Modifying The Yield Factor Based on More Efficient Use of Fertilizer

- The Environmental Impacts of Intensive and Extensive Agricultural Practices -

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Abstract

The aim of this article is to draw attention to calculations on the environmental effects of agriculture and to the definition of marginal agricultural yield. When calculating the environmental impacts of agricultural activities, the real environmental load generated by agriculture is not revealed properly through Ecological Footprint indicators,as the type of agricultural farming (thus the nature of the pollution it creates) is not incorporated in the calculation. It is commonly known that extensive farming uses relatively small amounts of labor and capital. It produces a lower yield per unit of land and thus requires more land than intensive farming practices to produce similar yields, so it has a larger crop and grazing Footprint. However, intensive farms, to achieve higher yields, apply fertilizers, insecticides, herbicides, etc., and cultivation and harvesting are often mechanized. In this study, the focus is on highlighting the differences in the environmental impacts of extensive and intensive farming practices through a statistical analysis of the factors determining agricultural yield. A marginal function is constructed for the relation between chemical fertilizer use and yield per unit fertilizer input. Furthermore, a proposal is presented for how calculation of the yield factor could possibly be improved. The yield factor used in the calculation of biocapacity is not the marginal yield for a given area, but is calculated from the real and actual yields, and this way biocapacity and the ecological footprint for cropland are equivalent. Calculations for cropland biocapacity do not show the area needed for sustainable production, but rather the actual land area used for agricultural production. The proposal the authors present is a modification of the yield factor and also the changed biocapacity is calculated. The results of statistical analyses reveal the need for a clarification of the methodology for calculating marginal yield, which could clearly contribute to assessing the real environmental impacts of agriculture.

1. Introduction

One of the greatest challenges to mankind is how to meet basic food needs for a growing population. The question arises how it is possible to increase agricultural production and minimize the detrimental impacts of agriculture at the same time. This question has clear practical significance, and it highlights a conflict between neoclassical economic theory and the 'ecological' approach, which takes into account the biophysical limits of production.

Agriculture creates significant negative externalities on the environment through impacting soil, water, air, biodiversity and landscape. . The introduction of a sustainable approach to agricultural practices would be the most effective solution. The goal of such an approach is maximization of the net societal benefits from the production of food and fiber and from ecosystem services (Tilman et al, 2002).

The major areas of agricultural environmental impacts are connected to the effective management of fertilizer use and ecosystem services; namely nutrient-use, water-use, maintaining soil fertility and sustainable livestock production.

The harmful environmental impacts of agriculture basically stem from the transformation of natural habitats to agricultural areas. Agricultural practices can change whole ecosystems through conversion of the landscape and the usage of fertilizers and pesticides. Due to the increase in the use of agrochemicals cereal production has doubled in the past 40- 50 years (FAO Database, 2010), in order to satisfy increasing demand for food - the consequence of a growing population and income level. On the positive side, the use of agrochemicals has saved natural habitats from conversion to agricultural land. However, fertilizers and pesticides (fungicides, herbicides, insecticides etc.) are mostly nitrogen- (NOx, ammonium), phosphorus- or potassium-based and their use and overuse causes leaching into the soil and resultant soil degradation and groundwater pollution. Nitrate loading of lakes and rivers induces over-enrichment and eutrophication endangering freshwater ecosystems. Crops can take up only 30-50% of nitrogen in forms of nitrate (NO_3^-) and ammonium (NH_4^+) and approximately 45% of phosphorus fertilizers, thus a great amount of the applied components are lost in the soil where they pollute groundwater.

Groundwater is the key element of freshwater purification and the main problem is that it can spread both nutrients and pollutants over a great expanse and load lakes and rivers over large distances, as well as increasing health risks for animal species, livestock and human beings. The health risk for mammals depends mainly on the dose-effect and dose-response relationships, the physical state of the product (fertilizer, pesticide), and exposure type (oral, dermal, etc.) (WHO, 1990). Through altering the terrestrial habitats of species fertilizer and pesticides affect ecosystems by decreasing biodiversity.

Sustainable agriculture posits an alternative which can provide increased crop yields through more effective fertilizer, pesticide, and water use and ecologically conscious practices in soil maintenance and livestock production (Tilman et al, 2002).

In this article we compare intensive and extensive agricultural practices and their environmental impacts using data from two countries: the Netherlands and Hungary. We analyze the relation between agricultural yield and its determining factors in order to reveal the impacts of agricultural practices in the quest to define the efficient use of fertilizer which would lead to more sustainable farming practices. Furthermore, a proposal is presented for how the calculation of the yield factor and biocapacity, taking into account the long term impacts of fertilizer overuse, could possibly be changed.

1. Research question

The Ecological Footprint indicator is designed to show the difference between a sustainable lifestyle and the actual or current way of life and its impacts. According to the calculation formula for the Ecological Footprint and for biocapacity (concerning the cropland component) the Ecological Footprint should not exceed biocapacity. The yield factor used in the calculation of biocapacity is not the sustainable amount of yield for a given area, but is calculated from the real and actual yields, and this way biocapacity and the ecological footprint for cropland show the same result. Thus the cropland biocapacity indicator does not show the production area that is sustainable, but the actual land used for agricultural production.

The reason for this method of calculation is that there is no available data to indicate what the sustainable yield is. The sustainable yield would surely be lower than the present amount, thus overexploitationcould be revealed by considering this factor. The importance of this research topic has already appeared in research by Wackernagel et al. (2004). They suggest taking into the calculation the productivity factor, which could be used as a time-series.

Data on optimal and sustainable production are needed to calculate the Ecological Footprint and to show the real overshoot. In this study we examine what the sustainable amount of yield could be and how it could be estimated. We start from the assumption that the regenerative capacity of the land should be taken into account in the calculation, therefore if (excessive) fertilizer use no longer contributes to increasing yield, then the yield production is not efficient. In a later section of this article, a detailed reasoning will be given for this.

