Title: Data Correction: Developing World Annual Crop Waste Generation and Resulting CO_2, CO_2e, Smog Precursor and PM2.5 from Burning

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For the past several years, I have stated that developing world farmers generate 300 gigatons of crop waste annually. Despite the regularity with which this figure appears in the literature, I now believe that it is erroneous. In fact, I believe that it exaggerates crop waste production by orders of magnitude.

In this note, I wish to correct my own errors, to identify a clear source of what I believe to be a more accurate number, demonstrate that number, break it into its constituent parts and from it generate new estimates for CO_2, CO_2e, Smog Precursor and PM2.5 releases from developing world crop waste burning.

The developing world

I focus exclusively on the developing world for three reasons. First, crop waste burning is not an issue in the developed world. It is very hard to imagine a German farmer clearing a weedy field by fire. Second, the climate change consequences of crop waste burning are significant. Third, the human consequences are significant. Whatever advances may have been made in reducing gross poverty in the developing world, as long as crop waste burning continues billions of people are exposed the life shortening risk of elevated PM2.5 levels. Whatever may be hoped for, there exists prima fascia evidence that rural poverty is unresolved and will not be eradicated any time soon. Addressing crops waste burning is imperative.

Data source

I have reviewed many alternative sources for data on developing world agricultural production. Two stand out: the US Department of Agriculture (USDA) and the UN Food and Agriculture Organization (FAO). I have chosen to use FAO data both because it is readily and easily available at FAOSTAT.fao.org and because it is more inclusive than the USDA data (which focuses on commercially important and traded crops).

FAOSTAT provides a wide variety of data. For the sake of simplicity and fact checking, I have confined my use to the FAOSTAT data provided in the section titled “Production” and sub-section “Crops.” Clicking through these offers accesses to a page on which the user can select country, countries or pre-set groups of countries, data element (production area, yield or production quantity), crop, crops or collections of crops (e.g., cereals), date by year or timespan from 1961 to 2017, and finally output type, formatting and whether to view on screen or to download.

Included countries

For the purposes of this note, I chose (1) the set of countries listed below, (2) production quantity (in some instances where FAO could not verify figures, the data is starred and a note of explanation is provided next to the cell’s content), for (a) all crops and (b) cereals + coarse grains, and (3) 2017 alone.

My list of “developing” countries may be idiosyncratic. I used the following rules to construct it. I removed all small population and/or developing oil states (e.g., Saudi Arabia) and/or all American, English and French overseas dominions (e.g., the Solomons, Bahamas, New Caledonia) and/or micro-states and economies (e.g., Djibouti, Niue), and Russia (although a developing country and heavily

agricultural). There are several surprising inclusions. These inevitably seem to involve bananas, coconuts or sugar cane. Where production broke 50,000 tonnes, I have included the country (e.g., Kirabati).

Included Countries

Afghanistan
Albania
Algeria
Angola
Argentina
Armenia
Azerbaijan
Bangladesh
Barbados
Belarus
Belize
Benin
Bhutan
Bolivia (Plurinational State)
Bosnia and Herzegovina
Botswana
Brazil
Burkina Faso
Burundi
Cabo Verde
Cambodia
Cameroon
Central African Republic
Chad
Chile
China
China, Taiwan Province of
Colombia
Comoros
Congo
Costa Rica
CÃ´te d'Ivoire
Croatia
Cuba
Cyprus
Democratic Republic of the Congo
Dominica
Dominican Republic
Ecuador
Egypt
El Salvador
Eritrea
Eswatini
Ethiopia
Fiji
Gabon
Gambia
Ghana
Guadeloupe
Guatemala
Guinea
Guinea-Bissau
Guyana
Haiti
Honduras
India
Indonesia
Iran (Islamic Republic)
Iraq
Jamaica
Jordan
Kazakhstan
Kenya
Kiribati
Kyrgyzstan
Lao People's Democratic Republic
Lebanon
Lesotho
Liberia
Libya
Madagascar
Malawi
Malaysia
Mali
Mauritania
Mexico
Mongolia
Montenegro
Morocco
Mozambique

