National Institute for Public Health
and the Environment
*Ministry of Health, Welfare and Sport*

# A spatially explicit LCA-indicator for P-depletion in agricultural soils

RIVM Letter report 2015-0198
A. Hollander | M. Zijp | H. van Wijnen

National Institute for Public Health and the Environment
*Ministry of Health, Welfare and Sport*

# A spatially explicit LCA-indicator for P-depletion in agricultural soils

RIVM Letter report 2015-0198

A. Hollander | M. Zijp | H. van Wijnen

# Colophon



A. Hollander (author), RIVM/DMG
M. Zijp (author), RIVM/DMG
H. van Wijnen (author), RIVM/DMG

Contact:
Anne Hollander
DMG
anne.hollander@rivm.nl

This investigation has been performed by order and for the account of Ministry of Infrastructure and the Environment, within the framework of Project Duurzaam consumentengedrag

This is a publication of:
**National Institute for Public Health and the Environment**
P.O. Box 1 | 3720 BA Bilthoven
The Netherlands
www.rivm.nl/en

# Publiekssamenvatting


## Een ruimtelijk expliciete LCA-indicator voor fosforverlies uit landbouwbodems

De kwaliteit van de bodem verslechtert door bodemerosie, verzilting, verschraling en verwoestijning. Dit is een steeds groter probleem in landbouwgebieden, vooral in Afrika, delen van Zuid-Amerika en Zuidoost Azië. De schade aan het milieu die door bodemdegradatie ontstaat, wordt echter nog niet meegenomen in de huidige zogeheten levenscyclusanalysemethoden (LCA). Met deze methoden wordt de invloed van producten en menselijke activiteiten op het milieu in kaart gebracht.

Een van de oorzaken van bodemdegradatie is dat moderne landbouwmethoden steeds meer voedingsstoffen uit de bodem onttrekken. Daarnaast kan de bodem door slecht beheer dichtslaan of wegspoelen en kunnen bodems uiteindelijk ongeschikt worden voor landbouw. Het RIVM heeft een eerste concept ontwikkeld voor een indicator waarmee deze verschraling van de bodem (nutriëntenverlies) kan worden weergegeven. De indicator kan in de toekomst dienen als een van de bouwstenen voor een integrale bodemkwaliteitsindicator in LCA.

In deze studie ligt de nadruk op het verlies van fosfor bij de teelt van acht gewassen (cassave, rijst, banaan, mais, soja, suikerriet, tarwe en oliegewassen). Fosfor is, naast stikstof en kalium, een belangrijke voedingsstof voor landbouwgewassen. Er is voor fosfor gekozen omdat het gedrag ervan in bodems beter is te beschrijven dan dat van stikstof en er meer gegevens over beschikbaar zijn dan over kalium.

Een methode is ontwikkeld waarmee kan worden berekend hoeveel fosfor aan de bodem is onttrokken na de oogst van een gewas. Dit geeft een indicatie van de mate waarin fosforverlies uit de bodem een probleem kan zijn. Per gewas en per land is aangegeven of de teelt de balans aan voedingsstoffen in de bodem mogelijk verstoort. De maat voor fosforverlies uit de bodem die zo is verkregen, geeft een eerste indicatie van de ernst van de bodemverschraling op een specifieke plaats of in een specifiek land.


Kernwoorden: Bodemdegradatie, Levenscyclusanalyse, LCA, fosfor, bodemnutriënten

# Synopsis


## A spatially explicit LCA-indicator for P-depletion in agricultural soils

Soil quality decreases due to soil erosion, salinization, depletion and desertification. This is an increasing problem in agricultural areas, particularly in Africa, parts of South America and South-East Asia. The damage to the environment caused by soil degradation is not incorporated in the current life cycle assessment methodologies (LCA). Environmental life cycle assessment (LCA) is a method for determining the influence of products and human activities on the environment.

One of the causes of soil degradation is that modern agricultural techniques remove an increasing amount of nutrients from the soil. RIVM developed a first concept of an indicator with which the depletion (nutrient loss) from the soil can be identified. This indicator may serve as one of the building bricks for an integrated soil quality indicator for LCA in future.

In this study, the emphasis is on the loss of phosphorus with the harvesting of eight crops (cassava, rice, banana, maize, soy, sugar cane, wheat and oil crops). Phosphorus is, next to nitrogen and potassium, an important nutrient for agricultural crops. We chose phosphorus, since its behavior is soils is easier to understand than that of nitrogen and more data are available than for potassium.

A method was developed describing the loss of phosphorus from soil by harvesting crops. This indicates whether phosphorus depletion might be an environmental problem at a specific location. Per crop and per country, a yes/no signature is provided, indicating a potential disturbance of the phosphorus balance in the soil. This indicator is a first measure of the severity of soil depletion on a specific location or country.


Keywords: Soil depletion, Life cycle analysis, LCA, phosphorus, soil nutrients

# Contents

## Summary

Soil degradation is an increasing problem in agricultural areas, particularly in Africa, parts of Southern America and Southeastern Asia (Smaling et al., 1993; Stoorvogel et al., 1993). Modern agricultural methods have removed increasing amounts of nutrients from the soil. Degradation of soil includes erosion, salinization, nutrient depletion, and desertification. Continued loss of arable land will eventually jeopardize our ability to feed the world population.

Environmental life cycle assessment (LCA) is a method for determining the influence of products and human activities on the environment. To this end, specific calculation models have been developed. In LCA, the life cycle of a product or activity is considered, from the mining of resources via production and use up to the waste (treatment) stage. The result of a LCA-study (the ‘impact assessment – LCIA’) is an environmental profile: a score list with environmental impacts. From the environmental profile, one can determine which environmental impacts are important in a specific life cycle.

As indicated above, impacts of land-use on soil quality are multifold. Although the issue of soil degradation is identified more and more as a severe problem, the assessment of the impact of soil degradation is not incorporated yet in the standard LCA-methods. Deriving such a method for the world would be very extensive or even impossible due to lack of data. Garrigues et al. (2012), proposed to separately derive impact indicators for all relevant soil processes and then work on aggregating these to one new impact.

In this study, we aim to develop a soil degradation indicator for LCA for the aspect of phosphorus depletion, which might serve as a building brick for such an ‘aggregated soil degradation’ impact category. We decided to focus the indicator of nutrient loss by agriculture to the area of LCA-work by defining characterization factors (CFs) on phosphorus (P) losses.

Ideally, to estimate the influence of harvesting crops on phosphorus (P) depletion, at first one should have insight in the soil P-budgets. If all inputs and outputs of P were known on a global scale, this would enable developing a ‘state’ indicator for nutrient depletion (indicating the P-deficit in soils) at this scale. Unfortunately, data on soil P-budgets worldwide are not available, neither are exact figures on fertilizer and manure application, P-availability and P-erosion. In absence of these data, we chose to develop a so-called ‘pressure’ indicator: an indicator that indicates the loss of soil nutrients by the amount of P removed from soil by harvesting crops.

The spatial information on P-removal per crop type was combined by the spatial coverage of either subsistence farming or low input farming. A stepwise approach was followed:

1. It was investigated on a global scale where rain fed, low input agriculture and/or subsistence agriculture is being practiced;

2. For nine types of common crops, it was identified where in the world they are grown. The selected crops were maize, soybean, rice, sugar cane, wheat, cassava, oil crops and banana.
3. A classified map was developed per crop type with classes for subsistence farming areas and low input rain fed farming areas on a grid basis (5 by 5 minutes).
4. The yield of a crop was estimated based on existing data, per crop type and per grid (for the year 2000 in kg/yr). A distinction was made between the areas with subsistence farming and low input rain fed farming.
5. For each of the crops, the average P-content per kg crop was estimated.
6. By multiplying the amount of yield per year of a specific crop per grid cell ($kg_{yield}$/yr) with the amount of P removed per kg crop, the amount of P removed per grid cell per year was calculated ($kg_p$/yr). Then the amount of P removed per grid cell was divided by the harvested area in that grid cell to derive the amount of P removed per ha:
   P-depletion ($kg_p$/ha/yr) = P-amount per kg crop ($kg_p/kg_{yield}$)* Yield of crop ($kg_{yield}$/yr) / harvested area per grid (ha).

The data were derived on a grid level with a resolution of 5 x 5 minutes. However, for performing studies on soil depletion impact of food products, often only the country in which a product was produced is known and not the exact grid. Therefore, the data on grid level were also aggregated to country level to be able to do estimations based on country information of food products.

In this way, a quantitative measure for the P-depletion was derived, which gives an indication of the severity of the problem. However, such a value alone is for not well-informed people difficult to interpret. To overcome this problem, and to make the results of the LCA for soil nutrient depletion more interpretable, also a table was made that indicates per country and per crop type if soil nutrient depletion is considered an issue yes or no.

# 1 Introduction

Soil degradation is an increasing problem in agricultural areas, particularly in Africa, parts of Southern America and Southeastern Asia (Smaling et al., 1993; Stoorvogel et al., 1993). Modern agricultural methods have removed increasing amounts of nutrients from the soil. Degradation of soil includes erosion, salinization, nutrient depletion, and desertification. The rate of degradation has increased dramatically with growth in human populations and technology. Continued loss of arable land will eventually jeopardize our ability to feed the world population.

The first global survey of soil degradation was carried out by the United Nations in 1988-1991. This survey, known as GLASOD - for Global Survey of Human-Induced Soil Degradation -, has shown significant problems in virtually all parts of the world. It has shown a steady decline in the 30 years from 1961 to 1991, amounting to a decrease of healthy soils between 20 and 30%, of which African croplands per capita have declined at the greatest rate. On the global basis, the soil degradation is caused by different kinds of impacts like overgrazing (35%), agricultural activities (28%), deforestation (30%), overexploitation of land to produce fuelwood (7%), and industrialization (4%; http://plasma-nrg.com/about-us/soil-degradation.html).

