Multicriteria Analysis of the Effects of Field Burning Crop Residues

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Abstract

Burning crop residues is frequently used by Romanian land users to clean agricultural fields after crop harvest for ease in post-harvest soil tillage. Huge amounts of crop residues biomass, on very large areas, were burned in Romania in the last twenty years, as compared to other countries. There are several reasons (e.g. the lack of equipment to gather the crop residues and to transport and store them, the diminishing of the livestock after 1990, the absence of other alternatives, especially in the 1990s, but also the lack of information regarding the good practices) that are evoked to support the use of this method. However, this method is not a sustainable one since it can cause many environmental damages, especially related to soil properties (physical, chemical and biological), greenhouse gas emission and crop yields. Contrary to the above stated, crop residues' addition to the soil may restore damaged soil structure, improve aggregate stability, soil water retention, soil fertility, increase total organic carbon (TOC) and total nitrogen (TN) etc. The purpose of this paper is to make a multicriteria analyze of the effects of crop residue management on the soil, agricultural productivity and environment. At the same time, the use of crop residues biomass as a source of energy is presented as an alternative, given its potential ability to offset fossil fuels and reduce CO₂ emissions.

Keywords: crop residues, soil properties, crop yields, greenhouse gases, sustainability

Introduction

Open field burning of crop residues is a simple method for land users to clean agricultural land after crop harvest to facilitate soil tillage. Crop residue burning has proved to be efficient in controlling insects, diseases, and the emergence of invasive weed species (Pintilie et al., 1985; Kutcher and Malhi, 2010; Estrellan and Iino, 2010; Gonçalves et al., 2011). But, as a general practice, its use has been questioned for several reasons, such as: economic loss (Liu et al., 2008; Kludze et al., 2013), environmental degradation (Campbell et al., 1998; Liu et al., 2008; Zang et al., 2008; Awasthi et al., 2010; Estrellan and Iino, 2010; Viana et al., 2013), adverse health impact (Viana et al., 2008; Awasthi et al., 2010; Agarwal et al., 2012) and loss of soil organic matter (Lal, 2008; Granged et al., 2011) which may contribute to the overall deterioration of agricultural soil productivity.

High soil quality equates to high productivity without significant soil or environmental degradation. Soil quality describes the status or specific condition of the soil as a result of its management (Karlen et al., 2003). Evaluation of soil quality is based on physical, chemical and biological characteristics, which vary as a function of the applied management, such as tillage, crop rotation, and the handling of crop residues (Carter, 1994). Management practices that simultaneously improve soil properties and yield are crucial to sustain high crop production and minimize detrimental impact on the environment. Crop residues are important in the maintenance and protection of soil quality (Kludze et al., 2013), and the returning crop residue associated with some other agronomic practices, such as no tillage and crop rotation may improve soil quality and productivity, and may also be useful for the environment (Malhi et al., 2006; Fuentes et al., 2009).

Concerns regarding the effects of field burning crop residues have arisen in Romania in the past twenty years. Therefore, the Romanian government, as well as researchers in the field of agronomy, the organizations fighting for environment quality and protection, and the civil society are acting against the practice of field burning crop residues that has taken place with regaining ownership of agricultural land and with the agricultural land privatization. However, in Romania, in the last twenty years, crop residues were burned on the largest areas, as compared not only, but also with European countries, even considering that before 1990 such practice was very rare and required very well-grounded scientific and economic approaches. The environmental consequences of field burning residues are not seen only in terms of air pollution, but also in terms of intake decreasing of organic matter in the soil, that is important to increase soil fertility and to improve its physical, chemical and biological properties which consequently affect the agricultural productivity.

The purpose of this paper is to analyze, from an agronomic, economic and environmental perspective, the effects of crop residues management on the soil, agricultural productivity and environment, to reveal the need to limit
the practice of field burning residues to strict needs and to illustrate the potential of crop residues to induce sustainable changes in dynamic soil quality (Franzluebbers, 2002). Also, the use of crop residues biomass as a source of energy is presented as an alternative. This is only the first step in the scientific approach of this problem. Several projects are ready for future research in this area.