Myanmar
Namibia
Nicaragua
Niger
Nigeria
Palestine
Oman
Pakistan
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Republic of Moldova
Rwanda
Saint Vincent and the Grenadines
Samoa
Sao Tome and Principe
Senegal
Serbia
Sierra Leone
Solomon Islands
Somalia
South Africa
South Sudan
Sri Lanka
Sudan
Suriname
Syrian Arab Republic
Tajikistan
Thailand
Timor-Leste
Togo
Tonga
Trinidad and Tobago
Tunisia
Turkey
Turkmenistan
Uganda
Ukraine
United Republic of Tanzania
Uruguay
Uzbekistan
Vanuatu
Venezuela (Bolivarian Republic)
Viet Nam
Western Sahara
Yemen
Zambia
Zimbabwe

FAOSTAT crop production data

At the end of this document, you will find an Excel workbook with three spreadsheets: (1) the list of countries above; (2) 2017 FAOSTAT data for all crops downloaded and edited using the country list on sheet (1); and (3) 2017 FAOSTAT data for cereals and coarse grains downloaded and edited using the country list on sheet 1. I focus on cereals and coarse grains because they are the largest, fastest growing and most commonly burned category.

Crop production to waste ratios

Some crops are "clean" producing little waste relative to the food value they generate; others are dirty. I have used the following ratios to convert FAO crop production figures into crop waste amounts:

Barley, etc.	1 tonne of cereal/coarse grain/grain "nes" (not elsewhere specified) produces 1 tonne of waste (Exception noted below, corn, millet, rice, wheat,) (Coarse grains include barley, buckwheat, canary seed, fonio, millet, rye, oats, sorghum, and triticale)
Cassava	1 tonne of cassava produces 100 kg of cassava peal waste
Coconut	1 tonne of coconut produces 650 kg of husk and shell waste
Corn	1 tonne of corn produces 4 tonnes of stalk, cob and husk waste
Fresh veggies	1 tonne of fresh veggies produces 1 tonne of waste
Ground nut	1 tonne of ground nuts produces 3.5 tonnes of hay

Millet	1 tonne of millet produces 2 tonnes of stalk and other waste
Plantains	1 tonne of plantains (or bananas) produces 2 tonnes of waste
Potatoes	1 tonne of potatoes/roots/tubers produces 200 kg waste (not including field losses)
Rice	1 tonne of rice produces 1.22 tonnes of straw and husk waste
Soy	1 tonne of soy beans produces 1.8 tonnes of straw and shell waste
Sugar beet	1 tonne of sugar beet produces 200-300 kg of waste
Sugar cane	I tonne of sugar cane produces 200 kg of waste
Tomatoes	1 tonne of tomatoes produces 200 kg of waste
Wheat	1 tonne of wheat produces 1.17 tonnes of waste

The data

The most important observation about the data is that it does not in any way bear out the claim that developing country farmers produce 300 billion tonnes of crop waste. According to the FAOSTAT figures, total, developing world, crop production runs about 10 billion tonnes annually.

Because many crops generate more waste than edible produce, total annual developing world crop waste production is greater than 10 billion tonnes, but not astronomically so. Combined cereals and coarse grains totaled 2 billion tonnes in 2017; combined waste from cereals and coarse grains totaled 4.2 billion tonnes. Even is this ratio applied to all crops, total crop waste in 2017 was 21 billion tonnes, a far cry from 300 billion tonnes.

Emissions from crop waste burning

Estimates of how much crop waste developing world farmers burn still range from 50 to 90 percent. I am sure that the higher estimate applies in some places, justified by the often-immense brush fires touched off by open field burning. Still, the best, hard data based study I know (conducted in Mae Chaem District, North Thailand by researchers from Mahidol University in 2018) concluded that only 41 percent of corn stalk was burned. Add this 41 percent to the large percentage of corncob and husk burned, and the total corn waste burn probably ran 50-55 percent. Because in many places corn stover, for example, is used for cooking, construction, or feeding animals, I am inclined to use the lower, 50 percent figure.

If we assume that developing world farmers burn 50 percent of crop waste – 10.5 billion tonnes – what are the consequences for the climate, environment and public health?

We worry primarily about emissions of CO, CO_2, CH_4 (methane), NOx, and PM2.5. Let me classify these by concern: Climate, Environment and Public Health. For emission factors (EFs), I have chosen to use S. Akagi, et al., "Emission factors for open and domestic biomass burning for use in atmospheric models," Atmospheric Chemistry and Physics, 2011: 4039-4071. There are many alternative EFs available for, for example, rice straw or corn stalk at specific locations. I have not found, however, another source that systematically combines EFs for all emissions for all open field burning everywhere. Such a source is required here, because this exercise is meant to apply to open field burning of all crop residues. Likewise, I have chosen to use the US EPA Global Warming Potentials (GWP). These are 100-year measures; nonetheless, they appear to be the most commonly used in the literature.

