Carbon and nitrogen stocks in the soils of Central and Eastern Europe

N.H. Batjes

Abstract. Soil organic carbon and total nitrogen stocks are presented for Central and Eastern Europe. The study uses the soil geographic and attribute data held in a 1:2 500 000 scale Soil and Terrain (SOTER) database, covering Belarus, Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Moldova, Poland, Romania, the Russian Federation (west of the Urals), Slovakia, and Ukraine. Means and coefficients of variation for soil organic carbon and total nitrogen are presented for each major FAO soil grouping. The mean content of organic carbon, to a depth of 1 m, ranges from 3.9 kg C m⁻² for coarse textured Arenosols to 72.9 kg C m⁻² for poorly drained Histosols. Mean carbon content for the mineral soils, excluding Arenosols, is 15.8 kg C m⁻². The top 1 m of soil holds 110 Pg C (Pg = 10¹⁵ g), which corresponds to about 7% of the global stock of soil organic carbon. About 44% of this carbon pool is held in the top 0.3 m of the soil, the layer that is most prone to be changed by changes in soil use and management. About 166 million ha in Central and Eastern Europe have been degraded by compaction, erosion of topsoil, fertility decline and crusting. The achievable level of carbon sequestration for these soils, upon adoption of ‘best’ management practices or restorative measures, is estimated.

Keywords: Organic carbon, soil, nitrogen, carbon sequestration, Central Europe, Eastern Europe, databases

INTRODUCTION

Information on current soil carbon stocks and possible changes therein are needed in the context of the United Nations Framework Convention for Climate Change (UNFCCC). Soil organic matter levels depend upon climate, hydrology, parent material, soil fertility, biological activity and land use. In the short-term, the carbon balance of terrestrial ecosystems is particularly sensitive to the impact of human activities: deforestation, land use changes and pollution. In the longer-term, plant growth and soil carbon sequestration may increase due to increased atmospheric CO₂-levels (CO₂-fertilization) and the associated improved water-use efficiency, as well as more favourable temperatures and increased anthropogenic nitrogen depositions (Bazzaz & Sombroek 1996; Watson et al. 2000).

Several recent studies have assessed global carbon stocks in the upper 1 to 2 m of soils (Sombroek et al. 1993; Eswaran et al. 1995; Batjes 1996). Estimates of soil organic carbon content and its geographical distribution at a continental scale (1:1 million and smaller) are available for Canada (Tarnocai 1998), the contiguous United States (Lacelle et al. 1997), and South America (Batjes 2000). So far, few countries seem to have adequate data for more detailed assessments (Meirvenne et al. 1996; Smith et al. 2000; Stolbovoi 2000; Arrouays et al. 2001).

This paper first presents estimates of the stocks of organic carbon and total nitrogen in soils of Central and Eastern Europe, using a recently completed soil and terrain database for the region (FAO & ISRIC 2000). Next, eco-technologically achievable increases in soil organic carbon upon the adoption of best management practices and restorative measures on degraded soils are estimated. Finally, recommendations are made for regional-scale modelling of soil organic matter at the pan-European level.

METHODS

The study area comprises 13 countries: Belarus, Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Moldova, Poland, Romania, Russia (west of the Urals), Slovakia, and Ukraine (Figure 1). Soil geographic and attribute data, as well as information on the status of soil degradation, are available at a scale of 1:2 500 000 (FAO & ISRIC 2000). Soil and terrain data have been compiled according to the SOTER methodology (Van Engelen & Wen 1995). Each polygon in the database has been described in terms of its main component soils, characterized at the soil unit level of the Revised Legend (FAO 1988), and their relative extent. These classes allow the aggregation of the available soil profile data and to link derived interpretations

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of soil properties with the polygons demarcated on the SOTER map.

The most appropriate way to study the organic carbon and nitrogen content of soil is on a unit area basis, for a specified depth interval. Weighted C and N contents for two depth zones, 0–0.3 m and 0–1 m respectively, were calculated for each soil profile as a product of thickness of horizon, concentration of C or N, bulk density, and volume percentage of fragments coarser than 2 mm. If measured data were lacking for some of these attributes, for example bulk density for a certain depth layer, surrogate values were estimated using pedotransfer rules derived from the available measured data. The calculation procedure has been described by Batjes (1996).