Another problem with the calculation of the cropland footprint is that an increase is shown in biocapacity if a more efficient agricultural production technique is found - but this may not be a sustainable improvement: the overexploitation of soil through addition of chemicals and fertilizer does not appear in the calculation and results. The real environmental load generated by agriculture is not revealed properly through Ecological Footprint indicators, as the type of agricultural farming (thus the nature of the pollution it creates) is not incorporated in calculation processes.

The research question discussed here is additionally of critical practical importance from the viewpoint of economics, as it involves a conflict between the need for providing food for a growing population and the ecological limits of increasing crop yields. Significant increases in yield are necessary in China, South Asia and Africa, but the environmental constraints will limit this outcome. According to Harris (1996), there is a conflict between the pressure to increase yields on the demand side and the requisites of long-term sustainability. There is an ecological cost to providing food for the global population and meeting conditions for sustainability. This costs associated with expansion of supply must be considered - not only the supply capacity of world agriculture.

Neoclassical economical approaches focus on yield increases as a result of technological advances and increasing inputs. In this way biophysical limits and carrying capacity are not taken into account. Neoclassical economists reject the necessity of taking into account the focus on limits, arguing that technological advances and trading activities will solve the problem of the excessive use of agricultural land. In contrast, the ecological economics perspective is based on the environmental limits of the economic growth (Harris, 1996). Ecological economists Martinez-Alier (1991) and Gever et al. (1991) argued that agricultural production must be considered according to ecological limits and carrying capacity.

2. Intensive and extensive agricultural practices in Hungary and the Netherlands

It is very difficult to define accurately the differences between intensive and extensive agricultural practices; they are usually both utilized on similar areas, depending on the availability of resources and farming practices. However, there are some peculiarities of each method.

Extensive agriculture generally uses a larger land area in order to produce the same yields as intensive agriculture and crop yields primarily depend on the natural fertility of the soil, climate and availability of water. Contrarily, intensive agricultural practices need larger amounts of capital and the application of fertilizers and pesticides and the use of irrigation equipment, which induces greater crop yields per unit of land than extensive agriculture.

A high and increasing level of agricultural pollution is common to Europe. In the case of Hungary, the present state of agriculture is not desirable from either an ecological or a social point of view, though the country is well-endowed for agricultural production having fertile soils and a high number of hours of sunshine. Agricultural traditions are nearly a thousand years old, and because of this and the advantageous geographic features, Hungarian agriculture can ensure good crop yields both in quality and in quantity. Hungary has a total area of 9.3 million hectares and almost two-thirds of the country's total area is under agricultural cultivation (a large amount when compared to other European countries). Only Denmark and the United Kingdom have higher proportions. 78% of this cultivable area is arable land and 17% is grassland, while kitchen gardens, orchards and vineyards take a combined share of only 5%. (MARD, 2009).

Agriculture has traditionally been an important sector of the Hungarian national economy. Because of the political transition, economic changes and restructuring have taken place so Hungarian agriculture has changed much during the last twenty years. In 1989, when the changes and transition started to take place, agriculture accounted for 13.7% of GDP; twenty years later, in 2009, it was only 3.7%.

As for employment, 4.5% of the total active population works in agriculture - the sector does not employ a relatively large fraction of the labor force.

Cereal production is important in Hungary, as in the foreign trade balance cereal exports contribute most to food exports. Hungary produces cereals on half of its agricultural area. The level of fertilizer application was very high in the 1980s, but after the transition it fell significantly. From an environmental point of view, fertilizer use is not desirable as in Hungary the rate of application keeps growing and the dominant practice is for unilateral nitrogenous fertilization - phosphorus- and potassium-based fertilization is of less importance. Irrigation is not widespread in Hungary; it accounts for only 2% of the total cultivable area (MARD, 2009).

In the case of The Netherlands, the country has long practiced intensive production methods. Dutch agriculture can be divided into three main areas: crop production, dairy and livestock production, and horticulture. As a result, agricultural land can also be classified into three types: grasslands, farmlands, and horticultural lands. Agriculture in the Netherlands accounts for 10% of the national value added and makes a large contribution to employment - also around 10%.

Because of the geographical situation of the country, extensive waterways and a network of dams and dikes have been developed and built which allow for easy irrigation and have produced very fertile soils. Fertilizer use is high because of scarcity of land, which has created environmental pressures.

Table 1
Comparison of the main features of Hungarian and Dutch agriculture

Intensity of farming in 2005	Hungary	The Netherlands
Proportion of utilized agricultural area to total area	83%	58%
Proportion of arable land to total area	49%	33%
Proportion of cereal area to total arable area	65%	19%
Nitrate content in rivers (mg/l)	6	11
Phosphate in rivers (mg/l)	0.07	0.08
Ammonia emissions (t)	94 252	121 000
Livestock density index (livestock units per hectare)	0.58	3.26
Labor force (1000 person employed full time)	229.40	173.90

Source: authors' compilation using Eurostat data (2010)

As biocapacity in Hungary is high, there is a rationale for extensive farming. For the Netherlands, land is a scarce resource, so intensive farming processes are utilized. The features of the different types of farming are shown in Table 1. The main agricultural land use is the growing of arable crops in both countries. Consequently, examining the type of agriculture is important.

It can be seen that the Netherlands has a smaller labor force and lower agricultural labor input and the share of agricultural product-specific inputs is lower as well. The Netherlands is a typical example of intensive agricultural practices. Hungary, using larger proportions of its land for farming, typically practices extensive farming. The livestock density index confirms these statements as well.

Comparing extensive farming with intensive farming, environmental impacts can be seen through the listed categories. Because of intensive farming, spending on fertilizers and soil improvers is 2.55 times higher, and spending on plant protection products is 5.6 times higher in the Netherlands than in Hungary. The results are the same concerning natural elements when considering the supply of nitrogen and phosphates, and ammonia emissions. Groundwater nitrate content is a good proxy for evaluating the environmental damages caused by agricultural fertilizer use.