Emission	EF*	GWP
CO_2	1,585	1
CO	102	
CH_4	5.82	25
NH_3	2.17	
NOx	3.11	298
$PM_{2.5}$	6.26	

*Measured in g/kg

Climate change

- **CO_2** is the most talked about and most emitted climate change gas. CO_2, however, is also the most problematic of the byproducts of open field burning. To grow, crops must remove CO_2 from the atmosphere, saving the carbon and releasing the oxygen. Burning 10.5 billion tonnes of crop waste releases **16.6 billion tonnes of CO_2** into the air. (Of which, 12.5 billion tonnes is oxygen and 4.5 billion tonnes carbon.)
- **CO_2e** (carbon dioxide equivalent) I have conservatively reduced to methane (CH_4) and NOx, both largely the product of the low temperature of smoldering field fires. Burning 10.5 billion tonnes of crop waste emits ((10,500,000,000 x 5.82)/1000) = 61,110,000 tonnes of methane and ((10,500,000,000 x 3.11)/1,000) = 32,655,000 tonnes of NOx. **CO_2e** = (61,110,000 x 25) + (32,655,000 x 298) = (1,527,750,000) + (9,731,190,000) = **11,258,940,000 tonnes of CO_2e**.

Environment

- **Smog** forms in the lower atmosphere because of reactions caused when "smog precursor" gases absorb energy from sunlight. WHO estimates that smog kills more than 3 million people per year, although it does not attribute most smog to crop fires. In Beijing, however, as much as 50% of the toxic mix over the city comes from crop fires in June/July, the burning season for rice straw. The three most important smog precursors are CO, NH_3 (ammonia) and NOx. Primary smog precursors emitted are CO = (10,500,000,000 x 102)/1,000) = 1,071,000,000 tonnes, NH_3 = (10,500,000,000 x 2.17)/1,000 = 22,785,000 tonnes, and NOx = (10,500,000,000 x 3.11)/1,000) = 32,655,000 tonnes or a combined **1,126,440,000 tonnes of smog precusors.**

Public health

- WHO classifies **PM2.5** (particulate matter 2.5 microns or smaller in diameter) as the fifth most important killer in the world today. It kills more people annually than dengue, hepatitis B, HIV, malaria and TB *combined*. PM2.5 is so small that it passes through the walls of the lung into the blood stream and settles in the brain, heart, liver and other organs. PM2.5 not only causes liver and lung cancers, but cirrhosis, COPD, heart attacks and strokes. Burning 10.5 billion tonnes of crop waste generates (10,500,000,000 x 6.26)/1,000 = 65,730,000 tonnes of PM2.5. (If you have a hard time imaging the weight of smoke, you are not alone. A simple trick is to remember that 1 kg of smoke is equivalent to the smoke of 71,429 cigarettes.)

Summary Figures

10 billion tonnes	Total developing world crop production, 2017
21 billion tonnes	Total developing world crop waste production, extrapolated
10.5 billion tonnes	Total developing world crop waste burned @ 50%, 2017
16.6 billion tonnes	Open field crop waste burning emission **CO_2** (EF 1585 g/kg)
11.3 billion tonnes	Open field crop waste burning emission **CO_2e**
1.1 billion tonnes	Open field crop waste burning emission **CO** (EF 102 g/kg)
61 million tonnes	Open field crop waste burning emission **CH_4** (EF 5.82 g/kg)
22.8 million tonnes	Open field crop waste burning emission **NH_3** (EF 2.17 g/kg)
32.7 million tonnes	Open field crop waste burning emission **NOx (**EF 3.11 g/kg)
65.7 million tonnes	Open field crop waste burning **$PM_{2.5}$** (EF 6.26 g/kg)
1	Global Warming Potential (GWP) **CO_2**
25	Global Warming Potential (GWP) **CH_4**
298	Global Warming Potential (GWP) **NOx**

Cereals and Coarse Cereals Only

2.1 billion tonnes	Total developing world cereal & coarse grain production, 2017
4.2 billion tonnes	Total developing world cereal & coarse grain waste production, extrapolated
2.1 billion tonnes	Total developing world cereal & coarse grain crop waste burned @ 50%