Food security impact of global equities

Annex Measurement methodology for *yield*

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P.O. Box 29703, 2502 LS The Hague, The Netherlands, T +31 (0)70 335 83 30, E communications.ssg@wur.nl, http://www.wur.eu/economic-research. Wageningen Economic Research is part of Wageningen University & Research.

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1. Yield improvement

1.1 Identifying key agricultural technologies

Five different types of agricultural technology can be identified

There are many agricultural technologies that determine the yield of the crops of farmers and thus affect the food security situation of a country. We distinguish the following five broad groups of technologies:

1. Technologies that improve plant characteristics, in particular new types of seeds (i.e. improved varieties)
2. Technologies that address water and nutrient supply, the two key factors that limit crop yield when not supplied in sufficient quantities: irrigation and fertiliser
3. Technologies that address so-called yield-reducing factors, including weeds, pests and diseases: Herbicides, fungicides and herbicides
4. General purpose or enabling technologies: Tractors, cultivators, ploughs, harvesters, etc.
5. Soft technologies, including farm management knowledge, training and extension services.

Agricultural technologies influence FNS, but should be seen within the wider food system

In general, the impact of technologies has been analysed in research focusing on yield gaps. In addition to the availability of technological advances, adoption rates are equally important since yields will not rise without the acceptance and correct application by farmers. The farmers' attitudes towards new knowledge and practices and their willingness to actually apply the technologies need to be taken into account when determining their impact on the yield. Furthermore, it should be noted that other relevant issues prevail when considering technological advances and their impact on yields and hence food security. First, as elaborated above, food security has several dimensions and in this research we only take into account the production of crops. More specifically, we focus on cereal crops, thereby neglecting possible varieties that may play a more prominent role in the food and nutrient security of a country. In addition, the issue of dependence on imports of technologies, i.e. inputs and solutions, is considered an important point when looking at the stability of the food security situation, which is a function of the respective imports and their delivery to the local farmers in developing countries.

We focus on two key agricultural technologies fertilisers and seeds

We limit the analysis to two technologies: fertilisers (technologies that address water and nutrient supply) and seeds (technologies that improve plant characteristics)[1]. One of the main constraints to agricultural productivity in developing countries is limited fertiliser (Morris et al., 2007). This especially applies to Africa, where average fertiliser use is only eight kilograms per hectare, only 10% of the world's average. For this reason, African countries agreed to increase the access and use of fertiliser in the 2006 Abuja Declaration. Apart from fertiliser, the development and adoption of improved seeds, as opposed to traditional seed varieties, are also frequently mentioned as a way to increase crop yield (World Bank, 2008). In addition, new types of drought-tolerant varieties are also regarded as an important technology for farmers to adapt to climate change (Rovere et al., 2014).

[1] As stated, even if inputs like improved seed varieties are available we do not know if farmers actually make use of them and apply them appropriately. Pingali (2012) evaluated the spread and sustainable adoption of improved seeds in the context of the green revolution. According to the author's conclusion and the evidence from case studies, lower adoption rates in marginal areas with poor soil and insufficient water supply undermined the potential benefits of improved seed-fertiliser technologies introduced during the Green Revolution. Next to the availability of inputs and new technologies, the farmers' access to financing, insurances and markets for their produce is important for ensuring food security and reducing poverty in the long run. The impact of fertiliser and improved seed depends on many factors that we do not specifically analyse in our calculation.

Figure 1.1 Impact logic

1.2 Impact logic

Agro-companies influence food availability by producing agricultural technologies including seeds and fertilisers

Agro-companies produce agricultural technologies which are essential for increasing yields and which, in turn, bear heavily on food security through food availability. The impact logic that connects agricultural technologies, such as fertiliser and seeds, to food security is illustrated in Figure 1.1. We adopt the structured approach of Vörösmarty et al. (2018) to define outputs, outcomes and impacts. The elements of this approach are depicted below in Figure 1.1. From the left hand side, companies produce technologies which are then used by farmers to grow cereal crops, which in turn leads to higher yields and finally to food availability, one of the four facets of food security[2].

The key output is delivery of fertilisers and seed

Output in the context of agricultural yields is the distribution of agricultural technologies that affect yields to (small-scale) farmers, in this case fertiliser and seeds. Output can be measured by the units of technology delivered to a defined spatial area (for example Nigeria).

The key outcome is higher yields achieved by (small-scale) farmers using the agricultural technologies

For example, applying fertiliser or improved seeds to grow maize leads to higher yields than would be achieved without these technologies. The quantitative link between the technology and crop yield is called the yield response function. This link depends heavily on spatially explicit variables like the local climate and soil conditions. The response of maize to fertiliser in a dry area with little rain and poor soil will be completely different from a more favourable setting. This suggests that assessing the role of a company in furthering food security should incorporate a spatially explicit approach. Of

[2] It is not uncommon to make a distinction between immediate outcome, the adoption of improved technologies; intermediate outcome, improved yield; and ultimate outcome, improved food availability. However, we follow the approach of Vörösmarty et al. (2018), who do not make this distinction.

course, the effectiveness of any technology also depends on the user, in this case the farmer. However, a correct appraisal of the technology would not take into account the actual use of the technology but the use for which it was intended.

The key impact relates to food security, in particular food availability/production

Our methodology allows us to establish the link between technology sales and food availability (through an increase in crop yield). However, this by itself does not ensure an improvement in food security. For example, production can be exported and therefore not be made available for domestic consumption. It could be that the additional production is exported and therefore not be available for domestic consumption. Another possibility is that farmers that use fertiliser are large commercial farmers, which are already food secure. Despite these considerations, we suggest that higher yields and higher food production imply greater food security.

1.3 Fertiliser

1.3.1 Selection of companies

Yara was selected as a case study given its size, geographical spread and availability of data

The companies for a case study needed to be selected from the FactSet Revere database provided by UBS. This database contains revenues from the listed companies by region and type of technology. The FactSet lists eight fertiliser companies that are eligible for investment:

- Yara International ASA
- Mosaic Co/The
- Nutrien
- CF Industries Holdings Inc
- Uralkali PJSC
- Sociedad Quimica y Minera de Chile SA
- PhosAgro PJSC
- Israel Chemicals Ltd

From these companies we selected Yara International ASA (hereafter Yara) as a case study because the company: (1) belongs to the top five largest fertiliser companies in the world (Table 1.1); (2) is active in a large number of developing countries, in particular within Africa (Figure 1.2); (3) showed interest in the project and provided additional data; and (4) presents regional data on volume of fertiliser sales. In particular the latter is of key importance in developing our methodology and, to the best of our knowledge, is not available for any of the other companies. The other companies did not meet these criteria[3].

Table 1.1 Yara International Profile

Company	Yara International (YARIY)
Headquarters	Oslo, Norway
Website	yara.com
Total revenue	11.4bn USD (2017), source: Factset Revere
Share of revenue	Mixed fertilisers (42%); Nitrogenous (44%); phosphate and potassium (6%); non-fertiliser (8%), source: Factset Revere
Code of conduct	Yes, business ethic and Global Reporting Initiative (GRI) reporting framework as our standard for sustainability reporting since 2007.
Employees	Approximately 13,000 employees in six countries
Operations	Top Five: Brazil, United States, France, United Kingdom, Canada; Africa: Nigeria, Angola, South Africa, Ethiopia and Sudan

[3] We also contacted Mosaic for more information but unfortunately they were not able to share additional data on deliveries that are needed for the case study. Two companies were excluded from the further analysis. Nutrien, the largest fertiliser company in the world, resulted from a merged of Agrium Inc. (Agrium) and Potash Corporation of Saskatchewan Inc. (PotashCorp) in January 2018. The FactSet Revere data, our main source of revenue information does not (yet) present data on the company. The other company, Uralkali, only produces one type of fertiliser, potassium, the impact of which we are not able to assess (see below).

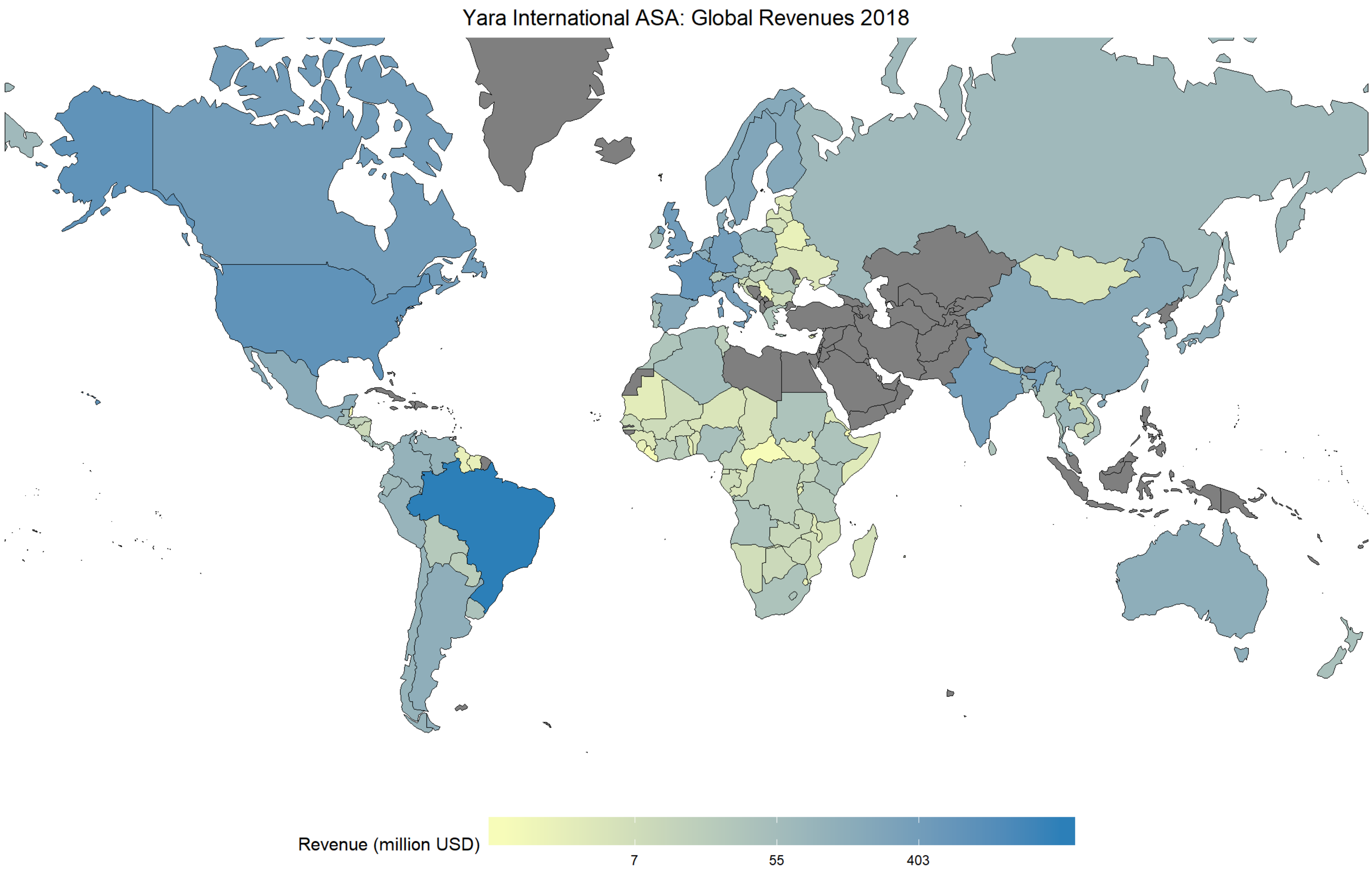

Figure 1.2 Yara International global revenues
Source: Factset Revere

1.3.2 Methodology

An eight-stage gold standard approach to assess impact of fertiliser on food availability

This section describes the gold standard approach to assess the impact of a fertiliser company on food availability. It follows the impact logic described above. Step 1 relates to estimation of output, steps 2 and 3 relate to the estimation of outcome and steps 4 to 8 describe to the estimation of impact.