**Life cycle analysis (LCA)**
Environmental life cycle assessment (LCA) is a method for determining the influence of products and human activities on the environment. To this end, specific calculation models have been developed. In LCA, the life cycle of a product or activity is considered, from the mining of resources via production and use up to the waste (treatment) stage. In other words: from cradle to grave.

The result of a LCA-study (the 'impact assessment – LCIA') is an environmental profile: a score list with environmental impacts. From the environmental profile, one can determine which environmental impacts are important in a specific life cycle. This may result in management of those specific impacts. Another use of LCIA is assessment on forehand: "is it expected that a proposed change in e.g. a production process will have a positive effect on specific environmental impacts?"
Different methods exist for performing an impact assessment. In all methods, (a part of) the following environmental aspects are considered: greenhouse gas emissions, human toxicity, ecotoxicity, ozone depletion, eutrophication, acidification, land use, water use, use of fossil fuels and use of mineral resources. For specific LCA-studies, e.g. those of food products, however, other environmental effects may also be relevant, which are currently not covered in the LCIA impact assessment methodologies. One of those is soil degradation, which is particularly interesting for life cycle assessment of agricultural products.

**Soil degradation in LCA**
As indicated above, impacts of land-use on soil quality are multifold and they depend largely on site specific and very (spatial and temporal) heterogeneous soil characteristics and their interactions with human

activities (Garrigues et al., 2012). Although the issue of soil degradation is identified more and more as a severe problem, the assessment of the impact of soil degradation is not incorporated yet in the standard life cycle analysis methods. However, some first proposals to include soil quality into LCA can be found in literature. Ranging from single indicator (Soil Organic Matter; SOM; Mila i Canals et al., 2007) to a rather comprehensive indicator (SALCA-SQ; Oberholzer et al., 2012). Limitation of the first is that this indicator covers only one impact type on soil quality. Limitation of the second is that it is only applicable on the area the methodology is trained on (in this case Switzerland). Deriving such a method for the world (which is needed when analyzing an activity with worldwide interactions and consequences, like in our case food consumption) would be very extensive or even impossible due to lack of data. Garrigues et al. (2012), propose to separately derive impact indicators for all relevant soil processes and then work on aggregating these to one new impact category at midpoint level.

In this study, we aim to develop a soil degradation indicator for LCA for the aspect of nutrient depletion, which might serve as building brick for such an 'aggregated soil degradation' impact category.

The goal of trying to include soil nutrient depletion in LCAs (e.g. on food consumption) is to raise awareness of this impact on ecosystem health. The hypothesis is that this impact is of comparable importance to the well-known and analyzed set of impacts. The indicator should ideally be easily applicable to a wide range of products from a wide range of production sites and preferably designed in such a way that they allow meaningful comparison to other types of impacts. This implies that spatially explicit characterization factors are needed.

# 2 Towards an LCA-indicator for nutrient depletion

In recent years, more and more attention is being paid to the sustainability of food products we consume. For example, RIVM currently develops a monitoring system and food database to estimate the sustainability of the Dutch food consumption. Previous LCAs on food (e.g. Blonk Consultants, 2013) mainly focussed on three impact categories: emissions of greenhouse gasses, fossil fuel demand and land use.

The question rose whether these three impact categories would be sufficient to make reliable estimations of all relevant aspects concerning the sustainability of food products. This question was discussed during a workshop with experts from universities (WUR, UU), consultants (including Blonk Consultants), research institutes, policy makers and a food company in November 2013 at RIVM. The participants advised to consider the following indicators:

1. Land use
2. Water use or scarcity
3. Climate change
4. Eutrophication
5. Acidification
6. Toxicity
7. Depletion of soil nutrients

For the first six indicators, LCA impact assessment methods already exist. The latter indicator on soil depletion was however not yet developed and used in LCA, but was unanimous mentioned by the experts as a necessity. Depletion of soil includes the processes of soil erosion, salinization, nutrient depletion, and desertification. Since the physical processes associated with these four aspects, it was already proposed by Garrigues et al. (2012) to separately derive impact indicators for all relevant soil processes and then work on aggregating these to one new impact category at midpoint level. In the current study, we chose to focus on the aspect of nutrient depletion, which may serve as one of the building bricks for an integral soil quality indicator in the future.

We decided to focus on an indicator for nutrient depletion by agriculture to the area of LCA-work by defining characterization factors (CFs) on phosphorus (P) losses. We chose P as a nutrient indicator, since the nitrogen cycle (N) is much more complicated and data are lacking on a worldwide spatially explicit base. For K, there is also very little information available. Our assumption is that if P is problematic, N and K will be in most cases too, vice versa (internal communication RIVM; Bouwman et al., 2011).

The conceptual model for calculation of the P-balance of agricultural soils is given schematically in Figure 1. The model starts with a soil with an actual P-content. When performing agricultural practices, P is both added by the application of manure and fertilizer, and removed by harvest (P in the plants), erosion and runoff. P can further be bound to the soil, which makes it unavailable for uptake by plants, which is counted as a loss also. All inflows of P to and outflows from a soil together indicate whether there is a balance (in = out, which is the ideal situation), or either a net P-loss (depletion) or a net P-gain, which may lead to P-leaching to surface water, and thus eutrophication. The issue of eutrophication is already covered as midpoint indicator in LCA, however P-depletion is not.

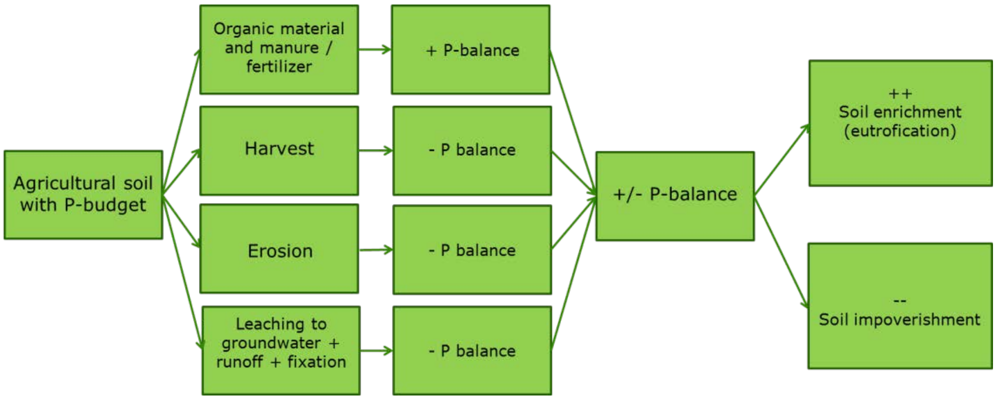



*Figure 1. Conceptual model for calculation of the P-balance of agricultural soils.*

Thus, ideally, to estimate the influence of harvesting crops on nutrient depletion following the conceptual model of Figure 1, at first one should have insight in the soil P-budgets worldwide. If also all inputs and outputs were known spatially, this would enable developing a ‘state’ indicator for nutrient depletion (indicating the P-deficit in soils). Unfortunately, data on soil P-budgets worldwide are not available, neither are exact figures on fertilizer and manure application, fixation and P-erosion.

In absence of these data, we chose to develop a so-called ‘pressure’ indicator: an indicator that indicates the loss of soil nutrients by the amount of P removed from soil by agriculture. The information on P-removal was combined by knowledge on agricultural areas where either subsistence farming or low input farming occurs. Both types of production refer to rain fed crop production which uses traditional varieties and mainly manual labor without (or with little) application of nutrients or chemicals for pest and disease control (www.mapspam.info). Thus the assumption is that P-depletion is problematic in these areas, because taking P out of the local system, by exporting products, depletes the available P-stock and there is hardly any replenishment. We know that this is not the ideal way to define P-depletion, but based on the existing information we currently consider it a reliable approach (see Discussion).

Based on the information on the locations of subsistence agriculture and low input agricultural areas in the world, combined with crop specific production data, it could be identified where in the world probably net depletion of P in soils occurs. To quantify the P-depletion, next the amounts of P removed per 5 x 5 minutes grid and per crop were estimated based on production data and crop specific P-contents. The followed methodology will be elaborated on in Chapter 3.

# 3 Method and data collection

First, it was investigated where in the world rain fed, low input agriculture and subsistence agriculture is being practiced. The information of areas in the world with rain fed, low-input farming or subsistence farming agriculture was derived from the Mapspam database, which follows the FAO/IIASA GAEZ project (Nachtergaele et al., 2012).

Second, for nine types of common crops it was identified where in the world they are grown. The selected crops were corn (maize), soybean, sunflower, rice, sugar cane, wheat, cassava, rapeseed and banana (Table 1), since these cover a large part of the agricultural areas in Africa and South America, and since data on production and P-contents were available for these crops.

From the Mapspam data, a classified map was developed per crop type with classes for subsistence farming areas and low input rain fed farming areas on a grid basis (5 by 5 minutes).

The production of a crop was identified per crop type and per grid (for the year 2000). This information was obtained also from Mapspam (www.mapspam.info). A distinction was made between the areas with subsistence farming and low input rain fed farming. Only for sunflower and rapeseed, no specific yield data were available; these were grouped into 'oil crops'.

Of each of the available crops, the average P-content per kg crop was estimated. The main source of information for this was USDA "Crop nutrient database" (2015), but also other sources where used in order to check the reliability of the data (see Table 1). The average P-contents and reported minimum and maximum values in crops used are given in Table 1. For the oil crops, the P-content of rapeseed was used as an estimate.

By multiplying the amount of production per year of a specific crop (kg/yr) with the amount of P removed per kg crop, the amount of P removed per year was calculated on a grid basis:
P-depletion ($kg_p$/yr) = P-amount per kg crop ($kg_p/kg_{yield}$)* Production of crop ($kg_{yield}$/yr). The total P-depletion per gridcel ($kg_p$/yr) was divided by the harvested area in each gridcel (ha). This resulted in the amount of P depletion per harvested area ($kg_p$/ha/yr). If, in a year, multiple harvests occur on a location, the harvested areas were summed up in order to derive the total area per gridcel that is harvested each year.