After comparing these figures, it can be concluded that intensive farming processes contribute to a higher environmental burden, which should be indicated by biocapacity.

Figure 1. shows the share of Hungarian and Dutch agricultural farms managed using high- medium- and low intensity inputs in 2007. The figure shows the result of the intensification indicator which was developed by Eurostat. Each farm was classified according to the level of input use per hectare, calculated on the basis of spending for intensive inputs (pesticides, fertilizers, animal feed, etc.). According to the indicator, a farm is qualified as high-input use if there is ongoing higher spending than 295 EUR per hectare. Below a spending of 125 EUR per hectare the farm is considered a low-intensity farm, otherwise it is 'medium'. This figure depicts well the different types of agricultural practices in the countries analyzed. High- input farms apply intensive farming practices which result in negative externalities to the environment to a greater scale than low-input farms.

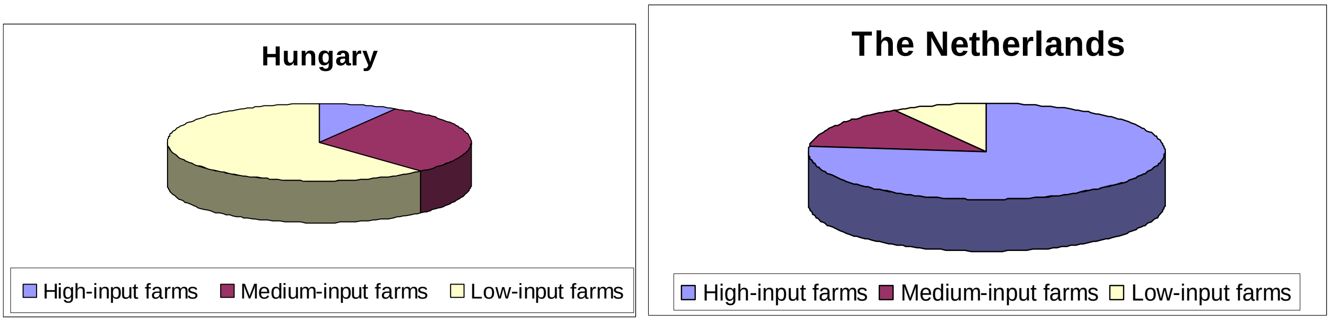

Fig. 1. Input intensity of farms in Hungary and The Netherlands (Eurostat, 2011)

4. Sustainable yield and the impacts of agriculture

Calculations on the environmental impact of agricultural practices on cropland have appeared in many studies. Concerning the methodology of the Ecological Footprint, Fiala (2008) argues that the environmental impact of agricultural practices is not properly represented in the Ecological Footprint. In this study the author shows that if there is a need for increased food production in a given country and there are two countries with different levels of efficiency in producing food, then due to this increased demand a new equilibrium will be reached in both of the countries because of the production and consumption of more food. The amount of land used and its environmental impact is unknown in both countries, as the method of agricultural production (extensive or intensive) is not indicated by the footprint for food production.

There is a need to know what the sustainable yield is in order to calculate the real environmental impacts of agriculture. It is highly difficult to define and measure what sustainable yield is. The agricultural yield is affected by soil quality, climate and of course management practices. According to Ferng (2005) agricultural management practices affect crop yield directly through the pest control, water supply, and indirectly though influences on soil quality. According to Doran and Zeiss (2000), soil quality is determined by natural factors such as geography and climate and can be altered by farming practices as well.

The difficulty in defining sustainable yield is also that the factors which influence yield change as time goes by and there may be interactions between them as well. Agricultural management practices may be the dominant determining factors of agricultural yield (Ferng, 2005) and the yield potential of a crop can be estimated though a long-time field study on the relationships between the yield crop and its established growth environment. Gilland (1979) examined food prospects and yield ceilings up to 2025 in an ecologically-oriented study of world agriculture. He calculated for a sustainable amount of cropland and yield. Harris argues (1996) that the application rate of chemical fertilizers is representative of a whole package of agricultural practices which characterize high-yield farming systems. It is for this reason tour study is designed to show the relationship between fertilizer use and crop yield. The cumulative effects of soil erosion and degradation, water shortage, and the environmental impacts of fertilizer and pesticide use all undermine the yield potential of agriculture and conditions for sustainability. Chemical and particularly fertilizer use in agriculture is regarded as a major source of lake, river and groundwater pollution, loading nitrogen, phosphorus and sediment into waterways. Agricultural chemicals detected in groundwater may be harmful to human health and the aquatic ecosystems.

Studies examining the effect of fertilizer use on production may show positive correlation, but some marginal rates studies have proven that in some circumstances no positive correlation exists - stagnancy or even declining yields have been found (e.g. Ko et al. (1998), Tong et al. (2003)) . In some regions and countries fertilizer use no longer contributes to growth in crop yields and, despite the increased use, yields are stagnating. Diminishing returns from fertilizer use may lead to yield ceilings in many areas. So the trend to growing crop yields seems to be reaching its limits.

Ko et al. (1998) examined the environmental impacts of economic activities and estimated ecological footprints for five countries (Costa Rica, Korea, Mexico, the Netherlands and the United States). In general, there is a remarkable linearity between resource use and economic and agricultural production over all countries and all years, suggesting severe biophysical constraints to sustainable objectives. Ko et al. found that there is an inverse relationship between fertilizer use and the yield per unit fertilizer use in the examined five countries.

The study also highlighted that the yield per unit fertilizer use can only be increased by reducing the intensity of fertilizer use and reducing the intensity of land use. This is a highly important observation.