Stage 1. Estimate fertiliser deliveries in volume terms by country and crop

The FactSet Revere database is converted into fertiliser volume measures relying on four assumptions

Ideally we would like to have volume information on all types of fertiliser delivered by a company to a region as well as the crops to which they are applied. Unfortunately, this data is not available. The only global company source of data we have is the FactSet Revere database. The database consists of two separate files that present different information: (1) GEOREV provides company global revenue by fertiliser (sector ID 266992), distinguishing between four types: nitrogenous (sector ID 260907), phosphate (sector ID 260906), potassium (sector ID 266993) and mixed and other fertilisers (sector ID 260905). SEGREV presents only total company revenue (including the sum of fertiliser and non-fertiliser activities) by country. To convert the FactSet Revere database into a fertiliser volume measure (e.g. tons), we make four assumptions.

We assume country-specific revenue shares approximate global revenue share

First, we assume that for each fertiliser company listed in Factset Revere/BOA[4] the country-specific fertiliser revenue share can be approximated by the company's global fertiliser revenue share. For example, suppose that for fertiliser company X, SEGREV reports that global fertiliser sector (ID 266992) revenue makes up 80% of the company's total global revenue, which can be broken down in the following fertiliser specific shares: 40% nitrogenous (sector ID 260907), 10% phosphate (sector ID 260906), 15% potassium (sector ID 266993) and 25% mixed and other fertiliser (sector ID 260905) revenue. We use this information to estimate country-specific fertiliser revenue R_t (USD), where t refers to one of the four fertiliser types, by multiplying total country revenue with the global revenue shares of nitrogenous, phosphate, potassium and mixed and other fertilisers.

We assume the average unit value can be used to convert revenue into tons of fertiliser

Second, we use data on global fertiliser sales in quantity units (e.g. tons) extracted from company annual reports to calculate a USD/kg unit value (U) to convert revenue into tons of fertiliser. We compared a number of approaches and data sources to estimate the unit value and decided to use an average (i.e. across all four fertiliser types t) unit value that is based on data from Yara only (see paragraph 1.3.4.1).

We assume revenue categories can be linked to standard fertiliser types

Third, we assume that all companies produce a 'standard' fertiliser type (Table 1.2), which can be linked to the fertiliser revenue categories in FactSet Revere. As mentioned above we exclude the potassium fertilisers from the analysis. The three selected fertilisers: nitrogenous, phosphate, and mixed and other fertilisers make up the largest market share in global fertiliser sales and are widely traded (Yara 2017). Apart from the standard nitrogenous fertiliser (UREA) also the phosphate (DAP) and mixed (NPK) fertilisers contain a (small) share of nitrogen (N). We use the information on the share of N (S_t) to convert the revenue data for all types of fertiliser into tons of N, which can subsequently be combined with the yield response function, which is only available for N (see stage 2).

[4] The BOA database is a list selected by UBS of companies upon which we needed to focus the research.

Table 1.2 Nutrient composition of standard fertiliser types used for all fertiliser companies

FactSet Revere fertiliser type	Most common type	N%	P%	K%
Nitrogenous fertilisers	UREA	46	0	0.0
Phosphate fertilisers	DAP	18	46	0.0
Potassium fertilisers	MOP	0	0	0.6
Mixed and other fertilisers	NPK	15	15	15.0

Source: Prepared by authors.

Note: Potassium fertilisers are excluded from further analysis.

We assume crop distribution N of the company approximates national level N per crop

Finally, we use IFA and IPNI (2017), Fertilizers Europe (2018) and Rosas (2012), which provide data on the share of total national level N per crop for a number of countries to allocate the fertiliser to crops and sum N over all fertiliser types. We assume that crop distribution of N supplied by the company is the same as the national average D_i. The calculation of total N delivered by a company Nd_{it} can then be estimated as follows:

$$Nd_i = \sum_{t=1}^{T} \left(\frac{R_t \times S_t \times D_i}{U} \right)$$

, where R_t is country specific revenue for fertiliser of type t in USD, S_t is the share (%) of N in fertiliser of type t, D_i is the share (%) of total national N applied on crop i, U is the average USD/kg unit value of the sum of all fertiliser types based on information from Yara (see below).

Stage 2. Estimate the yield response function by country and crop

Yield response functions capture the relations between key technologies and yields. Relationships between key technologies and yields (referred to as yield response curves) have received substantial attention in the scientific literature. For example, a robust relationship between yield variability and nitrogen and phosphorus application via fertiliser has been identified (see for example Velde et al. 2013). Similar evidence exists for other inputs including field trials of various seed types.

Yield response functions are based on the Environmental Policy Integrated Climate model. Spatially explicit yield response information at the global level, ideally used for yield response functions, is not available[5]. We therefore use an alternative approach which relies on the results of the EPIC (Environmental Policy Integrated Climate) model (IIASA 2015). EPIC is a crop model that simulates plant growth under a range of management practices and input levels using global gridded soil, climate and input datasets (Figure 1.3). The major advantage of using crop model results from EPIC to estimate yield response functions is the coverage of a large number of crops (e.g. maize, wheat and rice) at global level using a structured approach, which can easily be compared at the spatial and crop level. On the basis of the EPIC output, which is referred to as the 'HyperCube', it is possible to 'drop a pin' anywhere in the world and extract yields corresponding to various levels of fertiliser input. All data combined can be used to estimate the fertiliser yield response curve at various levels of aggregation, in this case the country level.

Yield response is limited to N (directly) and P (indirectly); K is not covered

There are three macro-nutrients that stimulate crop growth and quality: nitrogen (N), phosphorus (P) and potassium (K). Most synthetic fertilisers contain one or more of the macro-nutrients, although the exact combination can vary. Of the three components nitrogen is the most traded (60%) (Yara, 2017). The main reason for this is that it needs to be applied every year to maintain yield and biomass. P and K are absorbed by the soil and stored for a longer period and therefore do not always need to be applied. Most research that analyses and simulates the impact of fertiliser on crop growth has focused on N, while there is limited information on the impact of P and K. The HyperCube only simulates different application rates of N and (indirectly P), while K is not covered. For this reason our analysis is not able to address the impact of K (and hence K fertiliser producers) on crop yield and food availability.

[5] The potential for a given technology to increase yields should be drawn as closely as possible from the scientifically established yield response at the lowest spatial level possible. Ideally, we would like have spatially explicit yield response information at the global level, which can be applied to all companies in our sample. In practice this data is not easily available. The main problem is that studies that estimate yield response functions use highly localized data and apply a range of different methodologies that are not easy to compare.

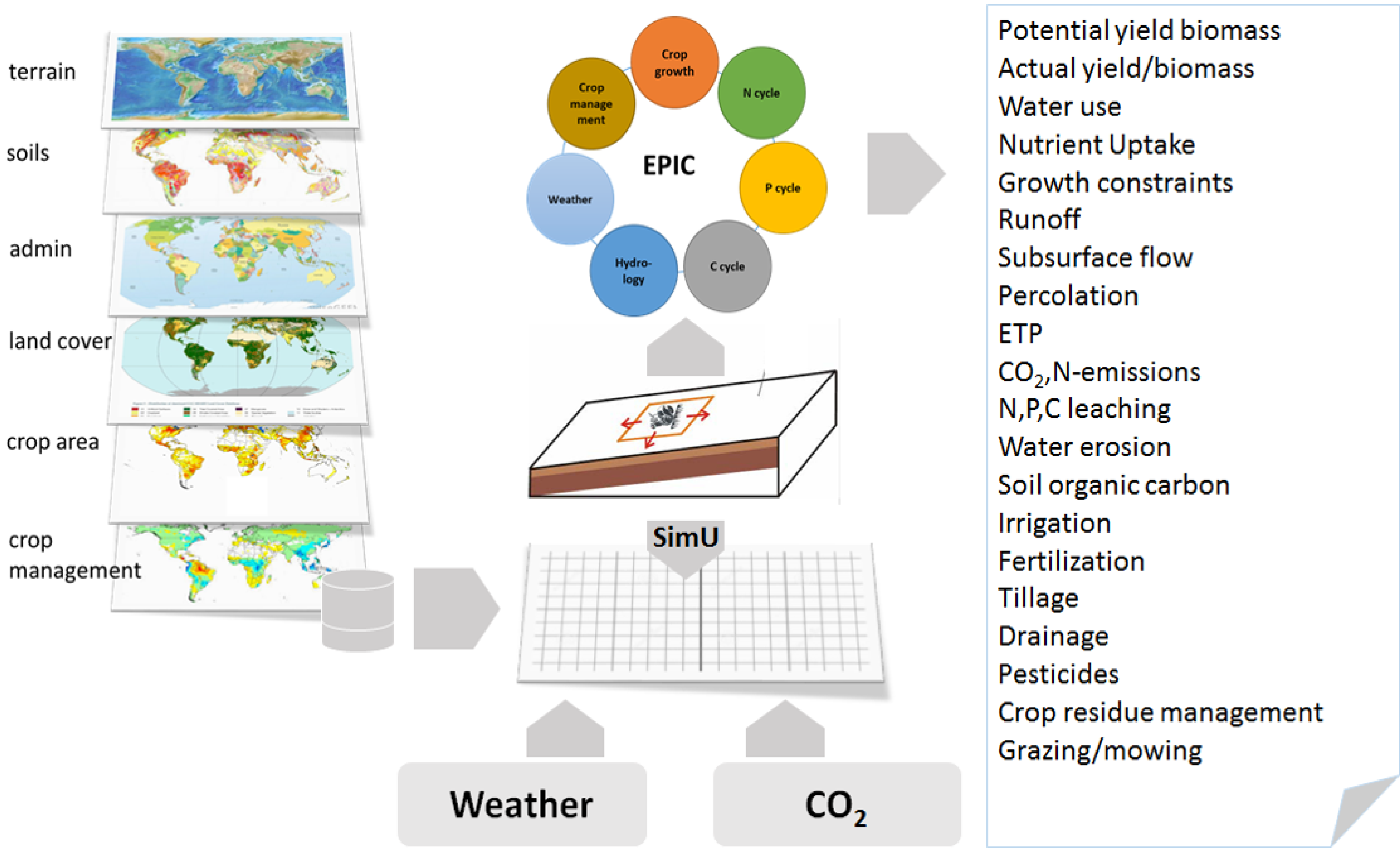

Figure 1.3 EPIC crop model
Source: Balkovič, Folberth, and Skalský (2018)

Yield response to N is estimated using a quadratic response function

Plants need both N and P to grow. Plant growth is therefore limited by the nutrient that is most deficient, which is known as Liebig's law of the minimum in agronomy. To account for this the HyperCube contains the results of simulations in which N application rates are varied, while at the same time we assume that P does not limit plant growth. We use these results to estimate a yield response function for N (with the knowledge that P is not a limiting factor) that is specific for each country and crop (i.e. maize, wheat and rice). When estimating the yield response function, the choice of functional form is dictated by practical considerations. Yields typically plateau at ever higher levels of fertiliser input, suggesting that a quadratic or linear plateau specification is appropriate. We use a quadratic response function, which is a continuous function and therefore can be estimated with ordinary least squares[6].

