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How much of the world's food do smallholders produce?

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1. Introduction

It has been widely reported that smallholder farmers (defined generally as being less than 2 ha) produce 70–80% of the world's food ETC, 2009; Maass Wolfenson, 2013; FAO, 2014), are central to conserving crop diversity (Altieri, 2008; Badstue et al., 2005; Conway, 2011), produce more food crops than larger farms (Horrigan et al., 2002; Naylor et al., 2005), and yet are largely food insecure (IFAD and UNEP, 2013). These arguments have been a linchpin in recent agricultural development policy. For example, in 2014, the 'International Year of the Family Farm', the United Nations (UN) and other food security agencies reiterated these arguments to garner increased support for family farmers, who are predominantly smallholders (FAO, 2014). The COP21 agreement (the 2015 UN Conference of Parties on Climate Change) includes mitigation and adaptation commitments pertaining to agriculture from 179 countries that include the need to bolster smallholder adaptive capacity to climate change. Goal 2 of the UN Sustainable Development Goals (SDGs) aims to end hunger and achieve food security through sustainable agriculture; a key target (SDG 2.3) is by '2030, [to] double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists, and fishers' (UN, 2015). Yet, despite progress in steering development policy towards smallholder farmers, there is scant empirical data on smallholder farms, and their role in the food system.

Key to enacting and monitoring progress on these international agreements and policies is a global baseline on the contribution of smallholders to global food production and security. However, the data underlying three widely reported claims on smallholder crop production remain non-transparent or contradictory. First, the source of various UN reports citing smallholder production is a communiqué from the ETC group (ETC, 2009), which suggests that 'peasants' grow at least 70% of the world's food; yet, the derivation of the estimate is obscure in this report. Second, the claim that smaller farms produce more food directly consumed by people, with larger industrialized farms producing more non-food crops, such as biofuels and animal feed (Horrigan et al., 2002; Naylor et al., 2005), has been brought into question by the observation that smaller farms have larger amounts of post-harvest loss due to lack of market and cold storage access (Hodges et al., 2011; Tefera, 2012). Thirdly, while some authors argue that economies of scale are needed for farms to produce a diversity of crops (Rahman and Kazal, 2015), others suggest that larger farms face labor constraints that hamper mixed-cropping systems (Van den Berg et al., 2007), so it is unknown if smaller farms produce a greater diversity of crop species than larger farms. In sum, our current understanding how much food smallholders produce, what kinds of food they produce, where their food is destined in the food system, and how much nutrition it contains, are all key knowledge gaps in global agricultural research.

The need to fill these knowledge gaps has been recently recognized by scientists (Graeub et al. (2016); Herrero et al. (2017); Lowder et al. (2016); Samberg et al., 2016 (referred to as Graeub, Lowder, Herrero, and Samberg respectively hereafter). In 2016, a pair of studies evaluated the contribution of smallholders and family farms to global crop and food production. Lowder was the first to report on global farm size trends from 1960 to 2010 derived from 167 countries in the World Census of Agriculture (WCA). They found that small-farms (defined as being < 2 ha) constituted only 12% of the global available farmland, but represented 84% of all farms. Their study did not report on crop production, but their results implied that smallholders do not produce 70% global crops; it is unlikely they could produce this much food on 12% of available farmland, even if we assumed that small farms had higher yields and produced more food crops than larger farms. The second of these studies (Graeub) quantified the number and extent of family farms in the world and their production contributions. By using national family farm definitions, defining family farms based on farm size, or a combination thereof to represent regionally appropriate family farm definitions they estimated that ~98% of all farms globally are family farms, collectively managing 53% of all cropland, and meeting an estimated 36–114% of domestic caloric requirements for different countries. While Graeub's study highlighted the contribution of family farms, they also challenge the idea that all family farms are small farms. For example, farms in Brazil may be family owned but are large in size (while ~ 85% of farms in Brazil are family owned and cover ~ 25% of agricultural land, only 21% of farms are less than 2 ha in size and cover only 0.25% of the agricultural area). Together these two studies, quantified the global number of smallholders or family farmers, their cropping area, and detailed the differences between

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smallholders and family farms.

Two additional studies were recently published that tried to better estimate the proportion of food coming from smallholder farmers globally. Samberg estimated the contributions of smallholders in an analysis of 41 crops and 83 countries in smallholder dominant regions (Latin America, sub-Saharan Africa, and South and East Asia) that represent 35% of global cropland. They estimated that smallholders (which they defined as all administrative units with a “mean agricultural area” < 5 ha) produced 52.5% of food calories in their cross-regional sample. While, this study was a valuable step in mapping the geographic distribution of smallholders, using mean agricultural area within an administrative unit as an index of smallholder production is problematic because farm size distributions are highly skewed (e.g. Lowder). Following this, Herrero presented an analysis which modeled crop and livestock production, micro-nutrition production, and agricultural landscape diversity. Crop and animal data were related to farm size classes by combining crowd-sourced data on field sizes (Fritz et al., 2015) with national farm size distributions (Lowder) as a proxy for per pixel production by farm size. They reported that farms < 50 ha produce 56% of commodities and nutrients in their sample of 41 crops, 7 livestock, 14 aquaculture and fish products, across 161 countries. They also estimated that ~18% of food calories globally come from farms < 2 ha, and highlighted the valuable micronutrient contribution of smallholders, with farms < 20 ha producing ~ 70% of the world's vitamin A. While both Samberg and Herrero provided clear steps forward in understanding the role of smallholders in the food system, and in particular Herrero covering both animal and crop products, they did not use direct measurements of crop production and/or area by farm size, compute diversity calculations based on these direct calculations of production and/or area, or report on the broader role of smallholders in the food system (e.g. how much of their food is wasted and destined to non-food crops).

