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Land take and food security: assessment of land take on the agricultural production in Europe

Ciro Gardi[a]*, Panos Panagos[a], Marc Van Liedekerke[a], Claudio Bosco[b] and Delphine De Brogniez[a]

[a]*European Commission, Joint Research Centre, Via E. Fermi, 2749 - I-21027 Ispra (VA), Italy;* [b]*Department of Civil and Building Engineering, Loughborough, UK*

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Soil is a multifunctional, non-renewable natural resource for Europe as clearly expressed in the European Union (EU) Thematic Strategy for Soil Protection (COM (2006)231). Soil carries out multiple functions, including the support of food production. Urban development and its associated land take poses a major threat to soil and could have significant effects on agricultural production. This paper aims to evaluate the potential productivity losses in European agriculture due to land-take processes between 1990 and 2006. Agricultural land take was calculated using CORINE Land Cover maps of 1990, 2000 and 2006. For 21 of the 27 EU member states, agricultural land take was computed to be 752,973 ha for 1990–2000 and 436,095 ha for 2000–2006, representing 70.8% and 53.5%, respectively, of the total EU land take for these periods. The impact of this land take on the production capabilities of the agricultural sector for the period 1990–2006 for 19 of the 21 states was estimated to be equivalent to a loss of more than six million tonnes of wheat. The paper demonstrates that Europe's intense urbanisation has a direct impact on its capability to produce food.

Keywords: land take; soil sealing; food security; agricultural production capability; European Union

1. Introduction

Soil is a limited and non-renewable resource, as pointed out in the Thematic Strategy for Soil Protection (EC 2006), through which the European Union (EU) defines its action plan for soil conservation in Europe. Eight soil degradation processes that constitute major threats to soil productivity in the EU have been identified by both the European Commission and the Council in the Thematic Strategy for Soil Protection (EC 2002). These are erosion, organic matter decline, contamination, salinisation, compaction, soil biodiversity loss, sealing and landslides. As a result of urban sprawl and growing demand for land from various sectors in the economy, land take and, more specifically, soil-sealing activities, are becoming significantly more intense in the EU. *Land take* generally manifests as an increase in artificial surfaces (e.g. residential areas, green city/town areas, manufacturing plants, business centres, public transport networks) over time, whereas *soil sealing* is the permanent covering of the soil layer with a persistent material (Prokop, Jobstmann, and Schönbauer 2011).

*Corresponding author. Email: ciro.gardi@jrc.ec.europa.eu

The EU's Thematic Strategy for Soil Protection also underlines the importance of a number of soil functions, such as food production, biodiversity habitat, biomass production, source of raw material and cultural environment for humans. Soil functions can co-exist, in that the maximum exploitation of one function does not necessarily exclude the maximum exploitation of others. The most relevant soil functions that can directly impede others are its use as a physical and cultural environment for humans and its use as source of raw material. Soil sealing inevitably prevents soil from performing some of its natural functions (such as biomass and food production, water storage and filtering) and decreases its ability to perform others, such as providing a habitat for biodiversity or a reserve for organic matter.

The status of soil sealing and land take in the EU is described in detail in a report issued by the European Commission (Prokop, Jobstmann, and Schönbauer 2011). In Germany, land-take rates reached 130 ha/day during the period 1990–2000 (Fischer el al. 2009). According to the latest EU country reports on the assessment of the state of environment (EEA 2010), Italy showed an increase in the area of its sealed surfaces, with higher rates occurring in northern Italy. In 2000, sealed areas in north-western Italy covered 6.7% of total land surface. By 2006, this figure had increased to 7.3%. The alarming situation is evident in some regions of Europe. For example, the Emilia-Romagna region lost 8 ha/day of agricultural soils to soil sealing during the period 1976–2003, and the Lombardy region lost 10 ha/day during the period 2000–2006 (ISPRA 2008). Estimates of land taken by soil sealing in Austria range between 15 and 25 ha/day (Nestroy 2006). There is an increasing attention and recognition to the importance of land take, as can be demonstrated by the rapid growth of scientific literature on this subject: from 19 papers in 1990 to more than 350 papers in 2013. The vast majority of this scientific literature deals with the estimation of the rates of soil sealing and land take (Sulzer and Kern 2009; Müller, Steinmeier, and Küchler 2010; Munafò, Salvati, and Zitti 2013; Xiao *et al.* 2013; Salvati 2013), while the remainder focuses on the impacts of soil sealing, such as on water regulation (Depietri, Renaud, and Kallis 2012; Pegado *et al.* 2012; da Silveira and de Oliveira 2013), on microclimate (Gardi, Dall'Olio and Cavallo 2007; Nobre *et al.* 2011; Depietri, Renaud, and Kallis 2012), and on microbial activity and diversity (Zhao *et al.* 2012; Wei *et al.* 2013).