Tong et al. (2003) carried out research on land use changes and the relationship between crop production and fertilizer use in China over a longer time period, from 1961 to 1998. Overall results showed that despite the fact that China has increased yield per capita dramatically in order to feed its growing population, this was achieved through a high increase in the use of fertilizer, and thus at increased ecological cost. This was possible as the Chinese government gave subsidies to farmers who produced certain extra cereals, which meant using more fertilizers in the agricultural process. The chemical fertilizer used per unit of area of total cereals increased from 4.6 kg/ha in 1961 to more than 200 kg/ha in 1995. There was a positive relationship between 1961 and 1996 between chemical fertilizer use and cereal yields. However, yield per unit of fertilizer use decreased dramatically over the years from 1961 to 1995. An important conclusion is that there is a clear inverse relation between fertilizer input intensity and yield per unit of chemical fertilizer input: the higher the fertilizer input the lower the yield per unit fertilizer input.

The decline can be explained through understanding the saturation effect of fertilizer use; one outcome of agricultural industrialization. Soil degradation, the inefficient use of fertilizer and unbalanced ratios of organic and inorganic fertilizers may also explain this phenomenon.

So it can be seen that excessive fertilizer use does not necessarily result in higher yields, but may have a negative impact on soil quality and cause environmental damage. The efficiency of fertilizer use has decreased because of fertilizer saturation.

According to a recent Eurostat study (Environmental statistics and accounts in Europe, Eurostat, 2010) inorganic fertilizers are the main materials used to restore nutrients to the soil and increase crop yield.

The study states, that Nitrogen, Phosphorus and Potassium are the main ingredients of fertilizers. Nitrogen is a key element for plant growth. However, when fertilizers are applied to agricultural soils the nitrogen, in form of nitrate (NO_3), can be very vulnerable in the soil. In the case of heavy rainfall, nitrate affects not only the surface of the soil, but the groundwater as well. Groundwater pollution is a good indicator for excessive use of inorganic fertilizers. It has to be noted that different types of soils are not equally subject to leaching and run-off and pollution risks depend on the type of crop as well. A given quantity of fertilizer applied in very different natural conditions can result in full uptake by plant roots or in leaching to groundwater. According to the Eurostat study, the following crops account for the highest applications of nitrogenous fertilizer: Wheat, barley, grain maize, potato, sugar beet, oilseed rape, vegetables and industrial crops. These crops are typically the main products of Hungary and the Netherlands. Not only fertilizers but also pesticides and fungicides can pose environmental risk and these are also utilized in intensive agriculture.

Agriculture is responsible for a great share of national water use and water abstraction in the Netherlands with the size of the irrigable area up to 24 % of the total farming area, while this share is only 3% for Hungary (Eurostat, 2010). Even the increase in irrigated area was high in the Netherlands between 2003 and 2007.

5. Methodology

In this study it was analyzed how sustainable yield can indicate overshoot in agricultural production and for cropland. We conducted statistical regression analyses on production yields and the main determining features: temperature, precipitation, the amount of chemical fertilizer used, irrigation and mechanization in the case of two countries: Hungary and the Netherlands. Hungary was chosen to represent a country where farming is mainly extensive, and the Netherlands to represent intensive farming practices. Regression and correlations were calculated for time periods between the years 1961 and 2007 using data from Eurostat Database (2010), International Fertilizer Association (IFA), European Environment Agency (EEA) Waterbase (2010), FAOSTAT Database (2010) and KNMI (Royal Netherlands Meteorological Institute) Climate Explorer (2010).

Furthermore, we constructed a marginal function for each country representing the relation between fertilizer use and yield per unit of fertilizer input. Fertilizer (per hectare) and mechanization were taken to be fairly good proxies for agricultural inputs which characterize intensive, high-yield focused agriculture. This proxy is used because, historically, yields are very strongly correlated to fertilizer input. The function can show to what extent additional units of fertilizer contribute to yield and serve to question the rationale behind excessive use of fertilizers.

In order to reveal the sustainable amount of fertilizer used in agricultural production we need to examine other factors which can influence national yields. The main determining features are temperature during the growing season of the crop examined, precipitation and agricultural practices and technology such as irrigation, and fertilizer use.

The area of land under irrigation is not significant in Hungary, thus we carried out a correlation analysis on monthly average temperature (Celsius) and precipitation (mm) variables for April, May and June from 1961-2007 in addition to total fertilizer consumption (nitrates + phosphates + potash) and yield. Total cereal yield was chosen for our analysis as it is the most important processed crop in Hungary and on a global scale as well, thus it has a clear role in strategic food supply.

A linear regression (at 5% significance level) analysis between fertilizer use (kg/ha), temperature (the sum of April, May and June), precipitation (the sum of April, May and June), irrigation (total area irrigated) and mechanization (number of tractors/ha) was carried out on total cereal yields in order to investigate the most influential factors of two different agricultural practices. When calculating the regression model, the break points of the trend line in fertilizer use were taken into account; therefore in the case of Hungary an analysis of three time intervals was conducted.

In order to specify the so-called marginal yield, which could be used to calculate biocapacity (as a modified yield indicator which can reconcile the long term damages of fertilizer overuse), we constructed a marginal curve showing the groundwater nitrate content per fertilizer unit in the case of the Netherlands. Our assumption is that the intersection of the marginal curve of the yield and groundwater nitrate content can show the amount of fertilizer which may indicates marginal yield.

Finally, we have calculated the modified yield factor and modified biocapacity using the marginal yield for the main four products of the Netherlands.

6. Results and Discussion

I. Hungary

Total fertilizer consumption (kg/ha) in Hungary has drastically changed twice from 1961 to 2007, as is indicated on Fig. 2. Because of the breaks in the overall trend, we calculated regression functions for three periods considering the break points of the trends as the end point of one period and the starting points of another. It can be seen that in the first period from 1961 to 1974 fertilizer used in production increased significantly and wheat yield followed the growth trend for fertilizer use with some time lag, but nonetheless following a linear (positive) trend.