To fill these gaps, we compiled the first open source dataset to estimate crop production by farm size derived from actual farmer surveys containing crop-specific measurements of production or area that are cross-tabulated against each farm size class. Our dataset includes 154 crop types and covers 55 countries, which represents 51.1% of global agricultural area. We compare these direct estimates to those from the previous modeling studies (e.g., Herrero et al 2017; Samberg et al., 2016). In addition, we provide global estimates of the type of production (i.e., food, feed, processing, seed, waste, and other) across farm sizes and within each farm size class, to understand if more production from small farms is wasted from storage and transportation, and if this cancels the larger losses to biofuels and animal feed grown on large farms. Finally, we evaluate how the type of crops grown, crop species diversity, and macro-nutrient production varies by farm size. Our study is the first to directly evaluate the relationship between farm size, crop types, and crop diversity across a large range of farm sizes and geographic regions, and to assess how this diversity influences the amount of macro-nutrients available from crops. Together, these results provide the most comprehensive empirically grounded estimates of crop production by farm size currently available.

2. Methods

2.1. Data compilation

We compiled a global convenience sample of datasets that directly measured crop production and/or area by farm size for 55 countries at either the national, or subnational level (for a total of 3410 national or subnational units; see Fig. 1). These datasets were either agricultural census data or nationally (or sub-nationally) representative sample surveys, aggregated by administrative unit ($n = 34$ countries) or available at the micro-level (e.g., anonymized individual household level records) ($n = 21$ countries; of which 18 were household surveys and 3 were censuses that captured both family and non-family farms). The median year of the data was from 2013, with the oldest datasets from 2001 and the newest from 2015. The database has 154 crops which we matched with commodity names outlined in the Food and Agricultural Organization's (FAO) statistical database (2017) [FAOSTAT hereafter]. Where farm size and production were not cross-tabulated in the survey instrument (i.e. for 33 countries), we calculated production by farm size by first extracting either harvest area, cultivated area, crop area, or planted area to calculate farm size, and then converted area to production using FAOSTAT's national yield data. We tested the validity of this method, and found it to slightly underestimate production (full details of bias tests, inclusion criteria, variable descriptions, summary statistics, and per country statistics are given in the accompanying Data in Brief article). When farm size data was not available for a country, but we had micro-level data, we used the sum of farm plot areas for a given household as a proxy for farm size. Internal validation of the use of micro-data to fill in data gaps was not possible with our data, because we did not have both micro-data and farm size metrics for any of our countries, but we think the impact of using aggregate plot area is likely to be negligible for our results, as this was only used on 4.8% of administrative units in our dataset. Finally, all crop production data was tallied per country and validated against available national level reports, and to the FAOSTAT crop production database, both of which are computed from aggregated crop area estimates. In total, our dataset captures 51.1% of global crop production and 52.9% of global cropland area. We harmonized the datasets to match the WCA farm size categories: 0–1 ha, 1–2 ha, 2–5 ha, 5–10 ha, 10–20 ha, 20–50 ha, 50–100 ha, 100–200 ha, 200–500 ha, 500–1000 ha, and above 1000 ha. While we recognize that per country definitions of smallholders may not fall within these farm size bins, the majority of the datasets included reported these farm size breaks. We report our estimates by each WCA farm size class and cumulatively to allow flexible definitions of smallholders that are consistent with past attempts to quantify the relationship between farm size and crop production. Future researchers may use the accompanying, open-access dataset to redefine smallholders based on country specific definitions. Where European data included a > 100 ha category, we included this in the 100–200 ha range, making our classification less precise in > 100 ha groupings, in comparison to < 100 ha. Future researchers may wish to aggregate all ‘large’ farms into a > 100 ha bin for their specific needs, but here we present the results maintaining the disaggregation for surveys that reported it.

2.2. Crop allocation

Following data compilation, we converted all tonnes of production to their kilocalorie (kcal/capita/day) equivalents using FAOSTAT conversion values per crop per country per year. We then applied the percent of feed, food, processing, seed, waste, or ‘other’ based on FAOSTAT's food balance sheets per crop per country per year. For example, in many countries maize can be used for human consumption, animal feed, a processed biofuel commodity, and seed, while some maize may be lost due to storage and transportation. FAOSTAT contains national totals for each of these types of crop allocation categories. We used these totals to calculate percentages per crop per country per year to allocate a certain portion of each crop's production towards food, feed, and the other crop allocation categories. While this approach does not account for the actual distribution of crop allocation by farm size, it is the most detailed information available and represents a proxy indicator based on what type and quantities of crops each farm size produces.

While certain FAOSTAT categories were straightforward to interpret and contained detailed definitions (e.g., ‘feed’ towards livestock and poultry and ‘seed’ set aside for sowing or planting), the processing category was ambiguous and required us to make assumptions. We followed Cassidy et al. (2013) and assumed that the processing category included oil crop production into oils for human consumption and for