The urbanisation of territories frequently occurs on the most productive soils at the expense of agricultural activities (Imhoff *et al.* 1997; Hathout 2002). This has a significant effect on the agricultural sector, reducing its ability to produce food and feed. Crop productivity (the quantity of harvested product per unit area) depends on many factors such as the characteristics of the soil on which the crops are grown, climatic conditions, management practices and the genetic material of the crops. During the past century, the productivity of most crops has increased (Sunding and Zilberman 2001; FAO 2008), although the rate of this increase has progressively diminished (FAO 2008; FAOStat 2012). It may prove difficult to compensate reductions in the extent of agricultural areas by increasing crop productivity.

The shrinking of the agricultural land area in Europe will cause an "indirect land use change" (Gnansonou *et al.* 2008). For example, if an area of arable land is lost in a certain area of Europe, this could be compensated by converting areas of natural or semi-natural land to agricultural use elsewhere. In fact, this is already happening in Africa, Latin America and North America, where parts of natural or semi-natural areas are converted to arable land for the production of cereals, soy beans, sugarcane, etc. (Harvey and Pilgrim 2011). The increasing demand for feed and food commodities (Tomlinson 2013), not only in Europe but also in China and other emerging countries, is reshaping the land use and land cover of the planet. Therefore, land take can be regarded as a major driver of land-use changes.

Soil sustains (directly or indirectly) more than 95% of global food production (FAO 2008). The estimated global increase of the world population from 6.8 billion in 2009 to 9.2 billion in 2050 (Speidel *et al.* 2009) will lead to a significant increase in both food demand and land take. The combination of these conflicting processes raised international concern for global food security. Major factors influencing global food security are cropland shrinkage, fisheries reduction, increased wealth in countries such as China and India with consequent increased demand for food (Godfray *et al.* 2010), global warming (Millennium Ecosystem Assessment 2005) and an overall intensification of agriculture and greater pressures on soils.

Biofuel production also represents a major concern with regard to land availability for crop production. The International Energy Agency scenarios for land use (IEA 2004) estimated that approximately 5% of the EU's cropland area would have to be converted to biofuel production in order to replace 5% of its petrol supply, while 15% of its cropland area would have to be converted to substitute 5% of the diesel supply (Escobar *et al.* 2009). A total of 1.5 billion hectares of land is currently used worldwide for crop production. This represents 11% of the planet's land surface (FAO 2003). The FAO (2003) also reports that 2.7 billion hectares of land with crop production potential remain unexploited. However, these figures might over-estimate the land available for agricultural production (Bot, Nachtergaele, and Young 2000). Some of the land that could potentially be used for agriculture is subject to ecological constraints and pollution, while other land is protected or occupied by other land uses (e.g. forests and woodlands, human settlements).

Sprawling cities tend to consume the best agricultural lands, forcing agriculture to move to less productive areas (Scalenghe and Marsan 2009). The extent of agricultural land and, to a smaller extent, woodlands and semi-natural and natural areas, is decreasing due to the development of sealed zones (EEA 2011). Urban centres often expand on the most productive land because cities are historically built on fertile soils (Satterthwaite, McGranahan, and Tacoli 2010). In addition, land take causes environmental perturbations that affect agricultural ecosystems (e.g. landscape fragmentation, changes in the water cycle and reduced habitats). There is increasing evidence that European cities tend to become more dispersed, as a result of the spread of low-density settlements (urban sprawl) (Kasanko *et al.* 2006), increasing similarities with urban areas of the US. However, differences among the urban structures and their dynamics between the US and Europe remain important, mainly because different relationships exist between central and local governments (Summers, Cheshire, and Senn 1999).

Land-take processes are occurring in other parts of the world at considerably higher rates than in Europe, especially in countries with rapidly growing economies. For example, 5.1% of the overall territory in China was lost to manufacturing and municipal activities during the period 1996 to 2003 (Chen 2007), and in the Beijing–Tianjin–Hebei region the urban area growth expanded by 71% between 1990 and 2000 (Tan *et al.* 2005). Similar growth rates have been recorded also in India (Fazal 2000) and in other fast growing countries. Worldwide urban areas are expanding at twice their population growth rates (Angel *et al.* 2011).

The main objective of this paper is to assess the effect of land take on Europe's ability to produce food, considering data from the period from 1990 to 2006.

2. Materials and methods

2.1. CORINE datasets

In 1985, the European Commission launched the CORINE (Coordination of Information on the Environment) programme. The two main objectives of the CORINE Land Cover (CLC) project were (a) to provide reliable quantitative data on land cover across Europe, and (b) to develop one complete spatial dataset covering the EU member states (MS) plus several other European and North African countries. The CORINE datasets (CLC 2011) were developed by image analysis and digitisation of Landsat photos in a GIS environment.