*Table 1: average, minimum and maximum P-content of crops found in literature.*

| | P removed | P removed | P removed |
|---|---|---|---|
| | kg P/tonne yield | kg P/tonne yield | kg P/tonne yield |
| | average | min | max |
| Corn[1,5] | 0.72 | 0.48 | 1.03 |
| Soy bean[1,5] | 5.97 | 5.89 | 6.04 |
| Sunflower[1,5] | 7.03 | 5.74 | 9.54 |
| Rice[1] | 2.54 | 2.54 | 2.54 |
| Sugar cane[1] | 0.56 | 0.56 | 0.56 |
| Wheat[1,5] | 3.37 | 2.57 | 3.85 |
| Cassava[2,3] | 0.77 | 0.52 | 1.00 |
| Rape seed[4] | 3.20 | 2.88 | 3.51 |
| Banana[1] | 0.20 | 0.20 | 0.20 |

Reference:

[1] USDA Crop nutrient database

[2] IFAD/FAO 2004, [3] Sarkiyayi and Agar, 2010

[4] Yang et al., 2010, [5] Ketterings and Czymmek, 2007

The data were derived on a grid level with a resolution of 5 x 5 minutes. However, for performing studies on soil depletion impact of food products, often only the country in which a product was produced is known and not the exact grid. Therefore, the data on grid level were also aggregated to country level to be able to do estimations based on country information of food products. To this end, the average of the amount of P removed per hectare in the grids covered by a country was taken.

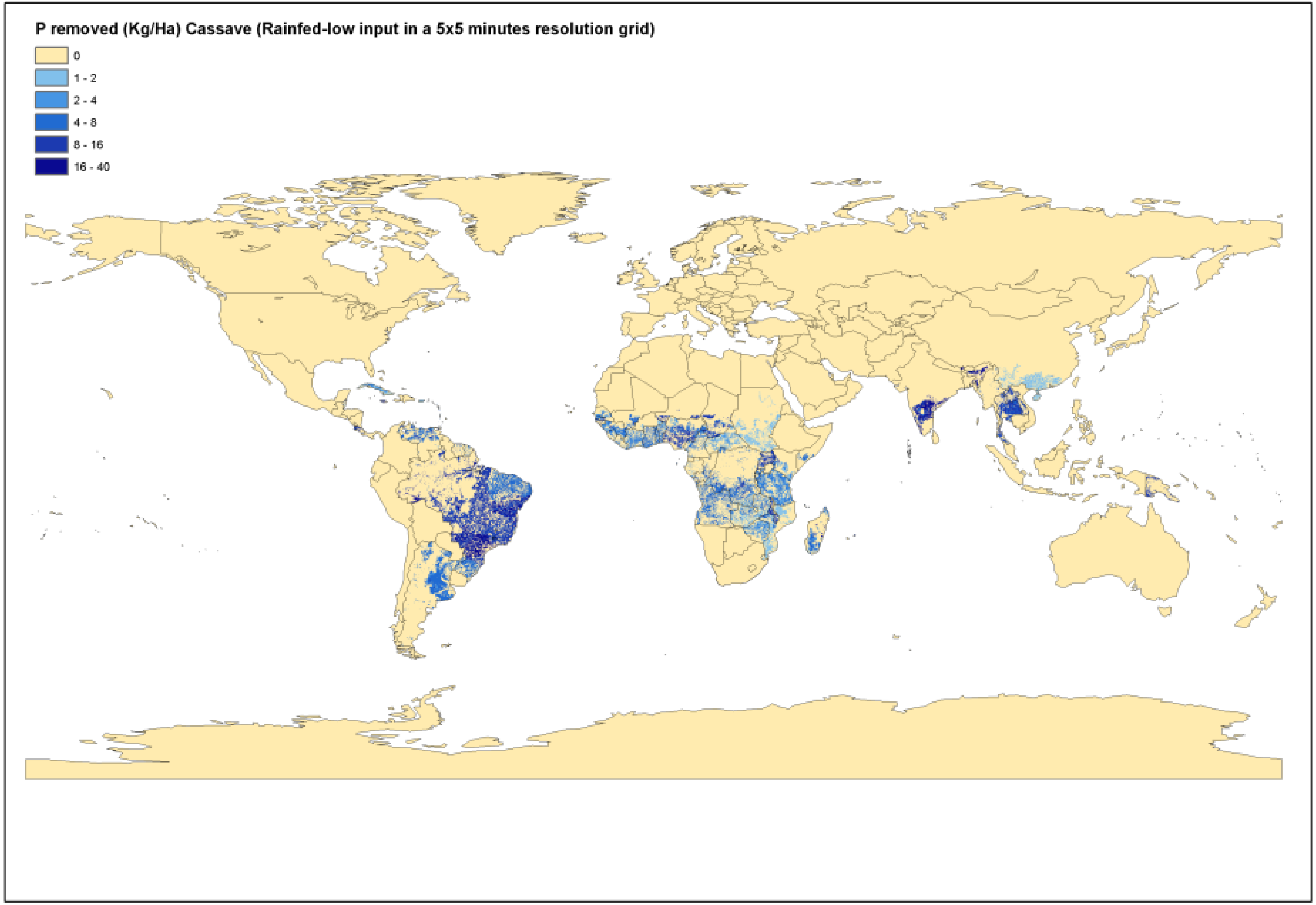
In this way, a quantitative measure for the P-depletion was derived, which gives an indication of the severity of the problem. However, such a value alone is difficult to interpret for not well-informed people. In LCA impact assessment methods, like ReCiPe (Goedkoop et al., 2009), several environmental impacts can be weighted to get an indication on the relevance of the different types of environmental damage. Soil depletion is not incorporated yet in such impact assessment weighting methods, so a good comparison and weighting with other environmental impacts is not yet possible.

To overcome this problem, and to make the results of the LCA for soil nutrient depletion more interpretable, a table was made that indicates per country and per crop type if soil nutrient depletion is considered a potential issue yes or not.

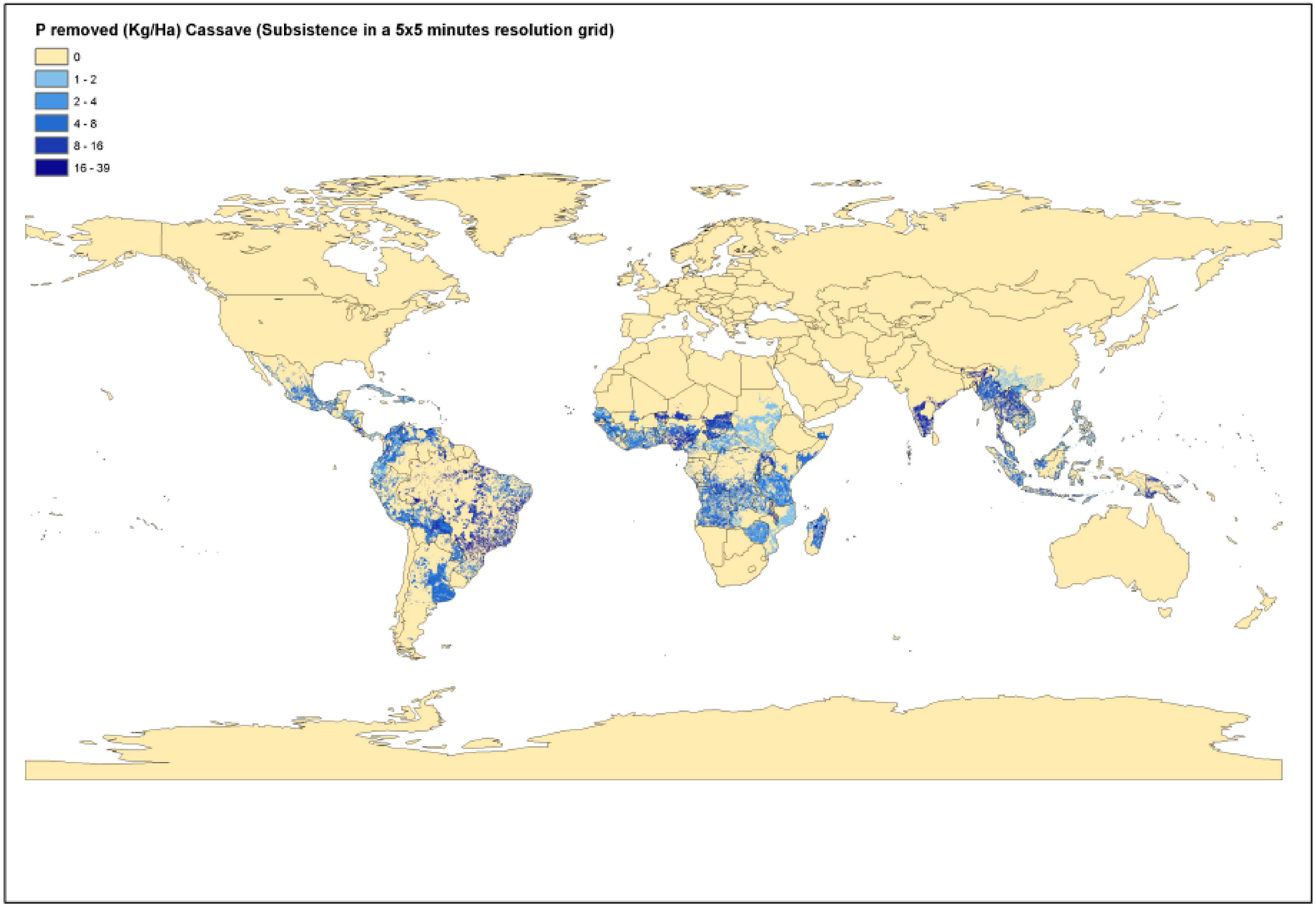
# 4 Results

The amount of P removed per hectare per year was calculated on a grid basis (5’ x 5’), both for areas with rain fed, low input farming and for areas with subsistence farming.