After weighted, mean contents for organic carbon and total nitrogen had been calculated by FAO soil unit and depth zone, area estimates of soil C and N stocks were made by combining data on mean C and N content by soil unit with data on the spatial distribution of each soil unit in the region, using GIS.

Litter is not included in the calculation, as this superficial layer is seldom sampled. However, the amounts of carbon stored in the litter layers of many virgin and forested soils can be considerable.

Generally, fewer samples are taken from the deeper layers than from the superficial ones, implying that the results are less reliable for the deeper layers. No attempt was made in this study to assess soil C stocks stored below a depth of 1 m, although the corresponding amounts can be considerable, for example in Histosols.

Most determinations of soil organic carbon content are according to Tyurin and Walkley-Black. The results of these two methods are considered comparable at this scale. Total nitrogen content in the soil was determined by the Kjeldahl method in all cases. Bulk density was measured according to either the core or wax method.

Soil units represented in SOTER for Central and Eastern Europe have been described by 663 typical profiles, selected as being representative by the various national coordinators. However, there are no data to indicate that the current selection of profile descriptions is statistically representative of the regional distribution of soil units in the region, nor is the land use history known for most profiles. Local effects of differences in microclimate, parent material and land use for soil carbon stocks of a particular FAO soil unit thus were not taken into account.

## RESULTS AND DISCUSSION

### Content of soil organic carbon and total nitrogen

Table 1 lists the amount of carbon held in the major soil groupings for Central and Eastern Europe. Mean soil organic carbon content in the upper 1 m is highest for Histosols (~73 kg C m⁻²), and is associated with the slow decomposition of organic matter under water-saturated conditions and prevailing cold continental and boreal conditions. The lowest carbon content is observed for coarse textured Arenosols (~4 kg C m⁻²). Mineral soils with the largest organic carbon content are Podzols, Chernozems, Fluvisols and Phaeozems. The value of ~24 kg C m⁻² found for Vertisols in the region is rather high in comparison with the global average for Vertisols (11 kg C m⁻², Batjes 1996). The fairly high value of ~15 kg C m⁻² found for Leptosols is due to the occurrence of mainly umbric and mollic Leptosols.

For definitions of major soil groupings see FAO (1988).

<table>
<thead>
<tr>
<th>Major soil grouping</th>
<th>Area (x 10³ km²)</th>
<th>Organic carbon (kg C m⁻²)</th>
<th>Total nitrogen (kg N m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–0.3 m</td>
<td>0–1.0 m</td>
<td>0–0.3 m</td>
</tr>
<tr>
<td></td>
<td>n mean CV (%)</td>
<td>n mean CV (%)</td>
<td>n mean CV (%)</td>
</tr>
<tr>
<td>Arenosols</td>
<td>102</td>
<td>17 2.2 62</td>
<td>7 3.9 71</td>
</tr>
<tr>
<td>Chernozems</td>
<td>912</td>
<td>76 9.0 37</td>
<td>59 22.0 38</td>
</tr>
<tr>
<td>Calcisols</td>
<td>27</td>
<td>1 2.1 –</td>
<td>1 5.3 –</td>
</tr>
<tr>
<td>Cambisols</td>
<td>269</td>
<td>58 6.9 73</td>
<td>31 11.8 51</td>
</tr>
<tr>
<td>Fluvisols</td>
<td>349</td>
<td>35 8.9 100</td>
<td>23 21.9 98</td>
</tr>
<tr>
<td>Gleysols</td>
<td>232</td>
<td>48 11.4 61</td>
<td>24 17.3 33</td>
</tr>
<tr>
<td>Grayzems</td>
<td>255</td>
<td>19 7.3 45</td>
<td>16 12.5 42</td>
</tr>
<tr>
<td>Histosols</td>
<td>376</td>
<td>100 22.1 44</td>
<td>88 72.9 25</td>
</tr>
<tr>
<td>Kastanozems</td>
<td>180</td>
<td>18 6.5 33</td>
<td>7 13.3 33</td>
</tr>
<tr>
<td>Leptosols</td>
<td>145</td>
<td>25 8.4 92</td>
<td>7 15.2 49</td>
</tr>
<tr>
<td>Luvisols</td>
<td>285</td>
<td>48 5.0 57</td>
<td>37 9.1 46</td>
</tr>
<tr>
<td>Podzoluvisols</td>
<td>1436</td>
<td>91 4.9 78</td>
<td>34 8.3 74</td>
</tr>
<tr>
<td>Phaeozems</td>
<td>203</td>
<td>34 8.4 33</td>
<td>25 19.5 36</td>
</tr>
<tr>
<td>Planosols</td>
<td>163</td>
<td>6 5.8 10</td>
<td>6 10.8 18</td>
</tr>
<tr>
<td>Podzols</td>
<td>659</td>
<td>37 12.0 187</td>
<td>11 29.6 146</td>
</tr>
<tr>
<td>Regosols</td>
<td>3</td>
<td>5 6.9 51</td>
<td>3 10.4 31</td>
</tr>
<tr>
<td>Solonchaks</td>
<td>6</td>
<td>4 4.4 42</td>
<td>1 4.0 –</td>
</tr>
<tr>
<td>Solonetz</td>
<td>71</td>
<td>10 7.1 50</td>
<td>6 13.7 55</td>
</tr>
<tr>
<td>Vertisols</td>
<td>33</td>
<td>13 8.2 36</td>
<td>11 23.6 37</td>
</tr>
</tbody>
</table>