The quadratic yield response function is defined as follows:

$$Yp_i = \beta_0 + \beta_1 N_i + \beta_2 N_i^2 + \epsilon$$

where N is the quantity of nitrogen in t, and Yp the potential yield in t/ha for crop i, which can be either maize, wheat or rice. The equation will be estimated for each country separately. For convenience, we do not use the country subscript.

Recalibrating yield response to get closer to actual yield estimations

If we want to produce realistic yield estimations that can be related to actual production and consumption statistics in a region, we need to recalibrate the yield response function so that it represents actual yields and application rates[7]. The inefficiency factor can be approximated by taking the fraction of actual and potential yield:

$$I_i = \frac{Ya_i}{Yp_i}$$

, where I_i is the inefficiency factor, Ya_i the actual observed yield from FAOSTAT in t/ha and Yp_{it} the potential yield in t/ha. To estimate I_i, we need to estimate the potential yield at the same application rate of N that corresponds with the actual yield. We calculate national N application rates Nap_i for each crop by dividing total N use by crop from a number of sources (IFA and IPNI 2017; Rosas 2012) by crop area in hectares from FAOSTAT. Next, we plug Nap_i into the yield response function to estimate Yp_i. The example for Brazil in the next section shows a graphical illustration of the yield response curve and the calculation of I_{it} and other elements of the procedure. The efficiency corrected yield response function can now be rewritten as:

$$Ya_i = I_i \times Yp_i = I_i \times (\beta_0 + \beta_1 N_i + \beta_2 N_i^2)$$

Stage 3. Estimate the increase in yield that can be attributed to fertiliser application

To estimate the increase in crop yield that can be attributed to a company's fertiliser sales, we need to know the counterfactual or baseline, which is the yield a farmer would have obtained if s/he had not applied fertiliser (the baseline). We can use the yield response function from step 1 to estimate the counterfactual. If we assume that farmers apply zero fertiliser, $N_i = 0$, resulting in a yield of:

$$Ya_{0i} = \beta_0 \times I_i$$

Finally the increase in yield is estimated as:

$$\Delta Y_i = Ya_i - Ya_{0i}$$

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[6] When estimating the yield response function, the choice of functional form is dictated by practical considerations. Typically, yields will plateau at ever higher levels of fertiliser input, suggesting that a quadratic or linear plateau specification is appropriate. Estimation of a plateau function is technically more complex because it is a non-linear function. The selection of the functional form will have an impact on the results. We therefore aim to explore and compare the performance of other functional forms in the future

[7] It is important to realize that HyperCube simulations reflect the relationship between fertiliser application and yield under perfect conditions, meaning an absence of growth-reducing factors (i.e. pests and diseases), no economic constraints (e.g. availability of equipment or animal traction to work the land), perfect management (e.g. the farmer is 100% efficient) and the use of one uniform global cultivar for each crop. Actual yield observed in the field (Ya_i) is expected to be considerably lower than potential yield in most developing countries because of poor management, economic constraints and lower quality cultivars. It might be higher in advanced countries which use high-yielding cultivars.[7] Fortunately, as will be explained below, this does not pose a problem for our analysis, as we use the yield response curve to estimate the difference between potential yield with and without fertiliser. We do not use it to estimate absolute yield levels, which might be under or overestimated, depending on the country.

Note that ΔY (t/ha) is country- and crop-specific but identical for all companies that deliver fertiliser to the country. The reason for this is that we assume all fertilisers have the same impact on crop yield because of the same national average application rate. As will be explained in the next section, what differs is a company's impact on total crop production and, hence, food availability, which is proportional to total fertiliser deliveries.

Stage 4. Estimate the increase in crop production that can be attributed to the company

Estimating total crop area where fertiliser is applied. Using our estimations on fertiliser delivery by crop from the previous step, we can estimate the total crop area where fertiliser of the target company is applied in the following way:

$$A_i = \frac{Nd_i}{Nap_i}$$

where A_i is the area in ha of crop i to which nitrogen is applied and Nap_i is the national application rate of nitrogen (t/ha).

Estimating additional production attributed to the company. The additional production that can be attributed to a company can then be estimated as follows:

$$\Delta P_i = A_i \times \Delta Y_i$$

where ΔP_i, is the additional production in tonnes of crop i, A_i is the area in ha of crop to which nitrogen is applied, $i\Delta Y$ is the increase in yield in t/ha for crop i that can be attributed to fertiliser use.

Possible expansion of crop area not taking into account. We take the simplifying assumption that the crop area is the same in the counterfactual case when farmers do not apply fertiliser. In reality this might not be the case as farmers might have an incentive to expand the crop area induced by the higher yield and, in turn, profitability caused by more intensive production.

Stage 5. Correct for exports and other uses than food consumption

Taking into account share of production not used for consumption. As our main interest is in national food availability, we need to correct for the share of crop production that is not used for human consumption (e.g. because of livestock feed, seed use and losses along the supply chain). To correct the production figures we use data on crop production and food availability from FAOSTAT to estimate the national share of maize, wheat and rice production that is used as food F_i and apply the following equation:

$$\Delta P_i' = F_i \times \Delta P_i$$

, where $\Delta P_i'$ is the corrected additional production.

Stage 6. Convert to raw energy equivalent

Converting additional production into energy. Food items like maize, wheat and rice differ in the amount of energy they provide to the human body after consumption. Hence a meaningful indicator of food availability needs to be expressed in a measure of raw energy equivalent (kcal/cap), the values of which can be aggregated over different food items. We use crop-specific technical coefficients $kcal_i$ from Cassidy et al. (2013) to $\Delta P_i'$ into kcal[8]

$$\Delta P_i'' = \Delta P_i' \times kcal_i$$

Stage 7. Express in people potentially being fed

Converting additional production into potential people being fed. Using information on the diet composition from FAOSTAT, we can translate the additional production in number of people that are supplied their annual diet in maize, wheat or rice H_i:

[8] The coefficients from Cassidy et al. (2013) are based on FAOSTAT and have coverage for all crops and countries. They are also used for raw energy equivalent calculations in the FAO Food Balance Sheets. Other sources [personal communication with Paul Hulshof, December 2018] indicate lower values might be appropriate, as it seems that the FAO technical coefficients relate to the whole cob, while the part that is suitable for human consumption is lower. This, however, might be compensated by the fact that a share of the maize production is used for feed, for which a larger part of the cob can be used.

$$H_i = \frac{\Delta P_i''}{diet_i \times 365}$$

, where $diet_i$ is the kcal/cap/day consumption of maize, wheat or rice.

Stage 8. Aggregate results

Using additional production as impact indicator for investment decisions. After the seven steps described above are implemented, the results for maize, rice and wheat can be aggregated to show by how much the company contributed to food availability at the global level or for a set of target regions, for example countries that are at risk of hunger as measured by the Global Hunger Index (https://www.globalhungerindex.org). The results can either be used to make a comparison between companies or as an indicator of the total impact of fertiliser companies that are in the investment portfolio of UBS/PGGM.

1.3.3 Case study fertiliser

Using the eight-stage approach to estimate impact of Yara's fertiliser sale on food availability in Brazil. This section provides an illustration of the methodology to estimate a fertilisers' contribution to food availability using Yara as a case-study. The example below shows the estimations for nitrogenous fertiliser sales (Urea) applied to maize in Brazil, one of Yara's largest markets. Step 1 relates to estimation of output, steps 2 and 3 relate to the estimation of outcome and steps 4 to 8 describe to the estimation of impact. The same methodology can also be applied to other fertiliser, crop and country combinations.

Stage 1. Estimate fertiliser deliveries in volume terms by country and crop

Total application of N from Urea in Yara-Maize-Brazil case is 467,886 tonnes We deliberately chose Brazil and Yara for our case study because deliveries of fertiliser are reported for Brazil in kilograms. Quantities of fertiliser are otherwise rarely reported by companies. We obtain from FactSet Revere that its total fertiliser revenue is USD 10.4 billion. We also know from the annual report that the total deliveries of fertiliser were 27.1 million tonnes. If we combine this we get a Brazil-based unit value of 384 USD/tonne, which can be combined with total Brazil revenue from nitrogenous fertiliser deliveries of USD 1.4 billion. Yara sells several types of fertiliser including Urea, NPK, DAP and MOP fertilisers. Each fertiliser has a different nitrogen content. Here we only provide the calculations for the nitrogenous fertiliser type: Urea, which has a nitrogen content of 46%. The calculations for mixed fertilisers (NPK) and phosphorus fertilisers (DAP) are the same[9]. Finally, we assume that the national share of nitrogen applied to maize of 27% taken IFA and IPNI (2017) can also be applied to Yara's deliveries. If we combine all information, we estimate that the total application of N (in tonnes) from fertiliser type t = Urea to maize in Brazil delivered by Yara is:

$$Nd_{it} = \frac{R_t \times S_t \times D_i}{U} = \frac{1425429 \times 0.46 \times 0.27}{384} = 467886$$

Stage 2 Estimate the yield response function by country and crop

Using data form the HyperCube to estimate yield response. We use data from the HyperCube to estimate the biophysical maize yield response curve for N fertiliser in Brazil where i = maize:

$$Yp_i = 2.0392 + 0.0805N_i - 0.0001N_i^2$$

[9] As mentioned above, we are not able to assess the impact of Potassium fertilisers (MOP), which make up only a very small share of Yara's deliveries.