An example of the output of this calculation on a grid level for cassava is given in Figure 2. Figure 2a indicates the amount of P removed per hectare in rain fed low input farming areas, whereas Figure 2b indicates the amount of P removed per hectare in subsistence farming areas. Similar Figures were made for the other seven studied crops; these are given in Appendix 1


P removed (Kg/Ha) Cassave (Rainfed-low input in a 5x5 minutes resolution grid)
0
1 - 2
2 - 4
4 - 8
8 - 16
16 - 40

a)




b)

*Figure 2: Amount of P removed per hectare per year with the yield of cassava. 2a: P-removal in rain fed low input farming areas; 2b: P-removal in subsistence farming areas. The yellow fields indicate that the specified crop is not grown in that area.*

Data on grid level were also aggregated to country level. Tables with P-removal per crop and per country in low input/subsistence farming areas are available on request via anne.hollander@rivm.nl.

A table with the indication whether nutrient depletion might be an issue in a specific country for a specific crop type, is given in Table 2. Since not all countries in the world are listed, but only those in which low input/subsistence farming occurs, the white fields mostly indicate that a specific crop is not grown in that country.

Countries in which less than 1% of the total country area was indicated as 'potential soil depletion' area were left out of the table, since we considered it not reliable to indicate all yield of a country with a 'red flag' if such a low percentage is assigned to a country. Moreover, little errors in the GIS-calculations, e.g. country borders that not exactly match with grid cell borders, can cause little errors in the outcomes that we filtered out by removing the < 1% countries.

*Table 2. Indication per country and crop type whether nutrient depletion might be an issue.*

| Country name | Cassava | Banana | Maize | Oil crops | Rice | Soybean | Sugarcane | Wheat |
|---|---|---|---|---|---|---|---|---|
| AFGHANISTAN | | | X | X | X | X | X | X |
| ALBANIA | | | X | X | | X | | X |
| ALGERIA | | | X | X | X | | | X |
| ANGOLA | X | X | | X | X | X | | X |
| ANTIGUA AND BARBUDA | X | X | X | | | | | |
| ARGENTINA | X | X | X | X | X | X | X | X |
| ARMENIA | | | X | | | | | X |
| AUSTRALIA | | X | X | X | X | X | X | X |
| AZERBAIJAN | | | X | X | | X | | X |
| BANGLADESH | X | X | X | X | X | X | X | X |
| BARBADOS | X | X | X | X | | | X | |
| BELARUS | | | | X | | | | X |
| BELIZE | X | X | X | X | X | X | X | |
| BENIN | X | X | X | X | X | X | | |
| BHUTAN | X | X | X | X | X | X | X | X |
| BOLIVIA | X | X | X | X | X | X | X | X |
| BOTSWANA | X | X | X | X | | X | | X |
| BRAZIL | X | X | X | X | X | X | X | X |
| BRUNEI DARUSSALAM | X | X | | X | X | | | |
| BULGARIA | | | X | X | X | | | X |
| BURKINA FASO | X | X | X | X | X | X | X | X |
| BURUNDI | X | X | X | X | X | X | | X |
| COTE D'IVOIRE | X | X | X | X | X | X | X | |
| CAMBODIA | X | X | X | X | X | X | X | |
| CAMEROON | X | X | X | X | X | X | X | X |
| CENTRAL AFRICAN REPUBLIC | X | X | X | X | X | | X | |
| CHAD | X | X | X | X | X | | | X |
| CHILE | X | | X | X | | | | |
| CHINA | X | X | X | X | X | X | X | X |
| COLOMBIA | X | X | X | X | X | X | | X |
| COMOROS | X | X | X | X | X | | | |
| CONGO | X | X | X | X | X | X | X | X |
| CONGO THE DEMOCRATIC REPUBLIC OF THE | X | X | X | X | X | X | X | |
| COSTA RICA | X | X | X | | X | | X | |
| CUBA | X | X | X | X | | | X | |
| CYPRUS | | X | | X | | | | X |
| DJIBOUTI | | | X | | | | | |
| DOMINICA | X | X | X | X | | | X | |
| DOMINICAN REPUBLIC | X | X | X | | | | X | |
| ECUADOR | X | X | X | X | X | X | X | X |
| EGYPT | | | X | | | | | |
| EL SALVADOR | X | X | X | X | X | X | X | X |
| EQUATORIAL GUINEA | X | X | | X | | | | |
| ERITREA | | | X | X | | X | | X |
| ETHIOPIA | X | X | X | X | | X | | X |
| FRANCE | | | X | X | | | | X |
| GABON | X | X | X | X | X | X | X | |
| GAMBIA | X | | X | X | X | | | |
| GEORGIA | | | X | X | | X | | X |
| GHANA | X | X | X | X | X | X | X | |

| Country name | Cassava | Banana | Maize | Oil crops | Rice | Soybean | Sugarcane | Wheat |
|---|---|---|---|---|---|---|---|---|
| GREECE | | | ■ | ■ | | | | ■ |
| GRENADA | ■ | ■ | ■ | ■ | | | ■ | |
| GUATEMALA | ■ | ■ | | ■ | ■ | ■ | ■ | ■ |
| GUINEA | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| GUINEA-BISSAU | ■ | ■ | ■ | ■ | ■ | | ■ | |
| GUYANA | ■ | ■ | ■ | ■ | ■ | ■ | | |
| HAITI | ■ | ■ | ■ | ■ | ■ | | ■ | |
| HALA'IB TRIANGLE (disputed territory) | | | ■ | | | | | |
| HONDURAS | ■ | ■ | ■ | ■ | ■ | ■ | | ■ |
| HUNGARY | | | ■ | ■ | | | | ■ |
| INDIA | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| INDONESIA | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| IRAN ISLAMIC REPUBLIC OF | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| IRAQ | | | ■ | ■ | ■ | ■ | ■ | ■ |
| ITALY | | | ■ | | | | | |
| JAMAICA | ■ | ■ | ■ | ■ | ■ | | ■ | |
| JORDAN | | | ■ | | | | | ■ |
| KAZAKHSTAN | | | ■ | ■ | ■ | ■ | | ■ |
| KENYA | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| KOREA DEMOCRATIC PEOPLE'S REPUBLIC OF | | | ■ | ■ | ■ | ■ | | |
| KUWAIT | | | ■ | | | | | ■ |
| KYRGYZSTAN | | | | ■ | | | | ■ |
| LAO PEOPLE'S DEMOCRATIC REPUBLIC | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| LEBANON | | ■ | ■ | ■ | | | ■ | ■ |
| LESOTHO | | | ■ | ■ | | ■ | | ■ |
| LIBERIA | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| LIBYAN ARAB JAMAHIRIYA | | | ■ | | | | | ■ |
| LITHUANIA | | | | ■ | | | | ■ |
| MACEDONIA | | | ■ | ■ | ■ | | | ■ |
| MADAGASCAR | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| MALAWI | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| MALAYSIA | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| MALI | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| MALTA | | | | ■ | | | | ■ |
| MAURITANIA | ■ | | ■ | ■ | | | | ■ |
| MAURITIUS | ■ | ■ | ■ | ■ | | | ■ | |
| MEXICO | ■ | ■ | ■ | | ■ | | ■ | ■ |
| MONGOLIA | | | | ■ | | | | ■ |
| MOROCCO | | ■ | ■ | ■ | | ■ | | ■ |
| MOZAMBIQUE | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| MYANMAR | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| NAMIBIA | | | | ■ | | | ■ | ■ |
| NEPAL | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| NEW ZEALAND | | | ■ | | | | | ■ |
| NICARAGUA | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| NIGER | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| NIGERIA | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| OMAN | | ■ | | | | | | ■ |
| PAKISTAN | | | ■ | ■ | ■ | | ■ | ■ |
| PALESTINIAN AUTHORITY | | | | ■ | | | | ■ |
| PANAMA | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |

| Country name | Cassava | Banana | Maize | Oil crops | Rice | Soybean | Sugarcane | Wheat |
|---|---|---|---|---|---|---|---|---|
| PAPUA NEW GUINEA | ■ | ■ | ■ | ■ | ■ | | ■ | |
| PARAGUAY | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| PERU | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| PHILIPPINES | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| POLAND | | | ■ | ■ | | | | ■ |
| PORTUGAL | | ■ | | | | | ■ | |
| PUERTO RICO | ■ | ■ | ■ | ■ | | ■ | ■ | |
| REPUBLIC OF MOLDOVA | | | ■ | ■ | | ■ | | ■ |
| REPUBLIC OF MONTENEGRO | | | ■ | ■ | | ■ | | ■ |
| REPUBLIC OF SERBIA | | | ■ | ■ | | ■ | | ■ |
| ROMANIA | | | ■ | ■ | | ■ | ■ | ■ |
| RUSSIAN FEDERATION | | | ■ | ■ | ■ | ■ | | ■ |
| RWANDA | ■ | ■ | ■ | | ■ | | ■ | ■ |
| SENEGAL | ■ | ■ | ■ | ■ | ■ | | | ■ |
| SIERRA LEONE | ■ | ■ | ■ | ■ | ■ | | ■ | |
| SINGAPORE | | | | ■ | | | | |
| SOMALIA | ■ | | ■ | | | | | |
| SOUTH AFRICA | ■ | ■ | ■ | ■ | | ■ | ■ | ■ |
| SPAIN | | ■ | ■ | | | | ■ | ■ |
| SUDAN | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| SURINAME | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| SWAZILAND | ■ | ■ | ■ | | ■ | ■ | | ■ |
| SYRIAN ARAB REPUBLIC | | ■ | ■ | ■ | | | | ■ |
| TAJIKISTAN | | | ■ | ■ | | ■ | | ■ |
| TANZANIA UNITED REPUBLIC OF | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| THAILAND | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| TIMOR-LESTE | ■ | ■ | ■ | ■ | ■ | ■ | | |
| TOGO | ■ | ■ | ■ | ■ | ■ | | | |
| TRINIDAD AND TOBAGO | ■ | ■ | ■ | ■ | | | ■ | |
| TUNISIA | | | ■ | ■ | ■ | | | ■ |
| TURKEY | | ■ | ■ | ■ | ■ | ■ | | ■ |
| TURKMENISTAN | | | | ■ | | | | ■ |
| UGANDA | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| UKRAINE | | | ■ | ■ | | ■ | | ■ |
| UNITED STATES | | | ■ | | | | ■ | ■ |
| URUGUAY | ■ | | ■ | ■ | | ■ | ■ | ■ |
| UZBEKISTAN | | | ■ | ■ | ■ | ■ | | ■ |
| VANUATU | | ■ | ■ | ■ | | | | |
| VENEZUELA | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| VIET NAM | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| YEMEN | | ■ | ■ | ■ | | | | ■ |
| ZAMBIA | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| ZIMBABWE | ■ | ■ | ■ | ■ | ■ | ■ | | |

# 5 Discussion and conclusions

In this study, we developed a concept on how nutrient depletion could be incorporated as environmental impact indicator in LCA. Moreover, we made a first attempt to work out this concept quantitatively for a number of crops. In the future, the concept presented here might serve as one of the building bricks for an ‘aggregated soil degradation’ impact category in LCA.