For definitions of major soil groupings see FAO (1988).
were available, while a default of 1.9 kg m\(^{-2}\) was used in the case of total nitrogen. Similarly, default values for the topsoil have been set at 7.7 kg C m\(^{-2}\) and 0.9 kg N m\(^{-2}\), respectively, for mineral soils where necessary.

There is a large variation in organic carbon content within each major soil grouping, with coefficients of variation ranging from 25% for Histosols to 146% for Podzols. Table 2 shows the range observed within subunits of these two major groupings, as well as for Podzoluvisols and Chernozems, as examples of the variation that occurs at soil unit level.

Mean nitrogen content to a depth of 1 m ranges from 0.47 kg m\(^{-2}\) for Arenosols to 4.80 kg m\(^{-2}\) for Histosols (Table 1). The C:N ratio generally ranges from 9–12, except for Histosols and Podzols (Table 3). In the subsoil, it is ~18 for Podzols and ~ 21 for Histosols reflecting a lower degree of decomposition of organic materials present in acid and poorly drained environments.

**Contribution of soils in Central and Eastern Europe to global soil carbon reserves**

Detailed information about the distribution of individual soil units within each SOTER or map unit may be found in FAO & ISRIC (2000). Figure 1 is a generalized map of the organic carbon content, to a depth of 1 m, for Central and Eastern Europe. Regional stocks are estimated at 48 Pg C (0–0.3 m) and 110 Pg C (0–1 m) for organic carbon, and at 5.3 Pg N (0–0.3 m) and 10.9 Pg N (0–1 m) for total nitrogen.

Organic carbon in the top 1 m of soils in Central and Eastern Europe accounts for about 7% of the global stock of about 1550 Pg C. About 44% of this pool is held in the top 0.3 m, the layer that is most prone to change upon land use conversion, changes in management practices and deforestation. In addition, a large part of the terrestrial carbon in the region is stored in the standing forest biomass, which forms a large potential source of greenhouse gas emissions subsequent to deforestation. Bouma et al. (1998) reviewed principal land use changes anticipated in Europe.

**Eco-technological options for restoring organic carbon in degraded soils**

About 166 million ha in Central and Eastern Europe have been degraded by compaction, loss of topsoil associated with water erosion, fertility decline and crust formation (Van Lynden 2000). Soils of the arable lands in the former Soviet Union have lost from 24 to 50% of their carbon since the onset of

