide the targeting of R&D resources.

5. In conclusion

Better estimates of the number and distribution of crop-specific farms provide an important foundational input for agricultural policy and R&D efforts in the Global South. Such indicators are important to refine priorities and operationalize efforts. In terms of priority setting there are trade-offs to consider. For instance, most countries and funders favor both food security and poverty alleviation. An emphasis on national food security in the face of urbanization calls for enabling markets to provide the needed and affordable staple and other foods – with potentially important roles for imports and the larger farms producing a marketable surplus. An emphasis on poverty alleviation calls for enabling rural transformation with potentially important roles for the development of the smallholder and family farms. Such considerations in relation to poverty alleviation and food security clearly call for the need to know the attributes of the crop-specific farms, including their number, distribution, size, and market integration.

Using a relatively simple approach, we have articulated an approach to generating reasonable estimates of the number and distribution of crop-specific farms, based on currently available data combining inter alia crop-specific farm census reports, crop area statistics and farm number estimates. The projected crop areas and farm numbers to 2030 thereby are the main drivers for the observed dynamics. Based on projected crop areas, maize is set to overtake wheat as the most widely grown crop in the world in the coming decade. We estimate that a third and a fifth of global farms cultivated maize and wheat respectively in 2020, increasing with 5% to 227 million maize farms globally and decreasing with 4% to 130 million wheat farms globally by 2030.

While our approach helps to address a critical information gap, further efforts are needed to extend this to other crops and add value by further disaggregating estimates using spatial modeling. Reliable estimates of farm attributes and supporting data merit more attention in global sustainable development efforts and the quest to understand and support economic and rural transformation across the Global South. Further investments in such estimates would be timely, given ongoing reforms in the CGIAR (CGIAR-SO, 2021) and elsewhere, and concerns about rising hunger and SDG 2 being increasingly out of reach.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.
trends across the globe. Global Food Secur. 5, 11–18. https://doi.org/10.1016/j.gfs.2015.03.001.

WorldBank, 2021. World Bank Country and Lending Groups. World Bank, Washington, DC. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

WorldCereal, 2021. WorldCereal, an EO Based System for Global Cropland Monitoring. VITO Remote Sensing, Mol, Belgium. https://esa-worldcereal.org/en.

Xiong, W., Asseng, S., Hoogenboom, G., Hernandez-Ochoa, I., Robertson, R., Sonder, K., Pequeno, D., Reynolds, M., Gerard, B., 2020. Different uncertainty distribution between high and low latitudes in modelling warming impacts on wheat. Nat. Food 1, 63–69. https://doi.org/10.1038/s43016-019-0004-2.

You, L., Wood, S., 2006. An entropy approach to spatial disaggregation of agricultural production. Agric. Syst. 90, 329–347. https://doi.org/10.1016/j.agsy.2006.01.008.

You, L., Wood, S., Wood-Sichra, U., Wu, W., 2014. Generating global crop distribution maps: from census to grid. Agric. Syst. 127, 53–60. https://doi.org/10.1016/j.agsy.2014.01.002.

Yu, Q., You, L., Wood-Sichra, U., Ru, Y., Joglekar, A.K.B., Fritz, S., Xiong, W., Lu, M., Wu, W., Yang, P., 2020. A cultivated planet in 2010 – Part 2: the global gridded agricultural-production maps. Earth Syst. Sci. Data 12, 3545–3572. https://doi.org/10.5194/essd-12-3545-2020.

Yue, Y., Zhang, P., Shang, Y., 2019. The potential global distribution and dynamics of wheat under multiple climate change scenarios. Sci. Total Environ. 688, 1308–1318. https://doi.org/10.1016/j.scitotenv.2019.06.153.