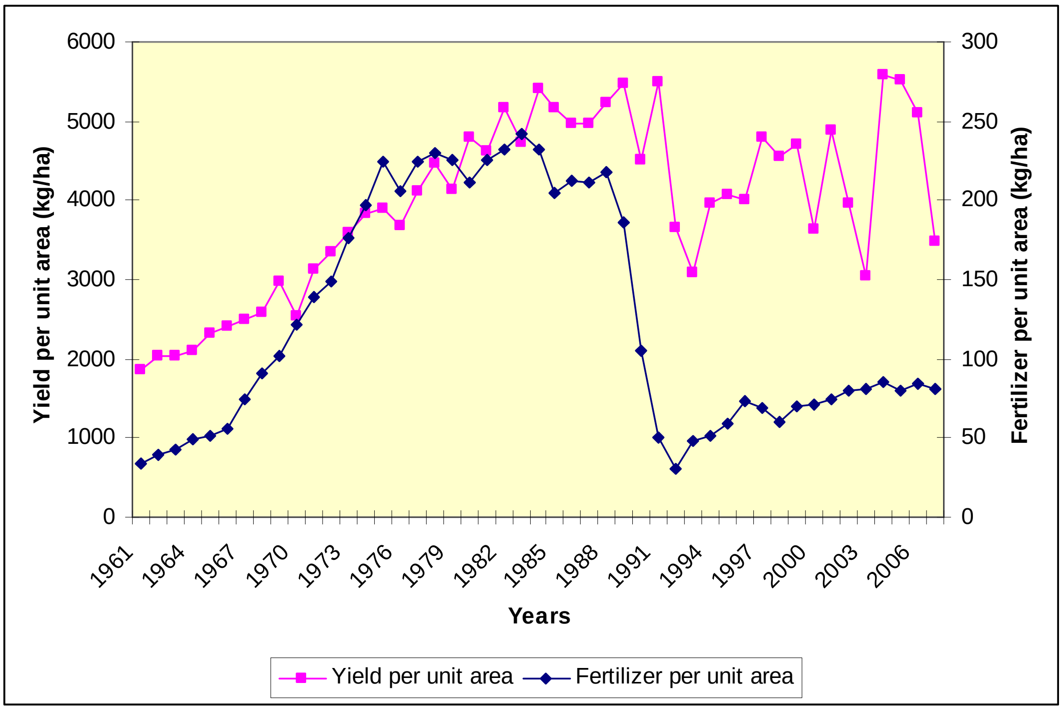

Fig. 2. Total cereal production yield and chemical fertilizer used per unit area in Hungary (Source: FAOSTAT data, 2010)

In order to investigate which factors influence yields most significantly, a regression analysis was conducted for total cereal production in Hungary. As cereals (e.g. wheat, corn etc.) are the major agricultural products in Hungary we used them as a proxy to show the impacts of fertilizer use, irrigation, temperature, precipitation and the use of tractors and other machines on yields.

Having a look at the regression results for this period, a significant connection can be detected only between cereal yields and the amount of fertilizer between 1961 and 1974. The regression equation suggests that fertilizer is the major driver of yield over this time period.

Table 2
Regression analysis results on total cereal production in Hungary for three time periods

Wheat	1961-1974			1975-1989			1990-2007		
R	.966			.921			.932		
R Square	.932			.848			.868		
Adjusted R-Square	.884			.763			.813		
SEE	2031.51264			2713.57536			3480.72410		
Coefficients									
	Unstan-dardized Coeff.	Stan-dardized Beta	Sig.	Unstandar-dized Coeff.	Standardized Beta	Sig.	Unstan-dardized Coeff.	Standardi-zed Beta	Sig.
(Constant)	15386.20		.301	171753.79		.000	107121.703		.000
Fertilizer	15.203	.919	.000	11.199	.201	.259	26.198	.339	.010
Temperature	-31.587	-.013	.910	-459.539	-.226	.199	-2039.706	-.862	.000
Precipitation	-4.480	-.037	.770	-13.815	-.135	.460	31.301	.267	.045
Tractor	22.791	.040	.770	-1068.708	-1.097	.001	74.785	.411	.005
Irrigation	4.819	.063	.569	10.828	.126	.564	20.111	.066	.566

In the next period from 1975 to 1989 it can be observed that fertilizer use stagnated around the level of 200 kg/ha, and at the time of transition drastically decreased due to structural changes and a sudden rise in fertilizer prices. As for yield, it kept on increasing at a modest rate on average, but - looking at Fig. 1., - it is clear that there were great variations in the examined years. It can therefore be concluded that in this time period there were other significant factors which determined yields. As a result there is a need to analyze further the variations in cereal yield and its influencing factors.

Even temperature, precipitation, irrigation and fertilizer use are not enough to explain the deviation in yield; only the number of tractors used was proven to be significant. Over this period the highest use of fertilizer per hectare could be observed and according to our analysis its aggregated effect was not significant - its coefficient is also smaller compared to the other two periods. On the whole we can conclude that from 1975 to 1989 cereal yields were not affected by fertilizer use, which also corresponds with our assumption; namely that there is a point where fertilizer use no longer contributes to increasing yield and it can even cause a decrease in average yield.

As of 1990, a drastic break can be noted in the trend of fertilizer use (Fig. 2.). The amount of fertilizer used was reduced by one third due to the price pressure around the time of the political transition and structural changes in the economy. For the time interval 1990-2007, although cereal yields were also influenced by fertilizer use, the extent of this impact was much less than the impact of temperature, tractors and precipitation.

Although during the first two examined periods total cereal yield and yield per unit increased, it is revealed through our analysis that the yield per unit fertilizer used indeed decreased. The relation between the fertilizer used per unit area (kg/ha) and the yield per fertilizer unit were also analyzed, as shown in Fig. 3.