Ideally, to estimate the influence of harvesting crops on phosphorus (P) depletion, one should have insight in the soil P-budgets on a global scale. If all inputs and outputs of P were known spatially, this would enable developing a ‘state’ indicator for nutrient depletion (indicating the P-deficit in soils). Unfortunately, data on soil P budgets worldwide are not yet available on a worldwide scale, neither are exact figures on fertilizer and manure application, fixation and P-erosion. In absence of these data, the best option we had was to develop a so-called ‘pressure’ indicator: an indicator that indicates the loss of soil nutrients by the amount of P removed from soil by agriculture. With this methodology, two types of uncertainty play a major role. First, although we used the best available data on a global scale, the accuracy of the input and output numbers is not very high: such numbers are very variable over small distances, so interpolating the known values to worldwide values leads to simplification and loss of detail. However, the level of detail we used was still high enough to distinguish clear regional differences in outcomes. Second, the question is whether our concept of the P-dynamics, as sketched in Figure 1, is detailed enough. Although we are aware of these uncertainties, we consider our conceptual model sufficiently accurate, and supported by literature (e.g. Bouwman et al., 2012).

A drawback of the indicator in its current form is that it is not yet possible to compare the environmental impact of soil nutrient depletion to other environmental impacts related to the agricultural production of (food) products. It is e.g. not yet incorporated in a life cycle impact assessment method like ReCiPe. If this is considered desirable, further research will be needed to enhance the quantification (midpoint level) to enable weighing this impact against others (endpoint level).

However, although a ‘state’ indicator would be preferable over a ‘pressure’ indicator, we consider this indicator, based on yield data combined with knowledge on where subsistence farming or low input farming takes place, a meaningful indication of where and for which crops nutrient depletion should be considered an environmental issue. In other words, the developed indicator can be used as first screening. Next to the results of an LCA with the default impact categories, it provides information whether nutrient depletion should be considered, or not. The user of the LCA-results can weight this information with the rest of the results in order to support a decision on what to do. Aggregation of the spatial data to country level enhances the user friendliness of the indicator. However, it also causes some loss of information: if only a small area in a country is depicted as low input farming, due to the aggregation, the whole country might get a ‘red flag’ for a specific crop. It is therefore recommended to always try to derive actual site-specific data instead of country averages.

# 6 References

Blonk Consultants, 2013. http://blonkconsultants.nl/publicaties/nieuwsbrief/blonk-consultants-levert-milieudata-aan-het-rivm.html.

Bouwman B, Klein Goldewijk K, Van den Hoek K, Beusen A, Van Vuuren D, Willems J, Rufino M, Stehfest E, 2011. Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. Proceedings of the National Academy of Sciences of the United States of America 110: p. 20882–20887. doi: 10.1073/pnas.1012878108.

Garrigues, E., et al., Soil quality in Life Cycle Assessment: Towards development of an indicator. Ecological Indicators, 2012. 18: p. 434-442.

IFAD/FAO, 2004. IFAD Cassava for livestock feed in Sub-Saharan Africa.

Ketterings Q, Czymmek K, 2007. Cornell University Agronomy Factsheet series - Factsheet 28.

Milà i Canals, L., J. Romanyà, and S.J. Cowell, Method for assessing impacts on life support functions (LSF) related to the use of 'fertile land' in Life Cycle Assessment (LCA). Journal of Cleaner Production 15: p. 1426-1440.

Nachtergaele F, Van Velthuijzen H, Verelst L, Wiberg D, 2012. Harmonized World Soil Database, version 1.2. FAO/IIASA/ISRIC/ISS-CAS/JRC, Rome (Italy) – Laxenburg (Austria). (http://www.iiasa.ac.at/Research/LUC/GAEZ/index.htm).

Oberholzer HR et al., 2012. A novel method for soil quality in life cycle assessment using several soil indicators. Agronomy for Sustainable Development 32: p. 639-649.

Sarkiyayi S, Agar TM, 2010. Comparative Analysis on the Nutritional andAnti-Nutritional Contents of the Sweet and Bitter Cassava Varieties. Advance Journal of Food Science and Technology 2, 328-334.

Smaling, Stoorvogel en Windmeijer, 1993. Calculating soil nutrient balances in Africa at different scales. II – District scale. Fertilizer Research 35: 237-250.

Stoorvogel, Smaling en Windmeijer, 1993. Calculating soil nutrient balances in Africa at different scales. II – District scale. Fertilizer Research 35: I – Supra national scale : 227-235.

USDA Crop nutrient database, 2015. http://plants.usda.gov/npk/DisplayCrops?sflag=common&source=html&croptype=Cereal+and+oil&searchstring=&submit_crop_type=View+Crop+List

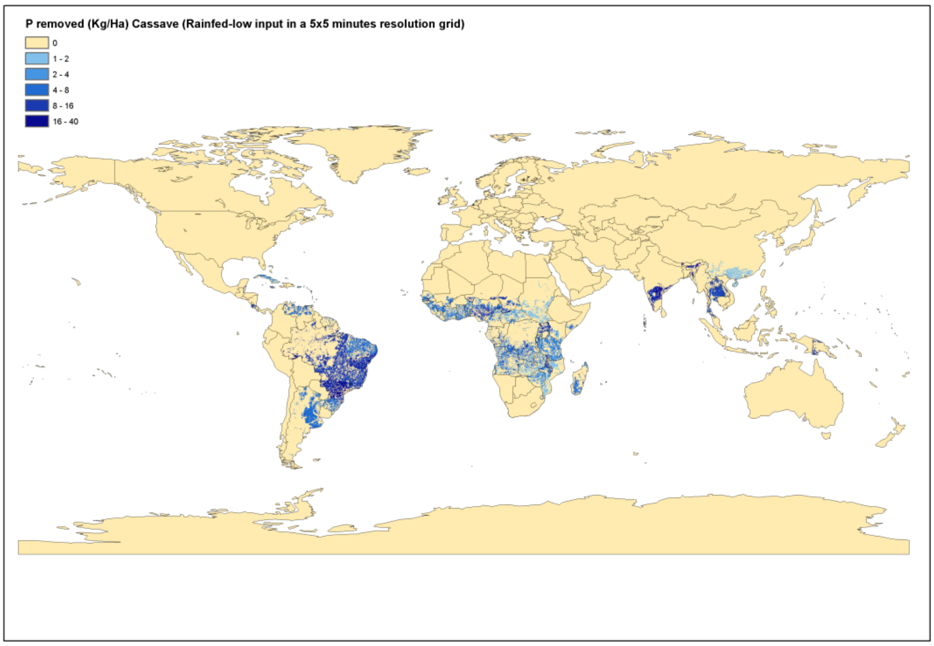
Yang G, Zuo Q-S, Tang Y, Shi J-F, Hui F-H, Leng S-H, 2010. Phosphorus absorption and utilization of rapeseed (Brassica napus L.) Cultivars with different yields. Bulgarian Journal of Agricultural Science 16, 590-596.

# 7 Appendix 1

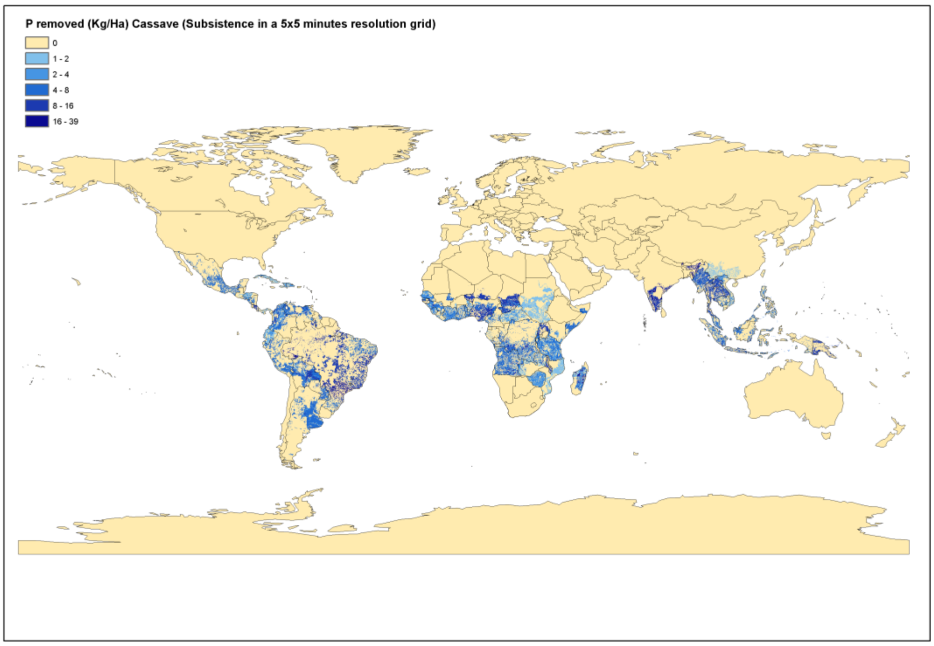
The amount of P removed per hectare per year was calculated on a grid basis (5’ x 5’), both for areas with rain fed, low input farming and for areas with subsistence farming.