Field burning crop residues: a Romanian study-case

Burning crop residues after harvest is becoming a very common practice in Romania (Fig. 1) since 1990. There are some reasons which have always been evoked by the land users to justify the field burning crop residues: (1) the lack of equipment to gather the crop residues and to transport and store them, especially for the small and medium farmers; (2) the diminishing of the livestock after 1990 (NIS, 2013) when Romania started the transition to the market economy; (3) the lake of information regarding the good practices especially for the small farmers; (4) the lake of interest for an alternative use of crop residues, especially during the period 1990-2000 or afterwards; (5) the argument brought up by most farmers (small or big farmers) that the soil tillage practice is of good quality if the crop residues are burned before. All these reasons are not sustainable, so the land managers need to know the effect of their management on soil ecosystem functioning, in addition to the effect of environmental factors beyond their control (Franzluebbers, 2002).

![Fig. 1. Evening open field burning of crop residues in Giurgiu county, Romania. Photo source: Vasilica Stan and Françoise Picard-Bonnaud, 26th August 2013](image1)

![Fig. 2. a. The quantities of biomass burned in Romania compared with different European countries (1990-1998), FAO (2013), all GHG Crops + (Total)](image2a)

![Fig. 2. b. The quantities of biomass burned in Romania compared with different European countries (1990-2006), FAO (2013), all GHG Crops + (Total)](image2b)

![Fig. 3. The quantities of biomass burned in Romania after EU accession (2007-2010) compared with different European countries, FAO (2013), all GHG Crops + (Total)](image3)

The Soil Quality Monitoring of Romania (Tab. 1) shows that 62.24% of agricultural soils are characterized by low humus content, 21.34% by a medium content, 13.28% by high content, and only 3.14% of soils are characterized by a high and an excessively high content. Generally, the reduced organic matter content is due to the slope processes and to the negligence of organic fertilization in the last 30-40 years, the agriculture being mostly based on chemical fertilization, and this, only at low rates. The content of humus that characterize the soil classes is presented in Tab. 2 (Canarache et al., 1987). Based on these considerations, a multicriteria analysis of the effects of field burning crop residues can be considered.
A multicriteria analysis of crop residues field burning effects

Concerns related to intensive agriculture and its effects on the environment have led many researchers, everywhere in the world, in the last 30-40 years, to study the effects of some agricultural practices, such as field burning crop residues, on soil or in the atmosphere (Malhi et al., 2006; Singh et al., 2007; Zhang et al., 2008; Fuentes et al., 2009; Soon and Lupwayi, 2012 etc.). Therefore, a multicriteria analysis of crop residues field burning effects will refer to soil properties (physical, chemical and biological), greenhouse gas emission and crop yields. In the same time, the energetic value of crop residues will be considered a very important criterion, as this is one of the most important alternatives to field burning residues.

The effects of residue removal on soil properties and environmental quality need to be investigated more vigorously, as it is essential for these effects to be carefully weighed on a site-specific basis when making a determination about residues removal (Kludze et al., 2013).

Crop residues and soil properties

The vast majority of soil organic matter (SOM) originates from plant inputs, although this material may pass through several trophic levels prior to acquiring the characteristics of stable SOM (Johnson et al., 2007). Soil C (soil carbon) sequestration benefits refers to: soil quality improvement, the increase of soil productivity, the reduction of soil erosion and sedimentation, the decrease of eutrophication and water contamination (Lal, 2007). Therefore, the soil deprivation of C and N (soil nitrogen) with removal of straw suggests that the practice of removing straw from fields for on-farm and industrial uses in the long run may result in soil degradation (Campbell et al., 1998).

Many authors (Malhi et al., 2006; Fuentes et al., 2009; Verhulst et al., 2011; Soon and Lupwayi, 2012; Li et al., 2013) have reported the effects of crop residues when they were retained on the top soil, especially when this practice was combined with crop rotation and soil tillage (minimum tillage or no tillage/zero tillage). Moreover, incorporation of crop residues, such as straw, into the soil, builds up soil carbon (C) as well as soil nitrogen (N) and returns valuable nutrients to the ecosystem. Such build-up of soil C and N will not take place if the straw is removed from the soil (Nguyen et al., 2013).