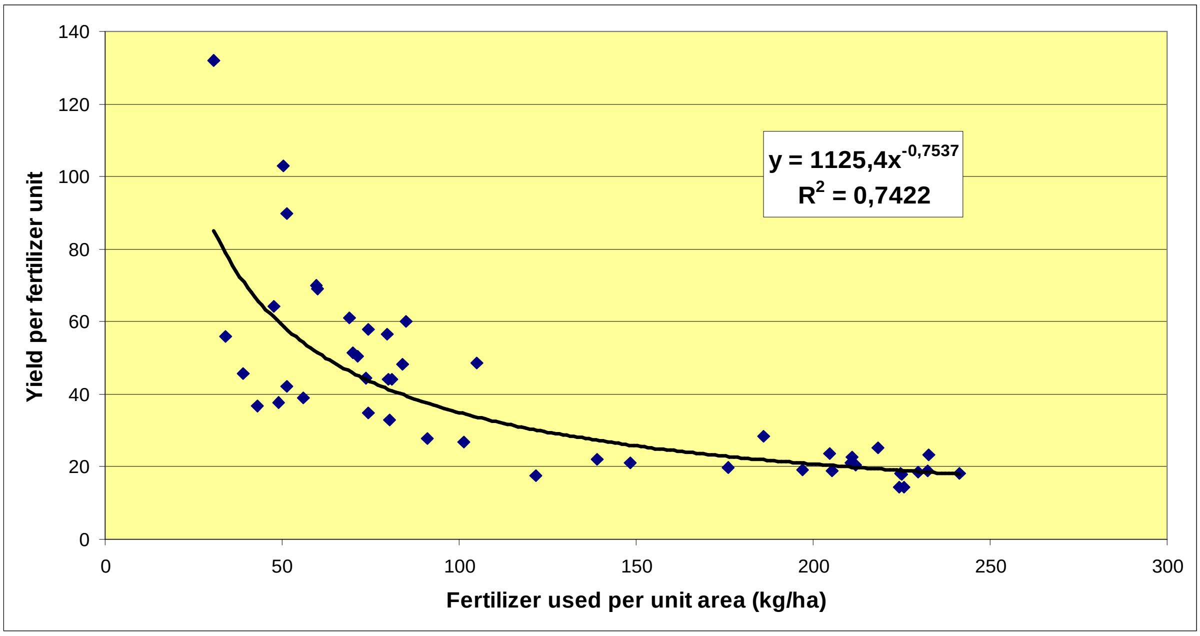

Fig. 3. The relationship between chemical fertilizer use and yield per unit fertilizer input in Hungary
(Source: authors' own calculation using FAOSTAT, 2010)

The relation which is depicted can be actually viewed as the marginal curve of fertilizer use. There is a clear inverse relationship between the amount of fertilizer used in Hungarian agricultural production and yield per fertilizer unit. The greater amount of fertilizer is used, the lower the yield per unit of fertilizer. This result confirms our hypothesis; namely that there is a soil saturation point and additional fertilizer input decreases marginal yield. Subsequently, the ecologically sustainable yield is where the saturation point meets the marginal function.

II. The Netherlands

In case of The Netherlands the fertilizer used and the yield per unit area can be seen on Fig. 4. Examination of the fertilizer use trends shows that there is a breaking point in the trend around 1985. Until that time chemical fertilizer used shows a clear trend to growth (from 1960 the use of fertilizer increased until 1984, which is followed by continuous growth in cereal yield as well). There was a peak in agricultural fertilizer use around the year 1985, and after this fertilizer use steadily decreased. Because of this major change in agricultural practices we divided the examined period into two parts using the break point of fertilizer use.

From 1961 to 1984 the positive effect of fertilizer use is clearly detected through the correlation coefficient ($r=0,708$ $p<0,000$), which indicates that the amount of fertilizer used very significantly correlated to the increase in yield.