Figures “a” indicate the amount of P removed per hectare in rain fed low input farming areas, whereas Figures “b” indicate the amount of P removed per hectare in subsistence farming areas.

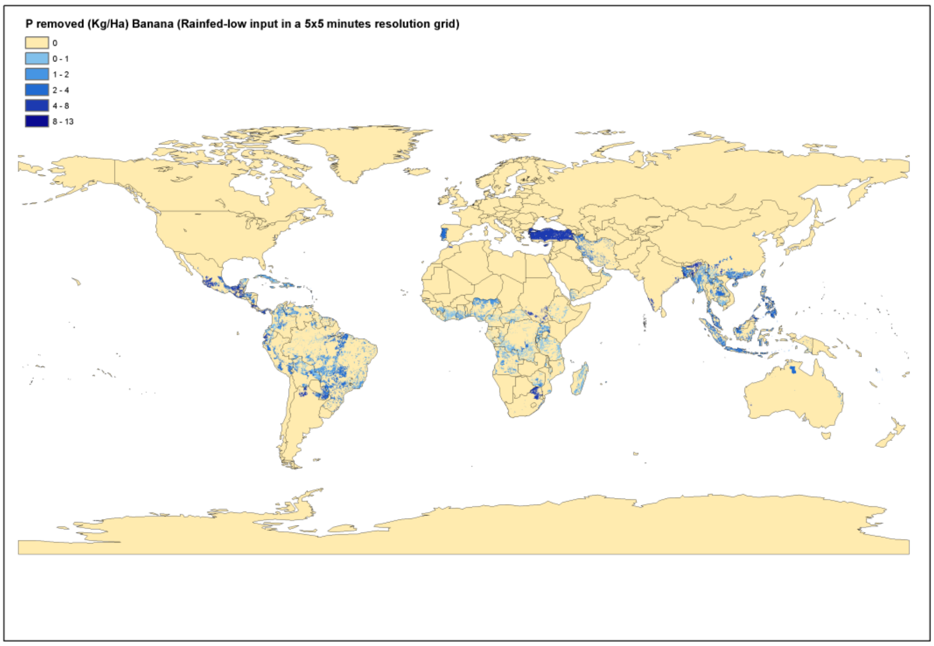
Figures are respectively presented for:
1) Cassava
2) Banana
3) Maize
4) Oil crops
5) Rice
6) Soy bean
7) Sugar cane
8) Wheat