<table>
<thead>
<tr>
<th>Soil unit</th>
<th>Organic carbon (kg C m(^{-2}))</th>
<th>Total nitrogen (kg N m(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–0.3 m</td>
<td>0–1.0 m</td>
</tr>
<tr>
<td></td>
<td>n mean CV (%)</td>
<td>n mean CV (%)</td>
</tr>
<tr>
<td>Chernozems:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- haplic</td>
<td>36 9.6 40</td>
<td>29 24.2 41</td>
</tr>
<tr>
<td>- calcic</td>
<td>23 7.6 28</td>
<td>17 18.3 33</td>
</tr>
<tr>
<td>- luvic</td>
<td>16 9.7 31</td>
<td>13 21.9 23</td>
</tr>
<tr>
<td>Histosols:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- fibric</td>
<td>33 18.9 32</td>
<td>28 69.9 11</td>
</tr>
<tr>
<td>- terric</td>
<td>65 23.7 47</td>
<td>58 74.0 30</td>
</tr>
<tr>
<td>Podzoluvisols:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- dystric</td>
<td>6 6.9 44</td>
<td>5 8.9 43</td>
</tr>
<tr>
<td>- eutric</td>
<td>71 4.3 59</td>
<td>22 6.9 66</td>
</tr>
<tr>
<td>- gleic</td>
<td>9 8.9 98</td>
<td>4 17.7 59</td>
</tr>
<tr>
<td>- stagnic</td>
<td>5 5.0 64</td>
<td>3 5.4 29</td>
</tr>
<tr>
<td>Podzols:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- cambic</td>
<td>5 12.2 38</td>
<td>1 18.4 –</td>
</tr>
<tr>
<td>- carbo</td>
<td>4 30.5 161</td>
<td>3 49.8 120</td>
</tr>
<tr>
<td>- gleic</td>
<td>9 5.6 66</td>
<td>3 10.1 40</td>
</tr>
<tr>
<td>- haplic</td>
<td>16 12.2 198</td>
<td>3 40.3 160</td>
</tr>
<tr>
<td>- gelic</td>
<td>3 4.8 23</td>
<td>1 6.9 –</td>
</tr>
</tbody>
</table>

For definitions of soil units see FAO (1988).

Table 2. Variation in carbon and nitrogen content for subunits of Chernozems, Histosols, Podzoluvisols and Podzols in Central and Eastern Europe.

<table>
<thead>
<tr>
<th>Soil unit</th>
<th>Organic carbon (kg C m(^{-2}))</th>
<th>Total nitrogen (kg N m(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–0.3 m</td>
<td>0–1.0 m</td>
</tr>
<tr>
<td></td>
<td>n mean CV (%)</td>
<td>n mean CV (%)</td>
</tr>
<tr>
<td>Chernozems:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- haplic</td>
<td>36 9.1 32</td>
<td>29 2.3 30</td>
</tr>
<tr>
<td>- calcic</td>
<td>23 0.73 34</td>
<td>17 1.93 25</td>
</tr>
<tr>
<td>- luvic</td>
<td>16 0.94 22</td>
<td>13 2.20 16</td>
</tr>
<tr>
<td>Histosols:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- fibric</td>
<td>33 1.22 35</td>
<td>28 4.56 15</td>
</tr>
<tr>
<td>- terric</td>
<td>65 1.61 46</td>
<td>58 4.93 33</td>
</tr>
<tr>
<td>Podzoluvisols:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- dystric</td>
<td>6 0.97 55</td>
<td>5 1.35 44</td>
</tr>
<tr>
<td>- eutric</td>
<td>71 0.43 95</td>
<td>22 0.80 93</td>
</tr>
<tr>
<td>- gleic</td>
<td>9 0.90 129</td>
<td>4 2.87 88</td>
</tr>
<tr>
<td>- stagnic</td>
<td>5 0.47 62</td>
<td>3 0.60 8</td>
</tr>
<tr>
<td>Podzols:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- cambic</td>
<td>5 1.00 26</td>
<td>1 1.20 –</td>
</tr>
<tr>
<td>- carbo</td>
<td>4 2.44 94</td>
<td>3 3.65 65</td>
</tr>
<tr>
<td>- gleic</td>
<td>9 0.91 83</td>
<td>3 0.92 59</td>
</tr>
<tr>
<td>- haplic</td>
<td>16 1.09 110</td>
<td>3 2.08 130</td>
</tr>
<tr>
<td>- gelic</td>
<td>3 0.51 106</td>
<td>1 0.41 –</td>
</tr>
</tbody>
</table>

For definitions of soil units see FAO (1988).

Table 3. C:N ratios for major soil groups in Central and Eastern Europe.