CORINE Land Cover datasets from 1990, 2000 and 2006 were used to assess the extent of land take of agricultural lands in the EU. The datasets contain homogeneous data on land cover areas which are represented as polygons (shapefiles). The data comparison was only performed for 21 of the 27 EU MS, due to the incompleteness of the data for six MS (Cyprus, Greece, Finland, Latvia, Sweden and the UK).

The CORINE Land Cover datasets were established following harmonised procedures based on a common classification system, and can therefore be easily compared (Neumann *et al.* 2007). Data are classified in 44 land-cover classes, grouped into three hierarchical levels (Bossard, Feranec and Otahel 2000). Their nominal scale is 1:100,000 with a Minimum Mapping Unit (MMU) of 25 ha and a change detection threshold of 5 ha. The CORINE Land Cover MMU size underestimates the landscape diversity trends (Saura 2002). A case study in Italy demonstrates that land take rate is underestimated, especially in rural areas (Munafò, Salvati, and Zitti 2013).

Quality assessment of the CLC data was performed to ensure an integrated, harmonised and consistent European database (Feranec *et al.* 2007). In addition, an independent interpretation that used LUCAS (Land Use/Cover Area Frame Survey) data (Buttner and Maucha 2006) showed that the reliability of CLC2000, at 95% confidence level, is $87.0 \pm 0.7\%$.

2.2. NUTS dataset

NUTS (Nomenclature of Territorial Units for Statistics) is a system used by the administrative authorities of EU institutions and MS for classifying the European territory into hierarchical levels (regions) with the objective of relating statistical data to geographical areas (Becker, Egger, and von Ehrlich 2010). Eurostat, the European Commission's statistical service, classifies three types of NUTS regions (Eurostat 2011) according to population, size and administrative divisions; NUTS1 regions cover areas with a population of 3–7 million, while NUTS2 and NUTS3 regions contain populations of 0.8–3 million and 150–800 thousand, respectively. The evaluation of land take of EU agricultural land was performed at the NUTS2 level, at which the EU regional policies are implemented and for which agricultural data are available. Soil-related indicators, such as soil organic carbon, are also typically aggregated at the NUTS2 level (Panagos *et al.* 2013).

2.3. Average winter wheat production in Europe

Cereals represent the most significant source of food in the world (FAO 2003) either directly, as food for human consumption, or indirectly, for feeding livestock. In the current assessment, winter wheat was used as the model crop because of its importance and its wide geographic distribution.

Agricultural production and productivity diverge to a great degree within the European Union, due to variability in weather, land and various economic factors. Bakker *et al.* (2005) demonstrated that spatial variability in wheat productivity is high in Europe.

Average yearly yields for each NUTS2 unit were provided by the European Commission's Joint Research Centre (MARS 2012) for the period 1992–2004, based on Eurostat data. A quality check was performed on these data in order to detect potential anomalies in the time series. For each NUTS2 area, the Coefficient of Variation (CV) was calculated for the time series of yields. Time series with a CV greater than 0.5 were carefully checked; values that differed from the average by more than the Standard Deviation were removed and a new average value was calculated. In this way, possible outliers (for example, due to extreme climatic events) were excluded from consideration in the calculation process.

In 2000, Rabbinge and van Diepen also used winter wheat as an indicator for regional production potential in Europe. They used the same data source (MARS) as input to a country-level production model. The MARS data should be considered accurate as it comprises annual yield data that are officially delivered by MS to Eurostat.

2.4. Methodology

Land Cover (LC) change within a geographic area is interpreted as a categorical change where one LC class or its parts are replaced by another LC class (Coppin *et al.* 2004). In this study, land take is defined as the change of land from agricultural to artificial use. Using the CORINE datasets, classes at the second hierarchical level were used to detect changes from agricultural land (arable land; permanent crops; pastures; heterogeneous agricultural areas) to artificial land (urban fabric; industrial, commercial and transport units; mining, dump and construction sites; artificial, non-agricultural vegetated areas). As a first step, two land-take maps were generated by applying a number of GIS operations to CORINE datasets, one for the period 1990–2000 and another for the period 2000–2006 (see Figure 1).

It should be noted that a land take of 5 ha is more likely to occur over 10 years (1990–2000) than over six years (2000–2006). It follows that the total land take might be underestimated in the six-year period studied. Another source of potential land-take underestimation is the low spatial resolution of CORINE Land Cover (1:100 000).

In a second step, each land-take map was overlaid with NUTS2 polygons, in order to compute the extent of agricultural land taken in each NUTS2 administrative unit. This step was taken because agricultural productivity data were only available at the NUTS2 level.

Potential Agricultural Production Capability (PAPC) for a certain area is defined as the potential agricultural production in this area. The output of winter wheat production activities is taken as a proxy for PAPC, expressed in tonnes (t). The calculation of the loss of PAPC in a NUTS2 region was based on land take (in hectares) and the average winter wheat yields (MARS data) (t/ha) for that region.