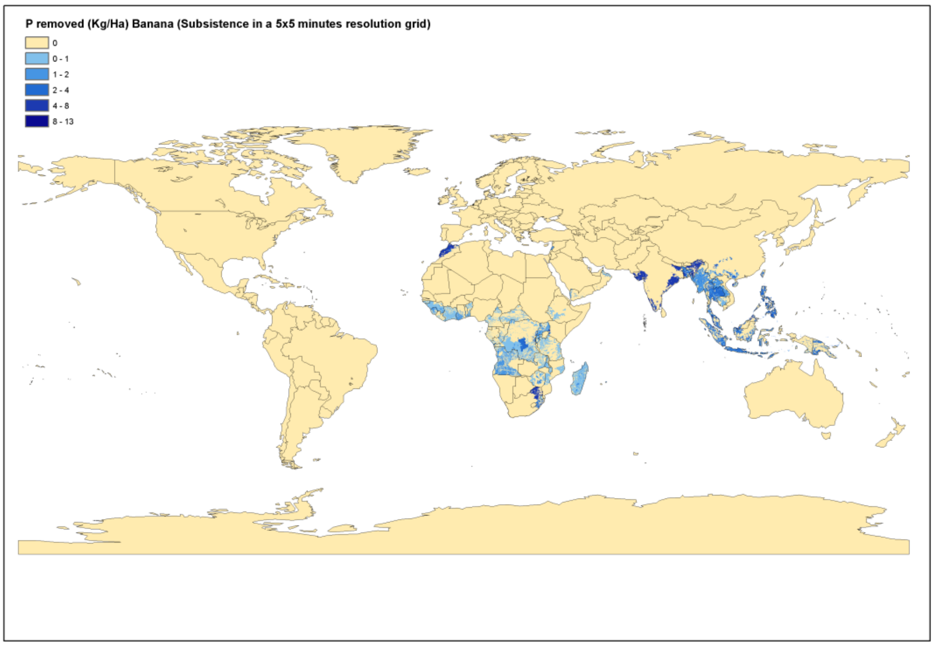

1a. Cassava low input farming



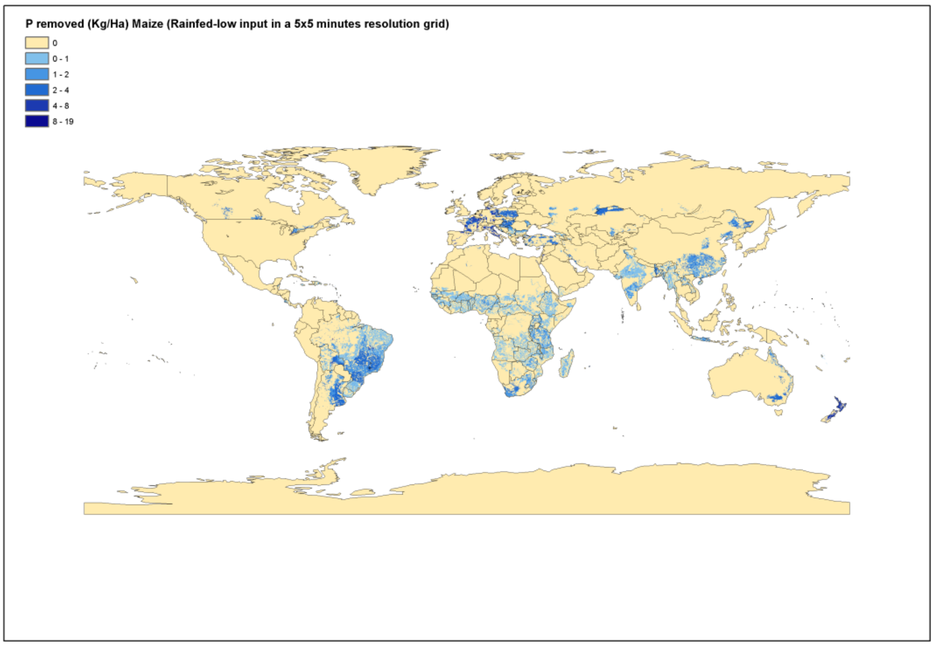

1b. Cassava subsistence farming



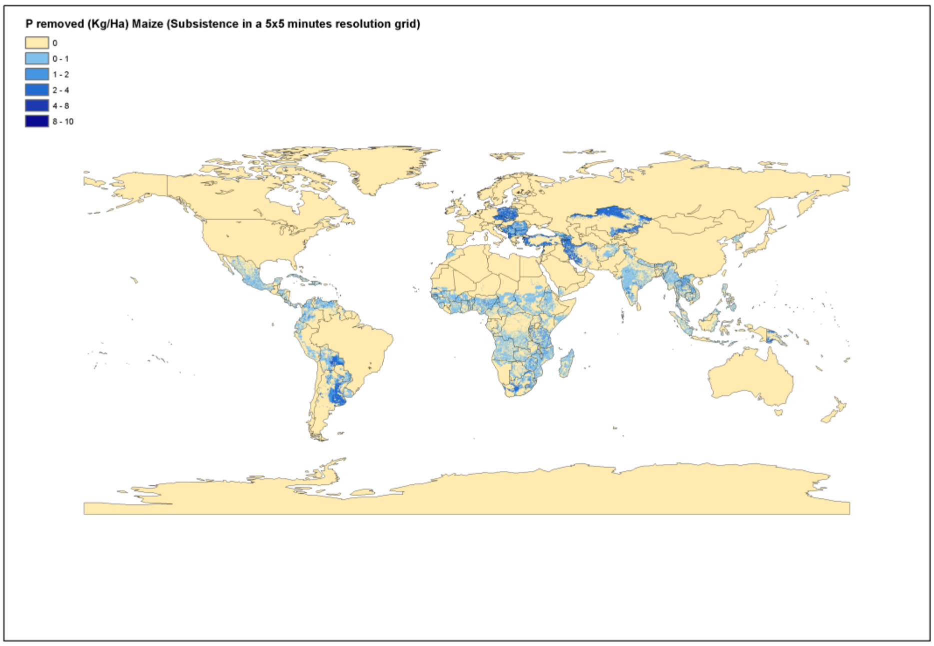

2a. Banana low input farming



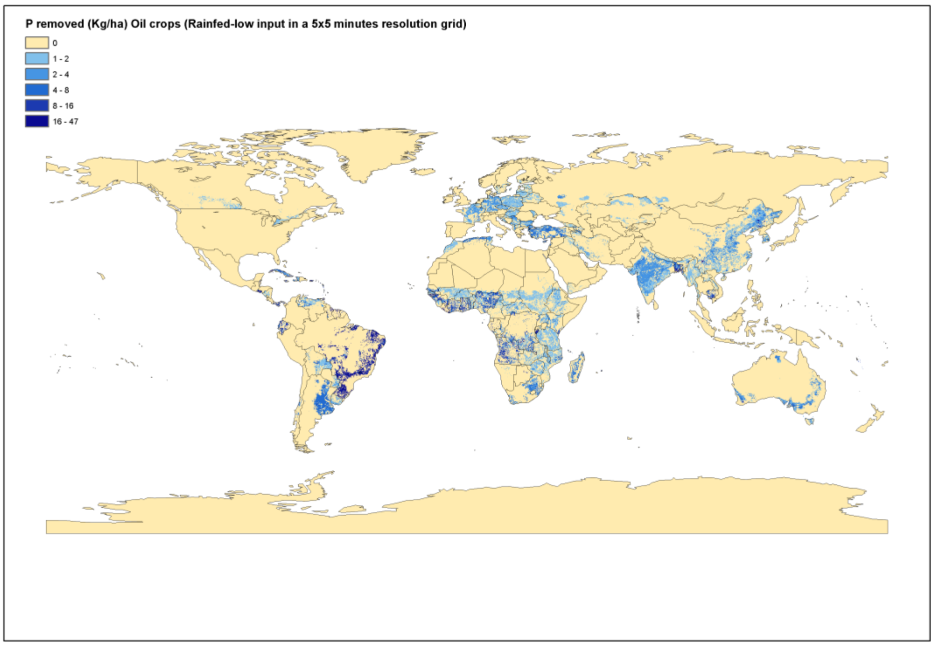

2b. Banana subsistence farming



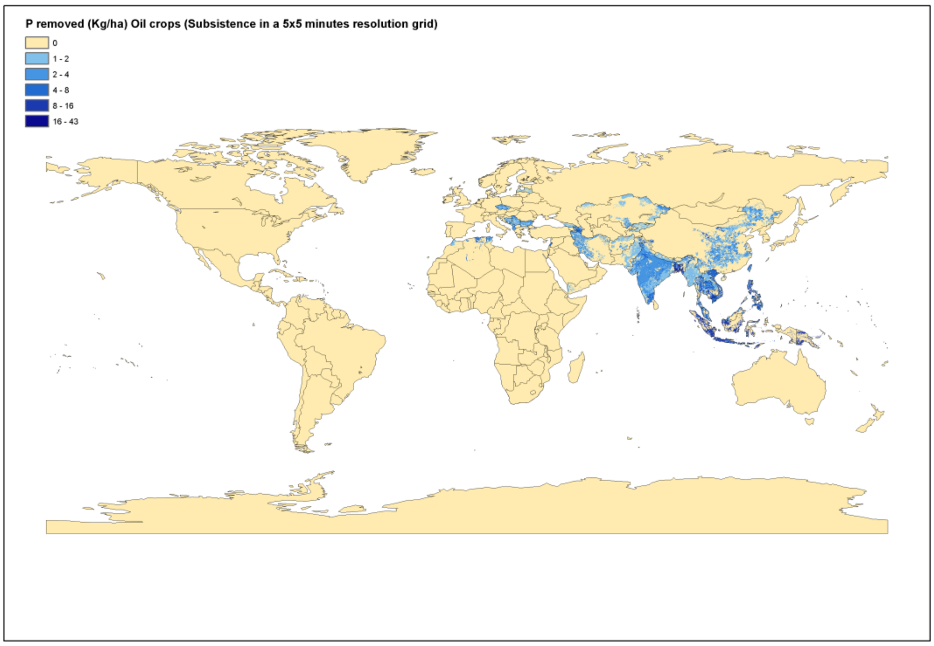

3a. Maize low input farming



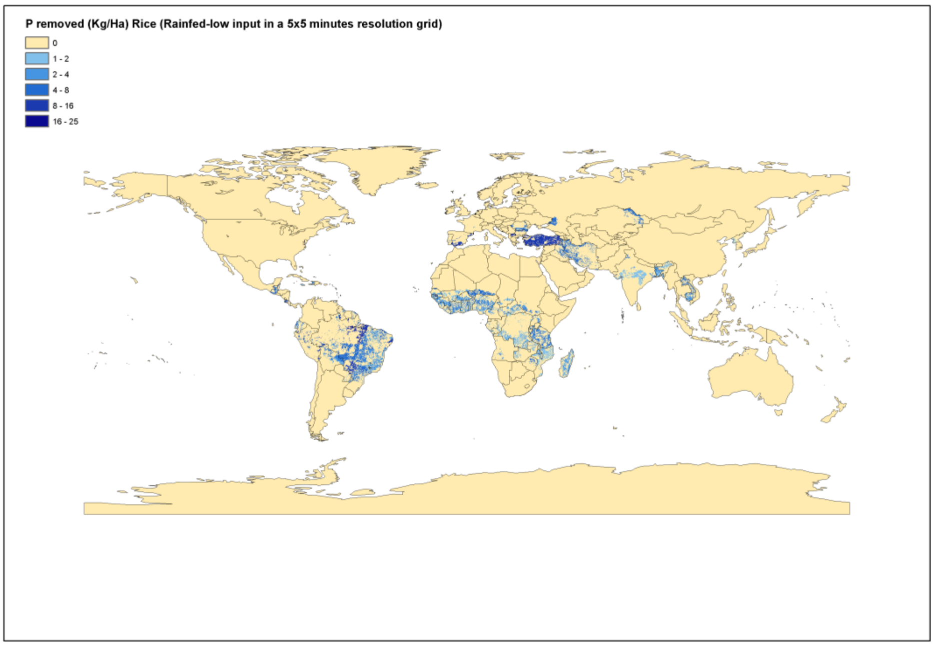

3b. Maize subsistence farming



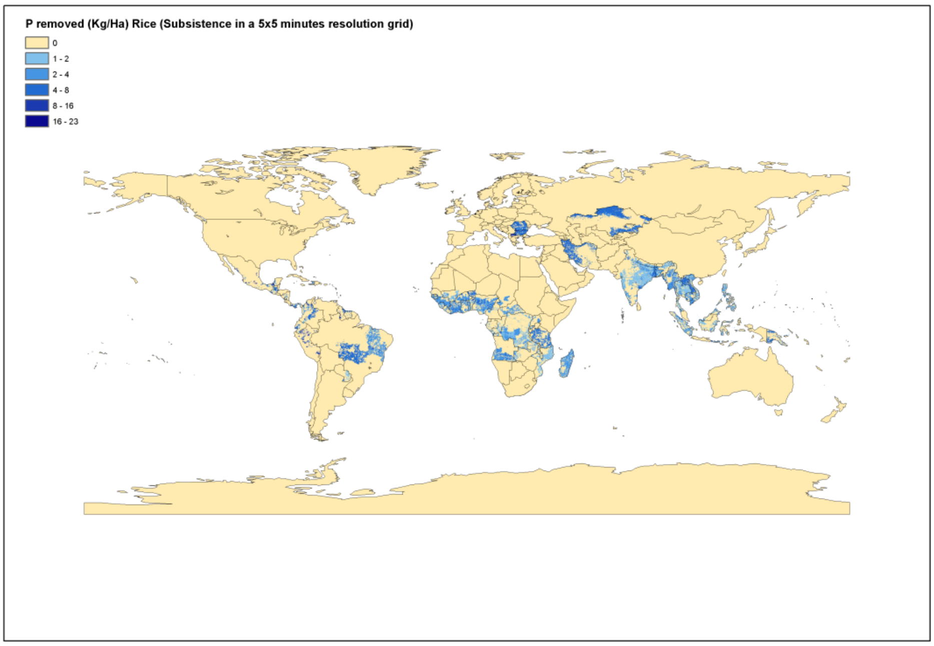

4a. Oil crops low input farming



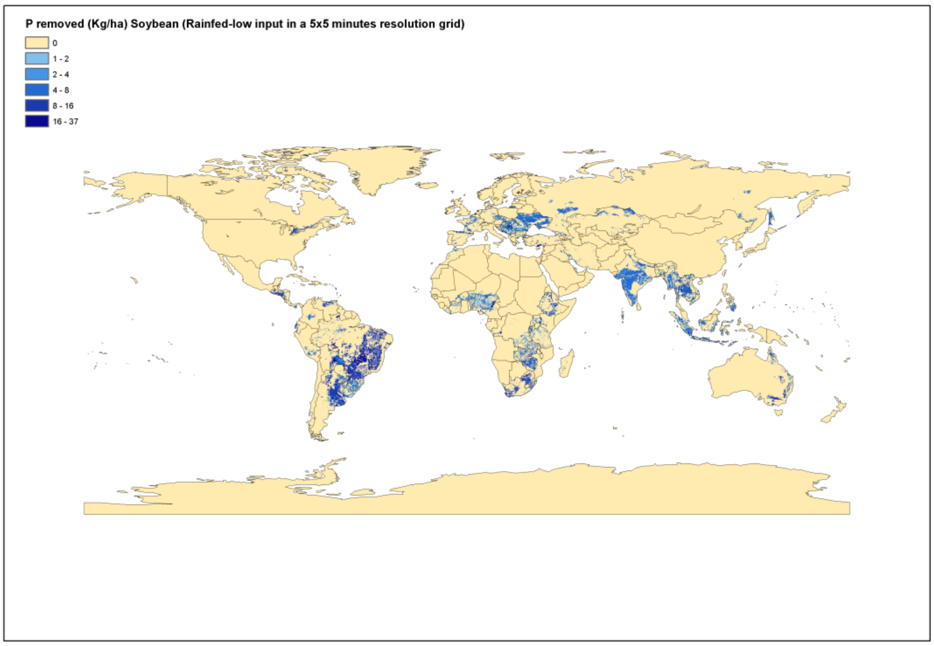