<table>
<thead>
<tr>
<th>Major soil grouping</th>
<th>Topsoil (0–0.3 m)</th>
<th>Subsoil (0.3–1.0 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n C:N CV (%)</td>
<td>n C:N CV (%)</td>
</tr>
<tr>
<td>Arenosols</td>
<td>12 11.6 41</td>
<td>12 8.5 61</td>
</tr>
<tr>
<td>Chernozems</td>
<td>66 11.2 18</td>
<td>65 10.2 31</td>
</tr>
<tr>
<td>Cambisols</td>
<td>39 10.3 37</td>
<td>35 10.0 69</td>
</tr>
<tr>
<td>Fluvisols</td>
<td>22 11.3 49</td>
<td>22 8.6 32</td>
</tr>
<tr>
<td>Gleysols</td>
<td>45 11.4 46</td>
<td>34 11.9 83</td>
</tr>
<tr>
<td>Greyzems</td>
<td>14 11.5 49</td>
<td>15 10.3 53</td>
</tr>
<tr>
<td>Histosols</td>
<td>19 18.2 49</td>
<td>19 20.7 54</td>
</tr>
<tr>
<td>Kastanozems</td>
<td>14 9.4 23</td>
<td>13 8.8 60</td>
</tr>
<tr>
<td>Leptosols</td>
<td>26 9.6 36</td>
<td>17 9.0 42</td>
</tr>
<tr>
<td>Luvisols</td>
<td>35 11.0 41</td>
<td>37 9.0 69</td>
</tr>
<tr>
<td>Podzoluvisols</td>
<td>86 11.5 42</td>
<td>78 10.7 67</td>
</tr>
<tr>
<td>Phaeozems</td>
<td>29 10.6 31</td>
<td>30 8.9 44</td>
</tr>
<tr>
<td>Planosols</td>
<td>4 9.8 22</td>
<td>4 6.0 47</td>
</tr>
<tr>
<td>Podzols</td>
<td>28 14.8 53</td>
<td>24 17.8 59</td>
</tr>
<tr>
<td>Regosols</td>
<td>4 11.5 20</td>
<td>2 7.5 85</td>
</tr>
<tr>
<td>Solonchaks</td>
<td>4 8.5 48</td>
<td>4 9.7 131</td>
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<tr>
<td>Solonetz</td>
<td>9 11.7 30</td>
<td>9 12.4 53</td>
</tr>
<tr>
<td>Vertisols</td>
<td>10 10.0 19</td>
<td>11 8.3 42</td>
</tr>
</tbody>
</table>

For definitions of major soil groupings see FAO (1988).
agriculture (Kolchugina et al. 1995). In particular, large areas of fertile Chernozems have been affected (Mikhailova et al. 2000). The organic carbon content of these degraded soils can be restored upon the introduction of management practices that increase the input of organic matter and/or decrease the rate of soil organic matter decomposition. These practices will generally include a combination of the following: tillage methods and residue management; soil fertility and nutrient management; erosion control; water management; and crop selection and rotation (Batjes 1999; Lal et al. 1998b). Sustainable management of forests can significantly increase the biomass-C in standing vegetation and subsequently in the soil, and thereby create a large carbon sink (Shvidenko et al. 1995; Krankina et al. 1996). Beneficial services associated with improved land practices will include changes in soil quality, soil productivity, biodiversity, and water and air quality (Wood et al. 2000).

As a first assumption, it seems realistic to assume that about 20% of the degraded soils in Central and Eastern Europe, as opposed to 100%, can be subjected to soil restorative measures or improved management practices (see Sampson & Scholes 2000). If it is assumed that from 0.2 to 0.3 t C ha$^{-1}$ yr$^{-1}$ can be sequestered upon restoration or improved management of the above mentioned soils (Lal et al. 1998b; Batjes 1999), the eco-technologically achievable soil carbon sequestration can be estimated at 6.6 to 10.0 Tg C yr$^{-1}$. Assuming a new steady state can be reached after 25 years, if ‘best’ management practices are sustained, the eco-technologically achievable sequestration would be about 0.17 to 0.25 Pg C. Whether such increases would be economically and environmentally feasible, however, still needs to be assessed. For the future, more detailed analyses based on simulation models will be needed in the context of UNFCCC-related assessments.

Regional scale modelling of soil organic matter
SOTER databases, linked to a range of auxiliary databases and models, can be used for a wide range of environmental applications within the broader scope of global change. One of these is a geographic assessment of areas considered suitable for implementing ‘Land Use, Land-Use Change and Forestry’ (LULUCF) related ‘carbon sequestration projects’, both at the regional and national level. First, the areas most suited biophysically for increasing overall agricultural and forest productivity, and leading to increases in soil carbon sequestration, can be identified using physical land evaluation (FAO 1976; Rossiter 1996). Subsequently, the achievable carbon sequestration for these areas can be
quantified using dynamic simulation models, such as RothC and CENTURY (Paustian et al. 1997; Smith et al. 1997, see e.g. Falloon et al. 1998).