Management that causes a decline in soil quality reduces its functional abilities, whereas stewardship preserves these abilities. Given the resilience of nature, appropriate soil management techniques can be expected to restore the ecosystem functions once degraded (Franzluebbers, 2002). Retaining instead of burning residues provides several potential benefits (Hartemink, 2008; Rayment, 2003) such as improving soil physical, chemical and biological properties, and reducing fertilizer requirements through recycling nutrients in the residues, sequestering C etc. Successful integration of crop residue management strategies into cropping systems requires understanding of how crop residues influence cycling of nutrients from soil and fertilizers, as well as their effects on soil chemical, physical and biological properties, and crop production (Malhi et al., 2006).

Effects of organic inputs over time on soil physical properties (soil aggregate stability, soil bulk density, water retention etc.) was reported by several authors (Zhang and Peng, 2006; Singh et al., 2007; Fuentes et al., 2009; Yao et al., 2009). The organic products additions to the soil increase aggregate stability by a factor of 1.1-10.0, and this increase is related to the decomposition dynamics of the inputs (Abiven et al., 2009). Soil aggregate stability is very important to avoid soil erosion. Malhi et al. (2006) reported that during a 4-year experiment, the addition of straw increased the proportion of larger aggregates by 3% for >38 mm and by 1% for 12.7-38.0 mm size and decreased the proportion of wind erodible aggregates by 1% for 0.42-0.83 mm and by 3% for <0.42 mm size. They also noted that the effects of straw retention (SR) on soil aggregate stability were improved when straw retention was combined with no tillage (NT) practice, which resulted in a lower proportion of wind-erodible aggregates (34%) and a higher proportion of large aggregates (37%), whereas conventional tillage (CT) + not straw retention (NSR) combination resulted in a

Tab. 1. The distribution of agricultural monitoring sample plots, level I by class of soil humus content (Dumitru et al., 2000)

<table>
<thead>
<tr>
<th>Humus content</th>
<th>No. Plots</th>
<th>Extremely low</th>
<th>Very low</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Very high</th>
<th>Extremely high</th>
<th>Excessive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>670</td>
<td>1.64</td>
<td>11.64</td>
<td>62.24</td>
<td>21.34</td>
<td>1.94</td>
<td>0.45</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Tab. 2. Classes of soil humus content (Canarache et al., 1987)

<table>
<thead>
<tr>
<th>Humus content for different texture classes (%)</th>
<th>Sand</th>
<th>Loamy</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely low</td>
<td>≤3.4</td>
<td>≤6.8</td>
<td>≤0.1</td>
</tr>
<tr>
<td>Very low</td>
<td>0.2-5.0</td>
<td>0.7-13</td>
<td>1.1-2.0</td>
</tr>
<tr>
<td>Low</td>
<td>0.6-1.0</td>
<td>1.4-3.0</td>
<td>2.1-5.0</td>
</tr>
<tr>
<td>Medium</td>
<td>1.1-2.0</td>
<td>3.1-6.5</td>
<td>5.1-10.0</td>
</tr>
<tr>
<td>High</td>
<td>2.1-5.0</td>
<td>6.6-10.5</td>
<td>10.1-16.0</td>
</tr>
<tr>
<td>Very high</td>
<td>5.1-8.7</td>
<td>10.6-13.9</td>
<td>16.1-21.0</td>
</tr>
<tr>
<td>Extremely high</td>
<td>8.8-20.0</td>
<td>14.0-26.5</td>
<td>21.1-35.0</td>
</tr>
<tr>
<td>Excessive</td>
<td>≥20.1</td>
<td>≥26.6</td>
<td>≥45.1</td>
</tr>
</tbody>
</table>
great proportion of wind-erodible aggregates (50%) and a low proportion of large aggregates (18%). Therefore, an appropriate management of organic matter additions to soils may increase aggregate stability and thus, reduce crusting and erosion problems (Abiven et al., 2009).

It was also shown that the increase of soil carbon content by using crop residues may restore damaged soil structure in the case of puddling in rice, and may increase the size and stability of aggregates, water retention and infiltration and decrease bulk density, dispersion ratio and soil strength (Singh et al., 2007). Moreover, the results of a tillage/crop residue management study (Sparrow et al., 2006) showed that wet aggregate stability was significantly higher with crop residues (16.2%) than without crop residues (13.8%) averaged across all tillage treatments.