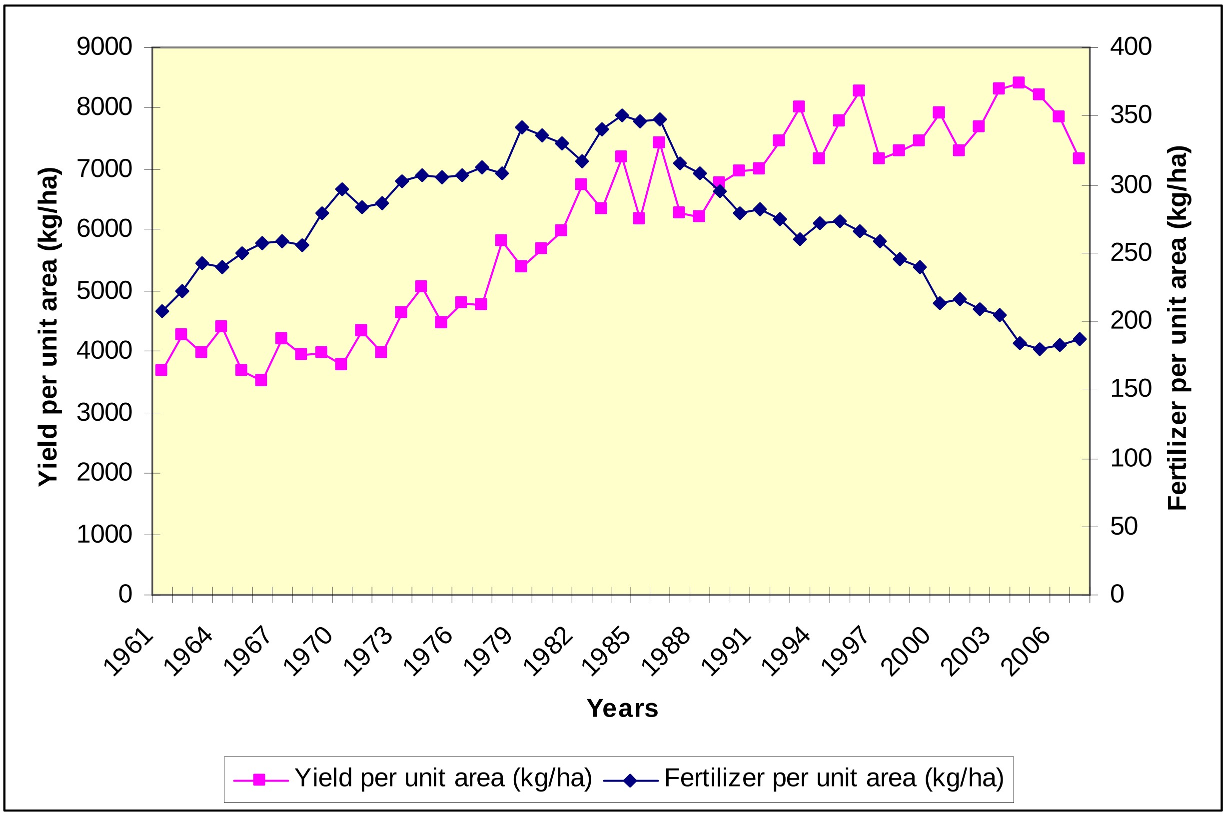

Fig. 4. Total cereal production yield and chemical fertilizer used per unit area in The Netherlands, (Source: FAOSTAT data, 2010)

Looking at the yield trends after 1985, it can be noticed that in spite of the decrease in fertilizer use, yields did not decrease but kept on growing (at a slower growth rate than before) while after 1995 variation in yield started to increase. There were years with a higher yield, but a stagnating trend can also be observed, which could turn easily and not surprisingly into a decrease. This phenomenon was due to saturation of the soil and the fact that even applying a smaller amount of fertilizer can result in the same yield, and also by the fact that it is not only fertilizer use which determined yield. This finding is underpinned by the negative correlation coefficient ($r=-0,682$ $p<0,000$) for the period 1985-2007.

Table 3
Results of Regression Analysis on Total Cereal Production in The Netherlands, over Two Time Periods

Wheat	1961-2007		
R	.875		
R Square	.765		
Adjusted R Square	.736		
SEE	8012.484		
Coefficients			
	Unstandardized Coeff.	Standardized Beta	Sig.
(Constant)	79345.079		.007
Fertilizer	-136.844	-.897	.000
Temperature	145.676	.027	.805
Precipitation	-23.590	-.078	.337
Mechanization	25.205	.671	.000
Irrigation	29.617	.128	.328

As for the regression results for the whole time period examined, it is shown in Table 3 that fertilizer use has a significantly negative impact on total cereal yield. The other influential factor proved to be mechanization (number of tractors/ha). The scale of intensity of agricultural practices can be clearly followed by the regression model, which also shows the significance of the relation of marginal yield to efficient fertilizer use. This analysis highlights that natural effects such as temperature and precipitation are clearly not significant; fertilizer use and mechanization are the main factors determining yield. Contrarily, in Hungary, where after the transition extensive agricultural practices were utilized, the impact of temperature played the main role and the use of fertilizer and machines influenced yield only secondarily.

6. 2. A Proposal for Defining the sustainable yield/efficient use of fertilizer/marginal yield

As mentioned above, this paper proposes a modification concerning the use of yield factors when calculating biocapacity and at correcting the distortion stemming from different agricultural practices in different countries. The aim of the analyses described above was to find out the relation affecting agricultural yield, and to find out how the marginal yield can be defined.

In order to represent real biological capacity, we have to take into consideration primarily the consequences of the agricultural practices utilized during the calculation process for Biocapacity. Increased yields show the real amount of land required, but not the sustainable amount, and may indicate environmental loading. The yield factor represents the national yield relative to global average yields, which does not include the harmful impacts of fertilizer and pesticide use or animal waste. In this way the yield factor used in calculating biocapacity does not show sustainability limits. As a result there is a need to modify the calculation process for biocapacity, taking into account the polluting features of agriculture.

In the previous section it was shown that applied fertilizer has the greatest impact on yield until the soil becomes oversaturated with nitrate, phosphate and other elements. After this point fertilizer use begins to become ineffective at raising yields and may degrade the soil, groundwater and surface water. It is suggested that national yield factors should be recalculated through accounting for the damage caused to over-fertilized soil. As nitrate contamination is currently one of the most crucial issues in soil conservation, it is proposed that marginal yield be determined with reference to the harmful nitrate content of soil. The yield factor should be modified to include the national sustainable yield correlated to real yields, and should express whether yield is in accordance with the sustainability of soil.

First, the so-called marginal yield was calculated in order to investigate the amount of inorganic fertilizers which may be efficiently applied and to contribute to the sustainability of agricultural practices. The calculation of this marginal yield (which in effect could represent the maximum yield), is based on the relation of groundwater nitrate content and the yield per fertilizer unit.

Fig. 5. shows the results of this calculation for the case of the potato production in the Netherlands. The amount of fertilizer used is within sustainability limits where the groundwater nitrate content per fertilizer unit is lower than the yield per fertilizer unit (the nitrate content of the groundwater was used in the calculations because of data availability).The maximum amount of fertilizer which can be used within sustainability limits is at the intersection of the two functions. From knowing the amount of fertilizer, marginal yield can be calculated.