When assessing this net potential, special attention should be paid also to any possible adverse environmental effects, such as increased N₂O emissions associated with higher N fertilizer use or increased CH₄ emissions from restored wetlands, that the recommended ‘best’ management practices might have (Schlesinger 2000). A socioeconomic module will be necessary to assess all potential costs and benefits associated with the various management options. The technical, socioeconomic and operational issues associated with soil carbon sequestration projects are very complex (Brown et al. 2000). Farmer’s acceptance of the recommended eco-technological options will be dependent on socioeconomic incentives.

CONCLUSIONS

Accurate assessments of carbon stocks by country for a chosen baseline year, for example ‘1990’ as stipulated under the terms of the Kyoto Protocol (Sampson & Scholes 2000), will often require more extensive soil profile datasets, with associated information on recent land use history and management practices, than are currently available for most countries. Data collection at representative sites, as well as data harmonization and analysis efforts, thus remain critical to monitoring changes in soil organic carbon pools. Detection of small increments in soil carbon storage over the relatively short time frames of relevance for monitoring and verification of article 3.4 of the Kyoto Protocol will require sensitive techniques (Lal et al. 1998a; Batjes 1999; Reichle et al. 1999). Uncertainties in national greenhouse gas inventories that consider variations in soil organic carbon stocks as a function of land use changes, are likely to be high (Bernoux et al. 2001). Worldwide, there are only a few countries that have an appropriate and operational monitoring system in place.

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BOOK REVIEW


In the early 1970’s about one third of crops grown on cereal growing land in England were established by reduced tillage techniques. At that time, some scientists were forecasting that by the year 2000, 75% of all cereals would be grown without ploughing. However, the popularity of non-ploughing techniques declined sharply. The reasons for the return to the plough were loss of yield due to increases in grass weeds, topsoil compaction and the need to incorporate straw. These were the findings of an HGCA review made in 1988, which are summarized in the first Section of the 2002 review. The 1988 review also concluded that the widespread reintroduction of shallow non-inversion tillage was only likely to be attempted ‘if the need to reduce costs of production assumes a high priority’. In the present economic climate such ‘a high priority’ has undoubtedly arisen.

A variety of expressions have been used to describe non-ploughing techniques, such as zero-till, no-till, and conservation tillage. In order to avoid ambiguity the 2002 review rightly begins with a definition of terms, which might be adopted as standard:

1. direct drilling – no cultivation prior to drilling
2. shallow tillage – <100 mm without inversion
3. deep tillage – >100 mm without inversion

All three may be with or without chopped straw.

Research Review No. 48 examines the various research programmes undertaken in the last 13 years, including those at Bramstone, Letcombe, Long Ashton and Bush Estate (Edinburgh). It also consulted widely, not only with researchers, but with farmers, consultants, machinery manufacturers and suppliers. The conclusions reached are therefore not based solely on research but also on the direct experience of those using non-ploughing techniques. The Review goes on to discuss recent changes in farming and emphasizes the smaller financial returns and the rapid decline in labour, both of which impinge on the choice of tillage. The consensus is that the site factors favouring reduced tillage are where mainly autumn-sown combinable crops are grown in drier arable areas. The soil types most suited are well drained clays, calcareous and other stable loams. Grass weed populations should be low and cereal straw should be baled and taken off or well chopped and evenly spread. The key to successful reduced tillage is good seedbed quality to ensure uniform and timely establishment.

It was also generally agreed that reduced tillage systems are not an easy option and require a higher standard of overall management than ploughing. Furthermore, the shallower the depth of work, the more the risk involved and the skill required.

The environmental implications of reduced tillage are discussed. In several instances, runoff and losses of soil were reduced compared with ploughed land. The implications for carbon storage are considered; long-term shallow tillage or direct drilling is one option for increased C sequestration. The review includes information and comment from machinery manufacturers and a description of the principle systems available for reduced tillage. The authors provide target areas for research and indicate priority topics for research and development and emphasize the need for better transfer and uptake of existing information and knowledge, rather than new research. Over 60 references were cited. There is also a list of web sites which may be consulted, for example, www.hgca.com. This series will be of interest to students and lecturers, as well as farming and environmental consultants.

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