The calculations were performed on the basis of Equation [1] for a given period:

$$\mathrm{PAPC\_LOSSES}_{NUTS2} = \mathrm{ALT}_{NUTS2} * \mathrm{AWWY}_{NUTS} \qquad [1]$$

where:

$\mathrm{PAPC\_LOSSES}_{NUTS2}$ = Losses of PAPC at NUTS2 level (in tonnes of winter wheat)

ALT_{NUTS2} = Land take of agricultural area at NUTS2 level (ha) for the given period

AWWY_{NUTS2} = Average Winter Wheat Yields at NUTS2 level (t/ha) for the given period

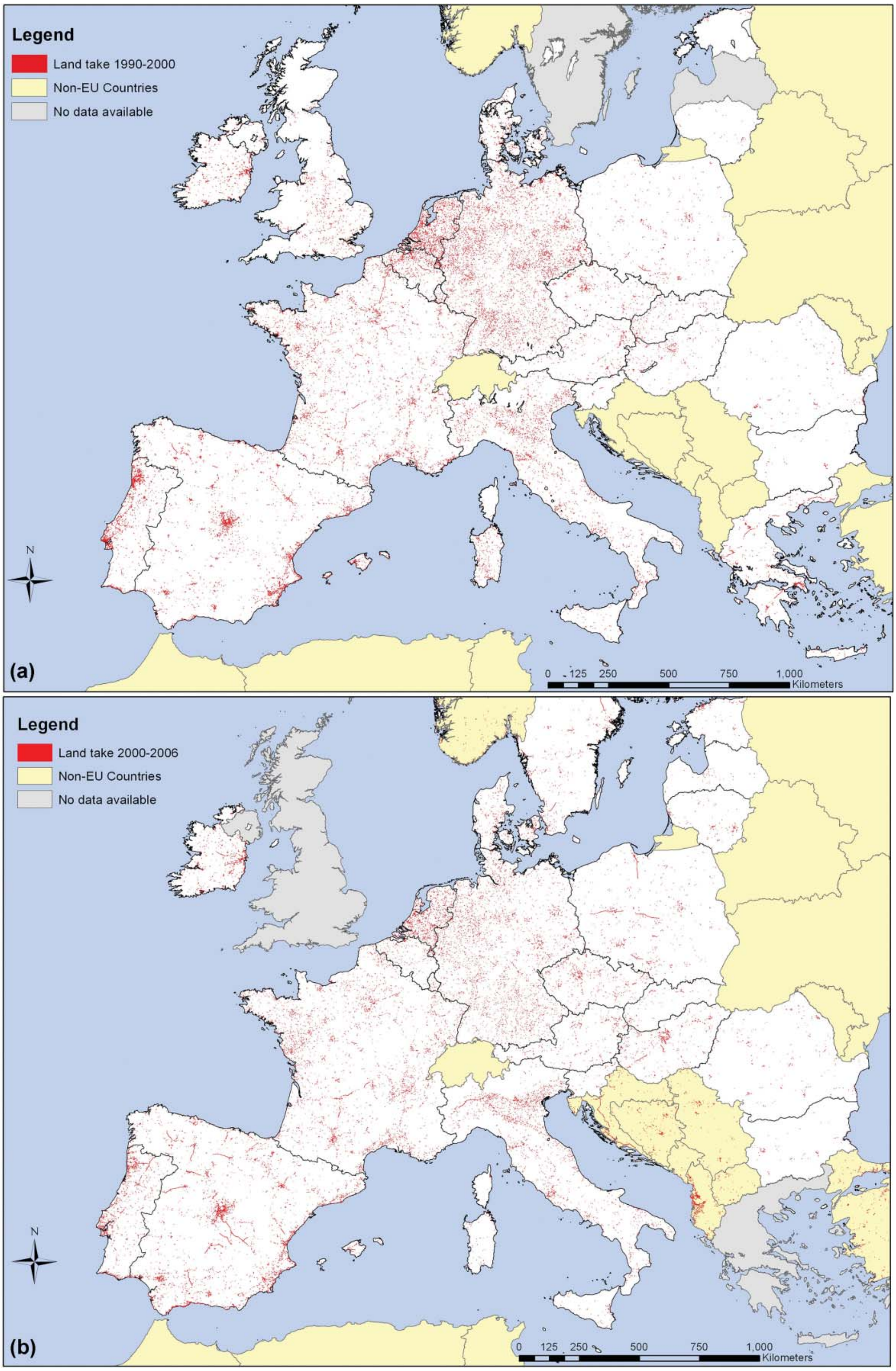

Figure 1. Spatial distribution of land take for two periods: 1990–2000 (a), 2000–2006(b). (See online colour version for full interpretation.)

This methodology allowed for the estimation of the loss of agricultural areas due to land-use change and the subsequent reduction of the PAPC at the NUTS2 level between 1990–2000 and 2000–2006.