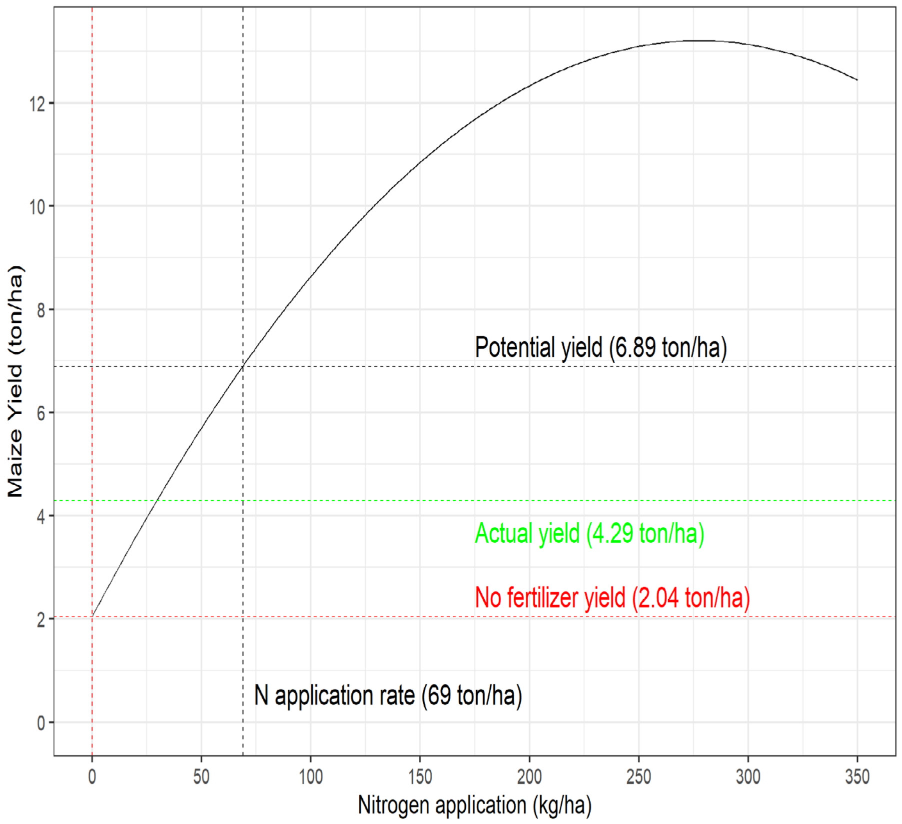

Figure 1.4 Maize yield response function for Brazil
Source: Yield response curve estimated using HyberCube; Actual yield from FAOSTAT. N application rate from IFA and IPNI (2017).

Differences between potential, actual and no fertiliser scenarios

The biophysical maize response curve is plotted in Figure 1.4. The horizontal red dotted line indicates a yield of 2.0392 tonne per ha, the yield if no fertiliser were applied. The horizontal dotted green line is the average fresh maize yield of 4.29 tonne/ha achieved by Brazil in 2016. The vertical dotted line is the average maize application of 69 kg/ha in Brazil, calculated using total N applied on maize from IFA and IPNI (2017) divided by total maize area from FAOSTAT. The horizontal dotted black line is the corresponding potential yield (i.e. the biophysical maximum) of 6.89 tonne/ha, which is calculated by substituting 69 kg/ha into the maize yield response curve:

$$Yp_i = 2.0392 + 0.0805 \times 69 - 0.0001 \times 69^2 = 6.89$$

Inefficiency factor is 62%

We can calculate the inefficiency factor by dividing the yield actually attained in Brazil at a nitrogen application rate of 69 kg/ha[10] with the biophysical potential yield which could theoretically be achieved at the same nitrogen application rate.

$$I_i = \frac{Ya_i}{Yp_i} = \frac{4.29}{6.89} = 0.62$$

Recalibrating the model to adjust for production inefficiencies

This calculation suggests that farmers in Brazil attain 62% of the biophysical maximum at the nitrogen application rate of 69 kg/ha. To take into account the inefficiencies in production we recalibrate the curve and shift the curve down so it cuts through the actual yield of 4.29 and average application rate of 69. The yield response after correcting for the efficiency of farmers is therefore:

$$Ya_i = I_i \times Yp_i = I_i \times (\beta_0 + \beta_1 N_i + \beta_2 N_i^2) = 0.62 \times (2.0392 + 0.0805 N_i - 0.0001 N_i^2)$$

Stage 3. Estimate the increase in yield that can be attributed to fertiliser application

When N_i is zero, actual yield (Ya_{0i}) is equal to:

$$I_i \times \beta_0 = 0.62 \times 2.0392 = 1.26$$

[10] An earlier report based on data gathered by FAO in 2002 indicated an average nitrogen application rate of 40 kg/ha on maize fields (http://www.fao.org/tempref/docrep/fao/009/a0787e/A0787E00.pdf). This indicates a rapid increase of 75% between 2002 and 2015/16 in the use of nitrogen fertiliser on maize in Brazil. It also demonstrates the flexibility of our methodology which can be updated over time as changes occur within the countries where companies like Yara International operate.

The increase in yield that can be attributed to fertiliser can then be estimated as follows:

$$\Delta Y_i = Ya_i t - Ya_{0it} = 0.62 \times (2.0392 + 0.0805 \times 69 - 0.0001 \times 69^2) - 1.2643 = 3.02$$

Yara contributes an extra 3.02 tonne/ha in maize in Brazil compared to no fertiliser use

This implies that fertiliser from Yara contributes an extra 3.02 tonne/ha but only when compared to the situation where no fertiliser is used. In other words, the comparison is between the baseline of no fertiliser application versus the currently observed fertiliser application in Brazil, the difference being wholly attributable to Yara International.

Stage 4. Estimate the increase in crop production that can be attributed to the company

Combining the deliveries with the average N application rate results in an estimation of the maize area that is fertilized by Yara:

$$A_{it} = \frac{Nd_{it}}{Nap_i} = \frac{467886}{0.069} = 6806659$$

Additional production of Maize in Brazil due to Yara estimated at 21.5 tonnes

In 2017 Brazil Yara supplied 7m hectares of land with nitrogen derived from their fertilisers, around 46 per cent of Brazil's total maize area. The additional production measured in tonnes of maize that can be attributed to Yara is then:

$$\Delta P_{it} = A_{it} \times \Delta Y_{it} = 6806659 \times 3.02 = 2144489$$

Stage 5. Correct for exports and other uses than food consumption

2.2 tonnes of additional maize (10%) is used for human consumption

We correct for the share of production not used for food (F_i), such as livestock feed, seed use and losses, or exported. According to FAOSTAT around 10% of maize production is used for human consumption, which is equal to 223871.3 tonnes.

$$\Delta P'_{it} = F_i \times \Delta P_{it} = 0.104 \times 2144489 = 223871.3$$

Stage 6. Convert to raw energy equivalent

Additional Maize equals 7.7e+12 in terms of raw energy equivalent

To convert the additional maize production into raw energy equivalent we use technical coefficients from Cassidy et al. (2013), which states that one tonne of maize contains 3,581,000 kilo calories

$$\Delta P''_{it} = \Delta P'_{it} \times kcal_i = rdeltaP_food \times 3581000 = 7.7e + 12$$

Stage 7. Express in people potentially being fed

From the additional production, 42% of Brazil's population could be supplied with their daily maize diet. According to FAO current total calories in Brazil seem to be 3,262 kcal/cap/day of which maize makes up 240 kcal/cap/day, or 7.4%. We can then calculate the number of people that could potentially be supplied with their daily maize diet:

$$H_{it} = \frac{\Delta P''_{it}}{diet_i \times 365} = \frac{7.7e + 12}{240 \times 365} = 87659705$$

which is equal to 42% of Brazil's population with the maize in their daily diet in 2017.

Stage 8. Aggregate results

The total impact of Yara on food availability as a result of fertiliser supply is estimated at 62,694m tonnes of cereals

The analysis as illustrated above can be repeated for all 107 countries Yara is active in across the three fertiliser types for which we can estimate the impact of food availability. Figure 1.5 depicts the results for additional food (cereals) production in kcal for major regions and the global total that can be attributed to Yara's fertiliser deliveries. The figure shows large differences depending on crop and region, which are caused by a combination of factors, including differences in regional deliveries of fertiliser, national fertiliser application rates, national yield response rates and kcal content.

The number of people supplied with dietary needs as a result of fertiliser supply by Yara is estimated at 659m people

Figure 1.6 shows the number of people potentially supplied with their dietary needs that can be attributed to Yara. It is important to note that it is not possible to aggregate the number of people per crop, as the same people are consuming maize, rice and wheat. To calculate number supplied with dietary needs for cereals we used a weighted average of the individual crop conversion factors using the national N deliveries as weights.

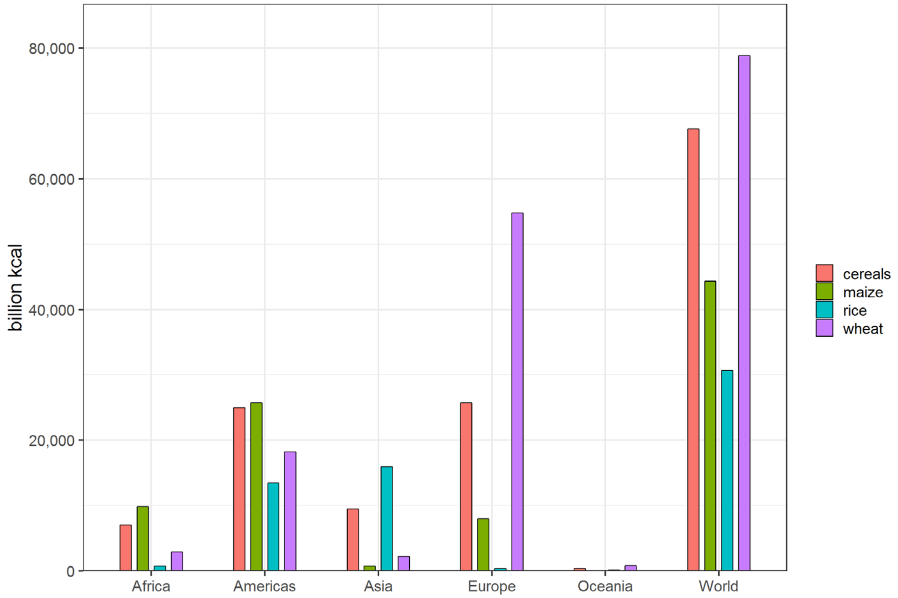

Figure 1.5 Additional food production in kcal attributed to Yara
Note: Cereal production is the total of maize, rice and wheat production.