Fuentes et al. (2009) reported that one of the benefits of retaining residues in the plots subjected to zero and conventional tillage was the reduction in both moisture spatial variability and soil mechanical resistance, but as no residues remained on the soil surface water flowed more easily and the surface was sealed because of the decreased aggregate stability. So, straw retention treatment combined with no tillage kept high soil moisture, rather than no straw retention treatment in the top soil (0-15 cm depth) as it was reported by Malhi and Lemke (2007), which is very important, especially for the arid areas.

Not only crop residues are a primary substrate for the replenishment of soil organic matter, but they also serve as an important source of plant nutrients (Lal, 1995). Crop residues have traditionally been incorporated into the soil as a source of nutrients and organic matter (Reddy et al., 2001; Soon and Lupwayi, 2012). Soil organic matter is an ecosystem component with agronomic and environmental functions and is affected by soil management (Franzluebbers, 2002; Dickow et al., 2005). Crop residues are a renewable and vital organic resource for maintaining soil productivity. Intensive cropping with no return of crop residues and other organic materials results in loss of soil organic matter and that is not sustainable (Singh et al., 2007). As it was already mentioned, build-up of organic matter in soil is a slow process and it takes many years to accumulate significant amounts of organic matter in soil (Malhi et al., 2006) that are able to improve soil properties.

Crop residues, such as wheat or soybean residues, added either alone or in combination with P fertilizers, can improve soil P fertility by decreasing P sorption capacity and favouring a building-up in labile inorganic P, and moderately labile organic P (Reddy et al., 2001). There are differences between residue types regarding nutrient content. As it was reported by Li et al. (2013), soybean residues have the highest total nitrogen concentration and the lowest C/N ratio, whereas maize residues show the opposite trend. The residue type and placement significantly affect cumulative C mineralization. The cumulative mineral N was higher in soils amended with soybean residues than in those amended with maize residues. For these reasons, crop rotation should be associated with the type of crop residues retention and no tillage, as another very important element for a sustainable soil management technique.

A significant increase of top soil organic carbon content, when crop residues were retained, was also reported by different authors: (Malhi et al., 2006; Singh et al., 2007; Cayuela et al., 2009; Fuentes et al., 2009; Thorburn et al., 2012; Navarro-Noya et al., 2013). Crop residue retention had a more pronounced effect on the soil bacterial communities when no tillage was applied. As it was reported by Navarro-Noya et al. (2013), retaining the crop residues significantly increased total organic carbon (TOC) and total N (TN) in soil, but decreased the pH. Also, regarding the soil pH, Fuentes et al. (2009) showed that when soil was cultivated with maize and wheat, the pH was significantly affected by treatments, but only in the first 5 cm layer. In conventional tillage with residue retention (CT+R), conventional tillage without residue retention (CT–R) and zero tillage (ZT) with residue retention (+R) treatments, pH ranged from 6.0 to 6.5.

Campbell et al. (1998) reported that 6 years of no tillage on a thin Black Chernozem in Saskatchewan, Canada, in a fallow-wheat-wheat rotation tended to reduce TOC and TN when straws were removed. At the end of four growing seasons, the mass of TOC and TN in the 0-15 cm soil depth tended to be higher, whereas light fraction organic matter (LFOM), light fraction carbon (LFC), and light fraction nitrogen (LFN) were significantly higher under straw retained (S) than under straw removed (NS) treatments. Compared to NS, the S treatment increased TOC by 3%, TN by 6%, LFOM by 23%, light fraction organic carbon (LFOC) by 37%, and LFN by 36% (Malhi et al., 2006). After eight crop seasons, tillage and straws management had no significant effect on TOC and total organic N (TON) in the top 15 cm of soil, but the LFOC and LFN were higher with S than NS, and also higher under NT than under CT. Compared to NS, the S treatment increased LFOC by 24% and LFN by 10%. Increase in light fraction of organic C and N fractions due to straw retention was closely associated with greater input of C and N to soil through straw and chaff in the S treatments compared to NS treatments (Malhi and Lemke, 2007). Sparrow et al. (2006) also reported that carbon (C) biomass in the 0-10 cm depth increased with decreasing tillage intensity. Soil microbial biomass C and N concentrations were much higher at the surface 10 cm than in the 10–20 cm depth (519 mg C kg$^{-1}$ and 39 mg N kg$^{-1}$ in the 0-10 cm depth versus 229 mg C kg$^{-1}$ soil and 13 mgN kg$^{-1}$ soil in 10-20 cm depth). Microbial biomass C:N ratio in the 0-10 cm depth was also the highest in NT and the lowest in disked twice. Therefore, crop residues returned to crop lands can sustain soil organic carbon (SOC) content and improve soil fertility and biological activity (Cayuela et al., 2009).