4b. Oil crops subsistence farming



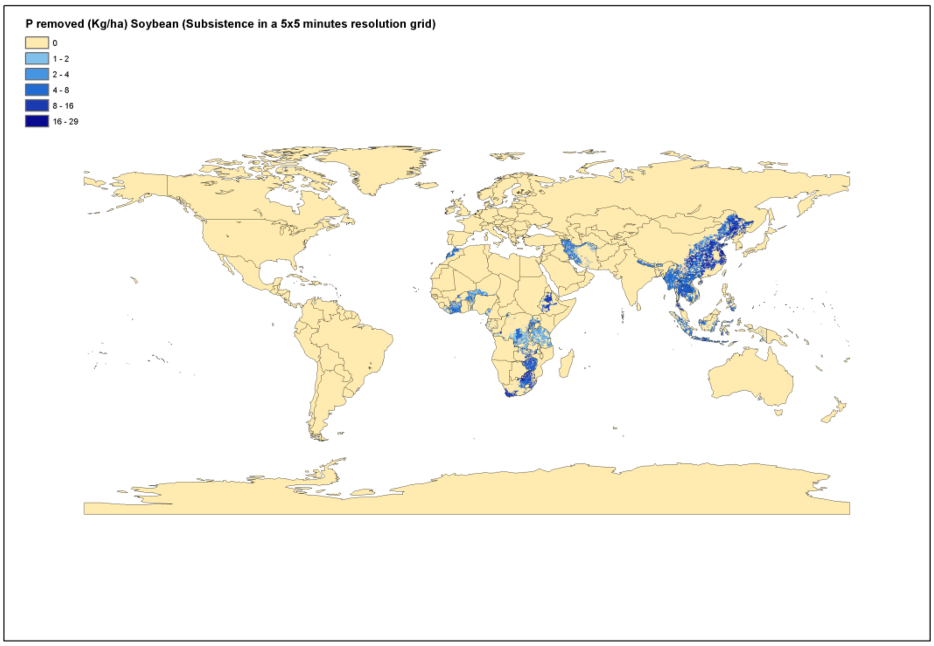

5a. Rice low input farming



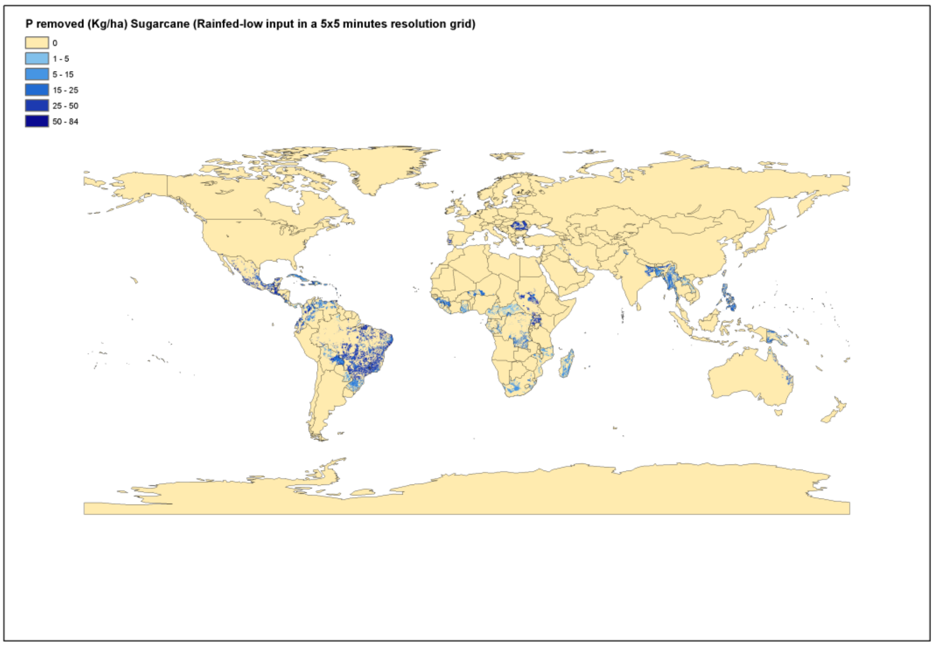

5b. Rice subsistence farming



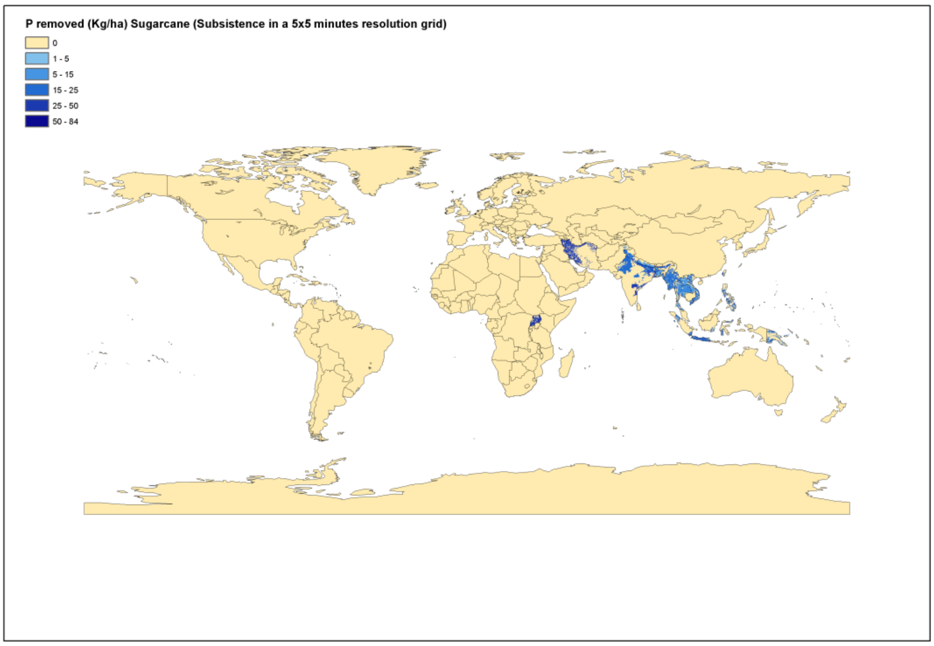

6a. Soy bean low input farming



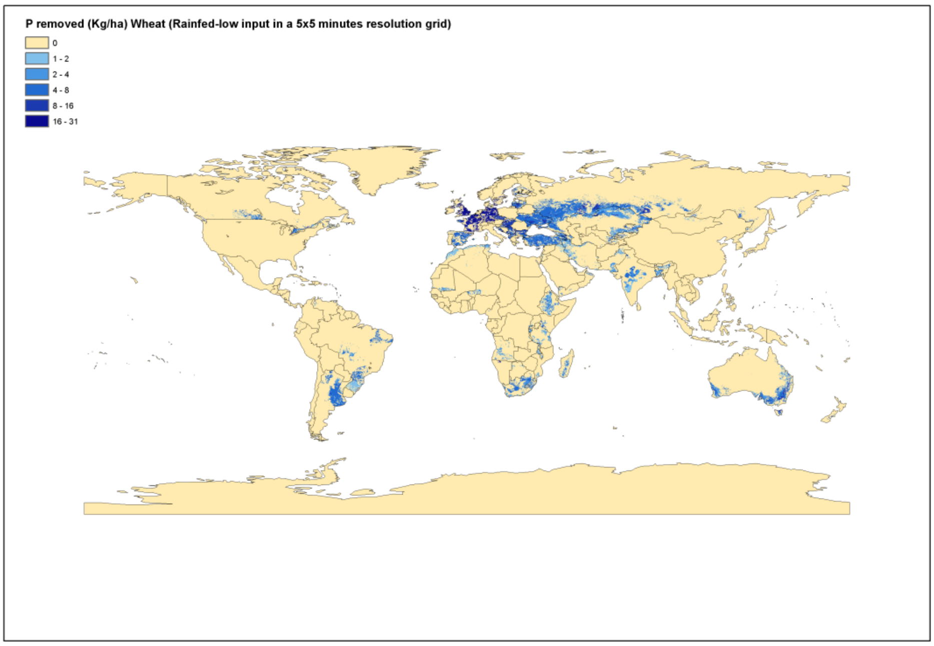

6b. Soy bean subsistence farming



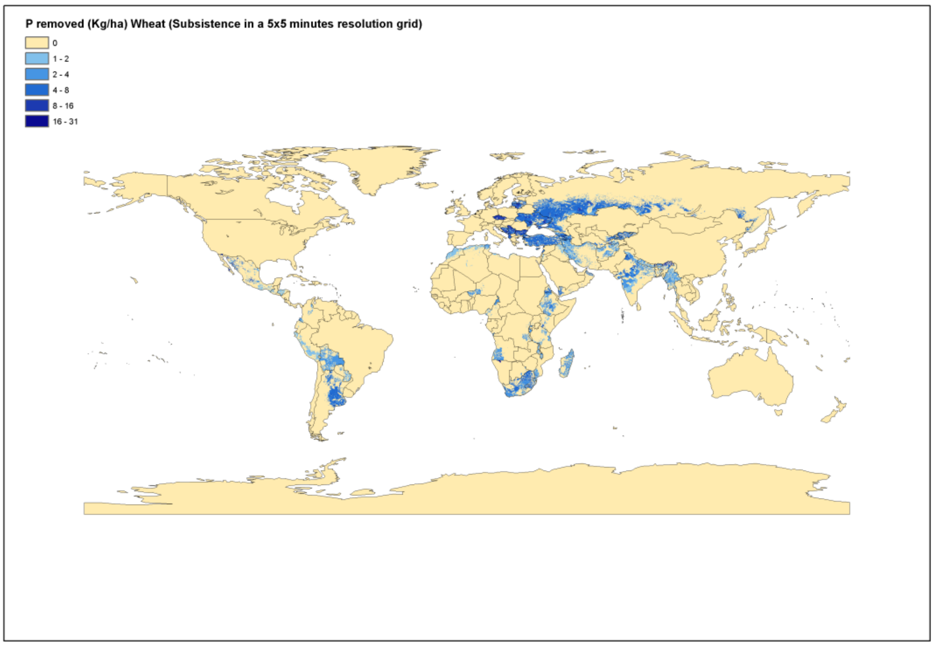

7a. Sugarcane low input farming




7b. Sugarcane subsistence farming




8a. Wheat low input farming




8b. Wheat subsistence farming

**RIVM**
Committed to *health and sustainability*