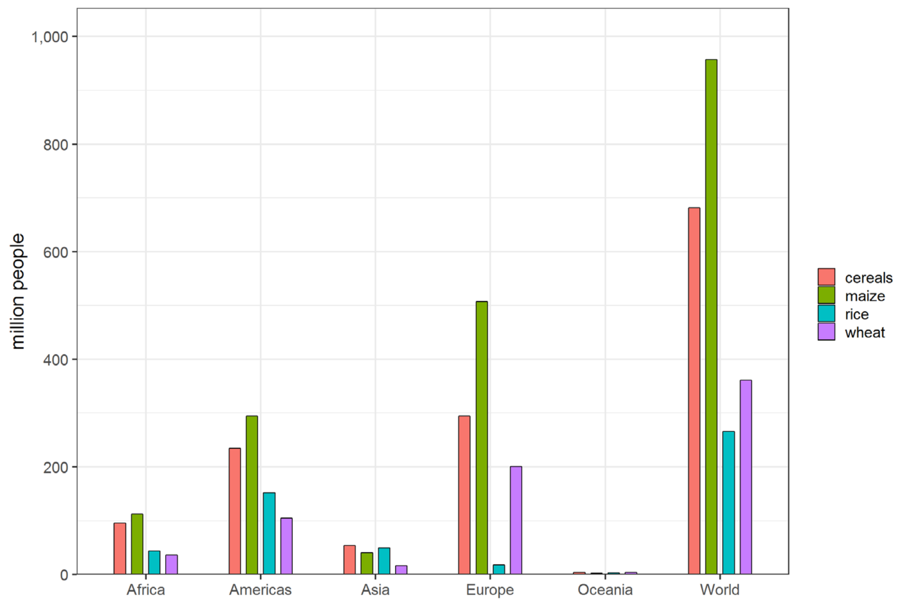

Figure 1.6 Number of people possibly supplied with dietary needs attributed to Yara[11]

1.3.4 Discussion of main uncertainties and key assumptions vis-à-vis the fertiliser model

Conversion of revenue data into deliveries

Different approaches for calculating fertiliser delivery

The 'gold standard' approach of the methodology described above requires data on fertiliser deliveries per company and per country in quantity units (e.g. tonnes). As these data are not directly available for the majority of companies, we used company revenue information by region for four years from the FactSet Revere database as a proxy. We explored two options to

[11] The model implicitly assumes that maize, wheat and rice are equally interchangeable in people's diet, which might not be realistic. Nonetheless, it provides a good proxy variable to measure the impact of Yara on total food availability. Also note that, as people consume a mix of maize, wheat and rice, aggregating the number of people per cereal would result in double counting. The cereals value uses the sum of maize, rice and wheat diet shares in the national diet, implicitly assuming that kcal consumption of maize, rice and wheat is perfectly substitutable.

convert the revenue data into quantity units: one relying on global and regional fertiliser deliveries and one relying on global prices.

Option 1: Using company-specific global and regional fertiliser deliveries to quantity units

First, we used additional information on global and regional fertiliser deliveries presented in annual reports of companies to calculate unit values. Unfortunately, we have only been able to find delivery data for Yara, whose annual report presents deliveries in thousand tonne units at the broad regional level (Table 1.1). Separate information is provided for Brazil, probably because it is one of the larger markets for Yara and it operates a production facility in the country. We also contacted Yara and Mosaic with a request for additional and more detailed information, but without success.

Option 2: Using global prices to convert to revenue values and then quantity units

A second option is to use global prices for the common N, P, K and mixed fertilisers (see Table 1.3) to convert the revenue values. In this case, regional revenue data for nitrogenous, phosphorus, potassium and mixed and other fertilisers is first converted to deliveries in tonnes and then aggregated to the regional level.

Table 1.3 Yara Fertiliser deliveries per region

Region	2017	2016	2015	2014	2013
Europe	9,159	9,418	9,381	9,755	10,199
Brazil	9,044	9,213	8,403	8,302	5,840
Latin America excluding Brazil	2,373	2,217	2,208	1,562	1,060
North America	3,034	3,106	3,007	3,320	3,265
Asia	2,221	2,080	2,125	2,011	2,279
Africa	1,328	1,217	1,420	1,368	1,026
Total	27,159	27,249	26,544	26,317	23,668

Source: Yara International ASA (2018).

Global fertiliser prices seem to result in biased values of quantity of fertiliser delivered

Figure 1.7 compares the actual Yara fertiliser deliveries by region with imputed values, using (a) global fertiliser prices for the four standard fertilisers and (b) the global Yara unit value of 384-419 USD/tonne, depending on the year. It is clear that the use of the global unit value results in a more accurate estimation of deliveries by region than applying global fertiliser prices. This is not surprising, as by definition, the global values are the same when the global unit value is used. The proxy using the global fertiliser prices is biased upwards, leading to an overestimation of deliveries. In the case of Asia this can be up to 50%, which is substantial.

Follow up required to test which approach of converting revenues into quantities of fertilisers delivered is best

Each approach has its advantages and disadvantages. Illustrated unit values are likely to give better results than global fertiliser prices, but company and region specific delivery data is required, and at the moment we only have delivery data for Yara. A key question is if the Yara global unit value can also be used to convert the revenue of other companies into physical tonnes for the purpose of our analysis. Due to lack of information for other companies, we are not able to test this. Using global fertiliser prices has the advantage that the same independent and fertiliser specific information is applied to all companies. The main disadvantage is that it seems to result, at least in case of Yara, in an overestimation of deliveries. For the moment we use the Yara global unit values to construct the conversion factor because it provides better results. If more company data on fertiliser deliveries in tonnes comes available we hope to test and compare the two approaches further.

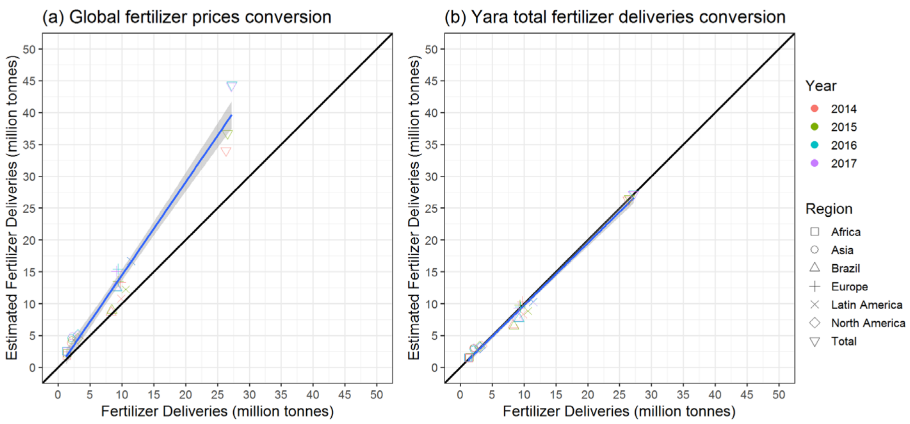

Figure 1.7 Comparison of conversion approaches
Source: Table 2 for Yara delivery data, Factset Revere for revenue data, World Bank (2018) and IFDC (2018) for fertiliser prices

Yield response curve estimation

Follow up analysis is needed to estimate the sensitivity of the yield response model

The estimation of the yield response function using simulated crop yields from the EPIC crop simulation model incorporates several assumptions, which affect the final results. First, at the moment we are using a quadratic function, which is only one of the functional forms applied in the literature (Berck and Helfand 1990; Jauregui and Sain 1992). Changing the functional form will have an impact on the yield response to fertiliser use and related impact measurements. We aim to explore and statistically compare the impact of several function forms in future research. Second, the fertiliser yield response function only accounts for the impact of N, P and mixed (N+P) types fertiliser, excluding the impact of K fertilisers. This will result in an underestimation of impact of fertiliser companies that (mostly) deliver K fertilisers (e.g. Mosaic). This should be taken into account when presenting the impact figures at a company or portfolio level. Moreover, this implies that the results cannot be used to compare the impact of companies without further clarification of differences. Finally, we use the estimated national average yield response in our analysis. If all of a certain company's fertiliser were used by farmers located in the least or the most fertile regions of the country, the impact would be respectively lower or higher. We plan to conduct a Monte Carlo analysis to investigate the impact of spatial heterogeneity on the yield response to fertiliser in a follow-up study.

Other

Several assumptions were made due to lack of data which may influence results

Due to lack of information we had to make a number of assumptions (see below). All these assumptions are subject to a high level of uncertainty and may therefore bias the final result.

- The same type of fertiliser (Urea, DAP and NPK) with fixed N and P composition is produced by each fertiliser company. If companies produce different fertiliser types, the results will change;
- The revenue distribution in terms of (a) fertiliser versus non-fertiliser sales and (b) revenue by fertiliser type for each region is the same as the global breakdown for which information is available;
- For each company national data is used to allocate fertiliser deliveries to crops (i.e. maize, rice and wheat). Moreover these data do not always reflect the most recent application rate. If the fertiliser application rate has increased over time, our approach will underestimate the actual impact of the company;
- A large number of countries, in particular developing regions, show a steady increase in fertiliser application rates over time. This implies that the results of our study and in particular the conversion factors, are only valid for the short to medium term (1-5 years). After this period, the conversion factors should be updated with the most recent information on national fertiliser use as well as unit prices to convert revenue into volume.

1.3.5 Conversion factors to convert company revenue into additional food produced

The equations above can be combined to produce conversion factors by country and crop that convert company revenue as stated in the FactSet Revere database into additional food (e.g. maize, wheat, rice and their sum: cereals) and the number of persons that can be fed their daily diet. These numbers can be used to convert the revenue of any fertiliser company in the FactSet Revere database into an impact measure. This type of analysis is potentially interesting for pension funds, banks and sustainable asset management companies with an interest in assessing the impact if their assets.

Merging all relevant equations, the conversion factor is calculated as follows:

$$C1_{it} = \frac{S_t \times D_i \times \Delta Y_i \times F_i \times kcal_i}{U \times Nap_i}$$

where $C1_it$ is the conversion factor to convert company revenue R for crop i and fertiliser type t into additional food production expressed in raw energy equivalent (kcal/USD), U is the fertiliser unit value (USD/kg) obtained from Yara annual reports, S_t the share of nitrogen in standard fertiliser types (i.e. UREA, DAP and NPK), D_{it} is the national share of nitrogen applied to a crop, ΔY_{it} the increase in crop yield attributed to the application of nitrogen on a crop (tonne/ha), F_i is the share of crop production used for human consumption, $kcal_i$ is the crop specific technical coefficient to convert tonnes of food into raw energy equivalent (kcal/tonne), Nap_i is the crop specific national nitrogen application rate (tonne/ha), i is maize, wheat, rice and their sum: cereals and t includes nitrogenous, phosphorus and mixed and other fertilisers.