3. Results

In general, observation of the CORINE Land Cover datasets (EC 2006) reveals that considerable land use changes (2.8%) occurred in Europe during the period 1990–2000, including a significant increase in artificial areas. Large variations between MS and regions exist, with land taken ranging from 0.3% to 10%. By 2006, almost 100,000 km^2, i.e. 2.3% of EU land was sealed, which translates into 200 m^2 of sealed surface per capita.

In the 21 MS studied, the land take from agriculture was calculated to be 752,973 ha for 1990–2000 and 436,095 ha for 2000–2006. In order to illustrate the evolution of agricultural area losses between 1990–2000 and 2000–2006 in these countries, the 'trend' was defined as follows:

$$\text{Trend} = \frac{\text{YALT}_{2000-2006} - \text{YALT}_{1990-2000}}{\text{YALT}_{1990-2000}} \qquad [2]$$

where:

$\text{YALT}_{1990\text{–}2000}$ = Yearly Average Land Take of agricultural area between 1990 and 2000

$\text{YALT}_{2000\text{–}2006}$ = Yearly Average Land Take of agricultural area between 2000 and 2006

The yearly data in Table 1 could also be expressed as a daily land-take rate in order to highlight the problem, raise awareness and alert policy makers. Countries that showed the highest daily land-take rate in absolute terms from 2000–2006 are Spain (48.3 ha/day), France (34.7 ha/day), Germany (26.5 ha/day) and the Netherlands (16.1 ha/day). In the 21 countries as a whole, approximately 206.6 ha/day and 199.2 ha/day were lost during the 1990–2000 and 2000–2006 periods, respectively. The latter figures show that the trend in the overall EU land take from agriculture is slightly negative (-3.6%). This trend may be due to the minimum detectable change being 5 ha, which is more likely to occur over 10 years than over six years. Gross Domestic Product (GDP) trend is demonstrated (Table 1) as it has been identified as the main driver for land take.

Since the 21 countries differ in size and amount of available agricultural land, the annual agricultural land take was estimated separately for each country. Figure 2 shows that some of them faced significant losses. For example, the Netherlands lost 2.3% of its agricultural land during the period 1990–2000, which translated into an average loss of 0.23% annually. Figure 2 also shows that Belgium, Germany, Ireland, Luxembourg and Portugal faced the same problem at a smaller scale during the period 1990–2000. Conversely, Spain, Ireland and Denmark show an increasing trend of land take during the period 2000–2006.

The loss of PAPC in a country was estimated using winter wheat as a model crop and following the methodology described above. Bulgaria and Malta were not taken into consideration for further analysis due to incomplete values of AWWY_{NUTS2}. Figure 3 shows the results of PAPC losses for the 19 countries studied.

AWWY_{NUTS2} varies significantly between Mediterranean and northern European countries, with a downwards north–south productivity gradient. The lowest AWWY_{NUTS2}

Table 1. Land take from agriculture and Gross Domestic Product (GDP) change.

	Country	Agricultural land take			Annual GDP		
		1990–2000 ($AgriLandTake_{1990\text{-}2000}$)	2000–2006 ($AgriLandTake_{2000\text{-}2006}$)	Trend	1990–2000 (average change)	2000–2006 (average change)	Trend
ISO	Full name	ha y^{-1}	ha y^{-1}	%	%	%	%
AT	Austria	1034.0	870.0	−15.9%	2.2	1.8	−0.5
BE	Belgium	1578.8	425.7	−73.0%	2.0	1.8	−0.2
BG	Bulgaria	281.1	569.6	102.6%	−0.4	7.5	8.0
CZ	Czech Republic	945.7	2011.1	112.7%	0.3	4.8	4.5
DE	Germany	19,097.1	9667.5	−49.4%	1.9	1.0	−0.9
DK	Denmark	1239.0	1728.6	39.5%	2.5	1.2	−1.2
EE	Estonia	147.9	365.5	147.2%	0.8	10.5	9.6
ES	Spain	11,871.7	17,638.1	48.6%	3.0	3.5	0.5
FR	France	11,570.0	12,697.4	9.7%	1.6	1.2	−0.3
HU	Hungary	953.2	2502.9	162.6%	1.0	5.0	4.0
IE	Ireland	3119.9	3274.6	5.0%	8.2	4.8	−3.4
IT	Italy	7931.5	7735.5	−2.5%	1.5	0.9	−0.6
LT	Lithuania	51.9	550.5	961.7%	−2.7	9.7	12.4
LU	Luxembourg	170.6	62.1	−63.6%	nd	nd	nd
MT	Malta	1.2	1.1	−13.9%	nd	nd	nd
NL	Netherlands	8130.2	5878.7	−27.7%	2.8	1.1	−1.8
PL	Poland	1708.8	2882.9	68.7%	4.3	4.0	−0.3
PT	Portugal	4243.5	1838.1	−56.7%	2.8	0.5	−2.2
RO	Romania	743.4	1395.5	87.7%	−1.4	7.4	8.8
SI	Slovenia	11.9	69.5	484.5%	1.9	4.6	2.7
SK	Slovakia	465.8	517.7	11.1%	0.6	5.9	5.3
Total		75,297	72,682	−3.5%			