Field burning crop residues and the greenhouse gas emissions

Generally, agricultural activities are significant producers of CH$_4$ and N$_2$O (IPCC, 2007). Of the three main gases that are influenced by land management and that are responsible for the potential greenhouse effect, CO$_2$ has the greatest climate forcing potential (57%), while CH$_4$ and N$_2$O account for 27% and 16%, respectively (CAST, 1992). Modern agriculture contributes to the production of atmospheric greenhouse gases (GHG) with about 14% of global net CO$_2$ emissions (IPCC, 2007).

Field burning of crop residue converts a great deal of nutrients to gaseous form, which is then lost from the site
benefits to sequestering C in forest and agricultural soils, a key sequestration pathway in agriculture. There are multiple routes by which C from plant biomass is incorporated into soil organic matter (SOM) as part of agricultural practices such as crop rotation, reducing the number of tillage operations, and on crop yield, is accomplished mainly through conservation of soil moisture in a dry year or in a dry region. Soil moisture content was higher in ZT than in conventional tillage (CT) by 1.5% in the 0-15 cm depth and by 1.9% in the 15-30 cm depth. Also, in Romania, large amounts of crop residues are burned in open field, a multicriteria analysis of the negative effects on the environment has been presented and the benefits of open field burning of biomass is estimated to emitting 0.37 Tg of SO$_2$, 2.8 Tg of NO$_x$, 1100 Tg of CO$_2$, 67 Tg CO and 3.1 Tg methane (CH$_4$) (Streets et al., 2003). There are different alternatives to field burning of crop residues (e.g. soil amendment, biomass feedstock for energy production etc.). As it was already argued, sequestration of C from plant biomass into soil organic matter (SOM) is a key sequestration pathway in agriculture. There are multiple benefits to sequestering C in forest and agricultural soils, beyond the obvious benefit of offsetting CO$_2$ emissions (Johnson et al., 2008).

Crops residues and their effects on crop yields

From an economic point of view, crop residues, such as straw, are valuable, as they may contribute to improve soil organic matter and soil properties which may result in agricultural productivity (Kludze et al., 2013). Crop residues can have significant effects on crop production, especially when their use is in association with other agricultural practices such as crop rotation, reducing the number of tillage or zero tillage. There are many ways in which crop residues may become beneficial for the crop yields (e.g. soil moisture conservation, soil properties improving nutrient content etc.). In a Gray Luvisol, sandy clay loam soil and a second 4 years cycle rotation experiments, Malhy and Lemke (2007) reported that the beneficial effect of zero tillage (ZT) and straw return, on crop yield, is accomplished mainly through conservation of soil moisture in a dry year or in a dry region. Soil moisture content was higher in ZT than in conventional tillage (CT) by 1.5% in the 0-15 cm and by 1.9% in the 15-30 cm depth and also higher in retained straw (R) than in not retained straw (NR) by 1.9% in the 0-15 cm and by 2.6% in the 15-30 cm depth. Also, zero tillage practiced for 14 years, with crop residues retained in the field, resulted in a clayey Cumulic Haplustoll soil with a better quality and, in addition, producing higher wheat and maize yields than the plots subjected to conventional tillage (Fuentes et al., 2009). Residues retention, on average, increased the wheat grain yield by 1.31 times (Balkht et al., 2009). Regarding plant growth, zero tillage with residue retention was characterized by a slower initial growth than conventional tillage practices, but this was compensated by increased crop performance in the later stages, with a crucial influence on final grain yield (Verhulst et al., 2011).