To derive the conversion factor which results in number of people potentially being supplied with their diet ($C2_{it}$), $C1_{it}$) has to be divided by average national consumption of crop i in kcal/cap/day times 365 days:

$$C2_{it} = \frac{C1_{it}}{diet_i \times 365}$$

Keeping in mind the limitations described above, the conversion factors can be used to translate fertiliser company revenue into impact on food availability at the most detailed level. To derive the total additional food production in kcal for a specific country where the company is active, $C1_{it}$ has to be multiplied with the revenue per fertiliser type (R_t) and aggregated over all fertiliser types:

$$\Delta P'_{it} = \sum_{t=1}^{T} (R_t \times C1_{it})$$

Similarly, to obtain the total number of people that can potentially be supplied with their annual diet for crop i, $C2_{it}$ has to be multiplied with the revenue per fertiliser type (R_t) and aggregated over all fertiliser types:

$$H_i = \sum_{t=1}^{T} (R_t \times C2_{it})$$

The results can be further aggregated to estimate the impact of a company at any desired regional aggregation (e.g. continents or food insecure countries) and be presented at the level of individual cereal (e.g. maize, rice and wheat) or total cereals similar to the example for Yara (Figure 1.5). The Supplementary Information contains an Excel sheet with $C1_{it}$ and $C2_{it}$ as well as all the variables that are used in the calculation. It also presents conversion factors for cereals using the national share of nitrogen use per crop as weights. Note that before the conversion factors can be combined with the FactSet Revere database, the total fertiliser revenue at country level needs to be split into the four fertiliser types for which revenue data is available at the national level. After this is done the FactSet Revere database can be linked to the conversion factors using the 'path' column, which is presented in both the FactSet Revere as well as the attached Excel file.

1.4 Seed

1.4.1 Selection of companies

Vilmorin was selected as a case study given its size, geographical spread and availability of data

The FactSet Revere lists six seed companies that are eligible for investment[12]. From these companies we selected Vilmorin & Cie SA (hereafter Vilmorin) as a case study because the company (1) belongs to the top five largest seed companies in the world (Table 1.4); (2) is active in a large number of developing countries (Figure 1.8); (3) showed interest in the project; (4) is predominantly engaged in the production of seeds; and (5) there is additional information

[12] Bayer AG, Vilmorin & CIE SA, KWS Saat SE, Monsanto, PI Industries Ltd, DowDuPont Inc

available on the regions where improved seeds are delivered[13]. The last factor is essential for estimating the impact of the seed companies on food availability.

Table 1.4 Vilmorin International Profile

Company	Vilmorin & Cie SA (RIN)
Headquarters	La Menitre, France
Website	vilmorin.com
Total revenue	1.63bn USD (2017), source: Factset Revere
Employees	750
Operations	Europe, North America, Asia, the Middle East, Australia

[13] For two companies, Vilmorin and KWS Saat, there was no regional revenue data included in FactSet Revere database. However, after request, additional data was supplied. Three of the companies are excluded from further analysis. Monsanto was acquired by Bayer in 2018 and therefore is no longer listed in FactSet Revere. PI Industries is not listed in FactSet. Du Pont Pioneer merged with Dow Agrosciences in 2017 to form DowDuPont. The company is listed in FactSet but, in contrast to the other companies, there is no revenue information that relates to revenue from seeds.

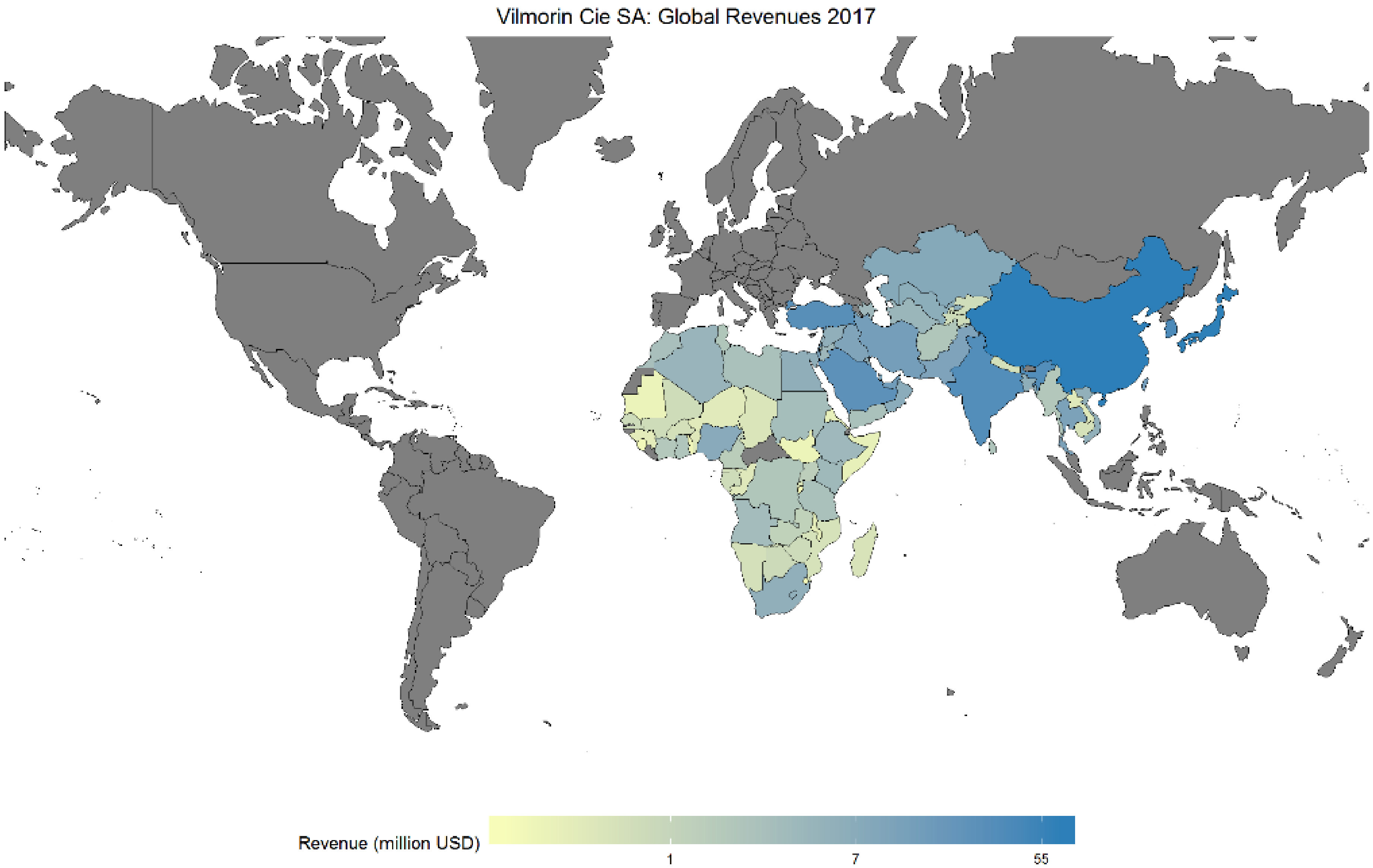

Figure 1.8 Vilmorin revenues in developing regions
Source: FactSet Revere
Note: Figure only shows revenue in developing regions, relevant for the impact assessment

1.4.2 Methodology

Gold standard approach to assess impact of seeds on food availability is available, but not yet possible to implement due to data constraints

The methodology to assess seed companies is similar to the one proposed for fertiliser companies. The approach has been discussed with experts of Vilmorin and KWS Saat, whose comments have been taken into account in the discussion. Unfortunately, in contrast to the fertiliser case, essential data to apply the methodology proved impossible to obtain despite considerable efforts to collect the data, including contacting KWS Saat and Vilmorin, the companies selected for model development, and a review of the literature. For this reason we argue that, given the lack of information on key variables it is not possible at present to properly assess the impact of seed companies on food availability. Nonetheless, for the sake of illustration, we use, in our view, bold and most likely unrealistic assumptions to illustrate the methodology for seed companies below. We would like to emphasize that this is for illustration purposes only and we discourage the use of this approach and presented results for the actual assessment of seed companies unless more detailed information becomes available. For this reason we also refrain from preparing conversion factors.

Stage 1. Estimate seeds deliveries in volume terms by country and crop

We encountered a number of problems with the conversion of revenue from FactSet Revere into volume. First, FactSet Revere does not include a sector ID for seed related revenue. In older versions the category 'Biotechnology and Genomics (GMO/Hybrids)' (sector ID 274011) was included. This sector might refer to improved seed sales but also includes GMOs. GMOs are a different category of seeds (although one might consider them as improved seeds) and difficult to compare to the non-GMO improved seeds we are interested in. In the most recent version of the database, a category 'Other Agricultural Support Activities' (sector ID 274013) is included which seems to replace the older category. It is not clear how the two categories compare and to which activities the most recent category refers. The FactSet Revere database could be improved by including a clear revenue category for seed sales.

A second and important problem for our analysis is the lack of any information to allocate the revenue data to crops by country. To assess the impact of seed deliveries of cereals (our prime focus), we need crop-specific delivery information. Companies often produce improved seeds for a large number of crops (e.g. cereals, vegetables, etc.) so it would be incorrect to allocate the total revenue stream to cereals. In the case of fertiliser, we used public and country specific information on fertiliser application rates per crop to split the revenue streams. Comparable information is not available for seeds, which makes it nearly impossible to break down the aggregated country revenues.

Finally, we need data on the unit price of seeds per crop to convert revenue into volume. Only the companies themselves can provide insights on their exact product and sales mix and unit price at the detailed crop and country level. Unfortunately and in contrast to the fertiliser case, a screening of company websites, annual reports as well as the direct contact with the companies selected did not result in any additional data on revenue by crop, unit price and delivery data in volume terms. Possibly, an official request for the data may deliver the respective company data. To overcome these problems we used secondary data sources and made some rather bold assumptions.

We used the following equation to estimate seed deliveries in volume terms:

$$SA_i = \frac{R_t \times C_i \times D_i}{SC_i}$$

where, SA_i is the area (ha) in a country supplied with seeds of crop i, Rt is Revenue (USD) for the 'Other Agricultural Support Activities' category in the FactSet Revere database in USD, C_i is the improved seed sales activity per region for each company. This information is taken from Access to Seeds Foundation (2019), which presents information on the regions in which major seed companies sell improved seeds and for which crop. Unfortunately, the information is very coarse and only covers a subset of the companies. D_i is the national share (%) of crop area for crop i from FAOSTAT. In particular this assumption, i.e. using national area shares per crop to break down a company revenue into crop-specific revenue, is highly problematic. There is no reason to believe that these two variables are related, however, it is the only available crop information we have at our disposal to break down the company revenue at the moment. Finally, SC_i is the average farmer seed costs (USD/ha) for crop i from a proprietary IIASA database.

Stage 2. Estimate the yield response function by country and crop

In contrast to fertiliser, the adoption of improved seeds is a dichotomous decision (yes/no). Hence, there is no point in estimating a yield response curve similar to the fertiliser case. Instead, for the analysis we need information (preferably spatially explicit) on the difference in crop yield between using traditional and hybrid seeds under a range of agro-climatic conditions (see next step).