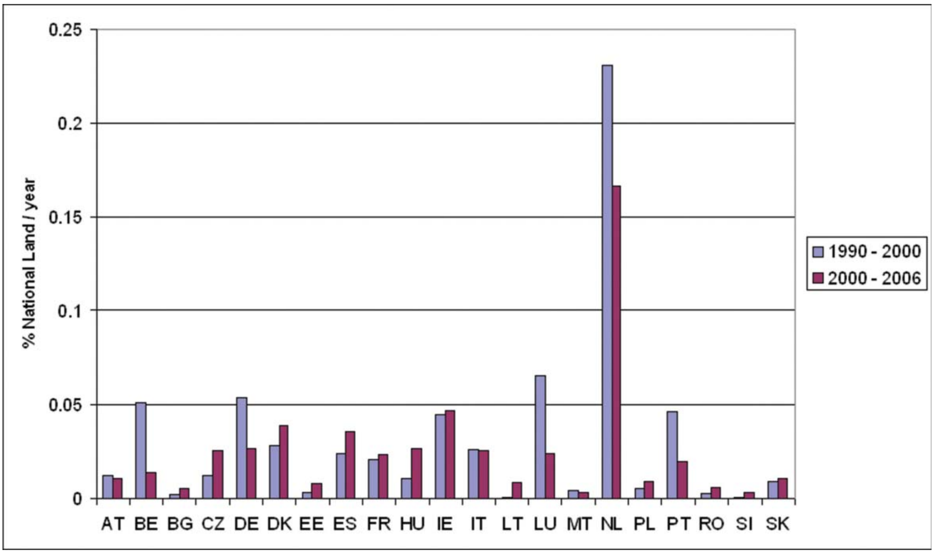

Figure 2. Annual agricultural land take (%) per country.

values are observed in the Algarve (PT) with 0.73 t/ha, Región de Murcia (ES) with 0.99 t/ha, and Norte (PT) with 1.20 t/ha. The highest values are observed in Schleswig-Holstein (DE) with 8.97 t/ha and the Border-Midland-Western region (IE) with 8.56 t/ha.

The loss of PAPC due to land take in the 19 countries (183 NUTS2 regions) for the whole period 1990–2006 was calculated at 6,122,400 tonnes of wheat. This loss will

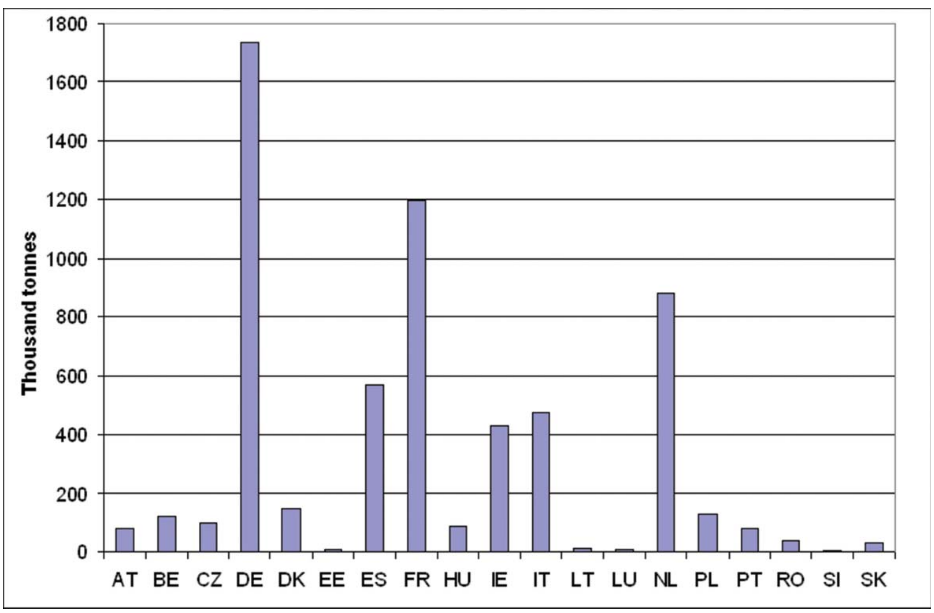

Figure 3. Potential wheat yield losses (Thousands tonnes) due to loss of agricultural land (1990–2006).