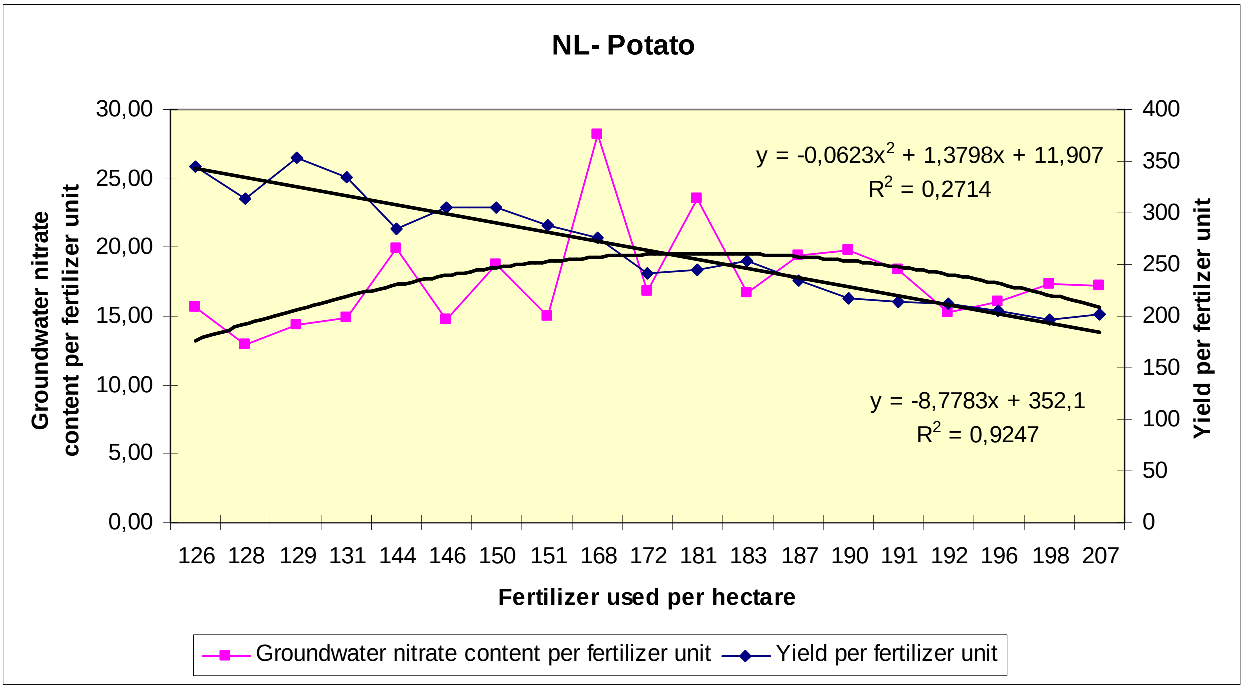

Fig. 5. The yield per fertilizer unit and the groundwater nitrate content per fertilizer unit, in case of the Netherlands (Source: EEA Waterbase, 2010 and IFA Database, 2010)

After calculation of marginal yield, the modified yield factor was calculated, as was modified biocapacity, using the modified yield factor. The results for the Netherlands are shown in the following table. It can be seen that, as the Netherlands uses a high amount of fertilizers in the case of each crop, it contributes to groundwater pollution. The new, modified yield factor is in all cases less than the original one (as given in the Global Footprint Network database), which means that, compared to the world yield, the national yield which is desirable from the point of view of minimizing the environmental impacts of agriculture is less than the actual yield. Biocapacity thus modified decreases as environmental impacts on the soil are taken into account. This methodology provides a way to show the difference between the real biocapacity of agricultural products and the actual ecological footprint.

Table 4 shows, for The Netherlands the results of calculations, modified yield factor and modified biocapacity for the main four agricultural products (FAOSTAT, 2011).

Table 4
Results of modification of the yield factor and biocapacity for The Netherlands for four crops

	The Netherlands			
	Potatoes	**Tomatoes**	**Maize**	**Sugar beet**
Fertilizer used per unit area (kg/ha)	172.5	133.4	39.3	112.9
Yield per fertilizer unit (kg/ha)	240.6	2 939.5	280.1	560.0
Yield (t/ha)	43 442.3	472 779.3	12 200.3	64 961.6
Yield factor	**2.56**	**17.0**	**2.49**	**1.40**
Marginal yield (t/ha)	41 488.0	39 2307.6	11 000.0	63 238.1
Modified yield factor	**2.44**	**14.11**	**2.25**	**1.36**
Area used (ha)	156 000	1 396	20 748	91 300
EQF	2.64	2.64	2.64	2.64
Biocapacity (ha)	1 055 950	62 771	136 601	337 969
Modified Biocapacity (ha)	**1 008 447**	**52 087**	**123 162**	**329 003**
Proportion of the modified biocapacity	**96 %**	**83 %**	**90 %**	**97 %**

Source: authors' own calculation using data from IFA(2010), GFN (2010) and EEA Waterbase (2010)

It can be seen from the results that the modification of the yield factor generates a significant change in the biocapacity as well. The greatest difference is in the case of tomato production, where the modified biocapacity is 83 % of the original. The marginal yield is attempting to express the amount of production which could sustain the long-term agricultural practices and knowing the marginal yield the efficient amount of fertilizer could be applied.

7. Summary

As the population of the world grows, there will be an increasing demand for greater agricultural output. This demand exacerbates the difficulty of managing agriculture sustainably. This study has shown the importance of defining the so-called marginal yield regarding the efficient use of chemical fertilizer.

We conclude that the structural differences in agriculture have a great impact on the calculation of biocapacity, which indicates rethinking the way this indicator has been calculated so far. We suggest that the long-term environmental impacts of intensive agricultural practices should be built into the Ecological Footprint model; namely that national yield factors should be modified when calculating the biocapacity of a country.

Fertilizer use and its marginal contributions to agricultural yield appear to be a useful proxy for to evaluating the impact and efficiency of agricultural practices. Results indicate that in the Netherlands the marginal benefits of additional fertilizer use can be even negative.

As for the marginal yield, one estimation method is presented herein, and a modification of the yield factor is proposed. Using marginal yield for calculating cropland biocapacity is a pressing requirement. Determining the real biocapacity of a country within sustainability limits could assist in planning agricultural production without causing irreversible ecosystem damage.

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