Stage 3. Estimate the increase in yield that can be attributed to the adoption of improved seeds

Similar to fertiliser, we need to define a baseline yield for farmers that do not adopt improved seeds. We take the use of traditional seeds and corresponding yield as a benchmark. To the best of our knowledge, there is no publicly available simulation or other model that is able to simulate the impact of using improved seeds on crop yield. As an alternative, we conducted a literature review to collect information on the yield response rate of hybrid seeds but found only a very small number studies. The only relevant studies date from the period 1980s-2000s, when hybrid seeds were introduced and comparisons were made with traditional seeds that were the most used by farmers at the time. Most of the papers are very specific case studies and it is questionable if the presented yield response rates can be considered representative.

There are no recent studies that investigate the difference between hybrid and traditional seeds because nowadays most farmers in developed countries only use hybrid seeds and therefore this type of research is no longer conducted. The hybrid seeds that are available today mainly target the tolerance to drought, resistance against diseases and similar. This means that modern hybrids can produce more with less input. It should be noted, however, that many other factors determine seed productivity. Brisson et al. (2010) identify the use of crop rotation practices and the application of fertiliser as a main determinant of the yield response, next to climate and other factors outside the influence of farmers.

Looking into the different types of hybrids was also a preference for the seed companies contacted, i.e. Vilmorin and KWS Saat. They indicated they expect a large difference in yield between older and recently developed hybrid types, depending on the year of release of the seed. They expect that hybrid seeds that were released 20 years ago would have a much lower yield response than modern hybrids. Furthermore, the yield response would vary between and within crop types. For example, hybrid technologies for wheat or soy bean do not improve the yield response due to the biology of the plant. For other crops, like maize, a considerable increase can be expected but there are no recent studies.

Unfortunately, the information about different types of hybrids, including detailed information about the years of their release, is not readily available. Moreover, in most developing countries, in particular within Africa, more than 50% of farmers use traditional seeds, with the exception of Nigeria (Sheahan and Barrett 2014).[14] Hence, we argue that the difference between hybrid seeds versus non-hybrid seeds is still important when looking at the food security impact in *developing countries*. We therefore decided to focus on hybrid seeds versus non-hybrid seeds rather than several different types of hybrids and the yield response. The latter could be included in a further step.

Probably the most comprehensive study comparing the difference in crop yield of different types of seed in developing countries was conducted by Evenson and Gollin (2003) (Figure 1.9). However, this study presents data for a small number of broad regions only. Moreover, the figures probably underestimate the real difference in yield between improved and traditional varieties, as the yield of the former has increased strongly since the study was published more than 15 years ago. To obtain the yield increase that can be attributed to the adoption of improved seeds (ΔY_i), the values in Figure 1.9 are multiplied with actual yield information from FAOSTAT.

[14] Results from the IFPRI DIIVA project, which collected data on the area under improved seeds in Africa, shows a similar picture: https://www.asti.cgiar.org/diiva [accessed 01-02-2019]

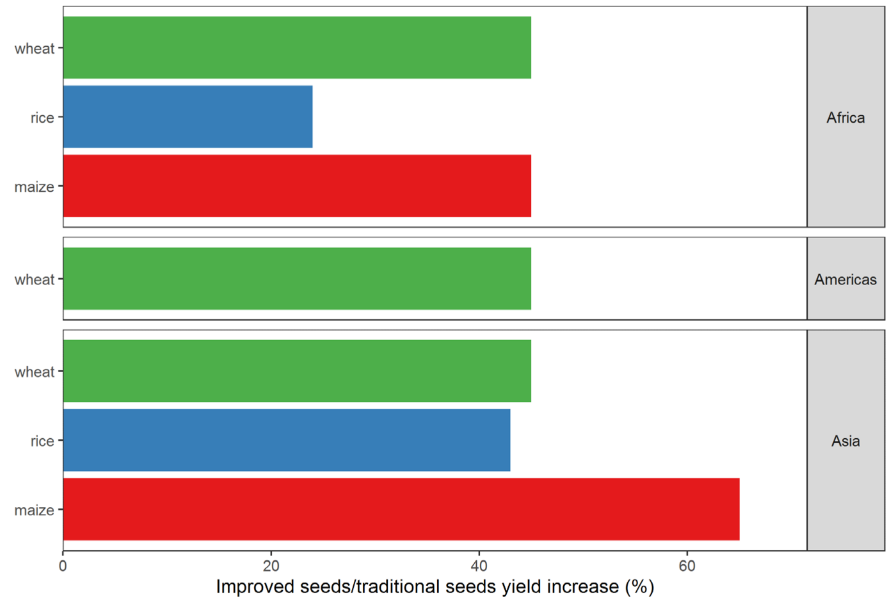

Figure 1.9 Cereal yield increase of improved seeds in comparison to traditional varieties
Source based on Table 22.3 in Evenson and Gollin (2003). Data reflect the period 1965/66 to 1994/95

Stage 4. Estimate the increase in crop production that can be attributed to the company

As the company revenue is already translated into a per ha measure, the additional crop production that can be attributed to the company can be easily calculated using the following equation:

$$\Delta P_i = SA_i \times \Delta Y_i$$

, where ΔP_i, measured in tonnes of crop i, is the additional production that can be attributed to a company, SA_i is the area (ha) of crop i on which company seeds are applied and ΔY_i is the additional yield as a consequence of using improved seeds in comparison to traditional seeds.

Stages 5 until 8. Convert estimated yield increase to additional food available

This is the same approach as used for the fertiliser analysis and data is readily available from FAOSTAT. This includes the correction for exports and other uses than food consumption (stage 5), the conversion to raw energy equivalent (stage 6), translation to people potentially being fed (stage 7) and the aggregation of results to estimate total impact on global level of food availability as a result of seed deliveries (stage 8).

1.4.3 Case study seeds

1. Estimate seeds deliveries in volume terms by country and crop
Figure 1.10 presents information on the regional activity of Vilmorin by crop from the website of the Access to Seeds Index. It shows that the company delivers improved maize seeds to two regions in Africa and improved rice seeds to Asia. The information for wheat is missing so we assume the company does not produce improved seeds for this crop. As the website only presents regional information we assume that Vilmorin delivers improved seeds to all countries in the respective regions for which FactSet Revere reports revenue. As described above the information from the Access to Seeds Index website is combined with other information to estimate the area that is supplied with improved seeds by country.

Field crops	Sales				Seed type		
	LA	WCA	ESA	SSEA	Hybrid	OPV	GM
Chickpea	●	●	●	●	●	●	
Maize			●	●	●		
Millets				●	●		
Rice, paddy				●	●		
Soybean			●			●	
Sunflower			●	●	●		
Wheat							

Figure 1.10 Vilmorin improved seeds by crop and region
Source: Access to Seeds Foundation (2019) Vilmorin country profile
Note: Access to Seeds reports information for Limagrain, which is the cooperative that owns Vilmorin. LA: Latin America; WCA: Western and Central Africa; ESA: Eastern and Southern Africa; SSEA: South and Southeast Asia

2. Estimate the yield response function by country and crop
This is not relevant.

3. Estimate the increase in yield that can be attributed to the adoption of improved seeds
We combined country level data on cereal yield from FAOSTAT with the data presented in Figure 1.9 to estimate ΔY_i per crop and continent.

4. Estimate the increase in crop production that can be attributed to the company
We combined the results from Step 1 and Step 3 to estimate the increase in cereal production that can be attributed to improved seeds deliveries by Vilmorin.

5. Correct for exports and other uses than food consumption
This is the same approach as used for the fertiliser analysis and data is readily available from FAOSTAT.

6. Convert to raw energy equivalent
This is the same approach as used for the fertiliser analysis and data is readily available from FAOSTAT. Figure 1.11 presents the results for Vilmorin by region and crop.

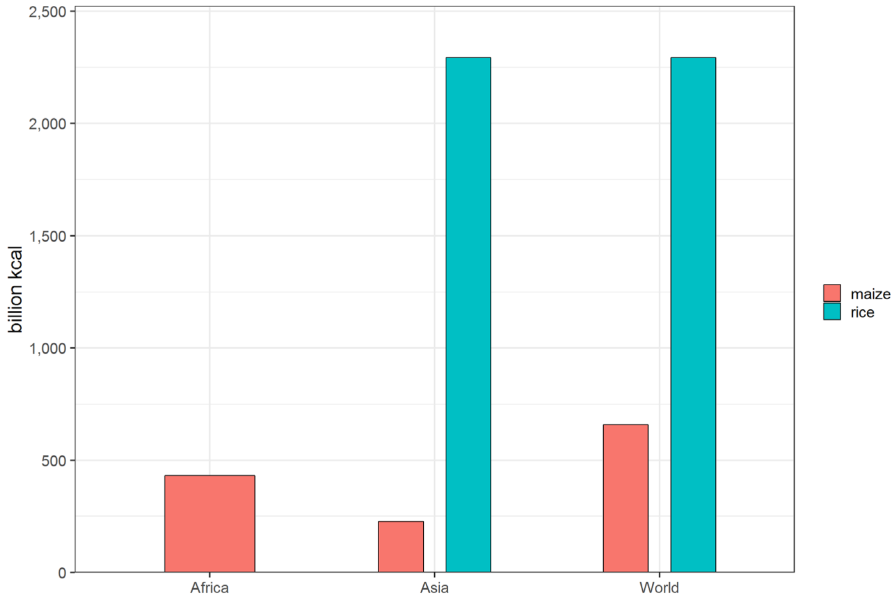

Figure 1.11 Additional food production in kcal attributed to Vilmorin
Note: Cereal production is the total of maize, rice and wheat production.

7. Express in people potentially being fed
This is the same approach as used for the fertiliser analysis and data is readily available from FAOSTAT. Figure 1.12 presents the results for Vilmorin by region and crop. In comparison with Yara, the number of people supplied with dietary needs by Vilmorin is much smaller (10m versus over 600m). A number of factors explain this result. (1) The total company revenue of Vilmorin is much smaller than that of Yara so a smaller impact is to be expected; (2) We use FAOSTAT shares to allocate the revenue to cereals. Possible this underestimates the allocation of revenue to cereals, resulting in an

underestimation of the deliveries of improved cereal seeds and, hence, food availability; and (3) the information from the Access to Seeds Index website is very rudimentary, perhaps resulting in biased estimates.