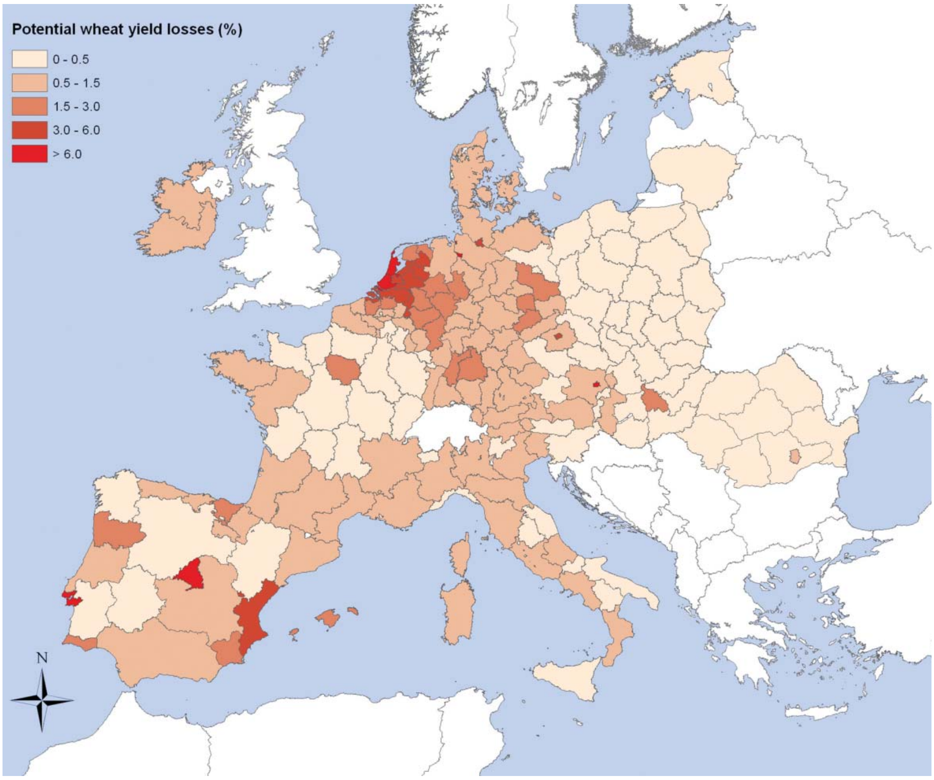

Figure 4. Potential wheat yield losses (%) of NUTS2 production for the period 1990–2006. (See online colour version for full interpretation.)

probably be larger for the EU as a whole when the UK, Finland, Sweden, Greece, Bulgaria, Latvia, Cyprus and Malta are also taken into account. Since the total PAPC is estimated to be 768,000,000 tonnes of wheat for the studies in the 19 countries (reference year 2000), it can be concluded that approximately 0.81% of PACP was lost due to land take in the EU during the period 1990–2006.

The spatial variability of the loss of PAPC that occurred during the 1990–2006 period is very large; 61% of the regions lost less than 1% of PACP while other regions lost more than 10%. The spatial distribution of PACP losses per NUTS2 region is shown in Figure 4. The regions with the highest loss of PACP have been investigated in greater detail. Analysis of the results shows that the greatest trends in agricultural land transformation are recorded near the largest cities and metropolitan areas of Central and Western Europe and along the coastal areas of Southern Europe. With a loss of 11.93%, Vienna (AT) shows the highest PAPC loss during the 16-year period (1990–2006), followed by the Comunidad de Madrid (ES) with 10.75%, Lisbon (PT) with 8.65%, Zuid-Holland (NL) with 8.03% and Bremen (DE) with 7.41%. The same applies to the coastal areas in Spain, where the Comunidad Valenciana has one of the highest rates of PACP loss, at 3.64%. According to Figure 4, approximately 80% of the NUTS2 regions show a PACP loss of less than 1.5%. Most of these regions belong to the new member states.

Given the reliability of the data inputs (CORINE, MARS data), the resulting data (land take, PACP) can also be considered to be reliable.

4. Discussion

A small country, characterised by high population densities, e.g. the Netherlands, presents, in relative terms, the greatest loss of agricultural area due to land take (Figure 2) and one of the largest when absolute values are considered (Table 1). This country lost almost 2.5% of its agricultural land during the period 1990–2000 and 1% during the period 2000–2006. The greatest land take in absolute terms took place in the largest EU countries: Germany, Spain and France (1990–2000) and Spain, France and Germany (2000–2006) (see Table 1).

Since the two observed land-take periods are of different durations, the yearly land-take rates were compared. Most of the new EU MS (BG, CZ, EE, HU, LT, PL, RO, SI, SK) observed an increasing trend in agricultural land take over the period 1990–2006 (see Table 1). This fact is correlated to their economic development (rapid increase in Gross Domestic Product – GDP) (UN 2014) and to the remittances of citizens of these countries working abroad, often used for the construction of a family house. In contrast, for the majority of older MS (AT, BE, DE, IT, LU, NL, LU, PT), the trend for land take is decreasing in accordance to the negative trend in their GDP growth (see Table 1). The increasing land-take trends for Spain and Ireland (see Table 1) could be explained mainly by the 'construction boom' that took place in these countries over the past 25 years (Honohan 2009; Burriel 2011), and is only partially linked to the demographic growth.