Crop residues and their energetic use

In 2010, about 62% of renewable energy in the European Union (EU) was generated from biomass (Szabó et al., 2011). Agricultural biomass continues to gain attention as a source of alternative energy, given its potential ability to offset fossil fuels and reduce CO$_2$ emissions, while simultaneously providing an added source of income to farmers (Kludze et al., 2013). The use of biomass as raw materials for bioenergy and biochemical production is encouraged by the need for a secure energy supply, a reduction of fossil CO$_2$ emissions and a revitalization of rural areas (Cherubini and Ulgiati, 2010).

Our strong dependence on fossil fuels results from the intensive use and consumption of petroleum derivatives which, combined with diminishing oil resources, cause environmental and political concerns (Cherubini and Ulgiati, 2010) and many problems such as energy crisis and global warming since the Industrial Revolution (Liu et al., 2008). An alternative can be represented by lignocellulosic materials. In fact, lignocellulosic feedstocks can be supplied either from dedicated crops or as residues from agricultural, forestry and wood industry (Cherubini and Ulgiati, 2010). Biomass fuels (e.g. wood waste, crop residues, energy crops), in contrast, are considered renewable and carbon neutral (Nguyen et al., 2013). This feedstock is made of three main components (cellulose, hemicellulose and lignin) which can be refined into different final products using a set of jointly applied technological processes. Among the different possible feedstocks, agricultural residues are a widespread lignocellulosic biomass source available in many countries (Cherubini and Ulgiati, 2010).

In areas where plants are cultivated on large surfaces, such as Romanian plain, there is a potential for removing straws or other crop residues for alternative uses, given the recent increasing interest for production of biofuels as a result of the EU Directive on the promotion of the use of energy from renewable sources (2009/28/EC), which sets an overall target of 20% renewable energy to be reached by 2020. In the framework of targets fixed by this directive, each member state had to adopt a National Renewable Energy Action Plan (NREAP) detailing the mandatory national targets in terms of sources and uses of renewable energy (Monforti et al., 2013). The agricultural crop residues contribution to primary energy production has to be evaluated in the NREAPs template (European Commission, 2009).

Given the concentrated crop production regions in the Romanian South Plain or the Romanian West Plain, crop residues from corn (Zea mays L.), wheat (Triticum aestivum L.), rape (Brassica rapa L.), sunflower (Helianthus annuus L.) and soybean (Glycine max L. Merr.) are considered to be particularly promising sources of biomass feedstock to replace conventional fuel. Employment of agricultural areas for the production of biomass crops, at the expense of food crops production and the burning of huge amounts of crop residues proves to be unprofitable.

Conclusions

In Romania, large amounts of crop residues are burned in open field. However, this is not a sustainable way to remove them from agricultural fields since it may affect environment (soil properties, air quality etc.), and agricultural productivity. In this study, based on current estimates of the quantity of crop residues burned in the open field, a multicriteria analysis of the negative effects on the environment has been presented and the benefits of incorporating crop residues in agricultural soils or their use for energy, have been given as alternatives. These alternatives can contribute to the increase of the sustainability of crop residue disposal and can reduce the
risks posed by the open field burning of crop residues. Increasing atmospheric emissions of greenhouse gases cause the biggest concerns on the effects of burning crop residues on the environment. This burning is associated also with the impoverishment of soil organic matter and consequently, with the degradation of the physical, chemical and biological properties of soil and its fertility reduction. Therefore, carbon sequestration in soil is a key solution to limit burning crop residues in the open field. Besides, using alternatives for agricultural crops residues, such as fuel production, is able to deliver new amounts of energy, but also to support farmers for land release and protect the environment.

To better control the effects of burning crop residues, as well as for the adoption of effective solutions, an up-to-date data of crop residue field burning and special investigations are necessary. Also, both the short and long-term effects of crop residues burning on soil properties and environmental quality need to be investigated more rigorously.

References


Commission Regulation (EC) No 1122/2009 of 30 November 2009 laying down detailed rules for the implementation of Council Regulation (EC) No 73/2009 as regards cross-compliance, modulation and the integrated administration and control system, under the direct support schemes for farmers provided for that Regulation, as well as for the implementation of Council Regulation (EC) No 1234/2007 as regards cross-compliance under the support scheme provided for the wine sector.


European Commission (EC). Commission decision of 30.6.2009 establishing a template for National Renewable Energy Action...
Plays under Directive 2009/28/EC.