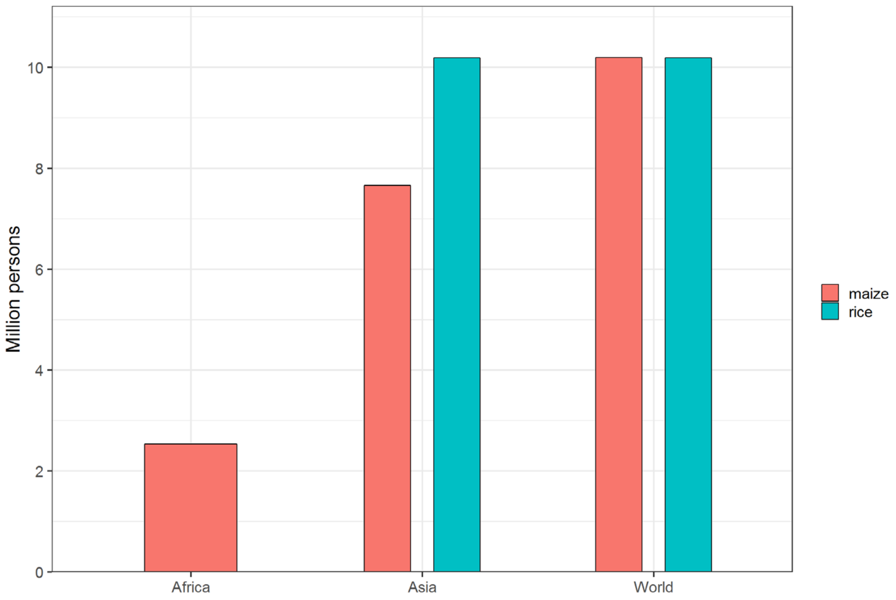

Figure 1.12 Number of people supplied with dietary needs attributed to Vilmorin
Note: As people consume a mix of maize, wheat and rice, aggregating number of people per cereal would result in double counting.

8. Aggregate results
The various impact indicators are estimated at the crop and country level and can be aggregated to represent broader regions (e.g. Figure 1.11 and 1.12) or total cereals.

1.4.4 Discussion

The assessment of seed companies appeared to be much more difficult than the one of fertiliser companies due to the lack of essential information needed in various steps of the methodology. Key problems include:

- Missing information on company revenue per crop and country. At the moment FactSet Revere only presents revenue data for a very broad category ('Other Agricultural Support Activities'). It is not clear if (1) the category relates to the sales of seeds, (2) if it covers improved seeds and (3) which crops are covered. In order to break down the revenue data in FactSet Revere, we used data from Access to Seeds Foundation (2019) and national area share per crop from FAOSTAT, which are both very imprecise and most likely involve making unrealistic assumptions.
- Outdated information on the difference in yield between improved and traditional seeds. The only comprehensive source of information we could find that presents global information on this topic is Evenson and Gollin (2003). The information provided only covers a limited number of crops for a limited set of regions. Moreover, the information on yields probably underestimates the actual yield difference between improved and traditional seeds as it refers to the period 2000, after which the yields of improved seeds have steadily increased.
- Lack of a proper baseline. To estimate the yield difference between improved and traditional seeds, we need to multiply the percentage values from Evenson and Gollin (2003) with actual yield information from FAOSTAT. As the actual yield is a function of the yield of traditional and improved seeds, which are both used in the same country, it will overestimate the actual yield difference. A proper baseline would be the yield of traditional seeds only, which is, however, not available.

For all of these reasons, we conclude that, with the present information, it is not possible to estimate the impact of seed companies on food availability. Only when the data gaps and problems listed above are addressed can a proper assessment be made.

References and websites

Access to Seeds Foundation (2019). 'Access to Seeds Index 2019.' https://www.accesstoseeds.org.

Balkovič, Juraj, Christian Folberth, and Rastislav Skalský (2018). 'IIASA EPIC for RESTORE+ Brazil.'

Berck, Peter, and Gloria Helfand (1990). 'Reconciling the von Liebig and Differentiable Crop Production Functions.' In *American Journal of Agricultural Economics* 72 (4): 985–96. doi:10.2307/1242630.

Brisson, Nadine, Philippe Gate, David Gouache, Gilles Charmet, François-Xavier Oury, and Frédéric Huard (2010). 'Why are wheat yields stagnating in Europe? A comprehensive data analysis for France.' In *Field Crops Research* 119 (1). Elsevier: 201–12. doi:10.1016/J.FCR.2010.07.012.

Cassidy, Emily S, Paul C West, James S Gerber, and Jonathan A Foley (2013). 'Redefining agricultural yields: from tonnes to people nourished per hectare.' In *Environmental Research Letters* 8 (3): 034015. doi:10.1088/1748-9326/8/3/034015

Evenson, R E, and D Gollin (2003). 'Assessing the impact of the green revolution, 1960 to 2000.' In *Science (New York, N.Y.)* 300 (5620): 758–62. doi:10.1126/science.1078710.

FAO (1996). *Rome declaration on world food security and world food summit plan of action*. Rome

FAO (2009). *Declaration of the World Summit on Food Security. World Food Summit 16-18 November 2009.* Rome

Fermont, A., & Benson, T. (2011). *Estimating Yield of Food Crops Grown by Smallholder Farmers. A Review in the Uganda Context.*

Fertilizers Europe (2018). 'Fertilizer data sheets.' European Fertilizers.

Fischer, R. (2015). 'Definitions and determination of crop yield, yield gaps, and of rates of change'. In *Field Crops Research*, Elsevier, 2015, 182, 9-18

IFA and IPNI (2017). *Assessment of Fertiliser Use by Crop at the Global Level: 2014-2014/15.* International Fertiliser Association (IFA); International Plant Nutrition Institute (IPNI)

IFDC (2018)*. 'AfricaFertiliser.org.' https://ifdc.org/africafertiliser-org/*

IIASA (2015). 'The Environmental Policy Integrated Model (EPIC).' http://www.iiasa.ac.at/web/home/research/researchPrograms/EcosystemsServicesandManagement/EPIC.en.html

Jauregui, M.A., and G.E. Sain (1992). *Continuous economic analysis of crop-response to fertiliser in on-farm research.* CIMMYT Economics Paper. Mexico, D.F.: CIMMYT.

Khoury C.K. and Jarvis A. (2014). The changing composition of the global diet: Implications for CGIAR research. CIAT Policy Brief No. 18. Centro Internacional de Agricultura Tropical. 6p.

Lobell, David B., Kenneth G. Cassman, and Christopher B. Field (2009). 'Crop Yield Gaps: Their Importance, Magnitudes, and Causes.' In *Annual Review of Environment and Resources* 34 (1). Annual Reviews: 179–204. doi:10.1146/annurev.environ.041008.093740

Morris, Michael, Valerie a Kelly, Ron J Kopicki, and Derek Byerlee (2007). *Fertiliser Use in African Agriculture*. Vol. 44. 01. doi:10.1596/978-0-8213-6880-0

Mueller, Nathaniel D., James S. Gerber, Matt Johnston, Deepak K. Ray, Navin Ramankutty, and Jonathan A. Foley (2012). 'Closing yield gaps through nutrient and water management.' In *Nature* 490 (7419). Nature Research: 254–57. doi:10.1038/nature11420

Pingali, Prabhu L. (2012). 'Green revolution: impacts, limits, and the path ahead.' *Proceedings of the National Academy of Sciences of the United States of America* 109 (31). National Academy of Sciences: 12302–8. doi:10.1073/pnas.0912953109.

Ray, D. K.; Mueller, N. D.; West, P. C. & Foley, J. A. (2013). *Yield trends are insufficient to double global crop production by 2050*. PloS one, Public Library of Science, 2013, 8, e66428

Reynolds, T. W., Anderson, C. L., Slakie, E., Gugerty, M. K., & Evans, D. J. (2015). *How Common Crop Yield Measures Misrepresent Productivity among Smallholder Farmers* (International Association of Agricultural Economists 2015 Conference, August 9-14, 2015, Milan, Italy).

Rosas, Juan Fransico (2012). *Fertiliser Use by Crop at the Country Level (1990–2010).* CARD Working Papers. Iowa State University.

Rovere, Roberto La, Tahirou Abdoulaye, Genti Kostandini, Zhe Guo, Wilfred Mwangi, John MacRobert, and John Dixon (2014). 'Economic, Production, and Poverty Impacts of Investing in Maize Tolerant to Drought in Africa: An Ex-Ante Assessment.' In *The Journal of Developing Areas* 48 (1): 199–225. doi:10.1353/jda.2014.0016.

Sheahan, Megan, and Christopher B. Barrett (2014). *Understanding the agricultural input landscape in Sub-Saharan Africa : recent plot, household, and community-level evidence*. World Bank Policy Research Working Papers 7014, no. August: 1–87. doi:10.1596/1813-9450-7014.

United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision, Key Findings and Advance Tables*. Working Paper No. ESA/P/WP/248.

Velde, Marijn van der, Linda See, Liangzhi You, Juraj Balkovi, Steffen Fritz, Nikolay Khabarov, Michael Obersteiner, and Stanley Wood (2013). *Affordable Nutrient Solutions for Improved Food Security as Evidenced by Crop Trials*. PLoS ONE 8 (4). doi:10.1371/journal.pone.0060075.

Verghese, K., Lewis, H., Lockrey, S., Williams, H. (2015). *Packaging's Role in Minimizing Food Loss and Waste Across the Supply Chain*. Packaging Technology and Science, 2015. DOI: 10.1002/pts.2127

Verghese K, Lewis H, Fitzpatrick L (eds) (2012). 'Designing for sustainability'. In *Packaging for Sustainability*. Springer. London

Verma, M. et al. (2018). *Food Loss: Practices, Causes and Indicators*. *Manuscript in preparation*

Vörösmarty, C.; Osuna, V. R.; Koehler, D.; Klop, P.; Spengler, J.; Buonocore, J.; Cak, A.; Tessler, Z.; Corsi, F.; Green, P. & others (2018). 'Scientifically assess impacts of sustainable investments'. *Science, American Association for the Advancement of Science,* **2018***, 359*, 523-525

World Bank (2008). *World Development Report 2008*. Washington, DC: The World Bank. doi:10.1596/978-0-8213-7233-3.

World Bank (2018). 'Pink sheet.' http://pubdocs.worldbank.org/en/451911543968504757/CMO-Pink-Sheet-December-2018.pdf.

World Resources Institute (2013). *Installment 2 of 'Creating a Sustainable Food Future' Reducing Food Loss and Waste*. Authors: Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R., Searchinger, T.

Yara (2017). 'Yara fertiliser industry handbook.'

Yara International ASA (2018). 'Annual Report 2017.'

https://postharvest.nri.org/scenarios/fruit-and-vegetables
http://www.agriinfo.in/default.aspx?page=topic&superid=2&topicid=2046
http://www.fao.org/docrep/T0073E/T0073E01.htm#Foreword
https://postharvest.nri.org/
http://www.tis-gdv.de/tis_e/ware/inhalt_gesamt.htm
https://www.theguardian.com/global-development/graphic/2012/oct/10/food-security-risk-index-map
https://www.iifiir.org
https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/ldc_list.pdf

Wageningen Economic Research
P.O. Box 29703
2502 LS The Hague
The Netherlands
T +31 (0)70 335 83 30
E communications.ssg@wur.nl
www.wur.eu/economic-research

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