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Analysis

The future of food — Scenarios and the effect on natural resource use in agriculture in 2050

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ABSTRACT

Do we have the natural resource base to feed future populations? This study gives a quantification of global land use, water use and fertilizer use for the year 2050, for a complete diet and four different futures. Agriculture will need to develop substantially to feed future populations. It is shown that there is a negative correlation between fertilizer use and land use, which makes the necessity of incorporating both in such assessments clear. Water use increases relative to total production and this is going to be a problem unless drastic measures are taken. The high wastage and high consumption of animal products in the developed regions are major contributors to the total global demand. Developing countries' aspirations to such practices are a major factor in increases in diet demand, as are population increases in those regions. In creating a more sustainable food system, a one-solution approach will not do and solutions should combine supply-side and demand-side options. Demand-side solutions should target wastage and animal product consumption. On the supply side, technological development and better feeding efficiency will increase yields. Feeding the future global population, which is necessary to increase living standards worldwide, will require a concerted effort.

1. Introduction

Resource use and food are popular topics in the current sustainability debate. Presently, a billion people are undernourished (UN, 2010) and the FAO estimates that food production needs to increase by 70% in 2050 to feed the global population (FAO, 2009). Population growth and also the change seen in diet composition related to increased welfare levels (e.g. Alexandratos et al., 2006; Gerbens-Leenes and Nonhebel, 2005; Grigg, 1995; Keyzer et al., 2005; Lotze-Campen et al., 2006; Rosegrant et al., 2001b; Smil, 2001; Vinnari and Tapio, 2009), with increased demand for animal products in developing countries, will increase future demand and resource utilization. Therefore, (future) use of natural resources in agriculture has been of critical interest to researchers, especially the use of water (e.g. Hoekstra and Chapagain, 2009; Hoekstra and Mekonnen, 2012; Van ham et al., 2013; WWF, 2012), land (e.g. Bruinsma, 2009; Fischer et al., 2002; Lotze-Campen et al., 2006; Wackernagel et al., 2002) and fertilizers (e.g. Galloway et al., 2007; Leach et al., 2012).

The aim of this study (Odegard, 2011) was to design four global 'What if…?' food scenarios for the year 2050 and to evaluate these quantitatively with respect to their use of the three main natural resources in agriculture: land, water and fertilizers. The question of whether we have the resource base to support the growing diet demand deserves special attention because of the substantial share agriculture has in our use of natural resources and the major impact of agriculture on our environment. Worldwide, agriculture is a main contributor to environmental problems such as climate change, deforestation, eutrophication of water bodies, salinization of soils and depletion of water resources (Foley et al., 2005; Nakicenovik et al., 2000; Tilman et al., 2001; Vitousek et al., 1997). Several (scenario) studies concerning agriculture and natural resources use have been done (e.g. Bruinsma, 2009; Ewert et al., 2005; Liu and Savenije, 2008; Rosegrant et al., 2001a; Tilman et al., 2001; Wirsenius et al., 2010). The aim of this scenario study, which has not, to the authors' knowledge been done before, is to give a quantification of global land use, water use and fertilizer use (N, P and K) in 2050 for a complete diet for a global population, for four different futures and compare it to resource use in the year 2005 and to the total resource base.

This study integrates three sub-studies:

1) Four food scenarios were designed, based on the IPCC SRES (Nakicenovik et al., 2000), quantified for the year 2050. The food scenarios include different trends related to population, economic development, policy, technological development and diet. The 4 IPCC regions also used here are: the OECD90 region (countries in the OECD in 1990), the REF region (the countries under reform such as the former Soviet Union), the ASIA region (Asia) and the ALM region (Africa, Latin America and the Middle East).
2) A methodology was developed – virtual resource content – with which the use of resources in agriculture was calculated. Factors for virtual land content, virtual water content and virtual fertilizer

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content (for N, P and K fertilizers separately) were established, which are all quantifications of required input per output.
3) A model was created, with which the scenarios were quantified with respect to their resource use. For a given diet demand the model calculates resource use per commodity group, per region and per scenario.

2. Material and Methods

2.1. Virtual Resource Content in Agriculture

To quantify resource use in agriculture in 2050 virtual resource content (VRC) factors were established (Odegard, 2011). The rationale for the VRC factors is based on the 'virtual water content' concept developed by Hoekstra and Chapagain (2008), which refers to the volume of freshwater needed to produce a product.

Virtual resource content factors were quantified to encompass the required input of land (ha kg^{-1}), water (m^3 kg^{-1}) and fertilizer (kg N/P/K kg^{-1}) per commodity group, per region and per scenario. When coupled to consumption projections, actual resource utilization can be calculated. This way, comparisons to e.g. total suitable land can be made, showing requirement vs. availability.

The VRC concept is a component of footprint methodology. A 'footprint' is a very useful indicator of resource use, which illustrates our environmental impact and can be expressed as a share of the earth's carrying capacity. Footprint methodology (e.g. the Ecological Footprint, the Carbon Footprint, the Water Footprint and the Nitrogen Footprint) takes a life cycle approach (Galli et al., 2012; Hoekstra, 2009; Leach et al., 2012; Wackernagel et al., 2002). Because the (global or regional) resource requirements calculated here refer to only part of the life cycle we chose not to call these "footprints".