A land take of approximately 1.2 million hectares over the period 1990–2006 in the 21 MS studied is the equivalent of approximately 500 football pitches being out of agricultural production every day. This also corresponds to the loss of an agricultural land area of approximately one-third the size of Belgium during a period of 16 years.

The estimated loss of PAPC resulting from this land take is more than 6.2 million tonnes of wheat for the 16-year period reviewed, or 0.81% of the total available PACP (reference year 2000). According to Eurostat data, this figure is comparable to the total wheat production of Spain or Romania for the year 2006, and corresponds to approximately 6% of the wheat production of the 19 MS studied.

The greatest land-take pressures were identified in regions which include large cities and metropolitan areas such as Vienna, Lisbon and Madrid, and in the coastal zones of the Mediterranean. The trend indicates that similar pressures could be experienced in the regions of the new MS where land take is increasing in areas close to large cities.

At European Union level, the reduction of land take is advocated in the European Commission Communication 'Roadmap to a Resource Efficient Europe' (EC 2011) which sets as an objective the reduction of land take by 20% by 2020 (compared to current figures) and by 100% by 2050. Several countries within the EU have implemented measures to limit soil sealing, or at least to protect the best agricultural soils (Prokop, Jobstmann, and Schönbauer 2011). Concern is also rising in China about the expansion of cities into rural landscapes (Chen 2007). Relevant legislative proposals have been made to address these concerns.

At the global level, the target of reducing land take was confirmed by the conclusions of the Rio+20 Conference (UNCCD 2012). The European Union led the Rio+20 Conference discussions on 'zero net land degradation' (including land take) and concluded that this is extremely important for global food security.

Technical options that could be adopted to reduce the impacts of land take have recently been published (Prokop, Jobstmann, and Schönbauer 2011). The first option is to reduce the rate of land take by limiting land use change from agriculture to artificial use or by promoting the re-use of areas already under artificial land use such as brownfields

(Schädler *et al.* 2011, 2012). Other options are to mitigate and compensate the effects of land take on the ecosystem services provided by soil, including water and carbon storage. The experiences gained from applying these options could also inform other countries, such as China, which face the same problem.

The impact of agricultural land take could also be analysed by considering the evolution of cereal yields in Europe. Brisson *et al.* (2010) showed that, after half a century of steady growth in cereal yields in Europe, the past two decades have shown a decline in such growth, even reaching a point of stagnation in some countries and for some cereal types. At the global scale, even if large areas have a potential for yield growth, other areas are experiencing a decline in growth similar to Europe. The reasons for this change in yield trends may be economic, genetic, agronomic or climatic. Some authors affirm that there may be an upper limit to the genetic improvement of cereals (Calderini and Slafer 1998).

In addition to the impact of land take on food security, other factors such as soil degradation, climate change, etc. affect Europe's ability to produce food and could lead to a stagnation or decrease in cereal yields.

5. Conclusions

Despite the increasing attention being generated by land take and soil sealing processes and despite ongoing initiatives at European policy level, further efforts should be made to tackle this irreversible soil degradation process more effectively, especially at regional and local levels. Soil sealing and land-take processes affect the ability of soil to perform its numerous functions, and this affects not only the agricultural sector, but also has economic and social implications. Awareness must be further raised at different levels, especially at the level of local governance where land planning takes place.

This paper proposed a methodology to quantify the impact of land take on food security at the European level. It was demonstrated that, taking a long term perspective (e.g. 100 years), land take could be an important threat to food security in the EU. In this assessment, it was estimated that 19 EU countries lost approximately 0.81% of their potential agricultural production capacity between 1990 and 2006, with large variability between regions. A more detailed analysis showed that certain regions, such as those around the largest cities, in metropolitan areas and coastal zones, experienced the greatest loss of their most fertile soils.

The importance of land take as a threat to soil varies among EU countries. In countries with high land-take rates and PACP, such as the Netherlands, land take is a particularly important issue. The same applies for most of the new MS where the agricultural land-take trend has doubled in the past few years. In many MS, governments and regional authorities should pay closer attention to and address the loss of agricultural land due to urban development. However, restrictions on land use may lead to an increase in land and housing prices.

EU policies, at various levels and in different sectors, can contribute to reducing the EU land-take rate. They should aim to achieve a more efficient use of resources without limiting economic development, as required by the new EU environmental agenda. Furthermore, to be more effective, policies have to operate in a multi-scalar governance framework. Programmes for integrated urban regenerations will also play a fundamental role on the limitation of land-take processes at the European level.

The data used in this study will be freely available for download from the European Soil Data Centre (Panagos *et al.* 2012) for further scrutiny and research.

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