2.1.1. Virtual Land Content (VLC)

Virtual land content (ha/tonne) is the inverse of yield. Scenario characteristics were assumed to influence future yields; it was assumed that technological development and economic development would result in a larger closure of the yield gap (the difference between the present and the maximum attainable yield (MAY) of a certain crop) in 2050. Total land use is compared to global estimates of land suitable for agriculture.

2.1.1.1. Virtual Land Content Data. Cereal yield projections were extracted from (De Fraiture and Wichelns, 2010). They assume that in an "optimistic scenario" 80% of the yield gap (difference between current yield and maximum attainable yield) is bridged, while in a "pessimistic" scenario 20% of the yield gap is bridged. Economic and technological development is high in the A1 and B1 scenarios, thus for these scenarios a bridging of 80% of the yield gap was chosen. Development in the A2 scenario is low, which makes bridging the yield gap with 20% reasonable. The yield gaps were calculated using the 2005 yield (according to FAOSTAT) and the maximum attainable yield (MAY) for high input levels under rainfed conditions. Such MAYs were defined by the FAO and the IIASA (Fischer et al., 2002). These MAYs are given for crops, not for commodity groups. To estimate MAYs for commodity groups in the different regions, the crop MAYs are averaged according to the proportion of production of the main crops in the respective commodity group in 2005, thereby assuming that the relative production stays the same. As the MAYs for these crops were determined for rainfed conditions, the upper boundary (representing the most productive cultivar) was chosen to compensate for the lower maximum yields under rainfed conditions. No MAY data was given for fruits and vegetables; maximum attainable yields were based on the average of the regional 'best practice'; the average of the highest three yields achieved regionally for the whole commodity group.

The extent of land available in the four regions was estimated using data from the Global Agro-Ecological Zones study by the FAO and the IIASA Fischer et al., 2002. It is assumed that similar yields can be attained on very suitable, suitable and moderately suitable areas which may lead to overestimation of attainable production quantities, because yields are most likely lower on less suitable areas.

2.1.2. Virtual Water Content (VWC)

The virtual water content factors are measured in m^3/tonne, and are based on the crop evapotranspiration rates calculated by Hoekstra and Chapagain (2008). Scenario characteristics were assumed to influence irrigation efficiency, which is included for cereals, the main irrigated crop group. Total water use is compared to the regional renewable water resources.

2.1.2.1. Virtual Water Content Data. Virtual water content is based on the assessment of crop evapotranspiration rates as assessed by Hoekstra and Chapagain (2008). These are based on current agricultural management practices. For the commodity groups roots and tubers, pulses, vegetables and fruits, the global average water appropriations (m^3/tonne) are assumed to be reasonable estimates for regional water use because of their relatively low contribution to total water consumption in agriculture. Adjustments were made to account for regional differences for commodity groups which account for large shares of the total global water use: the commodity groups cereals, oil crops and sugar crops. These adjustments on the regional level were based on the different production rates of five primary crops (i.e. rice, wheat, maize, soybeans and sugar cane) in the regions. It was assumed that relative production of these primary crops with respect to the total production of the commodity group will remain the same as it was in 2005. Irrigation is taken into account for cereals; irrigation inefficiencies raise water requirements for cereals to higher levels in the different scenarios. Cereal irrigation efficiency is based on assumptions made by De Fraiture and Wichelns (2010). Because pastures and such are generally not included in water use calculations they are excluded here.

2.1.3. Virtual Fertilizer Content (VFC)

Virtual fertilizer content is defined in fertilizer requirement per kg of crop output, for each of the three macro-fertilizers (N/P/K) separately. Because phosphate rock and potash are finite resources, predictions of years of use remaining (in 2050) are made if the management as defined for 2050 would continue, based on reserves of these resources. Requirements were based on crop responses to nutrients or nutrient removal by crops, converted to pure nutrient values (e.g. K instead of K_2O).

2.1.3.1. Virtual Fertilizer Content Data. Recommended fertilizer use varies with crop, region, local soil characteristics and management practices. Actual fertilizer use may, however, depend on factors that have nothing to do with proper agricultural management, e.g. subsidies may raise fertilizer use well above recommended values. On the other hand, the proper application methods and timing can significantly reduce use rates, without reducing yields, and can thus increase efficiency (Smil, 2001). Fertilizer use is reported in FAOSTAT, for N, P_2O_5 and K_2O fertilizers separately, but is not specified per commodity group or crop, and is therefore only valuable as a measure for comparison of aggregated values (FAOSTAT, 2011). The FAO does report fertilizer use per country per crop in their FERTISTAT database (FERTISTAT, 2007). This gives insight into regional differences in current fertilizer application rates, but does not give insight into requirements and nutrient removal. Furthermore, it does not give insight into input per output, as the yields of these crops to which the fertilizer applications apply are not reported.

In this scenario study the fertilizer requirements were based on fertilizer response (in the case of N for cereals), or nutrient removal or uptake by the crop (per tonne of product) as reported by the FAO (FAO, 1984, 2000, 2006). Data are given for different crops, not for cropgroups, so fertilizer requirements for the cropgroups were based on differences in the types of crops grown, and the share of the major crops in the